

Designing for Durability in Reinforced Concrete Structures, and Associated Economics

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...ent of the requirements for the degree of Master of Science in Engineering.

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DECLARATION

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ABSTRACT

This dissertation outlines a model developed to allow for the comparison of various design options on a life-cycle cost basis for reinforced concrete structures. The model consists of two interlinked components: the first part of the model is technical, and can be used to estimate the service life of a structure within a specified environment based on a set of prediction models; the second part of the model is used to determine the economic implications of the various design options over a specified evaluation period. The use of a particular predictive model is subject to the environment in which it was calibrated. In many cases the models which are presented were developed overseas and as such their values may not be directly applicable to South African environments. The approaches and development of the models are however useful and if calibrated to particular South African environments could be of considerable benefit.

A survey of consulting engineers was also conducted to determine common perceptions of various durability related issues. The results of the survey are presented in this project. The size of the sample was relatively small and as such it would be inappropriate to apply the results categorically to all engineers or organisations. The survey is of value however in that it identifies some areas of potential opposition to the concept of designing for durability and highlights other areas where its acceptance and implementation may be more favourable.

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1 INTRODUCTION

Despite considerable progress in the understanding of concrete and the factors affecting durability, modern concrete structures exhibit a greater lack of durability than was the case some 50 years ago according to Mehta (1991). The deterioration and subsequent repair of these structures represents a substantial financial burden to the economies of many countries (Arya and Newman 1990). There is clearly a need, in terms of limited resources, to address the current situation and ensure the future durability of concrete structures. It may be inappropriate to suggest concrete will be a maintenance-free building material for a century or more, but there is no excuse for the substantial deterioration of structures after only a few years in service. Aguado, Gettu and Shah (1995) have stated that there is considerable disharmony between what is technically possible and practical today and that which is being produced in the construction industry.

1.1 PROBLEM DEFINITION

The major obstacle to the construction of durable concrete structures is not a lack of technical knowledge or even desire to find a solution. The real problem lies with the co-ordination and integration of the key components, namely: the accurate forecasting of the service life of structures under specific environmental conditions (including maintenance cycle times), financial management and accounting for the full cost of structures over their entire life span using life cycle costing, and creating a market awareness of the true nature of problems and solutions for achieving durability (specifically, co-operation among the relevant sectors of the economy).

Rostam (1993) has suggested one of the first steps towards solving the durability problem involves co-operation among the parties who are involved in the various stages of the structure's life. These participants include: owner, designer, contractor and user. In many cases there may also be intermediate or preliminary owners, such as developers, who must be included in the overall assessment if a solution to the durability problem is to be found. Each of these parties has a significant influence upon the useful life and potential durability of the

structure. The co-ordination of the various groups who will have an impact upon the durability of a structure is a very extensive undertaking and one for which there are countless possibilities. A thorough review of all the ways in which this could be achieved is well beyond the scope of this project and, as it can be fairly subjective in nature, will not be discussed in great detail. This in no way minimises the importance of such research, and further studies into an appropriate manner for integrating the various components would be very helpful if not essential to the achievement of long term durability in concrete structures.

The single greatest cause of deterioration in concrete structures is the corrosion of the steel reinforcement (Mehta 1991). The processes for the corrosion of steel in concrete are reasonably well documented. The accurate predictions of time to failure and what is meant by failure however are another matter. Hookham (1992) has suggested that there are three requirements for predicting the service life of a structure: long-term materials behaviour data, knowledge of environmental conditions, and maintenance requirements of structures. There are numerous models with varying degrees of complexity and validity which attempt to predict the rate of ingress of harmful components into concrete. While no new models will be developed or proposed in this project, a number of models and approaches will be evaluated for their use in the prediction of the life of a structure. One of the major limitations of the research relates to a lack of data on the life of repairs to concrete structures. Bickley and Liscio (1997) have stated that many structures previously repaired continue to deteriorate and require a second or third repair, often at cost in excess of the original repair.

The need for economical solutions to the durability problem is of paramount importance. Economic principles can be both an aid and a potential menace to the durability of structures. The previous, and in many cases still practised, system of selecting a project design based on the lowest initial cost has resulted in considerable unforeseen or ignored future maintenance expenditures. Bull (1993) has stated that maintenance and other costs occurring during the life of the structure can account for as much as 80% of the total cost. Various economic theories and approaches will be discussed in this thesis with particular reference to the use of life cycle costing as a decision aid in project evaluations.

1.2 OBJECTIVES

The objective of this project is to provide a practical approach to the evaluation and selection of options for ensuring the service life of reinforced concrete structures. The approach must be based on an integration of the technical prediction models for determining the life of a structure and relevant economic theory and practice for the selection of financially sound options. The model should be compartmentalised in order that a particular section, for instance the section on the life of a repaired concrete member, can be revised without invalidating the other components of the model. As future advances and developments occur it is quite likely that sections will have to be modified, and thus versatility is an important element in the design of the model.

The question of when to pay for durability is one of the most important issues which must be addressed in the overall design of a structure. Whether the durability of a structure is achieved from the outset by appropriate design and construction practices or at some later point during its service life, the requirements and costs of durability will have to be accounted for in some manner. A further objective of this project is therefore to determine the optimal time and magnitude of the payments for ensuring the durability of reinforced concrete structures. Finally, it is important to realise that the approaches and methods which are outlined in the proposed model are considerably more important than the actual values used for illustration. Throughout most of this dissertation numerous examples will be provided and the values suggested are generally for illustrative purposes and should not necessarily be used in the evaluation of other projects.

1.3 GENERAL OUTLINE

A review of the fundamental properties of cement and concrete, with respect to durability, is presented in chapter two. The mechanisms of deterioration, specifically chloride and carbonation-induced, in reinforced concrete are discussed in some detail to provide the technical background upon which the project is based. Other areas discussed include the

various factors affecting durability and a review of selected options for achieving durability in reinforced concrete structures.

Chapter three entails an examination of a number of prediction models which may be used to forecast the life of a structure. The models are generally based on the time to depassivation of reinforcement due to carbonation or chloride-ion ingress. Some options are also suggested for the corrosion rates of steel in carbonated concrete. A review of various regions in South Africa was undertaken to provide a general assessment of the environmental aggressiveness to reinforced concrete structures.

An examination of repair strategies and approaches to maintenance form the basis of chapter four. Estimates of the time to depassivation of the steel are also developed according to the possible distribution of reinforcement in concrete structures. The latter sections of the chapter deal with predictions of the useful life of various repair options.

Chapter five provides a review of the economic principles involved in construction and project evaluation. A number of capital investment methods are evaluated together with various forecasting techniques. Equations for the time value of money are developed and a section is included on ways in which to address risk and uncertainty.

The principles of life cycle costing, together with the development of an economic model which can be used to evaluate the present cost alternatives, are presented in chapter six. The model is based on the present value assessment of four major costs which occur over the life of a structure: initial capital cost, maintenance costs, capital allowances and salvage value.

The proposed integrated technical prediction and economic evaluation model is presented in chapter seven. The procedures to be followed when using the model are outlined together with an example showing one of the intended uses of the model.

Chapter eight analyses a survey which was conducted with various consulting engineering companies. The purpose of the survey was to determine common market perceptions of

durability related issues in an effort to determine reasonable options for promoting and achieving long term durability in reinforced concrete structures. The various conclusions of this project and recommendations for future work and research are summarised in chapter nine.

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2 REVIEW OF DURABILITY AND DETERIORATION OF CONCRETE

The deterioration of concrete structures represents a very serious commitment of valuable resources by society. It has been established that some of the methods of construction and design which were previous thought to be adequate, if not excellent, have had negative consequences with respect to the durability of the structure many (and in some cases, a few) years later. One such example was the use of chloride-based chemical admixtures used to accelerate the rate of strength gain. It is now known that such chloride-containing compounds can lead to premature corrosion of the reinforcing, thus substantially reducing the life of the structure (Browne 1986).

Considerable work and effort have been directed towards furthering the current knowledge and understanding of issues relating to the durability of concrete structures. Mehta (1991) states: 'Tremendous strides have been made in the understanding of durability in corrosive environments, yet it still remains the foremost problem facing structural concrete used today'. Although various authors have proposed numerous theories and hypotheses for degradation effects on concrete structures, there is still poor agreement on many of the issues which are important to achieving durability in concrete structures. For example, there is considerable debate on the chloride level necessary to induce corrosion in reinforced concrete (R.C.) and the form of chlorides whether free, total or a ratio of chlorides to hydroxyl ion concentration.

Clearly further work is required on the issues relating to the deterioration of concrete structures. Before proceeding to a discussion on the various methods available to predict the life of structures it will be necessary to present some of the views on concrete deterioration. This section will briefly highlight some of the major causes and impacts of deterioration in concrete structures.

2.1 PROPERTIES OF CONSTITUENTS OF CONCRETE WITH PARTICULAR REFERENCE TO DURABILITY

Concrete can be defined as a heterogeneous multi-component material whose properties are an integration of the properties of the individual constituents and their interactions with one another (Addis 1986, Oberholster 1996). Consequently, there are numerous factors which affect both the durability and strength of concrete. The primary constituents of concrete are: cement, water, aggregate (coarse and fine), and possibly mineral extenders (supplementary cementitious materials). Chemical admixtures may also be used to achieve a specific objective thereby affecting both the strength and durability of the material. The proportion of admixtures to the total material used however is very small, normally within the range of a few percent or less. Water is also an essential component which can affect the properties of the concrete. Most water is normally quite acceptable for applications in concrete production provided it is not contaminated by sulphates, chlorides or various other ions. For the purposes of this discussion the chemical components of water will not be considered and it will be assumed that water used in the production of concrete will be of an acceptable quality (for instance normal tap water).

Before examining the properties of concrete of particular importance to durability, it will be necessary to first examine the individual components of the concrete both in their separate states and once they have been combined.

The first area of concern is the cement itself. Cement (when combined with water) can generally be defined as a binder or a matrix which holds the aggregate particles together. There are essentially three forms of material which are commonly used (Hansson 1995):

1. Hydraulic cement,
 - a material which when mixed with water will harden or set by forming hydrated compounds. Example: Ordinary Portland Cement (OPC).
2. Latent hydraulic cement,

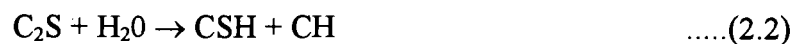
- a material which when mixed with water will harden very slowly and therefore require an activator to be of any value. Example: Ground Granulated Blast Furnace Slag (GGBS).

3. Pozzolanic material,

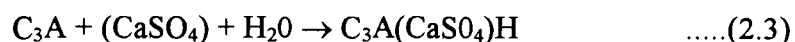
- a siliceous or alumino-siliceous material which in themselves possess little or no cementitious properties, but can react with lime in the presence of water to form stable hydrated cementitious compounds. Examples: Condensed Silica Fume (CSF), Fly Ash (FA).

Ordinary Portland Cement

The most common and widely used of the cement types is ordinary portland cement (OPC). There are numerous other portland cement types available such as Rapid Hardening and Sulphate Resisting, but the current discussion on concrete and cement will be limited to OPC. The primary element components of OPC are calcium (Ca), silicon (Si), aluminium (Al) and iron (Fe). Other elements which are present in 'trace' quantities include magnesium (Mg) and sulphur (S), usually in the form of gypsum. It is important to note that the constituents of cements do not exist in their elemental form but rather as oxides such as CaO and SiO₂ which combine at high temperature in the kiln to form cementitious (clinker) compounds (C₃S, C₂S, C₃A, and C₄AF). OPC generally has a CaO/SiO₂ ratio of approximately 3 and a fineness surface area of roughly 300 m²/kg. The principles involved in the hydration of OPC have been reasonably well established by numerous authors (reviewed for example in Addis 1986, Neville 1972). The hydration of cement can be summarised briefly by the two major reactions:



and a further reaction:



Where:

C₃S - tri-calcium silicate

C₂S - di-calcium silicate

CSH - calcium silicate hydrate

CH - calcium hydroxide

C₃A - tri-calcium aluminate

CaSO₄ - gypsum

C₃A(CaSO₄)H - ettringite

And:

C - CaO
S - SiO₂

A - Al₂O₃
F - Fe₂O₃

The primary hydrated materials of interest, for the purposes of the current discussion, are the CSH and CH. The conversion of C₃S to CSH is fairly rapid and responsible for most of the early strength gain. The conversion of C₂S to CSH on the other hand proceeds more slowly and is responsible for much of the strength gain past the 28 day period as can be seen in figure 2.1. The proportion and quantity of CSH present in the hardened cement is important from two perspectives: the CSH concentration will affect the porosity and structure of the hardened cement paste and thus determine characteristics such as diffusion which will influence the durability of the concrete; the CSH is also predominantly responsible for the associated strength of the particular cement.

South African OPC consists of between 35 - 55 % C₃S and 20 - 40 % C₂S (Addis 1986). There has been a gradual trend towards cements with higher C₃S and lower C₂S contents. This is partially in response to 'fast track' construction techniques which require the early stripping of shutters and rapid strength gains. It has also been suggested that reduction of C₂S concentration with respect to C₃S, for a given concrete strength and thus greater water/cement ratio, may significantly reduce the durability of the concrete (Mehta 1991).

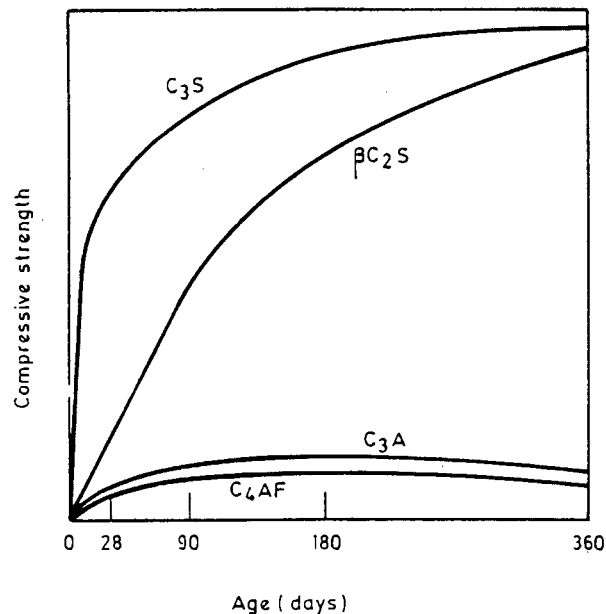


Figure 2.1 (from Taylor 1964): *Contribution to strength of the various constituents of hardened cement paste as well as the relative rate of strength gain.*

Figure 2.1 illustrates the rate of strength gain associated with the cement constituents over time and, while strength does not necessarily imply durability, there are some relationships between the type of cement, w/c ratio, strength, and porosity and permeability (which directly relates to durability). Generally a concrete with a high strength will also be more durable than a lower strength concrete, *ceteris paribus*. The relationship between permeability, porosity and durability will be further discussed in section 2.2.

Ground Granulated Blast Furnace Slag

Ground Granulated Blastfurnace Slag (GGBS) is formed by the rapid cooling of molten blastfurnace slag and subsequent grinding. GGBS, as previously noted, is a latent hydraulic cement and as such is deficient in CaO. The deficiency in CaO is evident from the Ca/SiO₂ ratio which is approximately 1. GGBS is generally finer than OPC and has a surface area of roughly 370 m²/kg. GGBS will react on its own with water but at a rate that makes it unfeasible for practical use in construction. An accelerator of some sort is therefore required. GGBS requires a highly alkaline environment for the reaction to proceed at a useful pace and OPC therefore provides the perfect condition for accelerating the reaction as the normal alkalinity is approximately 12.5 (pH). GGBS is normally mixed with OPC in proportions of 50 % to 70 % to form Blast Furnace Cement (BFC). Even with the high alkaline environment present with OPC, GGBS still requires a longer period to hydrate and gain strength. Therefore the effects of moisture loss will have a greater impact on the material and the effects of lack of curing on the blended cement will be more pronounced than those on OPC alone. Poor curing of BFC may seriously impair the hydration and thus permeability of the material and this can substantially reduce its resistance to the ingress of harmful elements. Thus the time necessary for curing is often longer and greater care must be taken if the benefits of GGBS are to be realised. Further implications of using GGBS in concrete will be discussed later in this chapter.

Fly Ash

Fly ash is a pozzolanic material which is obtained as a by-product from pulverised coal fired power stations. It is finer than GGBS, with a surface area of 400-700 m²/kg. FA has a CaO/SiO₂ ratio of approximately 0.1 with a silicate content of approximately 50% (Addis

1986). There is a second type of FA which has a higher calcium content. The high-calcium FA has both cementitious and pozzolanic properties (Malhotra 1993). For the purpose of this project only low-calcium FA will be considered as it is commonly available and applicable to the South African market. The silicates and aluminates of the fly ash react with the CH of the OPC to form compounds of CSH. Similar to GGBS, fly ash requires a longer period to hydrate than OPC and as such curing once again becomes an issue. Fly ash is normally blended with OPC at approximately 30% or less. The use of fly ash generally results in a finer pore structure thereby producing a less permeable and more durable concrete. The impact of fly ash on the properties of concrete will further be discussed later in this chapter.

Condensed Silica Fume

Condensed Silica Fume (CSF) is a highly pozzolanic material which is a by-product of the silicon metal and ferro-silicon metal industry. CSF acts both as a micro-filler and as a pozzolanic material. CSF is similar to FA in that it has a low CaO/SiO_2 ratio of 0.01 or less and reacts with the CH already present in the cement to form CSH. CSF has both a chemical effect, that of forming CSH, and a physical effect, in that it tends to block pores and act as a micro-filler. The blocking of the pores helps to reduce the permeability of the concrete which in turn influences the transport properties of the concrete and normally results in a more durable concrete. CSF is extremely fine and has a surface area of approximately $20,000 \text{ m}^2/\text{kg}$. In order to realise many of the benefits of CSF a superplasticiser is virtually a requirement. This is primarily due to the high specific surface area of the silica fume which, for CSF content in excess of 10 %, may result in a substantial increase in the water demand to maintain workability. CSF is blended in fairly small proportions of 5 % to 15 % with OPC. While CSF has been heralded as a possible answer for high strength and durable concrete, there is insufficient long-term and in situ data to validate its long-term effectiveness. Thus for the purposes of this dissertation CSF will not be considered prominently in the discussion on options for achieving durability in concrete.

Aggregates

Aggregates have an important role to play in the development of the characteristics associated with concrete. The two primary purposes of aggregate are to: a) provide dimensional stability

to the concrete and b) provide economic benefit as a replacement for cement and thus lower the overall cost. Aggregates are generally less porous than the cement phase of concrete but due to the continuity of cracks and fissures, of certain aggregates, their effective permeability may be quite similar. One of the greatest effects of aggregates on the durability of concrete is as a result of the hydration and permeability of the interfacial zone between the concrete and the cement paste. The impact of aggregates on the permeability of concrete will be discussed in greater detail later in this chapter.

Aggregates can be divided according to their size, thus the term aggregate can be used to refer both to fine aggregates, which are essentially the sands used to assist in achieving workability and cohesion of the mixture, and coarse aggregate or 'stone'. The term 'aggregate' in the current context will normally refer to coarse aggregate unless specifically stated otherwise. There are numerous types of aggregates available in South Africa with varying degrees of strength, porosity, dimensional stability (such as wetting expansion), chemical reactivity and cost. It is not the purpose of this project to provide a comprehensive review of all available materials and, while aggregates are important to the characteristics of concrete, it will be assumed throughout the remainder of the project that aggregates will be selected in a manner that will not adversely impact upon the strength or durability of the structure. Some of the implications and effects of alkali-aggregate reaction will however be briefly discussed later since they pertain to the degradation of concrete structures.

There are also two states of concrete which must be considered with respect to the influences of aggregates: fresh and hardened. The fresh state of concrete exists from the time of mixing until the concrete sets. The properties of fresh concrete are very important at the time of construction and will dictate the ease of construction and impact upon both the strength and durability of the structure. For instance, if the concrete has a very low slump and is unworkable there will be problems associated with compaction and consolidation, particularly in those areas where there is congested reinforcement. The requirements of the fresh state of concrete have a very real effect upon the selection of the mix parameters (and thereby eventual durability of the concrete) as practical constraints in construction will limit the possible options. It will be assumed throughout the remainder of the dissertation that the properties of

fresh concrete and selection of aggregate have been accounted for in the mix design and no further discussion (unless explicitly stated) will be necessary.

The hardened state of concrete ultimately determines the durability of the material and it is the interaction between the cement (and mineral extenders), aggregate, water and construction practices which must now be considered.

2.2 CONCEPTS IN DURABILITY

The two primary aspects of hardened cement paste are its strength and durability. The strength of the concrete is determined by the strength of the hardened cement paste, the strength of the aggregate and the properties of the aggregate paste interface (Mehta and Aitcin 1990). Durability, while related to strength, is more closely described by the porosity, permeability, and the physical and chemical nature of the hardened cement paste (for instance the chloride-binding ability of GGBS). Before expanding upon the factors affecting the durability of concrete it will be necessary to present a few definitions: (ASTM E 632-82 1988)

- *Durability* - the capability of maintaining the serviceability of the structure over a specified period of time. Durability is a function of the material placed and the environment to which it is exposed. Durability is also affected by structural aspects of design such as cover, orientation, detailing and drainage.
- *Serviceability* - the capability of the structure to perform the function for which it was intended.

Definitions for the various periods of analysis (for instance physical life) are presented in section two of chapter six. The term service life is closely associated with durability and can roughly be stated as the period of time over which the structure is to maintain its serviceability.

The environment has a significant impact on the durability of a structure. Two identical structures but in different environments will behave very differently with respect to the durability of the concrete. Some of the environmental effects on concrete will be discussed in

chapter three of this dissertation. The major consideration of the materials component of durability relates to the transportation of various substances through the concrete. The transportation of substances through the concrete can generally be described in terms of the concrete's porosity, permeability and diffusivity. Ideally it would be useful to know the rate of transport of substances (for instance water, oxygen and chlorides) through the concrete. As diffusion represents the movement of one substance through another including chemical interaction between the diffusant and the medium, appropriate diffusion values for concrete can be difficult to obtain. Therefore porosity and permeability are often used to represent the diffusivity of the concrete.

The porosity of the concrete is essentially the amount of voids present. The porosity of concrete is a function of:

- *mixing water* - plays a very significant role in the development of the porosity of concrete and particularly the cement paste. Where there is a substantial excess of water, large water-filled voids will form which contain no hydration products and thus significantly weaken the concrete and reduce its durability. The ratio of water to cement (w/c ratio) essentially determines the degree of porosity and permeability of the HCP and interfacial zone. The principles of hydration will be discussed later in this section.
- *intentionally entrained air* - may be employed to improve the workability of the mix or aid in the freeze-thaw resistance of the concrete. Entrained air usually forms small uniform pockets (approximately 0.05 to 0.5 mm in diameter) which may significantly affect strength or durability, depending on the air content (typically less than 3 to 5%).
- *entrapped air* - is a result of poor compaction or incomplete mixing. It results in large voids and will significantly impact upon both strength and durability.
- *aggregate* - it was previously noted that the porosity of the aggregate is normally many times less than that of the surrounding cement paste. A typical aggregate might have a porosity of 5% (for sedimentary rocks) compared to cement paste with at least 28% (Mehta and Monteiro 1993). Aggregates may help to reduce the overall porosity of the concrete (compared to cement paste alone) but, as will be seen, do not necessarily reduce the permeability.

- *bleeding* - is created where channels are formed due to water moving to the surface of the concrete. Some of the water becomes trapped under aggregate particles and forms voids free of the products of hydration, thus weakening the concrete and providing an easy access for potentially damaging agents.

It was noted that there are three phases present in concrete: the cement paste, the aggregate and the aggregate paste interface. In hardened cement paste (HCP) there exist two primary types of pores (excluding intentionally entrained air): capillaries and gel pores. Gel pores are inherent in the cement and are a result of the processes of hydration. The gel of HCP has a characteristic porosity of approximately 28% (Addis 1986). Gel pores are very small in size and do not greatly affect the durability of the concrete. For complete hydration to occur the theoretical minimum water/cement ratio (w/c by mass) of 0.23 is required; this assumes the cement is reground until all the cement capable of hydrating has done so (Hansson 1995). In practice there are two limiting states for the hydration of cement:

- *Limiting Space* - assumes that the space available for gel growth is determined by the initial w/c ratio and that water from an outside source is available to complete the hydration. The minimum theoretical w/c ≈ 0.36 .
- *Limiting Water* - assumes the cement is sealed and the water available in capillaries must equal that drawn into the gel by hydration. Minimum theoretical w/c $\approx 0.42 - 0.44$. Note in the case of limiting water there will still be capillaries even at full hydration.

(Hansen 1970)

Unlike gel pores, capillary pores are significantly affected by the w/c ratio and the degree of hydration. Capillary pores are formed when there is insufficient gel volume to occupy all the available space. This is associated with an excess of mixing water. Consider the case of limiting space for hydration. If there is an excess of water (w/c above 0.36) there will be more water filled spaces than can be filled by the products of hydration, thus those areas where there is full hydration can expect a gel porosity of approximately 28% and an additional degree of porosity will be added by those areas which have not been filled. The relationship between the amount of water and the resulting capillary porosity is illustrated in figure 2.2. It is the interconnection and volume of capillary pores in the cement paste which significantly affects both the durability and strength of the hardened cement. As Neville (1972) has stated the

capillary pores allow for the more rapid diffusion of moisture and various chemicals through the cement mass.

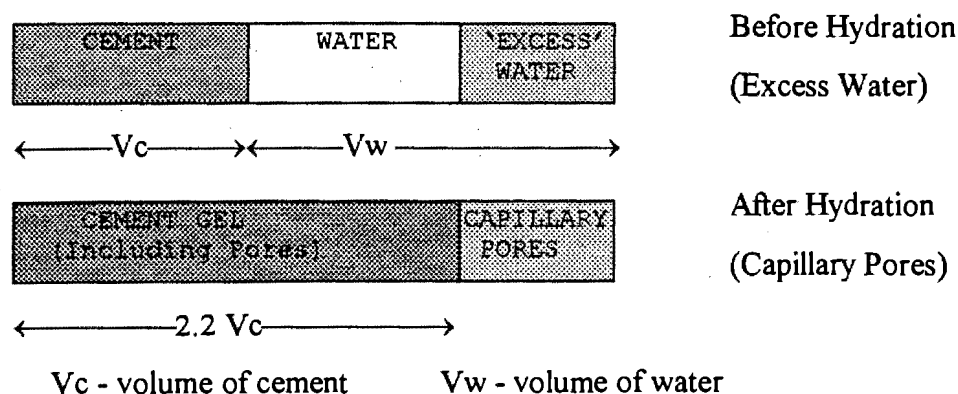


Figure 2.2: *Illustration of hydration occurring under limited space, where there is a surplus of mixing water and capillary pores are present (from Neville (1972)).*

When discussing the durability of a concrete structure it is the permeability of the concrete which is of significantly greater concern than simply the porosity. The permeability of concrete represents the ease with which substances can penetrate and flow through the material. Permeability is dependant upon the porosity and the degree to which the pores are interconnected. Thus gel pores are considered to be largely impermeable by virtue of their small size, regardless of interconnection. Those larger pores (capillaries) and channels created by bleeding and entrapped air are the primary contributors to permeability.

The aggregates affect the permeability of concrete in two ways. First, they are reasonably permeable in themselves (though not as much as the HCP) as they have a high percentage of interconnected pores which provide a pathway for the movement of fluids. Secondly, the boundary created between the aggregate and the HCP (known as the interfacial or transition zone) may be considerably more porous than the HCP and has fewer products of hydration particularly CSH. Where CSF is used as a mineral extender, the transition zone may be denser and less permeable than if OPC alone was used. Mehta and Monteiro (1993), state the increase in permeability is attributed to presence of micro-cracking of the cement paste in the transition zone during the early periods of hydration. The crack widths in the transition zone are generally larger than the capillary cavities found in the cement paste and the interconnected

cracks and micro-cracks form pathways conducive to the transport of water. Thus the effects of aggregate-cement interface, capillaries and bleeding represent the most serious factors affecting the permeability and durability of concrete.

2.3 INFLUENCE OF EXTENDERS ON DURABILITY PROPERTIES OF CONCRETE

The use of cement extenders to replace a portion of OPC can have a profound effect on the strength and durability of the concrete. Until fairly recently, however, the majority of work in the field of concrete research was directed towards improving the strength characteristics, particularly 28 day requirements, with little or no concern for the future durability of the material (Mehta 1991). While this statement may have been true, it is now apparent that the future of durable concrete probably lies with the use of extenders of various types. The primary extenders for application in concrete construction are Ground Granulated Blast Furnace Slag, Fly Ash, and Condensed Silica Fume.

Ground Granulated Blast Furnace Slag

As previously noted GGBS is a latent hydraulic cement and is usually blended with OPC at approximately 50-70%. The term Blast Furnace Cement (BFC) will be used to denote cement which has been blended with GGBS. BFC hydrates more slowly than normal OPC and as a result has a slower strength gain. BFC however continues to gain strength well beyond 28 days and generally has a higher ultimate strength than OPC provided adequate curing is used. The slower rate of hydration also results in a lower heat of hydration which makes BFC particularly useful for massive concrete structures such as dams. The thermal effects are less pronounced with fewer cracks developing.

The overall porosity of BFC may be similar to that of OPC, but with a more refined pore structure characterised by an increased volume of fine gel pores and a reduced connectivity of capillary pores (Parrott 1995). The finer pore structure produces a less permeable and potentially more durable concrete (provided adequate curing is employed). GGBS produces

very little CH and, as will be seen in the discussion on carbonation of concrete, the lower quantities of CH may allow for more rapid carbonation of the BFC concrete. The reduced CH levels are somewhat offset however by the improved impermeability, thus the rate of carbonation may not be as great as first expected. Other benefits of BFC include improved resistance to sulphate attack (at high replacement ratios) and a reduction in the effects of Alkali Aggregate Reaction. Perhaps the greatest potential benefit of BFC is its ability to bind chlorides. BFC has reasonably high ability to bind chlorides which can substantially reduce the rate of diffusion of chlorides through concrete. BFC clearly has potential applications in the marine environment and possibly in those regions where de-icing salts are used. BFC is considered to provide an economic benefit as it replaces some of the OPC and is a by-product of the steel process itself.

The primary disadvantage of BFC is the relatively slow rate at which it hydrates thus allowing for greater susceptibility to moisture loss. For the benefits associated with BFC to be realised it must be well cured. This has both an immediate economic expense and may also impact upon its usefulness in certain site applications where timing is of the utmost importance.

Fly Ash

Fly Ash is one of the most widely used extenders and has been employed in construction for some time now. Its applications include: Chicago's Water Tower Place (859 feet, FA concrete used in first 25 floors), and the Texas Commerce Tower (75 stories) to name but a few (Mehta and Monteiro 1993). Fly Ash cement (FAC) like BFC hydrates more slowly than normal OPC and as a result has a slower strength gain; however, after 28 days FAC usually has a higher ultimate strength than similar OPC. FAC will result in a finer pore structure with a lower permeability which provides considerable advantage from a durability perspective in minimising the ingress of potentially harmful substances. The fineness of the fly ash is partially responsible for the reduced permeability, coupled with the conversion of CH to CSH. The conversion of CH (a relatively weak solid which contributes little to the strength or impermeability of the concrete) to CSH produces a stronger and denser concrete with improved durability characteristics. It has been suggested however that the reduction in CH content may lead to increased carbonation but there is some debate on this and in general FAC

does not appear to be affected to a greater extent by carbonation than OPC (Addis 1986). FAC also requires a longer period of curing for its benefits to be realised.

FAC is of particular benefit when applied to reducing the effects of sulphates and Alkali Aggregate Reaction (AAR). It may also be used to reduce the heat of hydration and its associated effects. The abundance of coal fired power stations in the north eastern areas of South Africa means FA is readily available and should have an economic benefit when employed in concrete structure. Its use in the Western Cape however may be less profitable as a result of the distance required for transport. The binding of chlorides is generally associated with the reaction between chlorides and C_3A . The high aluminate content of FA may be responsible for its ability to bind chlorides as has been suggested for BFC (Neville 1995). While the diffusion of chlorides through FA-containing concrete is somewhat greater than that of BFC concrete, there is still a marked reduction in diffusion of chlorides compared with concrete made with OPC alone (Hansson 1995). One of the primary limitations of FAC is its relatively poor ability to allow for air entrainment.

Condensed Silica Fume

CSF is a super pozzolan in that it is almost entirely SiO_2 and is extremely fine. CSF, as previously noted, can be blended with OPC in the range of 5 - 15%. CSF cement results in increased strength before 28 days and has been used to achieve concrete strengths in excess of 100 MPa. CSF concrete is very dense and has a substantially reduced permeability. The improvements in durability of concrete made with CSF are associated with the refined and denser pore structure (including fine filler effects) and not its chemical interaction characteristics (with chlorides) as is the case with FA and BFC. CSF can be used either as a cement replacement (by using CSF it is possible to reduce the quantity of OPC used to obtain the same strength concrete and thus achieve economic savings) or as a cement addition to achieve high strength relatively 'slender' columns and beams. CSF strength gain occurs fairly early in the hydration process. CSF is also used to reduce AAR.

Despite CSF's many advantages there are a few disadvantages which must be noted. CSF can be very difficult to handle due to its fineness. CSF may also result in greater plastic shrinkage

cracking and has a higher water requirement. As with the other pozzolans and GGBS, curing is an important aspect to the success of the material in improving the durability of the concrete (although not as susceptible as the previous two extenders). For CSF to be of benefit a water-reducing admixture is almost always necessary.

Summary of Effects of Extenders on Properties of Fresh and Hardened Concrete

The following tables provide a summary of the effects of the various extenders.

Table 2.1: Properties of Fresh Concrete

<i>Property</i>	<i>Fly Ash</i>	<i>GGBS</i>	<i>CSF</i>
Workability	improved	improved	reduced
Setting Time	increased	increased	not affected
Bleeding	reduced	reduced	no bleeding
Water Demand	reduced	reduced	increased

Table 2.2: Properties of Hardened Concrete:

<i>Property</i>	<i>Fly Ash</i>	<i>GGBS</i>	<i>CSF</i>
AAR	improved	improved	improved (@15%)
Pore Structure	refined	refined	significantly finer
Chloride Binding	good	very good	similar to OPC
Strength	increased(>28 days)	increased marginally	substantial increase

2.4 MECHANISMS OF DETERIORATION

The rapid growth in the construction industry, pressure for greater strength performance, and shorter construction times has led to significant problems with the deterioration of modern concrete structures. Furthermore environmental changes such as use of de-icing salts in cold climates and increases in land, water and air pollution have exacerbated the durability problem

that is currently being faced (Mehta 1991). There are essentially four main types of deterioration in concrete and reinforced structures: internal reaction (e.g. alkali-aggregate reaction), aggressive chemical attack (e.g. sulphate attack), reinforcement corrosion which is only applicable to reinforced concrete structures (carbonation or chloride-induced), and physical degradation (e.g. abrasion, and free-thaw). The last of these, freeze-thaw, while important to cold climates, is of minor importance to South Africa and is therefore not considered in the analysis of mechanisms of deterioration. The most prevalent form of reinforced concrete deterioration involves the degradation due to reinforcement corrosion. Reinforcement corrosion prediction models have also been established which help to predict when corrosion is likely to occur and how quickly it will proceed. The study and prediction of the corrosion of reinforcing is an important consideration in the current project. Other issues such as AAR and Sulphate attack will be briefly discussed as they represent a concern to the durability of concrete structures but will not be explicitly considered in the prediction models or elsewhere in this thesis. It is sufficient to say that with proper precautions and appropriate care in the selection of materials most of these potential problems (sulphate attack and AAR) can be eliminated, or at least minimised.

Alkali-Aggregate Reaction

There are three types of possible alkali-aggregate reactions: a) alkali-silica, b) alkali-carbonate, c) alkali-silicate. It is the first of these, alkali-silica, which is the most prevalent in South Africa and will be briefly examined. The alkali-silica reaction (ASR) is a chemical process which occurs between hydroxyl ions in pore water and aggregate containing significant quantities of reactive silica. The effect of this reaction is to create expansion and swelling of the matrix. The results of ASR are not visible at first and it can take from five to twelve years to become evident (Swamy 1992). A silica which has a well ordered crystal structure, such as quartz, is stable and will not normally react causing ASR; however, a silica such as opal which has a highly disordered structure is readily susceptible to attack. In South Africa, ASR usually involves a form of reactive silica resulting from straining of quartz or silica grains due to metamorphism and tectonic action. There are three requirements for ASR to proceed: a) a high level alkali concentration, b) a form of reactive silica, c) moisture. ASR will not generally

occur at a relative humidity (RH) of less than 75%, but once a RH (of the concrete) of 80% is reached the rate of the reaction increases markedly (Swamy 1992).

It should be noted that ASR will not always lead to cracking of the concrete. If the gel growth rate is low and the gel can migrate through the concrete, no cracking will occur. This may be one of the few instances where a permeable concrete may be of some value, though the increased permeability and resulting moisture content in all likelihood will more than offset any gains from the movement of the gel. If the reaction proceeds at a fast rate then internal stresses will build up and cracking will occur. Generally with ASR there is no spalling of the concrete but characteristic map cracking should become visible and the cracked concrete may accelerate other forms of corrosion as it allows for the ingress of potentially aggressive elements such as chlorides or carbon dioxide.

ASR is best controlled by using non-reactive aggregates. Where this is not practical from an economic viewpoint or other aggregates are simply not available, ASR can be controlled by reducing the alkalinity of the concrete. As previously noted, the various cement extenders such as GGBS, FA and CSF will adequately perform this function and produce a stronger, more durable concrete in the process. Additional methods include limiting the total cement content. Even though the exact nature of the ASR is not fully understood and there are numerous theories not discussed here, there are proven and effective ways to control ASR and thus prevent deterioration of concrete structures due to ASR.

Sulphate Attack

Sulphate deterioration is primarily due to the formation of expansive products of ettringite ($3\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 3\text{CaSO}_4\cdot 32\text{H}_2\text{O}$). There are two basic steps to sulphate attack. The first is gypsum corrosion where the CH reacts with sulphate ions; this reaction produces only a minor increase in volume and is only considered a problem at very high levels of sulphates. The second and more serious process is that of the ettringite formation. A reaction between gypsum and monosulpho-aluminate results in the formation of ettringite which causes a considerable increase in the volume of solids leading to large internal stress and cracking (Addis 1994). Sulphates may also play a role in the depassivation of the reinforcing. While the

effect of sulphate ions is less severe than that of chlorides, the primary contribution of sulphates to reinforcing corrosion is by the reduction of pH associated with the CH-sulphate reaction (Shamim 1992).

Sulphate attack can be reasonably well controlled by decreasing the permeability of the concrete and reducing the CH concentration and the levels of tricalcium aluminate. The use of extenders such as FA or GGBS and good curing practice will greatly reduce the risk and effect of sulphate attack (Mantel 1991).

Corrosion of Reinforcing Steel

Corrosion of reinforcing is the major cause of most durability problems experienced today in reinforced concrete structures. There are two processes which are responsible for the corrosion of reinforcing. Either one, on its own, can cause corrosion but if the two occur simultaneously the situation can be far worse. Carbonation is the process whereby cement hydration products (CH and CSH) and any unhydrated C_2S and C_3S are converted into calcium carbonate through reactions with atmospheric carbon dioxide (Loo et al 1994). As the carbonation front moves through the concrete it dramatically lowers the pH value of the concrete. Reinforcing steel in concrete is protected by a passive layer of gamma ferric oxide surrounding the reinforcing. The film is stable in highly alkaline environments but becomes unstable once the pH falls below approximately 11. Some of the principles of the protective film and the factors affecting it will be further discussed later in this section. Once the pH of the concrete is reduced by the carbonation front the passive film is destroyed thus rendering the reinforcement vulnerable to corrosion (Mantel 1991).

The second form of attack comes from chloride ions. Chloride ions, once they have reached the reinforcement, depassivate the steel and permit corrosion to occur.

Reinforcement corrosion is an electro-chemical process in which iron enters solution at the anode as Fe^{++} permitting free electrons to flow to the cathode where they react with oxygen and moisture to form OH^- . The Fe^{++} then reacts with OH^- and oxygen to form rust products. The new ferrous oxides (rust products) occupy a volume many times greater than that of the

original steel and thus cause internal expansive pressure which can lead to spalling of the concrete cover layer. The requirements for reinforcement corrosion to occur are as follows:

1. for the anode process to occur, iron must be available in a metallic state at the surface of the reinforcing steel and oxygen must be present,
2. oxygen and moisture must be available for the cathodic process,
3. resistance of the concrete must be sufficiently low to facilitate the flow of ions.

If any of these are missing then corrosion will not occur.

Steel reinforcing in concrete is protected by a passive layer which is formed on the surface of the reinforcing. There is some debate as to the exact nature of the film and whether the passive film is composed of a single layer, two or even three layers which protect the steel. For the purposes of the current discussion however it will be sufficient to state that in an alkaline environment in excess of 12.5 pH, a film of gamma ferric oxide on the surface of the steel effectively renders the steel passive and prevents the formation of ferric oxide compounds even in the presence of oxygen and moisture. While the general principles of corrosion are the same for both carbonation and chloride depassivation there are substantial differences in some of the mechanisms and factors affecting them.

Carbonation-Induced Corrosion:

Carbonation corrosion, as previously noted, is caused by the conversion of CH and CSH to calcium carbonate through reactions with CO_2 . The carbonation front represents the extent to which CO_2 has penetrated the concrete and reacted to form calcium carbonate. The progress of the carbonation front is illustrated in figure 2.3 together with the reactions for CSH and CH. The area ahead of the front has not been affected by the CO_2 but as the front advances through the concrete the pH in the carbonated section is dramatically lowered to a value of approximately 8.5. When the carbonation front reaches the steel the passive film protecting the steel becomes destabilised and the steel is free to corrode. The corrosion of the steel reinforcing will proceed fairly uniformly over the bar and sites of intense pitting action are not normally found in carbonation induced corrosion. The effects of the steel corrosion can become apparent when cracks form as a result of the expansive pressure on the concrete associated with the formation of 'rust' products.

Reaction of CSH and CH with CO₂ (Loo et al. 1994):

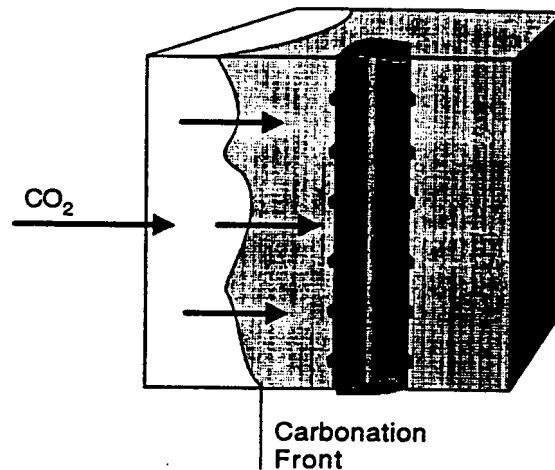
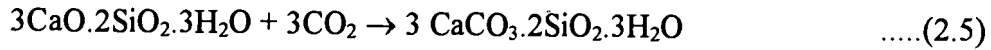
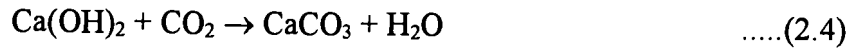


Figure 2.3 (Rostam 1993): *Progress of the carbonation front through concrete.*

Note the front is not necessarily uniform and thus certain sections of the reinforcing will become depassivated before others.

The rate of carbonation of concrete is influenced by a number of factors, but there are essentially two processes which control the rate: 1) CO₂ diffusion, 2) mechanism of CaCO₃ formation. CO₂ diffusion is controlled by: the moisture content of the concrete, temperature, and concentration of CO₂ in the atmosphere. As the diffusion process is partially determined by the concentration gradient, the concentration of atmospheric CO₂ will play a role in the rate of carbonation. The variation in atmospheric CO₂ concentrations however, is normally fairly small and such variations will not be directly considered in the present work (Note however, that in industrially polluted environments and in congested city environments, CO₂ concentrations may be considerably higher). CO₂ has a fairly low rate of diffusion into water, thus concrete in which the pores are completely saturated will not permit the CO₂ to penetrate freely and the rate of CO₂ diffusion will be very slow.

The second process involved in the carbonation of concrete is the formation of CaCO_3 . The formation of CaCO_3 requires both oxygen and water, not to mention CO_2 . The CO_2 combines with water to form carbonic acid which in turn reacts with alkali hydroxides to form calcium carbonate (Saetta, Schrefler and Vitaliani 1993). Unlike CO_2 diffusion, CaCO_3 formation proceeds rapidly where the RH of the concrete is high. There are therefore competing interests between the two processes involved in the carbonation of concrete. CO_2 diffuses through the material quickly when the RH is low. The formation of CaCO_3 on the other hand will not proceed unless sufficient quantities of moisture are present. A RH of approximately 50% to 70% appears to provide a high rate for the carbonation of concrete (Hansson 1995). Additionally, Saetta, Schrefler and Vitaliani (1993), have shown the rate of carbonation also increases with temperature. It will be shown in chapter three of this thesis that the progression of carbonation through concrete is roughly proportional to the square root of time.

Although carbonation of concrete can lead to depassivation of the steel, the formation of CaCO_3 results in an increase in volume and may lead to blockage of some of the pores and a lower permeability. The lower permeability may therefore inhibit the further ingress of CO_2 , O_2 and moisture into the concrete (hence the progression of the carbonation front is proportional to the square root of time). It is generally agreed that the CaCO_3 precipitates first in the smaller pore spaces and only once they are filled will the larger capillaries become blocked and thus impact upon the permeability of the concrete (Marshall 1990). There has however been some work which tends to dispute the idea of carbonation reducing the permeability of the concrete. Saetta, Schrefler and Vitaliani (1993) have suggested that the resultant volume change caused by carbonation can lead to microcracking which in turn may change the effective permeability. De Ceukelaire and Van Nieuwenburg (1993) have also suggested that carbonation will result in microcracking and increase the permeability of the concrete. Their experiments however were based on accelerated tests with CO_2 concentrations of 10%, well in excess of 0.03% which is naturally occurring. One explanation for the increased permeability involves the possible formation of calcium bicarbonate (which is soluble and can be leached away) from calcium carbonate where there is excess carbonation due to aggressive CO_2 (Mehta 1991). The validity of certain accelerated tests can only be established once sufficient in-situ data has been obtained. Therefore the premise that carbonation will cause cracking and

increase the permeability should be treated with some scepticism until long-term results become available.

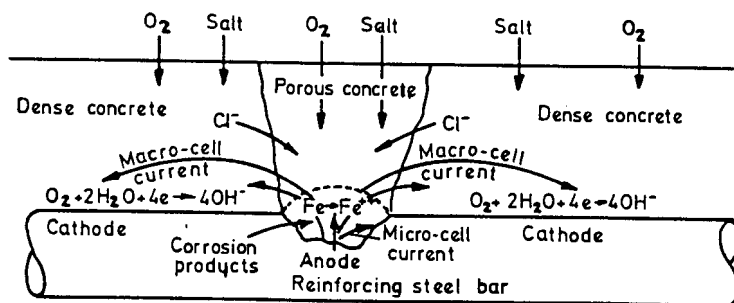
Chloride Induced Corrosion:

The corrosion of concrete due to the ingress of chloride ions is a more serious and immediate effect than that of carbonation-induced corrosion in the marine environment. The chloride ions can quickly penetrate a concrete structure and initiate reinforcement corrosion even at fairly low concentrations. The corrosion associated with chlorides is generally localised and intense, thus there can be relatively few outward signs of distress and still significant damage to the reinforcing. The danger is that the pitting effects on the reinforcing will reduce the cross-sectional area of the steel and thus compromise the structural integrity of the structure. Normally the visible signs are similar to those of carbonation-induced corrosion: cracking or spalling of the concrete parallel to the reinforcement. The process of reinforcement corrosion in the presence of chlorides can be clearly seen in figure 2.4.

The destabilisation of the passive layer by chloride ions is a process which is not yet fully understood and there are a number of theories proposed to explain this occurrence:

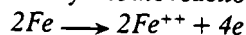
1. *Oxide film theory* - chloride ions are able to penetrate the oxide film and thus break down the passive layer,
2. *Adsorption theory* - chloride ions are preferentially adsorbed to oxygen and hydroxyl ions. They react with the metal and form soluble species,

Complex formation theory - chloride ions form soluble complexes with ferrous ions. The chloro-complexes migrate away from the passive layer and when in the presence of higher levels of oxygen break down and the chloride ions are free to start the process again. (Sagoe-Crentsil and Glasser 1990, and Arya and Newman 1990).

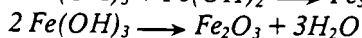
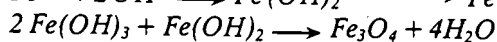
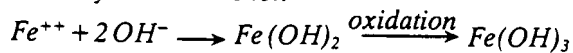


Macro-corrosion cell of reinforcing steel in concrete

Primary anodic reaction

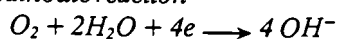


Secondary anodic reaction



(pH reduced)

Cathodic reaction



(high pH maintained)

Figure 2.4 (Addis 1986): *Process of corrosion of reinforcing steel in concrete, due to chlorides.*

While a thorough understanding of the exact mechanism of degradation would be of some benefit, it is sufficient to say for the purpose of this study, that chlorides lead to a destabilisation and breakdown of the passive layer which may then be followed by corrosion of the reinforcing steel. A chloride concentration of approximately 0.4% (by mass of chlorides to cement) is often considered as a practical limit for deciding on the onset of corrosion, although there is considerable debate even as to this value. It is apparent however that corrosion of steel reinforcing can occur even in the highly alkaline environment which normally protects it, thus the chlorides do not initiate corrosion by reducing the alkalinity. As with carbonation-induced corrosion both oxygen and moisture are required for the actual corrosion of steel to occur.

The penetration of chloride ions into saturated concrete is given by Fick's Second Law and takes the form (Mangat and Molloy 1994):

$$\frac{\partial C}{\partial t} = D_c \frac{\partial^2 C}{\partial x^2} \quad \dots(2.6)$$

Where:

C - chloride concentration D_c - diffusion coefficient

x - depth from surface t - time

The rate of chloride penetration depends upon a number of factors and there are essentially three ways in which chlorides normally enter concrete. Capillary suction may occur if the concrete is relatively dry and then exposed to moisture. Cyclic periods of wetting and drying will quickly draw chlorides into the concrete through the capillary voids (Schiesl and Raupach 1990). The second way for chlorides to enter concrete is by means of ionic diffusion through water-saturated pores. As noted, Fick's Second Law of diffusion provides a basis for this form of analysis. The final way in which chlorides may enter a concrete structure is at the construction stage. In the past accelerators such as calcium chloride have been used. While their use is no longer advised due to the implications of reinforcement corrosion, past use does raise some concerns. Chlorides may also enter through contaminated mixing water and aggregates, and sea water or other brackish waters should never be used in the mixing of concrete. As noted earlier in this chapter the water used in mixing should be comparable to normal tap water.

Factors such as sea spray and location of the structure relative to the high and low tide marks and splash zone will significantly affect the rate of chloride penetration. Consider the splash zone for instance where a member is subject to repeated wetting and drying, and where high concentrations of chlorides can quickly build up on the concrete surface. The diffusion of chlorides through concrete will also be driven by the concentration gradient of the chlorides. Thus a high concentration of chlorides will result in a faster rate of diffusion than a similar environment with low chloride concentrations. The permeability of the concrete is obviously an important factor as it dictates the relative ease with which elements can penetrate the concrete. As chlorides diffuse through the concrete there may be a tendency for them to react with the products of hydration. This process, known as chloride-binding, can greatly impact upon the rate at which the chlorides penetrate the concrete and their final concentration. BFC

concrete has a high affinity to bind chlorides and while its pore structure may not be as dense as a CSF concrete, the diffusion of chlorides through BFC concrete is usually slower than through a comparable CSF concrete. Thus the type of cement employed will have a significant impact upon the advance of chlorides through the concrete. Other issues such as the presence of cracks will also impact upon the penetration of chlorides through concrete.

There is some debate, as previously mentioned, about the critical concentration of chlorides required to initiate corrosion. The debate centres around what form of chloride concentration should be considered. One proposal suggests that the corrosion of reinforcing be based on the ratio of chloride ions to hydroxyl ions. Arya and Newman (1990) have stated that the primary determinant of critical chloride level is that of the concentration of free chlorides at the steel surface and this would exclude those chlorides which have been bound. The most commonly accepted measure however is simply the percentage content of total chlorides with respect to cement.

Carbonation can also have an impact upon chloride levels as the carbonation of concrete will liberate those chlorides which have already been bound. The effect is to increase the amount of chlorides capable of destroying the passive layer. As the penetration of chlorides and subsequent reinforcing corrosion is generally much faster than that of carbonation, it is unlikely that the carbonation of concrete (in the marine environment) will significantly impact upon the life of the structure.

2.5 OPTIONS FOR ACHIEVING DURABILITY

It has been established that there are many issues and factors which affect the durability of concrete structures. In this section the primary methods for achieving durability in concrete structures will be discussed with particular reference to control of reinforcing steel corrosion. There are essentially two concepts in the management and effective control of corrosion:

1. To use the concrete itself such that an 'impermeable' cover will be created which controls the ingress of chlorides, oxygen and moisture and limits the rate of carbonation (if required). Additional factors such as increase in the resistivity of the concrete, chloride-

binding effects, or possible use of corrosion inhibiting-admixtures could also be considered.

2. To assume that the concrete itself is incapable of meeting the requirements and that the reinforcing must be isolated or protected from the environment. Included within this concept is the protection of the concrete surface as a whole (for instance cladding or surface coatings), as well as protection of the steel surface itself.

Protection Based on Concrete Acting as Protective Layer

The first premise of creating a reasonably impermeable concrete is not unrealistic. With the appropriate selection of materials and care in construction it is possible to achieve an acceptable level of resistance to attack. The primary determinants of durability to be considered are: cover to reinforcement, cement content, water/cement ratio, cement type, and curing.

1. Cover to reinforcement

The cover to reinforcement can be considered to be one of the most important aspects of achieving durability in concrete structures. Cover is probably one of the easiest variables to control, but at the same time the one most often neglected. Consider the impact of carbonation on a structure. The depth of carbonation is proportional to the square root of time, therefore for a relatively small increase in cover there will be a substantial delay in the depassivation of the reinforcing steel. A similar effect is also experienced with chloride ingress. A sufficient cover and appropriate concrete quality will delay if not prevent the onset of corrosion. A trade-off however does exist in that as the cover increases so does the likelihood of crack development which may increase the permeability of the concrete. Neville (1995) states that in practical terms the cover thickness should not exceed approximately 80-100 mm.

2. Cement Content

The permeability of the concrete can be improved by adjusting the microstructure of the hardened cement paste and cement-aggregate interface. An increase in the cement content of the mix will yield a stronger and denser material which is less permeable. As the cement content increases so does the degree of plastic shrinkage, thermal cracking due to elevated temperatures, and cost of the material. Another concern with high cement contents is the

possibility of AAR. Ideally an aggregate should be selected which will avoid this problem where the durability of the concrete is an issue. It will be shown in chapter three of this project that a trade-off exists between increasing cement content and cover to achieve similar durabilities. The increased cost of cement will be offset somewhat by the lower total material requirement as the cover to reinforcement can be reduced. Additionally the member itself can probably be made smaller due to the increased strength of material.

3. Water/Cement ratio

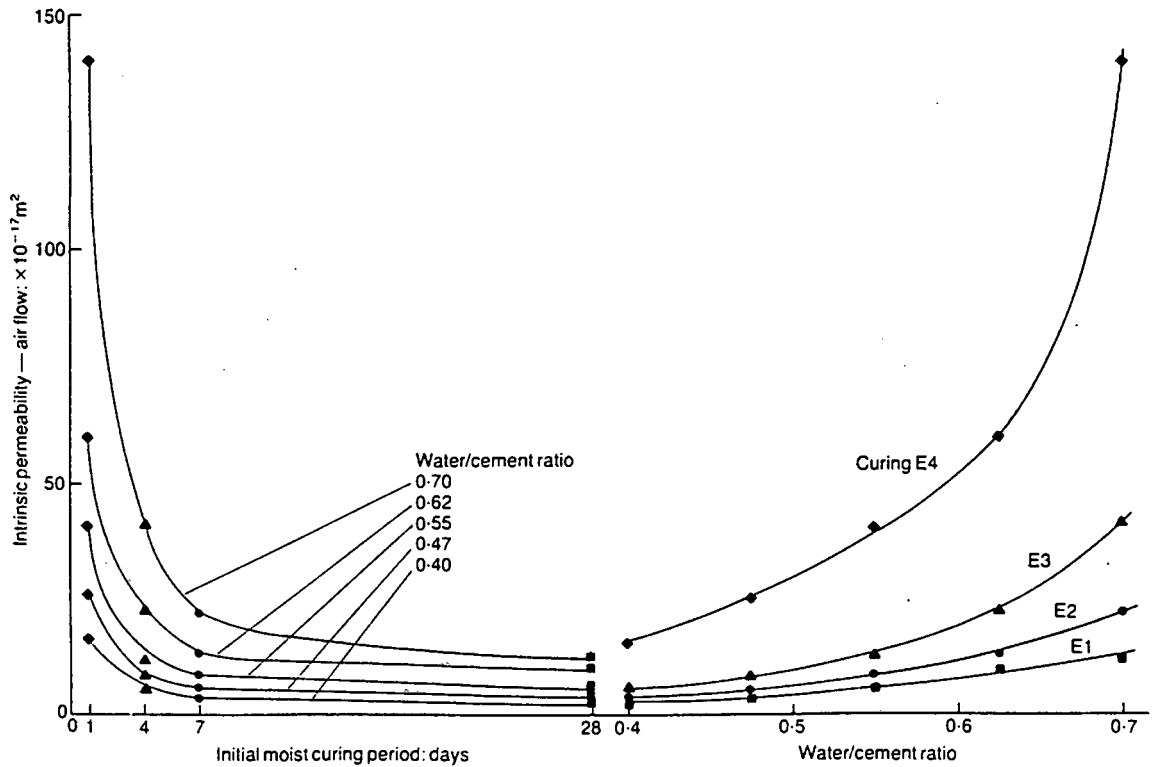
The water/cement ratio is crucial in the determination of the concrete's strength and permeability. It was previously noted that a theoretical minimum water/cement ratio of approximately 0.42 exists for complete hydration under sealed conditions. The permeability of HCP increases dramatically as the w/c ratio increases. Figure 2.5 shows the relationship between the permeability of concrete and the w/c ratio and the impact of curing.

A w/c ratio in the range of 0.4 to 0.5 is often advisable. To achieve low w/c ratios is normally only possible through the use of water reducing admixtures or superplasticisers. FA however, as previously noted, results in a more workable mix with a lower water demand. The particular requirements and details of chemical admixtures will not be specifically discussed here but their use may be necessary to achieve the requirements for certain concrete mix designs.

4. Cement type

As previously noted there are numerous cement types and extenders which are available. The primary extenders of concern in the South African market are Fly Ash and Ground Granulated Blast Furnace Slag. Condensed Silica Fume may also be used but its applications have not been extensively considered in this work, due to insufficient data. The use of FA in concrete can lead to improved impermeability, lower water requirements and higher ultimate strengths. Other benefits include reduced AAR and improved sulphate resistance and the effects of carbonation are assumed to be roughly the same as that for OPC. GGBS also produces a less permeable concrete with its primary application in the marine environment where chloride-binding properties will be of

benefit. GGBS has been shown to perform slightly poorer than OPC however where carbonation is the primary means of degradation (Parrott 1996).



Curing conditions were:

E1 - continuously water cured at 20⁰C

E2 - 6 days water cured, then air at 20⁰C, 55% RH

E3 - 3 days water cured, then air at 20⁰C, 55% RH

E4 - Air at 20⁰C, 55% RH

Note: Specimens were oven dried at 105⁰C and tested at 28 days.

Figure 2.5 (Dhir, Hewlett and Chan 1989): *Relationship between w/c ratio and permeability of concrete under various curing regimes.*

5. Curing

Curing is an issue which can have an impact on the quality of the concrete regardless of the cement type, content, w/c ratio or cover. Cement will continue to hydrate provided there is

sufficient moisture and unhydrated material. Curing provides the necessary moisture for hydration to continue beyond the first few days. It is particularly important to the cover concrete as this is the area which is most sensitive to moisture loss. The heart concrete is protected from moisture loss by the cover concrete and continues to hydrate for years. The cover concrete on the other hand will be especially sensitive in hot dry regions which are prevalent throughout much of South Africa. The curing of concrete requires effort by the contractor and without proper attention the curing that may be provided will serve little purpose. Curing is particularly important when extenders such as FA or GGBS are used. Figure 2.5 illustrated the impact of curing on the permeability of concrete. Possible methods for curing include application of a coating to 'seal' the concrete surface and prevent moisture evaporation, ponding of water on the surface (applicable for slabs), and leaving the shutters or formwork in place for a certain period.

Protection Based on Isolation of Reinforcement from the Environment

The second concept, using a material other than the concrete to protect the steel reinforcing, may be valid under some circumstances. Where the structural or architectural design of a building does not allow for adequate steel cover, special measures can be employed. The options which will be discussed in this section of the project are the use of galvanised and epoxy-coated reinforcing. The use of surface coatings and sealers on concrete will be discussed in chapter four of this dissertation under the section on preventative maintenance as their use involves fairly constant attention to ensure the integrity of the protection afforded.

1. Epoxy-coated reinforcing

Epoxy-coated reinforcement (ECR) has been available for a relatively short period of time and there is considerable debate as to its effectiveness in preventing reinforcement corrosion. ECR was first used on a bridge deck in Pennsylvania (U.S.A.) in 1973 and since that time it has found continued and extensive use throughout Canada and the United States in bridge decks (prone to corrosion due to the widespread use of de-icing salts) and for some marine applications (Baldwin 1982).

The thickness of the epoxy coating is crucial from two conflicting perspectives; first the purpose of the epoxy is to protect the reinforcement from aggressive agents, thus the thicker the epoxy the greater the protection afforded; secondly adequate bond strength (between the concrete and the reinforcement) is essential for structural integrity and too thick a layer may adversely impair the bond. ASTM specifications allow for a range of epoxy covers between 5 and 12 mils (0.13 - 0.3 mm) to try and solve the conflicting interests of design (Abrishami, Cook and Mitchell 1996). A recent study by Abrishami, Cook and Mitchell (1996) examined two thicknesses of epoxy (6-8 mils and 10-12 mils) using a number 15 (16 mm) reinforcement and a concrete with w/c ratio of 0.45 (21 day strength of 27.6 MPa-cylinder test). It was found that the 6-8 mils epoxy coating resulted in only a marginal increase in the strain associated with the deflection of the slab under an applied load, while the reinforcement with 10-12 mils epoxy coating resulted in a 30% increase over the uncoated reinforcing. However, the increase in epoxy coating thickness also resulted in a larger number of cracks with larger average crack widths. While there is some slip involved in using ECR the lower bond strength can normally be easily overcome by increasing the bond development length.

The major limitation of the epoxy coating is its inability to withstand the relatively rough handling requirements of the construction site. It should be noted that the material which is initially produced and subsequently shipped can be assumed to be relatively defect-free, provided the requirements detailing manufacturing and inspection have been meticulously followed. It is questionable if a material which requires such care in handling during construction and is prone to damage (breaches of its protective layer) is really capable of providing the long-term durability which is required. Gustafson (1983) outlines a number of requirements for the on site handling of ECR:

- when hoisting bars, nylon or padded wire slings should be used and the bars lifted at third points,
- coated bars should be stored on padded or wooden cribbing,
- workmen should be careful not to drop tools or machinery on the reinforcing and avoid walking on the bars,
- epoxy-coated or nylon ties should be used to fasten the reinforcement.

Other recommendations include extreme care when vibrating the concrete so that the vibrator does not come in contact with the reinforcement. The use of a rubber sleeve over the vibrator is also recommended. Thus there are numerous requirements far in excess of normal site

practice which would be required to ensure the continuity of the epoxy coating and thus the durability of the structure. If all necessary precautions are taken and there is adequate site supervision, epoxy-coated reinforcement may perform to the level that its proponents claim.

It has been suggested that small holes in the coating will lead to an intensified local corrosion at that point. The work of Theophilus and Woodman (1993) however suggests that intensified local corrosion will not occur and the small opening would be forced to act as both the anode (as is normally the case) and as a cathode thus limiting the rate of corrosion. The danger to ECR is not found in a few isolated holes or defects but rather areas where there is substantial cracking and damage to the epoxy coating due to poor or careless workmanship. Furthermore, as ECR is still a relatively new technology (just over 20 years), there is little long-term data to substantiate the durability claims. Gonzalez et al. (1996), have stated that extensive corrosion over 10 years has been reported involving the formation of large pits in reinforcement, loss of adhesion, and spalling of concrete in the subtropical marine environments of Florida.

2. Galvanised Reinforcing

Galvanised reinforcement (GR) has had a much longer period to establish itself as a viable method for achieving durability in reinforced concrete structures. Galvanised reinforcement was first used in the 1930's in Bermuda to provide reinforcement protection due to the high level of chlorides found in the construction materials (Gonzalez et al. 1996, Clarke 1993).

Galvanising works on the premise of providing a sacrificial layer (zinc coating) which corrodes more slowly than the underlying steel. Even if there are cracks or breaches in the coating the zinc will still provide protection. Thus the care required to avoid damage in GR is not nearly as great when compared with ECR. Furthermore the corrosion products of zinc are not as great volumetrically as those of iron and the resulting expansive pressures are much less. Spalling and cracking is therefore much less likely.

It is generally agreed that GR performs well under conditions of carbonation where there is little or no chloride contamination (Nishimura 1982, Clarke 1993, Theophilus and Woodman 1993). What is less certain is the performance of GR where chlorides are the primary cause of corrosion. It has been suggested that galvanising raises the chloride corrosion threshold level by up to 4 or 5 times over ordinary reinforcement (Thomson 1985). Other researchers claim that once the chloride level exceeds 1% (by weight of cement) zinc will freely corrode and the

sacrificial layer offers only a marginal increase in life (Schiessl 1988, Bird and Strauss 1967). Assuming 1% is the chloride threshold level for GR, this still represents a significant increase (at least double) in resistance compared to normal steel. The period to initiation of corrosion is thus increased and the GR will have been successful in achieving its objectives of longer life for the structure.

There is a third option to achieving durability and preventing reinforcing corrosion and that involves the use of non-ferrous reinforcing. With growing research in the area of 'plastics' and ceramics there are a number of possible options including kevlar reinforcing. Generally these options are very expensive and are only considered in extreme cases. The use of stainless steel and 3CR12 (a form of 'stainless' steel) are further options for the prevention of reinforcement corrosion. Once again however the cost of these alternatives is normally considered to be somewhat prohibitive, but that should not exclude their consideration when the environmental conditions warrant such extreme measures.

2.6 CONCLUSION

There are a number of deterioration mechanisms associated with reinforced concrete structures, with the most prominent and potentially dangerous in marine environments being chloride-induced reinforcing corrosion. Despite the numerous deterioration mechanisms there are a number of ways in which concrete, and specifically the reinforcement, can be protected. The integrity of the reinforcement can be maintained either by using the properties of the concrete itself to prevent the ingress of harmful substances such as moisture, oxygen and chlorides or using other materials to isolate the reinforcement, including epoxy coatings, surface sealers and non-ferrous reinforcement.

The protection of reinforcement using the concrete as a barrier requires a careful examination of the individual constituents of the concrete and their interaction. The appropriate selection of cement type, content, cover, w/c ratio, aggregate, curing and good construction practice, is essential if premature and rapid deterioration of the reinforced concrete structure is to be avoided. Furthermore particular attention should be paid to the use of extenders such as Fly Ash and Ground Granulated Blastfurnace Slag in marine applications.

The general principles and requirements for ensuring durability in reinforced concrete structures are clear. The uncertainty with respect to durability however lies with the accurate prediction of time to deterioration and the exact magnitude of the degradation. The following chapter will outline a number of prediction models which may be used for estimating the rates and amount of deterioration in reinforced concrete structures.

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3 DURABILITY AND SERVICE LIFE PREDICTION MODELS

The primary mechanisms of degradation in concrete structures were discussed in chapter two of this thesis. One of the major aims of this work is to examine the life cycle costing approach to assessing the economic viability of reinforced concrete construction. The accurate prediction of the deterioration rate of concrete, however, is essential if life cycle costing exercises are to be of any value. The primary criticism of the life cycle costing approach to investment appraisal decisions has been the inaccuracy of the estimates of the service life of structures. While the uncertainty cannot be removed completely, the amount of research in the field of concrete durability has greatly expanded our current knowledge and understanding of the mechanisms of deterioration and factors affecting them. The use of accelerated testing on numerous concrete samples, correlated with real site data (much of which takes well in excess of 10 years to determine), permits a reasonable estimate of the expected life of a structure.

There are two stages for service life predictions of reinforced concrete structures. The first stage is known as the initiation period. During this period the aggressive agents penetrate the concrete and destabilise the passive film protecting the reinforcement. There should be no visible signs of deterioration during the initiation period. The initiation period is then followed by the propagation period in which active corrosion of the reinforcing occurs. In some cases the environment in which a structure is situated may be conducive to the rapid initiation of degradation but the actual reinforcement corrosion processes may be very slow. As previously noted, for corrosion to occur there must be moisture, oxygen, a depassivated steel surface, and concrete with a sufficiently low resistivity. If any of the first three requirements are not present, corrosion will not occur and the resistivity of the concrete helps to determine the rate at which the reaction will proceed. The relationship between the two corrosion periods can be seen graphically in figure 3.1.

The overall process in the determination of the service life of a concrete structure begins with a knowledge of the environment in which the structure is situated. It is important to determine what the primary aggressive agents are likely to be and the probable method of deterioration which will take place. Section 3.1 will attempt to identify the primary aggressive agents and

the associated regions in South Africa where they predominate. Once the primary cause of deterioration is known it will be assumed that only one (carbonation or chloride ingress) is acting on the structure and any interactions between the two will not be considered. It was previously noted that the carbonation of concrete containing bound chlorides may result in the liberation of those chlorides and alter the rate of diffusion and thus initiation and possibly propagation but, for simplicity of predictions and the current discussion, these interactions will not be considered. This assumption is also reasonable in that the two processes do not generally occur simultaneously in South Africa.

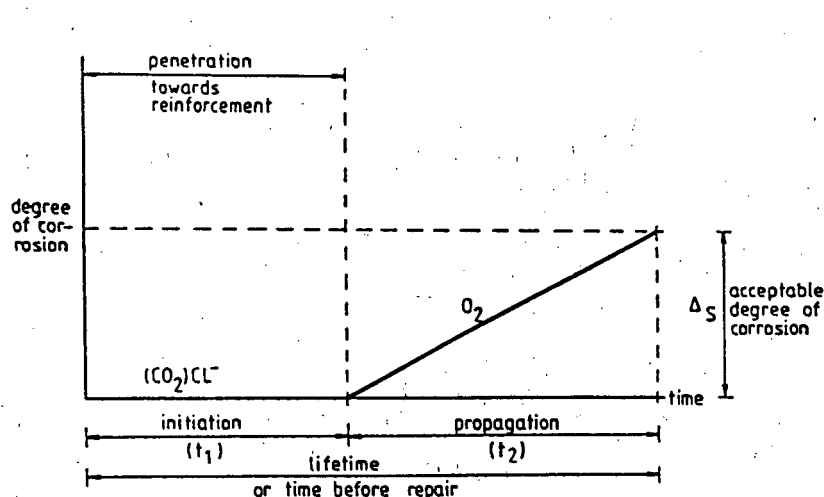


Figure 3.1 (Tuutti 1982, given in Bijen, J. (Ed.) 1989): *Relationship between the initiation and propagation periods in the deterioration of concrete structures. The fundamentals of the corrosion process are the same for both carbonation and chloride ion degradation.*

The various prediction models for carbonation and chloride-induced damage are discussed later in this chapter. Ideally there should be adequate site (or at least region) specific data based on rates of deterioration for real structures. Where this information is not available one of the more general prediction models may be used and the results evaluated.

Note that in the context of this thesis, “service life” is very closely associated with the state of corrosion; thus “service life prediction” essentially reduces to proper prediction of the state of corrosion.

3.1 ENVIRONMENTAL INFLUENCES ON THE DETERIORATION OF CONCRETE

The environment to which a structure is exposed will significantly impact upon the durability of that structure. It has been established that the two primary mechanisms of deterioration of reinforced concrete are carbonation and chloride ingress. The two deterioration mechanisms have very different processes and the environmental effects causing them are also quite different. The objective of classifying the environment to which a structure will be exposed is to determine which of the corrosion mechanisms will dominate and thus allow for the design of the structure to resist that method of deterioration. SABS 0100-2 (1992) classifies the environment to which a structure is exposed according to one of 5 groups as follows:

Table 3.1: Exposure Classification of Structures to the Environment

Mild	- concrete exposed generally to unpolluted air. For example: <ul style="list-style-type: none"> • indoors (but not including industrial areas); or • outdoors in arid areas (Karoo).
Moderate	- concrete: <ol style="list-style-type: none"> a) sheltered from severe rain; b) buried in non-aggressive soil; or c) subject to polluted air (but not corrosive fumes) For example: <ul style="list-style-type: none"> • indoors in industrial areas; or • outdoors in rural Highveld areas.
Severe	- concrete exposed to: <ol style="list-style-type: none"> a) wet conditions in which water is mildly to fairly aggressive; b) corrosive fumes; or c) salt-laden air. For example: <ul style="list-style-type: none"> • outdoors in industrial areas; • outdoors in marine atmospheric conditions (up to 15 km from the sea); or • outdoors in the Cape winter-rainfall area.
Very Severe	- concrete exposed to: <ol style="list-style-type: none"> a) wet conditions in which water is mildly to fairly aggressive b) abrasive action under wet conditions; or c) highly corrosive fumes.
Extreme	- concrete exposed to wet conditions in which the water is highly aggressive.

The environmental classification as proposed by the SABS is useful as a general guide but it lacks specific environmental data which could be of benefit in refining the effects of the environment. For the purposes of this project it will be assumed that any structure which is within 15 km of the sea (in accordance with SABS 0100-2) will be considered in a severe environment where the possibility of contamination due to chlorides exists. The impact of a structure's location within the chloride degradation region can be subdivided into a number of more specific classifications as given by Mackechnie (1996^b) based on BS 8110 definitions:

Table 3.2: Classification of Marine Exposure Conditions

<i>Marine Exposure Category</i>	<i>Marine Tidal and Splash Zones</i>	<i>Marine Spray Zone</i>
Extreme	Structure exposed to sea water and heavy wave action abrasion or heavy splash action	N/A
Very Severe	Structure exposed to sea water in a sheltered location or exposed to minor splash action	Structure adjacent to sea (<50 m) with heavy wave action, strong onshore winds and splashing
Severe	N/A	Structure near sea (50 - 1000 m) with wave action and onshore winds
Moderate	N/A	Structure near sea (<1000 m) in a sheltered location or inland marine conditions (1-30 km)

Table 3.2 more clearly outlines the various zones of potential damage to concrete associated with marine conditions (degradation due to chloride-induced corrosion). The moderate marine zone presents a problem when assessing the primary cause of degradation. In this case it is possible that either chlorides or carbonation will play the primary role in reinforcement damage. When assessing the likely cause of degradation in such a region, expert judgement will have to be used. Consider the case of Cape Town where Table Mountain effectively

shelters a large section of the city. Although the city would lie within 30 km of the sea, chloride contamination is probably not a concern in areas such as Newlands or Claremont which are protected by the mountain; in such locations carbonation-induced corrosion is probably the primary cause of deterioration. There are some differences in the classification provided by SABS 0100 and that given by Mackechnie (1996^b), particularly with respect to the effective range of chloride contamination. As previously noted, for the purposes of this project, possible chloride contamination associated with the immediate marine zone will be limited to a distance of 15 km from the sea as given by SABS 0100.

South Africa can be roughly divided into 8 environmental regions, six of which are discussed as follows (Schulze 1974, Walton ed. 1984, Addis 1986):

1. Cape Town (C.T.) and the South Western Cape
 - has a Mediterranean climate with dry summers and cool wet winters.
 - RH high: 83 % low: 71 % mean annual: 78 % (for C.T.)
2. Port Elizabeth (P.E.) and George, Southern Cape coast
 - a temperate climate zone with warm summers, cool winters and year round rainfall.
 - RH high: 81 % low: 75 % mean annual: 79 % (for P.E.)
3. Kimberley, and Bloemfontein, interior of country (Karoo), includes large sections of the Free State and Northern Cape
 - a semi-arid region characterised by hot summers with some rain and cold dry winters.
 - RH high: 63 % low: 41 % mean annual: 53 % (for Bloemfontein)
4. Upington, desert and poor steppe region
 - essentially arid region with hot dry summers and cool dry winters. Rainfall is due to convection and occurs in the summer.
 - RH high: 49 % low: 28 % mean annual: 39 % (for Upington)
5. Durban, and southern coast of Natal.
 - a sub tropical region with humid wet summers and drier warm winters.
 - RH high: 82 % low: 72 % mean annual: 78 % (for Durban)
6. Pretoria and Johannesburg, highveld area,

- characterised by warm wet summers and cold dry winters. Majority of precipitation in the form of thundershowers during the summer. The mean maximum RH can however reach the high 70's (during peak rainfall in the summer periods).

RH high: 68 % low: 47 % mean annual: 59 % (for Johannesburg)

Note: The relative humidities are based on the average of mean hourly values for a particular period. The high and low RH values represent monthly values and the mean annual the average yearly.

The primary factors to consider when examining the environmental effects to which the structure will be exposed are the temperature, RH and degree of rainfall which will have an impact upon the RH of the concrete and thus influence the permeability of the material to carbon dioxide and oxygen. The proposed classification is primarily based on the mean annual RH. It is quite possible for instance to have two cities with identical annual average humidities but where one of the cities has a considerable variation throughout the year, allowing for rapid carbonation over part of the year and rapid corrosion of reinforcement over the other period. Thus the damage to reinforced concrete in the city with a highly variable RH will probably be considerably greater than the city where the RH is relatively constant. It is important therefore to recognise the effects of variation in the RH when examining the environmental classification which is being proposed. There is no substitute for good local knowledge of the corrosion conditions.

By examining the description of the various regions it is possible to further generalise and propose three major climate types or zones (excluding the immediate marine zone which is classified as "very severe" or "extreme" - table 3.2) with respect to concrete deterioration (attempts have been made to stay within boundaries as suggested by SABS 0100 for environmental risk).

Coastal Severe

The severe zone may be considered as those regions where the RH is sufficiently high to allow for corrosion of the reinforcement but not so high as to prevent carbonation. Included within these areas are Cape Town, Durban, Port Elizabeth, and George, essentially all areas where

the mean RH is between 70% and 80% and where the minimum RH is in excess of 70% (this includes most of the coastal region).

It should also be noted that in such areas which are close to the sea (within 15 km) there exists a reasonable chance that chlorides will form the primary agent of reinforcement deterioration.

Interior Moderate

The moderate region represents an area which is conducive to the carbonation of concrete and will also allow for the corrosion of de-passivated steel. The highveld regions of Johannesburg and Pretoria will allow corrosion of steel to occur but the rate is generally low as moisture is the limiting requirement, particularly in the winter. The most likely time for corrosion of steel is during the summer months where a structure is directly exposed to rainfall. The mean annual RH for such a zone should be in excess of about 60%, (59% for the case of Johannesburg will be considered acceptable) and have an average monthly maximum in the mid to high 60's if the corrosion of steel is to occur.

Interior Mild

The final region for consideration comprises those areas where there is generally insufficient moisture to allow for the corrosion of de-passivated steel, or where the rates are so negligible as not to be of relevance. Such areas include the Karoo and arid and semi-arid regions of Bloemfontein, Kimberly, and Uptington. The mean annual RH should be less than approximately 55% with an average monthly maximum RH in the low 60's. Even within the interior mild region, corrosion of reinforced concrete is still possible where poor design detailing (for instance insufficient or poor drainage or where ponding can occur) or the nature of the structure's operation could influence the immediate environment of the concrete, such as a water retaining structure.

The degradation of concrete structures exposed to the immediate marine environment under classification of severe, very severe and extreme will be considered to be similar around the coast for the purposes of this work. In practice however there are numerous site-specific environmental characteristics (such as temperature and prevailing wind direction and strength)

which have an impact upon the degradation of reinforced concrete structures. The development and validity of the prediction models are very sensitive to environmental regions (particularly their effect upon the RH of the concrete) and thus a model, which is applicable for the coastal region, would be inappropriate for the Johannesburg or Pretoria environment. Once again the determination of the primary mechanism of deterioration can be somewhat subjective and further research, specifically in the moderate and severe zone (as classified by Mackechnie 1996^b), would be of great benefit.

It is important to realise that the RH of the environment and the RH of the concrete will not necessarily be the same. The variation in environmental RH will be significantly greater than that experienced in the concrete. It is therefore likely that in an environment where the RH varies between 60% and 80% the long-term RH of the concrete will oscillate about some point (perhaps 70%) but in a smaller band than that of the environment. The RH of the concrete will clearly be affected by the environmental RH and factors such as rainfall exposure but their exact relationship is not precisely defined. The various prediction models outlined in this chapter generally use the RH of the concrete for the experimental values but are then calibrated to site-specific structures or models in an attempt to account for environmental effects. Further information on the relationship between the specific environments and the RH of the concrete would be of significant benefit to the accuracy and validity of the prediction models.

Table 3.3 provides a summary of the likely causes of deterioration in concrete structures which are further than 1 km from the sea in the three environmental classification zones. It is reasonable to assume that the primary cause of deterioration for most (but not all) structures which are less than 1 km from the sea will be as a result of chloride ingress. Where the structure is less than 1 km from the sea the appropriate marine classification, as provided in table 3.2, should be used.

Table 3.3: Summary of Environment and Likely Deterioration Mechanism
(structures further than 1 km from the sea)

<i>Region</i>	<i>Primary Cause of Corrosion</i>
Coastal Severe Zone	<ul style="list-style-type: none"> • either chloride contamination or carbonation where the structure is closer than 15 km from the sea • carbonation where the structure is greater than 15 km from the sea
Interior Moderate	<ul style="list-style-type: none"> • carbonation induced corrosion, • rapid carbonation but low corrosion rates (Ballim and Lampacher 1996)
Interior Mild	<ul style="list-style-type: none"> • carbonation induced corrosion, • low to moderate carbonation with very low corrosion rates

Table 3.3 is essentially a modification of SABS 0100-2 (Table 3.1) and may be used to classify the environment to which a structure will be exposed. The general procedure for evaluating the cause of corrosion is first to determine in which region the structure will be situated followed by the primary cause of deterioration as outlined in the second column. If the structure is situated in the CSZ corrosion can be either carbonation or chloride-induced according to the situations described. Once again the use of sound engineering judgement is critical in those areas where there may be some doubt, particularly the region between 1 km and 15 km from the sea.

3.2 CARBONATION-INDUCED CORROSION PREDICTION MODELS

Carbonation represents a serious threat to the longevity of reinforced concrete structures. It is however a slow process that can take many years before the first signs of corrosion become evident. As carbonation-induced corrosion results in a fairly general or uniform attack on the reinforcing there will normally be ample time between the first warning signs of corrosion (cracking and spalling) and subsequent reductions in structural integrity. It is reasonable that

the time to corrosion-induced damage be given as the sum of the initiation period and the propagation period until the appearance of cracking (Sarja and Vesikira 1996).

It has been established that concrete carbonates most rapidly where the relative humidity (RH) of the concrete is between 50% and 60% (Oberholster 1996), although fairly rapid carbonation of concrete will continue up to approximately 70% RH (Hansson 1995). The corrosion of the steel however will generally not proceed where the internal RH is less than 60%. Table 3.4 provides the likely probability of corrosion of reinforcement for given relative humidities.

Table 3.4: Probability of Reinforcement Corrosion and Carbonation

(Compilation from Addis 1986, Hansson 1995, Oberholster 1996, and Watkins and Jones 1993)

<i>RH of Concrete</i>	<i>Remarks</i>	<i>Corrosion Risk</i>	<i>Carbonation Risk</i>
Concrete submerged in water	- capillaries filled with calcium hydroxide solution - CO ₂ must diffuse through filled capillaries	No corrosion risk, or small risk	No carbonation risk
90 to 95%	- pores filled with solution through which CO ₂ must diffuse	Small to large risk	Little or no risk
60 to 90%	- pores only partially filled. Water and CO ₂ can easily reach steel	Great risk	> 80% low risk 70-80% moderate risk < 70% high risk
Below 60%	- no or very little solution in pores	No risk	Greatest risk between 50 and 60% - falls off below 40%

The optimal range of RH for which damage due to carbonation-induced corrosion occurs is therefore between about 60% and 70%. Additionally factors such as cyclic wetting and drying should provide periods where the carbonation front will advance fairly quickly (dry periods) and once the steel has been depassivated the wet period will contribute to the relatively rapid corrosion of the reinforcement. The models which are discussed in this chapter do not however provide for environmental factors such as cyclic wetting and drying (for instance,

winter rainfall and summer heat and low humidity). If the environment in which the structure is being built is subject to such conditions it should be noted and the analysis modified to account for the RH variation between the periods (both environmentally and internally).

3.2.1 Initiation Period Models (Concrete Carbonation)

It has been established that the depth of carbonation is roughly proportional to the square root of time (Addis 1986, Browne 1986, Sarja and Vesikari ed. 1996). Equation 3.1 provides a general model based on empirical results for the carbonation of concrete. The coefficient 'k' is a function of the properties of the concrete and environmental conditions to which it is exposed, including the following factors (Ballim and Lampacher 1996):

- cement type,
- near surface permeability,
- carbon dioxide content of the air,
- humidity and temperature

$$d = kt^{0.5} \quad \dots(3.1)$$

where:

d - depth of carbonation (mm)

k - carbonation coefficient

t - time (years)

The carbonation coefficient implicitly takes into account the various factors previously mentioned. Quite often this formula is useful when applied to long-term site data for a particular area. Over time a data base of the depth of carbonation for given cement types, cement contents, strengths, w/c ratios, permeabilities and other characteristics of the concrete can be established and then used to make predictions for the future use of concrete in that region subject to those environmental conditions. The work of Ballim and Lampacher (1996) was based on the relationship of carbonation depth versus time for the Johannesburg area. Their results are presented as the first model.

Other work has been directed towards more precisely defining the relationship by either varying the time exponent or explicitly accounting for the particular influences. In virtually all cases the results based on empirical analysis resemble the basic formula to some extent. A fundamental formula for the carbonation of concrete was developed by Papadakis, Vayenas and Fardis (1991). The formula was derived from the physicochemical processes involved in carbonation including: diffusion of CO_2 , dissolution of solid $\text{Ca}(\text{OH})_2$, and reaction of CO_2 with CSH to name a few. Their approach represents a novel concept in the determination of carbonation depths and while there is some merit to this approach and future investigations are warranted, it will not be developed further in the current discussion on carbonation prediction models, in part due to the complex nature of the model.

Model 1: (Ballim and Lampacher 1996)

The first carbonation model represents the results of a study conducted by Ballim and Lampacher on carbonation rates in Johannesburg. The Johannesburg environment can have a wide range of average (presumed daily) RH between a maximum average of 79% (normally in February) and a low of approximately 30% during the winter dry season with a CO_2 concentration of the air of approximately 0.035% (Ballim and Lampacher 1996). The environmental conditions therefore appear reasonably favourable to the progression of carbonation. The results for the Johannesburg environment may be considered similar to those anticipated for other locations in the Interior Moderate Zone (IMZ) and, while the environmental conditions of a particular area will vary, the use of the Ballim and Lampacher model in the IMZ should provide a reasonable estimate for that region.

Tests were conducted on concrete motorway structures ranging in age from 19 to 30 years and with strengths between 20 MPa and 40 MPa. Ten structures were assessed with 45 sampled areas being considered. The depth of carbonation was determined based on cores sprayed with a phenolphthalein solution. The results of the tests indicate an average carbonation coefficient ' k ' of 3.76, with the maximum rate observed being 2.5 times the average. The majority of results for the carbonation coefficient however lay in a band between 2 and 5. The range of carbonation coefficients presented in this study is fairly broad, and may

be explained by the variations in factors such as strength of the concrete, exposure conditions and initial curing conditions. With further study however it should be possible to obtain a large set of data which could be used as the basis of a probabilistic approach for determining the carbonation coefficient. A large set of data points would take into account the variation in the measured values and allow for a probability based estimate of the time to depassivation. By way of illustration, it may be determined that there is a 95% probability that k is equal to or less than 3.7 and there is an 80% chance that k is equal to or less than 3. The use of a probabilistic assessment could greatly improve the quality of the prediction. Based on the current assessment of the results and the quantity of data available, an average value of 3.7 appears to be a reasonable estimate for the carbonation coefficient in the Johannesburg environment and may be considered 'normal' for the Highveld and applicable to the Interior Moderate Zone. The Johannesburg environment however is fairly polluted compared to other areas of the Highveld and IMZ. The ' k ' value obtained may therefore overstate the likely carbonation in other areas not subject to identical conditions. Where specific data more relevant to a particular location is available that information should be used. Furthermore it should be noted that the data is not differentiated according to strength or other characteristics of the concrete.

The time to depassivation prediction model of Ballim and Lampacher may be generally used for the Interior Mild Zone as well. Since the data available for the Interior Mild Region is either very limited or not available, the Ballim and Lampacher model may provide some measure of service life prediction, but should be used with caution. It should also be noted that the rates of corrosion in the mild region are less than those in the Highveld and surrounding area and the model would probably overstate the degree of protection required.

Probable region of validity:

climate	Interior Moderate	
	(RH) low: 47 % winter	high: 68 % summer rainfall
concrete	strength 20 - 40 MPa	Cement type: OPC assumed.
Equation:	$d = k t^{0.5}$ (general equation for carbonation depth)	
	where $k = 3.7$	

The summary of results for times to depassivation for various concrete cover thicknesses can be found in Appendix A, under the Interior Moderate Zone section. A graph of the depth of carbonation versus time for the IMZ is also shown in figure 3.3.

Similar studies would be particularly helpful if strategically selected to allow for comparisons in the Coastal Severe Zone (such as Cape Town and Durban). This approach to carbonation of concrete prediction is relatively simple and, as previously noted, the chosen format for the model is reasonably well accepted.

Model 2: (Watkins and Jones 1993)

The second carbonation model (developed by Watkins and Jones), while similar in concept to that of Ballim and Lampacher, employed a slightly different version of the carbonation equation and provided for more precise classification of the concrete based on strength. The model was based on a study of public housing blocks in Hong Kong during the late 1980s. The RH in Hong Kong generally varies from a mean daily value of approximately 70% during the winter months to a high of 84% during the summer. The mean annual RH is given as 78% with a mean annual temperature of 22.8°C. The CO₂ concentration in the air ranges from 0.03 to 0.1% in well-ventilated office blocks. The samples were generally taken from the interior of structures or in semi-sheltered locations such as balconies. It would appear, based on RH and temperature means, that the environmental conditions in Hong Kong are not very different to those found in the coastal regions of South Africa. It would be questionable however to apply the work of Watkins and Jones to the exterior of structures in coastal regions of South Africa as the effects of rainfall have not been considered.

Approximately 25 cores were taken from each of the 828 public housing blocks tested. The age of concrete varied from 5 years to just over 30 years. The vast majority of concrete contained OPC conforming to the BS12 code and the concrete under consideration varied in strength from 15 MPa to 45 MPa. The general formula used to model the results is given as:

$$d = kt^x \quad \dots(3.2)$$

where:

d = depth of carbonation (mm)

k = carbonation coefficient

t = time (years)

x = time exponent

The expression is very similar to the generally accepted formula (3.1) except that the time exponent 'x' is assumed to vary between 0.5 and 1. Watkins and Jones (1993) claim the increase in the exponent above 0.5 accounts for "fractal growth of the calcium carbonate within the pores". The number of records initially used was 14 321 and after screening to remove outliers, in accordance with Chauvebet's criteria, 14,132 results remained for the final analysis and determination of the model's coefficients.

The prediction model of Watkins and Jones may provide some use when examining possible carbonation of concrete in the interior of structures or in sheltered regions which are subject to the following conditions:

climate	Coastal Severe Zone
	(RH) Low: 70 % high: 84 %
concrete	strength 15 - 45 MPa Cement type: OPC

Once again it must be stated that the values proposed by Watkins and Jones may not be entirely appropriate for the South African environment but the development of the model, with the classification of concrete based on strength and the variable time exponent, could be of some use. A study of specific South African structures would be helpful in determining the possible relationship between certain South African exposure conditions and those of Hong Kong. In the absence of local South African data the values proposed by Watkins and Jones may be employed for the interior of structures (or sheltered structures) in the coastal region, but care should be taken. The coefficients for the carbonation prediction model are given in table 3.5.

Table 3.5: Coefficients for Carbonation Prediction Model

<i>Strength of Concrete: MPa</i>	<i>k</i>	<i>x</i>
15 - 24.99	6.43	0.570
25 - 34.99	4.28	0.592
35 - 44.99	3.07	0.614

The summary of results for the time to depassivation for various concrete cover depths and strengths can be found in Appendix A (see the section on Coastal Severe Region). The strengths in the summary chart have been grouped under 20 MPa for the 15-24.99 range, 30 MPa for 25-34.99, and 40 MPa for the 35-44.99 range. The tables provide for a range of carbonation depths for times between 5 and 120 years. A graph of carbonation depth versus time for a 30 MPa concrete in the CSZ may be found in figure 3.2. The results are reasonably close to the comparable results (for similar RH and strength) from Dhir, Hewlett and Chan (1989^a). The model developed by Dhir, Hewlett and Chan (1989^a) is presented as model 4 later in this section.

Model 3: (Parrott 1994^a)

Parrott has proposed a model which is potentially quite broad in application. The carbonation model takes into account variations in cement type (through calcium oxide content), w/c, strength and curing through permeability, and is applicable for a variety of RH. The formula is similar in concept to the generally accepted empirical carbonation model but explicitly considers the variables previously mentioned thereby allowing for a broader range of application.

The formula is given as:

$$d = \frac{a \cdot k^{0.4} t^n}{c^{0.5}} \quad \dots(3.3)$$

where:

n - is the time exponent. n is normally close to 0.5 but will decrease above RH of 70%. The lower n values account for the decreased rate of carbonation observed at elevated RH.

$$n = 0.02536 + 0.01785r - 0.0001623r^2 \quad \dots(3.4)$$

where:

r - is the relative humidity of the cover concrete (in percentage, for example 50)

k - is the air permeability of the concrete and is dependant upon the RH of the concrete. Where the permeability of the concrete is not known it may be estimated by drying a specimen at 60% RH and then testing for the permeability (Parrott 1994^a). k is expressed in units of 10^{-16}m^2 .

$$k = m \cdot k_{60} \quad \dots(3.5)$$

where:

$$m = 1.6 - 0.00115r - 0.0001475r^2$$

$$m = 1 \quad \text{if } r < 60$$

The permeability is based on measurements of the concrete under the various moisture conditions. As the air permeability of concrete is very sensitive to moisture content the drying or wetting of the concrete will significantly affect its permeability at the time of measurement. Therefore a representative sample(s) must be taken which is likely to capture the most probable or usual RH of the concrete.

a - is a calibration coefficient for particular environmental effects. a was determined to be 64 for the 'European' climate. Clearly the climate in the various regions of South Africa will differ greatly from that of Europe and for the results of the model to be applied in a meaningful manner, South African site data would have to be collected and an appropriate calibration coefficient determined.

c - calcium oxide content in the hydrated cement matrix which can react with carbon dioxide and is expressed in kg/m^3 of cement matrix. c is dependant upon the cement type, relative humidity and proportion of cement which has reacted.

Note: where c is not expressly given it can be approximated by:

$$c = \left(\frac{1000D_c}{(D_c w / c) + 1} \right) cc \quad \dots(3.6)$$

where:

D_c - is the relative density of the cement

w/c - is the water/cement ratio

cc - is the percentage calcium oxide content of the cement. This value for c assumes that 100% of the CaO will be available for conversion to calcium carbonate.

Parrott (1995) conducted a further study in which the effects of cement type and curing were tested to determine their impact upon drying and permeability of the cover concrete. A 35 MPa OPC concrete which was wet cured for 3 days had a RH of the cover concrete of 75.3% after 6 months of drying at 60% RH. The majority of concrete reached a RH of approximately 70% after 18 months of drying. The variations in RH of the concrete were fairly small after 18 months of drying and there was still a level of RH which was capable of promoting corrosion of the reinforcement and allowing for the carbonation of the concrete to occur. The permeability of the concrete measured at 6 months was 1/2 that measured at 18 months. Parrott has attributed the differences in permeabilities to variations in the RH over time. Therefore the air permeability of the concrete should be based on the expected long term RH of the concrete taking into account seasonal variations due to specific environmental conditions.

When using the carbonation depth prediction model of Parrott it is important to note the four assumptions which have been made:

1. the coefficient of carbon dioxide diffusion can be represented by the air permeability of the cover concrete,
2. the binding capacity is related to the calcium oxide content and degree of hydration of the cement,
3. variations of atmospheric concentrations of carbon dioxide can be ignored,

4. under wetter exposure conditions there is a progressive departure from the square root time function predicted by simple diffusion theory.

These assumptions are crucial to the use of the model as given in equation 3.3.

The results of this model differ somewhat from the values proposed by both Dhir, Hewlett and Chan (1989^a) and Watkins and Jones (1993) for the CSZ. As previously noted, the model developed by Watkins and Jones was based on assessment of concrete which was either in the interior of the structure or sheltered, and the work of Dhir, Hewlett and Chan was based on 'normal' exposure conditions in Dundee Scotland. The model developed by Parrott however was derived from the comparison of accelerated tests on road bridges in the United Kingdom up to 60 years of age. Therefore the direct comparison of results would be somewhat difficult and inappropriate. If the calibration coefficient '*a*' was varied to account for the specific climates then some comparison of results might be valid.

A summary of carbonation depths from the model of Parrott may be found in Appendix A. The results include both the CSZ and the Interior Moderate Zone (IMZ) and a sample of the results is graphically illustrated in figures 3.2 and 3.3. Once again it is important to realise that the calibration coefficient '*a*' is based on European (U.K.) climatic conditions, thus the direct application to South African conditions would not be advisable. In the absence of any further information however this model may provide an initial estimate for the prediction of time to depassivation of the reinforcing steel. The predicted results for three concrete types made with CEM I cement (which is 95% Portland Cement and 5% pozzolan or other extenders conforming to the European requirements) are presented in the prediction tables found in Appendix A. Concrete specifications used were:

- 45 MPa OPC concrete,

w/c ratio 0.59	Cement content 300 kg/m ³	Strength (28 day) 42.2 MPa
CaO content 65.4%	Curing 3 days wet	RH 77% and 60%
Cement Density 3095 kg/m ³		
- 55 MPa OPC concrete,

w/c ratio 0.46	Cement content 315 kg/m ³	Strength (28 day) 55.4 MPa
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CaO content 65.4% Curing 3 days wet RH 77% and 60%
 Cement Density 3095 kg/m³

- 45 MPa OPC/GGBS concrete,

w/c ratio 0.59 Cement content 320 kg/m³ Strength (28 day) 45 MPa

CaO content 59.1% Curing 3 days wet RH 77% and 60%

Cement Density 3050 kg/m³

Note: The results for the IMZ and CSZ were based on a series of graphs and values interpreted from work by Parrott (1994^b) on the Moisture Conditioning and Transport Properties of Concrete Test Specimens.

Model 4: (Dhir, Hewlett and Chan 1989^a)

Dhir, Hewlett and Chan (1989^a) have proposed a model for predicting the carbonation depth of concrete based on the intrinsic permeability of the material. The intrinsic permeability of concrete is simply the permeability in the ‘absence’ of moisture. The permeability and CO₂ diffusion depends on the microstructure of the concrete, and is thus primarily dependant upon cement type, content, w/c ratio and curing. Dhir, Hewlett and Chan’s model was based on the results of experiments in which a number of concrete mixes under various curing conditions were subjected to accelerated carbonation testing and compared to “normal outdoor exposure” conditions of Dundee Scotland (Dhir, Hewlett and Chan 1989^a). Concrete samples were cured for either 0, 3, 6 or 28 days (in water) and then tested after 28 days to determine their intrinsic permeability. The samples were oven dried at 105 °C until the change in weight was less than 0.1% over a 24 hour period (Dhir, Hewlett and Chan 1989^b). It has been suggested by Parrott (1994^b) that drying at elevated temperatures can lead to alterations of the microstructure of the concrete and thus increase the permeability of the sample above that which would be expected. A less damaging proposal for drying of the concrete might involve a longer period of time in the oven but at 50 °C which should result in less damage to the concrete. The concrete carbonation samples were placed in a carbonation-acceleration chamber with a RH of 50%, temperature 20°C, and a CO₂ level of 4%. The samples were then left in the chamber for a period up to 20 weeks. The equation based on the observed values with respect to the normal exposure conditions is given as:

$$d = (t/20)^\gamma (22.8 \log k - 6.9) \quad \dots(3.7)$$

where:

d - is the depth of carbonation (mm)

t - is the time in years

k - the intrinsic permeability of the concrete (10^{-17} m^2)

γ - the time exponent

$$= 0.5 \text{ if } w/c \leq 0.6$$

$$= 0.4 \text{ if } w/c > 0.6$$

The concept of employing the intrinsic permeability in a prediction model is particularly appealing as a number of test specimens for a variety of concretes can be made and the permeability measurements easily obtained after 28 days. The principle of using the inherent characteristics of the concrete, in the absence of site environmental conditions, to obtain estimates for carbonation performance of concretes appears to be reasonable provided the intrinsic values are compared to actual site-specific data to validate the model. The same principle as proposed by Dhir, Hewlett and Chan could then easily be applied to South Africa. The values given in this model may not however be directly applicable to South Africa as they were based on the climatic conditions of Dundee, Scotland, but the approach and methodology could be of use. As with the three other models previously mentioned, the formula (3.7) and values suggested by Dhir, Hewlett and Chan could be employed to provide an initial estimate for time to depassivation of the reinforcing steel in the absence of more appropriate site-specific data. Once again extreme caution should be taken when applying these values to the South African context.

A summary of carbonation depths for the various concrete types may be found in Appendix A. In addition a graph of carbonation depth versus time is given in figure 3.2. The carbonation results in Appendix A are for seven concrete mix designs which were based on equivalent intrinsic air permeabilities presented by Dhir, Hewlett and Chan (1989^b) as follows:

- 30 MPa OPC concrete,

$$w/c \text{ ratio } 0.7 \quad \text{Cement content } 265 \text{ kg/m}^3 \quad k_{\text{air}} = 38.7 \times 10^{-17} \text{ m}^2$$

- 35 MPa OPC concrete,
w/c ratio 0.62 Cement Content 300 kg/m³ $k_{\text{air}} = 22.3 \times 10^{-17} \text{ m}^2$
- 45 MPa OPC concrete,
w/c ratio 0.55 Cement content 340 kg/m³ $k_{\text{air}} = 12.7 \times 10^{-17} \text{ m}^2$
- 55 MPa OPC concrete
w/c ratio 0.47 Cement content 400 kg/m³ $k_{\text{air}} = 9.7 \times 10^{-17} \text{ m}^2$
- 65 MPa OPC concrete
w/c ratio 0.4 Cement content 490 kg/m³ $k_{\text{air}} = 6.9 \times 10^{-17} \text{ m}^2$
- 45 MPa OPC/FA concrete (27% Fly Ash)
w/c ratio 0.44 Cement 285 kg/m³ FA 105 kg/m³ $k_{\text{air}} = 11.5 \times 10^{-17} \text{ m}^2$
- 45 MPa OPC/MS concrete (8% Micro Silica)
w/c ratio 0.59 Cement 305 kg/m³ MS 25 kg/m³ $k_{\text{air}} = 10.9 \times 10^{-17} \text{ m}^2$

Note: - Strength refers to the 28 day design strength of the concrete. All samples wet cured for 3 days (Dhir, Hewlett and Chan 1989^b).
- Micro silica (MS) is equivalent to condensed silica fume (CSF).

Notes on the Determination of Intrinsic Permeability k

The intrinsic permeability of the concrete, as noted by Dhir, Hewlett and Chan can be useful in making predictions for the carbonation of concrete. The permeability measurements can be obtained based on a fluid flowing through the material. Ideally the fluid should not react with the concrete (at least not in the time required to conduct the test). Normally air, oxygen or water are used for assessing the permeability of the concrete. The general equation for intrinsic permeability allows for any gas with known viscosity and is given as (Cabrera, Gowripalan, and Wainwright 1989):

$$k = \frac{2vl\eta P_2}{A(P_1^2 - P_2^2)} \quad \dots(3.8)$$

Where:

- k - is the intrinsic permeability of the concrete (m²)
- v - flow rate (cm³/s)

l - length of specimen (m)

A - area (m^2)

η - viscosity of gas (2.02×10^{-5} Ns/ m^2 for oxygen)

P_1 - absolute applied pressure (bars)

P_2 - pressure at which flow is measured (bars)

By using the equation for intrinsic permeability and drying the sample such that the moisture is removed (for instance 50°C until weight change is less than 0.1% over 24 hours) it is possible to compare the results of numerous permeability tests and thereby increase the base of available data which can be used in the assessment of the carbonation of concrete.

Cape Town Site-Specific Data

One recent study involving the carbonation of concrete in Cape Town was conducted by Mackechnie (1996^a) in which a structure approximately 25 years in age (built in the 1970s) was assessed for carbonation depths. The strength of the concrete core samples ranged from 25 to 38 MPa. For the purposes of comparison in this thesis, however, and based on the range of core strengths, it will be assumed that the concrete strength is approximately 30 MPa, although the initial mix design may have been for a 25 MPa concrete. There were two general exposure conditions for the structure: essentially protected and unprotected areas. In the protected areas (not exposed to direct rain) the RH of the concrete would generally be lower and more conducive to carbonation. An average carbonation depth of about 20 mm was measured in the sheltered areas compared to 16 mm in the exposed sections. Despite the lower carbonation depth the exposed sections showed greater signs of reinforcement corrosion. It was evident that there was insufficient moisture in the protected areas of the structure to promote corrosion. The values for carbonation depths in the Cape Town study are considerably less than those suggested by Watkins and Jones (1993) and Dhir, Hewlett and Chan (1989^a). Based on the general carbonation prediction model (equation 3.1) a carbonation coefficient of approximately 3.2 might provide an initial estimate for exposed sections of 30 MPa concrete in Cape Town. Clearly more research will be required as it would be very unwise to make predictions about carbonation of concrete in the Cape Town area based on the results of only one structure. Thus great care must be taken when applying the various

prediction models and such models should not be used outside their intended region of validity.

Summary of Initiation Period Prediction Models

The estimates of carbonation depth with time for the various prediction models are graphically presented in figures 3.2 and 3.3. The estimates are based on a 30 MPa concrete with figure 3.2 representing the CSZ and figure 3.3 the IMZ. It should be noted however that the estimates from Parrott's prediction model are based on a 45 MPa concrete as there are no estimates available for a 30 MPa concrete.

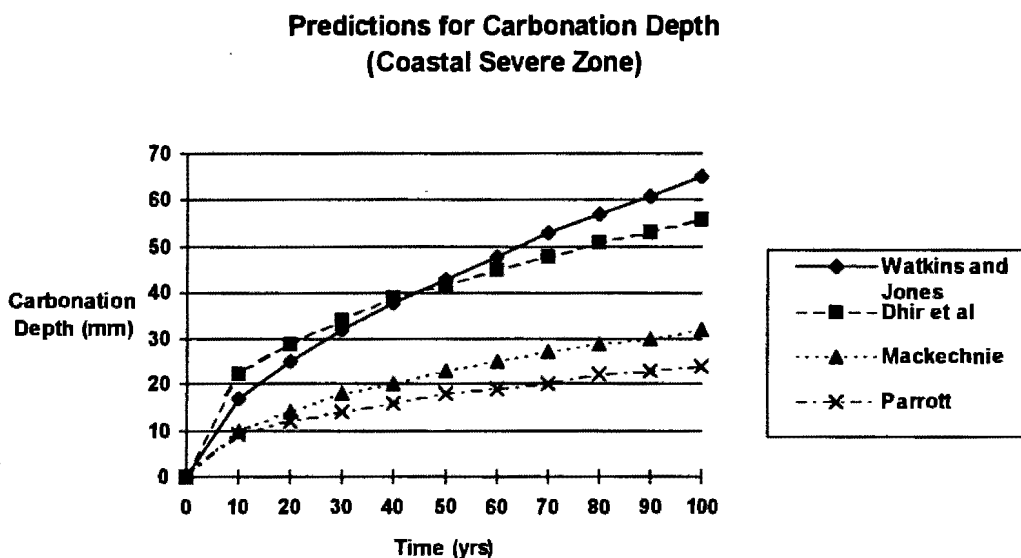


Figure 3.2: Carbonation depth estimates based on various initiation prediction models for the Coastal Severe Zone.

The values suggested by both Dhir et al and Watkins and Jones appear reasonably close, while the site-specific estimates for Cape Town differ substantially. As previously noted the Cape Town estimates are based on the study of only one structure, and thus basing predictions of carbonation depths for the entire region on that one study would be inappropriate. The substantial difference in predicted values from the site-specific information for the CSZ suggests that considerable care should be taken if the two predictive models (Watkins and Jones and Dhir et al) are to be used in the CSZ. For the results of the various prediction models to be of value they must be calibrated to account for local conditions. Further study

into the relationship between the various prediction models and structures in the CSZ would be beneficial. Values for Parrott's estimates are provided in figure 3.2 and 3.3 but as they are based on a 45 MPa concrete they are not directly comparable. In both the CSZ and the IMZ the predicted values for carbonation are greater than the site-specific values which is consistent with the conservative approach to predictions usually taken.

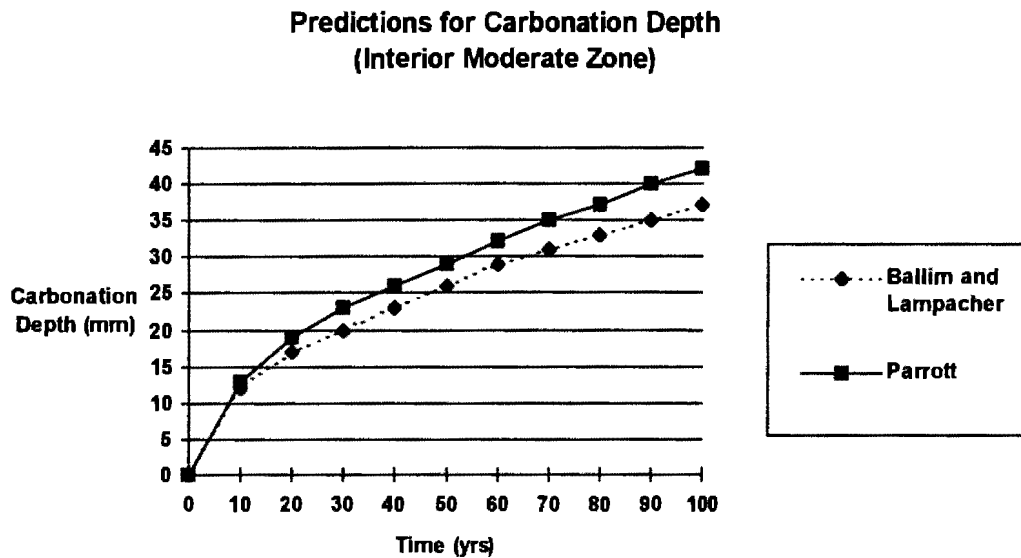


Figure 3.3: *Carbonation depth estimates for the Interior Moderate Zone.*

3.2.2 Propagation Period Model (Concrete Carbonation)

The propagation period of corrosion represents the time from depassivation of the steel until signs of reinforcement corrosion (cracking and spalling) become visible. The propagation period in a benign environment can sometimes be as long or longer than the intended service life of the structure, thus even if the carbonation front reaches the steel there is still little chance of any serious damage occurring to the structure. There are a number of models which attempt to describe the corrosion process and predict the length of time required for sufficient corrosion products to be produced which will initiate spalling and cracking. As previously noted, the corrosion of steel requires sufficient moisture, oxygen and a low resistivity of the concrete once the steel surface has become depassivated.

The moisture content and availability of oxygen is dependent on the permeability of the concrete and the atmospheric conditions to which the structure is exposed. The propagation model shown below does not explicitly take into account the variations in corrosion rates between concretes of different permeabilities. It is based on the RH of the concrete and considers effects of reinforcing bar diameter and concrete cover. The formula for propagation of reinforcing corrosion is given as (Sarja and Vesikari ed. 1996):

$$t = 80 \frac{c}{Dr} \quad \dots(3.9)$$

where:

- t - is time to cracking of concrete (years)
- c - thickness of the concrete cover (mm)
- D - diameter of the reinforcing (mm)
- r - rate of corrosion of steel in concrete ($\mu\text{m} / \text{year}$)

Equation 3.9 may be used for both carbonation and chloride-induced corrosion. A number of corrosion rates for reinforcement in carbonated concrete have been given based on the relative humidity of the concrete. Sarja and Vesikari ed. (1996) have provided a number of anodic corrosion rates which may be used to form the basis of the current analysis of propagation time for the reinforcement corrosion due to carbonation. These corrosion rates are found in table 3.6.

There are a number of problems with directly using the values suggested by Sarja and Vesikari. First there is insufficient data pertaining to the corrosion rates of reinforcement in concrete. The rates are not specific to the particular type of concrete, permeability or resistivity. They represent some arbitrary concrete mix and are not necessarily reflective of other concrete mix designs. Furthermore there is no accounting for various types of climates, or local environments where concrete resistivities can be altered. The rates are based on a standard temperature of 20 °C, thus variations in temperature would have to be accounted for in some manner.

Table 3.6: Corrosion Rates for Reinforcement in Carbonated Concrete (after Sarja and Vesikari 1996)

<i>Relative Humidity</i> (%)	<i>Corrosion Rate</i> ($\mu\text{m}/\text{year}$)
99	2
95	50
90	12
85	3
80	1
75	0.1
70 and below	0

The variations in RH must also be evaluated. Consider the Johannesburg environment for instance: the mean annual RH is 59% which would suggest no corrosion of reinforcement (if the RH of the concrete were the same), however the maximum RH (usually occurring in February) is approximately 79% and clearly any building exposed to rain will also have a higher RH in the concrete (Ballim and Lampacher 1996). The exterior concrete of an exposed structure, during the wet summer months, could have a RH well in excess of the average and therefore the probability and rate of corrosion could be much higher than the values would suggest.

Corrosion rates for reinforcement in carbonated concrete would be helpful but any rates suggested should address the concerns previously mentioned. Ideally in-situ data for corrosion rates in the various regions in South Africa should be obtained for a variety of different concrete mix designs. Those values could then be applied to the model suggested in equation 3.9 or some other appropriate model. Thus the approach which has been suggested is not without merit but any attempt to apply a general corrosion rate to a specific site would be inappropriate.

A summary of the propagation periods, as suggested by the corrosion rates found in Table 3.6, can be found in Appendix A for the CSZ and IMZ for various bar diameters and concrete

cover thicknesses. The calculated corrosion rates are for illustrative purposes only and, while they may provide some guidance in the determination of corrosion rates based on average RH, they should not be used in an actual assessment of propagation times unless other more appropriate information is not available. Even if further information is not available, the determined corrosion rates should be treated with considerable caution. The corrosion rate for the CSZ was assumed to consist of two equal periods:

1. a dry period where the mean RH of the concrete is at a low of approximately 70%. During this period no corrosion would occur.
2. a wet season characterised by rain and a mean RH in the concrete of approximately 85%. For those structures which are directly exposed to the rain the RH was assumed to be 90% for this period.

Therefore the corrosion rates for the CSZ are as follows:

- a) for structures sheltered from rain the corrosion rates are 0 and 3 providing an average of 1.5 $\mu\text{m}/\text{year}$.
- b) for structures exposed to the rain the corrosion rates are 0 and 12 yielding an average of 6 $\mu\text{m}/\text{year}$.

The corrosion rate for the IMZ was similarly assumed to consist of two equal periods:

1. a dry period where the mean RH of the concrete is at a low of approximately 50%. During this period no corrosion would occur.
2. a wet season characterised by rain and a mean RH in the concrete of approximately 75%. For those structures which are directly exposed to the rain the RH was assumed to be 85% for this period.

Therefore the corrosion rates for the IMZ are as follows:

- a) for structures sheltered from rain the corrosion rates are 0 and 0.1 providing an average of 0.05 $\mu\text{m}/\text{year}$.
- b) for structures exposed to rain the corrosion rates are 0 and 3 yielding an average corrosion rate of 1.5 $\mu\text{m}/\text{year}$.

As previously stated the estimated corrosion rates are for illustrative purposes only and their use, other than for example in this project, is not recommended. With further study on corrosion rates in the various regions of South Africa the estimates could improve and be of considerable value in estimating the propagation period and service life of structures.

3.3 CHLORIDE-INDUCED CORROSION PREDICTION MODEL

The corrosion of reinforced concrete due to chloride ingress represents a serious threat both to marine structures and those structures which are subject to the use of de-icing salts. Corrosion attributed to the use of de-icing salts is a serious problem in North America and Europe and is responsible for some 200,000 bridge decks which require repair in the USA alone (Browne 1986). Reinforcement corrosion due to de-icing salts is not of particular relevance to South Africa and, as such, the study of corrosion in reinforced concrete will be limited to the marine environment where the chlorides are a result of external ingress from the sea or where chlorides are found in contaminated ground water.

Once the chlorides have reached the steel in sufficient quantity, the propagation of corrosion may proceed quickly and the pitting action of chloride-induced corrosion can seriously affect the load carrying capacity of the structure. The service life design should therefore be considered up to the point where the chlorides reach the steel in sufficient quantity to initiate corrosion (Sarja and Vesikari 1996). Sufficient chloride concentration will be considered to be 0.4%, taken as the ratio of total chlorides to cement content. Arya and Newman (1990), state total chloride content below 0.4 % presents a low risk, 0.4 to 1.0 %, a moderate risk and above 1.0 % a high risk of corrosion.

The point at which corrosion of reinforcement becomes visible is usually associated with staining, cracking and spalling of the concrete and it is at this point that the repair and maintenance of the structure is usually first considered. Prior to this few people are concerned with the possible implications of deteriorating concrete at some future date, especially when there are no visible signs that repairs are or will be necessary. Once the corrosion becomes

visible it is possible that there is already significant loss in the cross-sectional area of the reinforcement and thus reduced load-carrying capacity of the structure. It is therefore important, from a design and operating perspective, to have some idea about the time to depassivation of the reinforcement and it could be argued that the service life of the structure should coincide with the length of initiation period (time to depassivation) and not simply the time until damage is first noticed. If the initiation period approach to design is to be used it should be done so with sound engineering judgement. If a concrete structure is submerged, for instance, or has a very low RH (although not likely to be found in a marine environment) such that corrosion is not likely to occur, the propagation period could be almost indefinite and repairs would clearly not be required at the point where chlorides reach the steel. Thus a more appropriate time period should then be established.

3.3.1 Initiation Period Corrosion Model

The primary model employed for the prediction of chloride penetration into concrete will be based on the work of Mackechnie (1996^b). There are a number of other models available such as Mangat and Molloy (1994) but they are not as applicable to the South African marine environment or as general in application. The model proposed by Mackechnie is based on a modified solution to Fick's law and is provided in equation 3.10.

$$C_x = C_s \left(1 - \operatorname{erf} \left(\frac{x}{2\sqrt{D_i t^{(1-m)}}} \right) \right) \quad \dots(3.10)$$

where:

- C_s - Chloride concentration at the surface of the concrete
- C_x - Chloride concentration at depth x (cm)
- x - depth of chloride penetration (cm)
- D_i - initial diffusion coefficient
- m - diffusion coefficient reduction factor
- t - time (seconds)

Note: Values for the error function (erf) were taken from Mackechnie (1996^b)

The surface concentration of chlorides is dependent upon a number of factors including cement type, content and curing of the concrete. It has also been established that the surface concentration of chlorides is dependent upon the chloride-binding capabilities of the cement. The determination of surface chloride content of concrete in structures where chlorides are wind-deposited is a somewhat greater problem. Under windblown conditions the chloride concentration depends upon the rate of salt deposition, rainfall, drying and pore structure (Mackechnie 1996^b). The effects of windblown chlorides (correlating to the Coastal Severe Zone) will not be discussed further in this chapter as there is little empirical evidence available. Table 3.7 provides a list of surface chloride concentrations for various marine zones and cement types based on analysis of concrete in the Western Cape.

Table 3.7: Surface Concentration of Chlorides (mass percentage of binder)
(Mackechnie 1996^b)

<i>Cement Type</i>	<i>Tidal, Splash, and Very Severe Spray</i>	<i>Severe, Moderate and Mild Spray</i>
100% OPC	3.00	1.50
30% Fly Ash	4.50	2.25
50% GGBS	5.00	2.50

The analysis does not divide the concrete into particular strengths or curing regimes but does give a general guide to surface chloride concentrations for OPC, FA and GGBS concretes. The first column of chloride concentrations would be applicable to the Extreme and Very severe exposure conditions and the second to Severe conditions.

The information required next is the diffusion reduction coefficient m . The reduction coefficient accounts for the reduction in diffusion of chlorides with time. The reduction in the rate of diffusion with time is observed in practice and can be attributed to the blocking of pores and chloride-binding and thus decreased permeability of the concrete. Table 3.8 provides suggested values for m based on the three cement types.

Table 3.8: Diffusion Reduction Coefficient (Mackechnie 1996^b)

<i>Cement Type</i>	<i>m</i>
100% OPC	0.29
30% Fly Ash	0.68
50% GGBS	0.68

The determination of the diffusion coefficient is the next stage. The diffusion coefficient used in the prediction model is based on the initial diffusion coefficient at a time of one second. The rapid chloride conductivity test, developed by Streicher at the University of Cape Town, was used as the basis for diffusion determination as it can be used relatively quickly and at an early age to determine the ease with which chlorides will penetrate the concrete (Mackechnie 1996^b). The chloride conductivity test is sensitive to both material effects (such as type and content of cement) and construction effects (such as curing), but does not directly account for long-term effects such as continued hydration of cement or chloride-binding. Therefore an accelerated test after 98 days of wet curing and exposure to a 5M NaCl solution was compared to the 28 day values and the combination of the two used to produce a modified chloride conductivity (Mackechnie 1996^b). Mackechnie has developed a nomogram which can easily be used to determine the diffusion coefficient based on the chloride conductivity with respect to cement type, time and exposure conditions. While the nomogram is very useful, for the purposes of this project, a table of two year diffusion coefficients (D_c) which was produced by Mackechnie has been converted to initial diffusion coefficients which are available for use in the prediction model (equation 3.10). The conversion from two year diffusion rates to initial diffusion rates is given by the formula:

$$\log D_i = \log D_c + m \log t \quad \dots (3.11)$$

The initial diffusion coefficients for a variety of cement types and exposure conditions are given in table 3.9 and are based on data from the Western Cape.

Table 3.9: Initial Diffusion Coefficients D_i (cm^2/s)

Cement Type	Environment	20 MPa	30 MPa	40 MPa	50 MPa	60 MPa
OPC	Extreme	1.04E-04	3.84E-05	1.19E-05	8.95E-06	6.39E-06
	V.Severe	2.56E-05	1.33E-05	7.49E-06	5.30E-06	4.38E-06
	Severe	1.32E-05	8.04E-06	5.11E-06	4.02E-06	3.29E-06
FA 30%	Extreme	1.65E-02	1.04E-02	7.03E-03	5.43E-03	4.42E-03
	V.Severe	8.04E-03	6.23E-03	4.82E-03	4.02E-03	3.42E-03
	Severe	5.63E-03	4.62E-03	3.62E-03	3.22E-03	3.01E-03
GGBS 50%	Extreme	1.37E-02	7.84E-03	4.62E-03	4.02E-03	3.42E-03
	V.Severe	7.23E-03	5.22E-03	3.42E-03	3.22E-03	3.01E-03
	Severe	5.22E-03	4.02E-03	3.22E-03	3.01E-03	2.81E-03

The values were based on tests conducted by Mackechnie for 20, 40 and 60 MPa OPC, FA and GGBS concretes with interpolations for 30 and 50 MPa values. The summary of time to threshold chloride content for the various concretes can be found in Appendix A and a graph showing the relationship between chloride penetration and time is provided in figure 3.4. The values are divided according to three marine zones of extreme, very severe and severe and are based on correlations with Western Cape structures and environmental conditions. The summary of concrete mixes is also provided in Appendix A. As the correlation of laboratory data was derived from exposure conditions in the Western Cape, it is questionable whether the values should be applied to other coastal areas such as Natal. With further research and analysis of exposure conditions in those regions it is quite likely that this approach could be effectively used there as well to provide enhanced service life predictions.

As previously noted, in the design of structures, it may be advisable to produce a structure where the intended service life is equal to the period required for the depassivation of the steel. Where the active corrosion of steel will proceed relatively slowly some allowances for the propagation of corrosion are recommended. As the data for the propagation period of chloride-induced corrosion is limited the more conservative approach of using just the initiation period is used in this project.

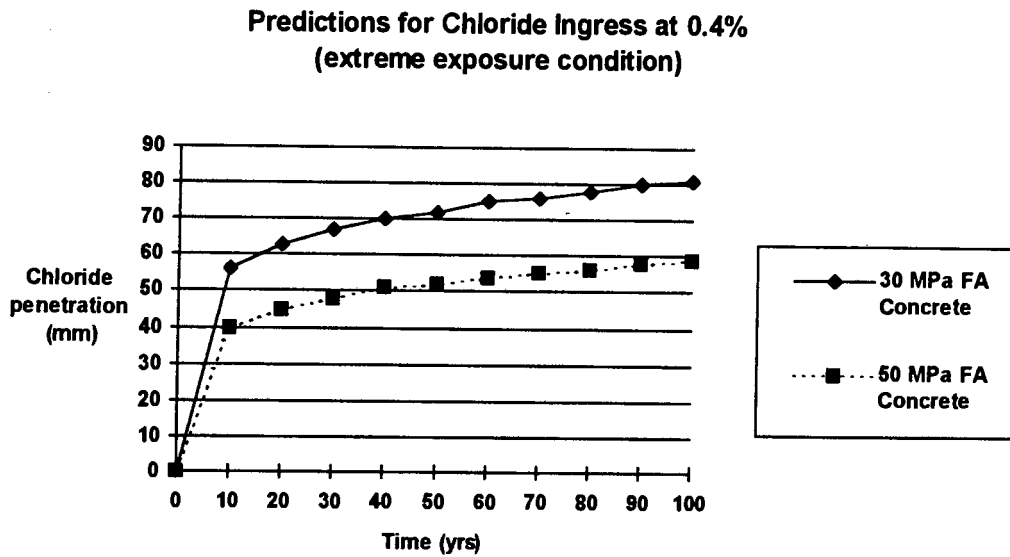


Figure 3.4: Chloride ingress for the extreme marine exposure conditions of 30 and 50 MPa Fly Ash concrete.

3.3.2 Propagation Period Model (Chloride-Induced)

There is limited data available on the time from depassivation of the steel to the first appearance of stains, spalling or cracking. One formula and set of corrosion rates for steel in chloride contaminated concrete has been proposed by Sarja and Vesikari, ed. (1996). The equation is given as (Sarja and Vesikari ed. 1996):

$$t = 80 \frac{c}{Dr} \quad \dots(3.12)$$

where:

- t - is time to cracking of concrete (years)
- c - thickness of the concrete cover (mm)
- D - diameter of the reinforcing (mm)
- r - rate of corrosion in concrete ($\mu\text{m}/\text{year}$)

The corrosion rates for steel in chloride contaminated concrete are based on various RH of the concrete and can be found in table 3.10. The corrosion rates are simply substituted into equation 3.12 and the time from depassivation to first appearance of cracks obtained.

Table 3.10: Effects of Relative Humidity on Chloride-Induced Corrosion
(Sarja and Vesikari ed. 1996)

<i>Relative Humidity (%)</i>	<i>Corrosion Rate (um/year)</i>
99	34
95	122
90	98
85	78
80	61
75	47
70	36
65	27
60	19
55	14
50	9

The chloride-induced propagation model proposed by Sarja and Vesikari ed. (1996) is essentially identical in concept and form to that of the carbonation-induced corrosion model previously discussed in section 3.2.2. The criticisms of the previous model therefore also apply to the current propagation model under consideration. The current model does not take into account variations in the cement type or content, nor does it consider specific environmental effects such as variations in RH throughout the year or direct exposure to rainfall. Furthermore, the model does not directly account for variations in the level of chlorides or the resistivity of the concrete which can affect the rate of reinforcement corrosion. The model may serve to provide an initial estimate for propagation period, but the time from depassivation to appearance of cracks is usually relatively short compared to the initiation phase. Thus the great degree of inaccuracy in the current propagation prediction model seriously limits its effective use. It is therefore advisable that the design period (whether repair period or otherwise) should be based on the time to depassivation and not include the propagation period for chloride-induced corrosion if a more appropriate prediction model cannot be found.

A summary of the propagation times for 25 mm reinforcement is provided for illustration in table 3.11. It was previously assumed that concrete in the Cape Town environment (as used in the carbonation propagation model) would have a RH of 90 % during half the year (for

structures directly exposed to the rain) and 70 % for the other half of the year. Taking an average of the two corrosion values provides for a chloride-induced corrosion rate of 67 $\mu\text{m}/\text{year}$. The corrosion rate was then applied to equation (3.12) and the time to cracking for various cover depths is presented in table 3.11.

Table 3.11: Propagation Time for Chloride-Induced Corrosion (Illustrative purposes)

Cover (mm)	Time to Corrosion Damage (years)
20	1.0
30	1.4
40	1.9
50	2.4
60	2.9
70	3.3
80	3.8
90	4.3
100	4.8

It is important once again to state that the values for the time to cracking of the concrete after depassivation are subject to a large degree of uncertainty and their use should be limited to that of an initial estimate in the absence of other more relevant or site-specific data. Their use in conjunction with the initiation period model would simply reduce the overall accuracy of the prediction as the model developed by Mackechnie (1996) makes explicit allowances for site conditions, concrete types and designs. It has been established that even where depassivation has occurred, corrosion may not necessarily follow. Consider a member which is completely water-saturated; the chlorides may reach the reinforcing in 15 years or less but no corrosion will occur as oxygen is prevented from entering. Thus there is no replacement for sound engineering judgement and expert advice when determining the probable life of a structure or a repair.

3.4 CONCLUSION

A number of models for the prediction of reinforcing time to depassivation of the steel have been presented in this chapter. The combination of the initiation and propagation periods was discussed and recommended for carbonation-induced corrosion. When using the models discussed in this chapter it is essential to note the region of validity over which they are intended to operate. For instance, the carbonation model proposed by Ballim and Lampacher (1996), while useful in the Johannesburg environment, would not be appropriate if applied to Cape Town. Similarly, the model of Watkins and Jones (1993) was based on data generally taken from the interior of structures in Hong Kong. Unless it can be established that the environmental conditions in Natal, for instance, are very similar to that of Hong Kong it would be inappropriate to use their model under those conditions.

The greatest value of these prediction models lies in the examination of the various approaches of the models and their differences. The model of Ballim and Lampacher is relatively simple with a fixed time exponent and carbonation predictions dependent only on one coefficient. The Watkins and Jones model was more developed with variations in time exponent and carbonation coefficient due to concrete strengths. The next level of advancement came from Parrott who attempted to define the carbonation of concrete more explicitly by including calcium oxide concentrations and permeabilities based on RH. The work of Dhir, Hewlett and Chan had one advantage, with respect to potential breadth of application, in that the permeability of the concrete was based on intrinsic properties of the material and thus their model may be generally applicable to other environments, provided sufficient calibration studies were made. It is the methodology and procedures of the prediction models which are important to consider. For accurate predictions to be made, the various models would have to be calibrated using in-situ data relevant to a particular location or climate. At the very least a representative calibration 'sample' should be used for each of the three climatic regions previously identified.

Similarly, the chloride prediction model is applicable to the Western Cape but with further study its use may be appropriate for other regions. The major limitation with respect to

chloride-induced corrosion rests in the lack of data for wind-deposited chlorides. There is unfortunately little information available and any predictions of service life under such conditions would be questionable at present. Further research in these areas is clearly necessary.

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4 REPAIR STRATEGIES AND SERVICE LIFE ESTIMATES FOR REINFORCED CONCRETE STRUCTURES

Any evaluation of repair strategies must include estimates for the time and magnitude of the repair. The concept of 'when to pay for durability' is very relevant to this discussion and will, to a significant extent, dictate the type of durability option to be employed. If 'sufficient' durability is not built in during design and construction, it will have to be provided later by undertaking repair and maintenance. Repair and maintenance of structures represents an economic cost for ensuring durability and this must be understood by the owners of structures. The various repair options discussed in this chapter are subsequently used in chapter seven to form part of the overall economic analysis on the cost and timing of durability options.

Before attempting to undertake repairs or maintenance on a structure, it is necessary to determine the cause and effect of the deterioration (Emmons 1994). For the purpose of the current discussion on repair and maintenance it will be assumed that the deterioration of concrete will be as a result of corrosion of the reinforcement. Reinforcement corrosion implies there is sufficient moisture and oxygen reaching the steel and the passive layer protecting the steel has been destroyed by either carbonation or chloride damage. It is from this point that maintenance analysis and the examination of alternatives can proceed.

Emmons (1994) has identified three performance objectives or criteria when considering the deterioration of concrete, namely: protection, appearance, and load carrying capacity of the structure. In most cases cracking and spalling initially represent a cosmetic effect and are not likely to impact upon structural performance. Continued corrosion of the reinforcing however can lead to a loss of bond strength and a reduction of the cross sectional area of both steel and concrete. Somerville (Ed.) (1992) has stated that generalised corrosion can reduce the cross section of the reinforcement by up to 1 mm/year, and 2 to 3 mm/year for localised pitting. Thus the cosmetic effect of cracks and spalling can quickly lead to very real structural threats particularly in prestressed structures. There are a variety of approaches which may be employed when determining the need and requirements for the repair of structures. Figure 4.1

graphically illustrates one such approach and outlines a series of steps to be taken when evaluating the requirements for repair.

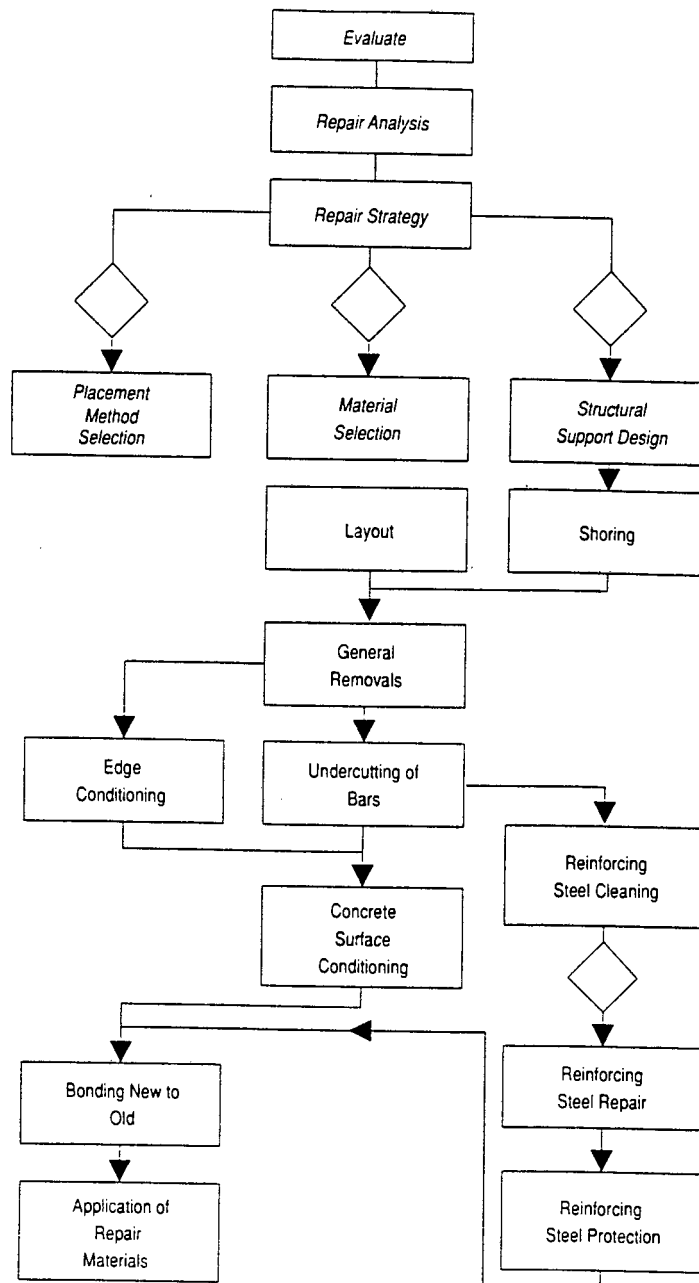


Figure 4.1 (Emmons 1994): *Procedures to be taken when examining the requirements for repair of a structure.*

Five major repair strategies and two general approaches to maintenance will be considered in this work. Repair strategies generally refer to specific applications or work required to be

performed on damaged areas of the structure. The strategies range from doing nothing and allowing the structure to deteriorate, with the only repairs in the form of propping to maintain structural service, to complete replacement of the member or element. Maintenance is somewhat broader in concept and can be used to define an overall framework within which specific repair strategies can be conducted. The first signs of a problem generally are the formation of cracks or appearance of rust staining. At this point the aggressive agents have already penetrated the concrete to sufficient depth and with high enough concentration to induce corrosion of the reinforcement. It is at the sight of these cracks and subsequent spalling that most people first start to think about the implications of deterioration and what must be done to correct the situation.

4.1 REPAIR STRATEGIES

4.1.1 Do Nothing

This form of 'repair' indicates one of a number of possibilities with respect to the state of the structure. Where the "do nothing strategy" is employed, it is likely that the deterioration is considered to be relatively minor and not worth repairing at the present; alternatively the structure may be nearing the end of its service life and it would be inappropriate to undertake extensive repairs when it will be scrapped within a few years (Mackechnie 1996). The general procedure is simply to leave the structure alone and use only structural propping as appropriate. Additional requirements however may be necessary to ensure the safety of people from falling portions of spalled concrete.

4.1.2 Application of Surface Treatments to the Concrete

Surface coatings and treatments can be used to help reduce the penetrability of the concrete and thereby limit or at least slow the rate of penetration of aggressive substances (including moisture and oxygen). There are a number of treatments available which vary in both cost and effectiveness. Two forms of surface treatment in general use are:

- *surface coatings* - these form barriers or membranes which prevent aggressive agents from penetrating the concrete. Coatings generally have low vapour transmission and can inhibit moisture in the concrete from escaping. Some precautions such as ensuring an adequate

bond between the coating and the concrete and if possible a low moisture content of the concrete should be taken when using such surfacing coatings. Surface membranes and coatings include epoxies and urethanes (Emmons 1994).

- *surface penetrating sealers* - these are used to impregnate the concrete and reduce the ingress of certain aggressive agents. Sealers normally permit the free movement of vapour in and out of the concrete. Sealers can penetrate low to moderate strength concrete to a reasonable depth thereby providing an added measure of protection. With high strength 'impermeable' concrete however their penetration is substantially reduced and their effectiveness must be questioned (Clarke (Ed.) 1993). Surface penetrating sealers include silane and siloxane-based materials (Emmons 1994).

Surface treatments will normally require fairly routine maintenance to ensure the continuity of the coating. For areas where accessibility is difficult there may be problems (primarily financial) in returning every few years to re-coat the structure. While surface coatings have been included in the section on repair strategies, they are often employed in a preventative manner to avoid corrosion of reinforcement or in combination with one of the other repair strategies after corrosion has been initiated.

4.1.3 Reconstruction of Damaged Areas

The reconstruction of damaged areas occurs once corrosion of the reinforcement has already started. Cracking and spalling of concrete will be visible and the reinforcement will have corroded to some extent. The procedure is fairly simple in concept: a) remove the contaminated material in front of and behind the reinforcing until sound concrete is reached, b) clean the reinforcing to remove all corrosion products and possibly apply a protective coating (such as epoxy) over the steel, and c) patch the area with concrete or mortar and possibly apply a surface treatment. The major problem with this sort of repair occurs at the interface where the old and new concrete meet the steel. The old concrete will still contain some level of contaminants and a new and localised corrosion site can be established involving the repaired section as the cathode. To combat the incipient anode problem it is necessary to select repair materials which closely approximate the old concrete to avoid the presence of electrical potential between the two areas (Strohmeier 1994). When cracks first start to appear, the amount of reinforcement which is actively corroding is probably fairly small and

the extent of repairs required is limited. It is at the early stages of corrosion in reinforced concrete structures that the strategy of reconstruction of damaged areas may have a reasonable chance of success in preventing or delaying further damage.

4.1.4 Cathodic Protection and Prevention of Corrosion

Cathodic protection works by impressing a current through the reinforcing and reducing its potential to a point where the passive nature of the steel is re-established. A sacrificial anode (normally a titanium mesh) is placed on the concrete's surface and connected to the reinforcement which acts as a cathode. If the potential of the steel is excessively reduced (approximately -900 mV or less) hydrogen embrittlement of the steel may occur. However, since the normal potential for cathodic protection is approximately -700 mV with a current density of 5 to 20 mA/m², there is little danger of hydrogen embrittlement. The general method of repair involves the removal of all contaminated concrete, cleaning the reinforcement and subsequent patching of the damaged area. The amount of energy required to operate the system and its associated cost is negligible and will not be considered in the overall analysis.

The principle of cathodic protection can also be applied in a preventative manner by impressing a low potential of -400 mV which will prevent pitting from initiating. If this system is used from the beginning of the structure's life no pitting will initiate and the structure will be free from reinforcement corrosion problems (Wyatt 1995).

4.1.5 Complete Replacement of Damaged Member of Section

The final method involves the complete removal and reconstruction of the damaged member. This is essentially a last resort method where the deterioration is at such a stage that the rehabilitation of the structure or member is clearly not justified. The replacement of a section or member may sometimes be used in conjunction with (or as a result of) the initial "do nothing strategy". If an initial decision was taken not to repair a member and simply prop the structure as required and it subsequently became necessary to extend the useful life of the structure, it is likely that the state of deterioration in that member will be so great that replacement is the only viable option for maintaining load carrying capacity and extending the life of the structure.

4.2 REINFORCEMENT DEPTH ESTIMATES AND THEIR EFFECT ON TIME TO DEPASSIVATION

The determination of the percentage of the concrete surface spalled or cracked presents another problem in assessing the life of a structure. It would be useful to know how much of the reinforcement has been depassivated and what percentage of the reinforcing is actively corroding. An estimate for the proportion of the concrete surface which has been affected by spalling and cracking is essential if estimates for the magnitude and costs of repairs are to be of value. One possible method for estimating the degree of spalling or cracking involves examining the distribution of cover to reinforcement and basing corrosion estimates on the percentage of reinforcement which is exposed to sufficiently high chloride concentrations. The same principle can be applied to carbonation-induced corrosion by examining the percentage of reinforcement which has been exposed to carbonated concrete. The remainder of this chapter will focus on chloride-induced corrosion but, as noted, the principles are the same for carbonation effects to which they can be easily applied.

If all the reinforcement were at the same depth, as specified in the design, it is likely that any section of the reinforcement could corrode (given sufficient requirements for the cathode, moisture, oxygen and low resistivity of the concrete). The location of reinforcement in practice however is not so exact and there will be some distribution of reinforcement depths. Thus the reinforcement where the passive layer has been destroyed will have a greater probability of corrosion than other areas of the reinforcement (*ceteris paribus*). The distribution of reinforcement depths can therefore form a basis for estimating the time to corrosion and possible extent of corrosion. For the purposes of discussion in this thesis it will be assumed that there is a direct linear relationship between the percentage of reinforcement depassivated and the percentage of surface area which is either cracked, spalled, or will potentially crack or spall in a given time period. Practically, however, this relationship is only an approximation since clearly not all of the depassivated reinforcement will actively corrode and furthermore a fairly small portion of corroding reinforcement can have a significant effect on the proportion of cracking or spalling visible on the concrete's surface. It will further be assumed, for the purposes of discussion in this work, that the distribution of reinforcement is normally

distributed about the stated design value for cover. The distribution of reinforcement depths is dependent on a number of factors including the expertise and history of the particular contractor. One contractor may have a fairly narrow distribution of reinforcement depths while another may have a much greater variation. It is also possible that the distribution of reinforcement does not actually follow a normal distribution and may be skewed to some extent. Further research on the distribution of reinforcement depths would therefore be helpful. For the purposes of illustration later in this chapter a statistical coefficient of variation of 20% of the design cover will be assumed as standard. If this approach is to be employed and there is data available for a particular contractor or structure, that information should be used to determine a likely profile of reinforcement depths.

The assumed distribution (in this case a 20% coefficient of variation under normal distribution) of reinforcement depths for each design cover can be easily plotted and the time taken for the chlorides to reach a certain percentage of the reinforcement can be determined based on the predictions for chloride penetration as outlined in chapter three. Table 4.1 provides the maximum depths for a given percentage of reinforcement within contaminated concrete based on a series of design covers. For instance a structure with a stated design cover of 30 mm would have 10% of the reinforcement at a depth of 22 mm or less and 60% of the reinforcement at a depth of 32 mm or less. The values for table 4.1 are based on a coefficient of variation of 20% but a similar table can be easily constructed for any coefficient of variation desired to suit the specific conditions of the site and contractor.

Table 4.1: Normal Distribution of Reinforcement (coefficient of variation = 20%)

Design Depth (mm)	Maximum Depth of Penetration of Contaminants (mm)									
	Percentage of Reinforcement Within Contaminated Concrete (%)									
	10	20	30	40	50	60	70	80	90	99.9
20	15	17	18	19	20	21	22	23	25	32
30	22	25	27	28	30	32	33	35	38	49
40	30	33	36	38	40	42	44	47	50	65
50	37	42	45	47	50	53	55	58	63	81
60	45	50	54	57	60	63	66	70	75	97
70	52	58	63	66	70	74	77	82	88	113
80	60	67	72	76	80	84	88	93	100	129
90	67	75	81	85	90	95	99	105	113	146
100	74	83	90	95	100	105	110	117	126	162

Table 4.1 assumes the contractor will achieve a normal distribution of reinforcement about the design depth. Very frequently however the design cover depths are not achieved and the mean of the actual reinforcement depths is less than the stated cover. A lower mean cover depth will seriously affect the distribution of reinforcement and compound the durability problem. Table 4.2 illustrated the effects on a normal distribution (for a 20 % coefficient of variation) where the mean cover depth is 20 % less than the stated design depth. For illustrative purposes design depths of 30 and 60 mm were chosen.

The effects on the distribution of reinforcement of a lower mean cover depth are clearly seen in table 4.2. 10 % of the reinforcement would be at a depth of 22 mm or less for a 30 mm design depth. Where the actual mean achieved was 20 % lower (24 mm), 10 % of the reinforcement was at a depth of 18 mm or less. The decreased cover over the first 10 % of reinforcing may represent a substantial reduction in the time before the first appearance of cracking or spalling.

Table 4.2: Normal Distribution of Reinforcement (coefficient of variation = 20%) with a 20 % Reduction in Achieved Cover Depth

Design Depth (mm)	<i>Maximum Depth of Penetration of Contaminants (mm)</i>									
	Percentage of Reinforcement Within Contaminated Concrete (%)									
	10	20	30	40	50	60	70	80	90	99.9
30 design	22	25	27	28	30	32	33	35	38	49
24 achieved	18	20	22	23	24	25	26	28	30	39
60 design	45	50	54	57	60	63	66	70	75	97
48 achieved	36	40	43	46	48	50	53	56	60	78

The usefulness of the various prediction models outlined in chapter three can be further enhanced if there is data pertaining to the variability of the penetration and corrosion rates. The ingress of chlorides and carbonation of the concrete is a probabilistic process with numerous variables. It is unlikely that carbonation rates for two 20 MPa concretes will be identical and as such there is some variability in the results. If the variability in results could be analysed it would be possible to produce a probabilistic distribution of penetration depths with

time. The integration of the reinforcement depth distribution with the penetration probabilities would produce a more realistic model which expressly states the uncertainty associated with predictions involving the deterioration of concrete. Further research into the variability of penetration rates associated with the various prediction models would improve their usefulness, particularly when integrated with the distribution of reinforcement estimates.

4.3 ASSESSMENT OF USEFUL LIFE OF REPAIR SYSTEMS

The quantity and usefulness of information available on the life of repairs of concrete structures is very limited. What is known is that repairs are often short-lived and further maintenance is required. Deterioration of surface treatments under abrasion or ultraviolet light and the incipient anode problem in patch work, all contribute to the rapid deterioration of repaired concrete. Assigning accurate figures to the life of a repair option is questionable given the current state of knowledge. With further work in this field the usefulness of the information is expected to improve and more realistic data should become available.

The following discussion attempts to provide some ideas on the life of repair options. It is important to realise that the life of the repair is dependent upon the specific environmental conditions to which the structure is exposed, the original materials used in construction, the repair materials, and quality of workmanship of the repair, to name but a few factors. Therefore the discussion on service life of repairs is meant simply to provide additional information and outline requirements for a reasonable assessment. Where values are given they should only be taken for the purposes of illustrating some of the ideas which may be useful in assessing the viability of the repair options and allowing for some degree of numerical comparison among the options.

4.3.1 Surface Treatment

The use of surface protection for concrete structures has been suggested as one form of protection or preventative maintenance. There is a wide variety of surface treatments available as previously stated, broadly falling into the categories of coatings and penetrating sealers.

The effectiveness of coatings is very much dependent upon the quality of the surface preparation. Ideally the concrete should be dry to prevent the build-up of moisture behind the surface coating. Debonding between the coating and the concrete may occur even where the surface has been well prepared and this is generally due to the differences in thermal properties and possible temperature variation between the two layers (Bijen (Ed.) 1989).

The use of surface impregnators (penetrating sealers) has the advantage of restricting the absorption of water by the concrete and at the same time allowing the concrete to 'breathe' and water vapour to escape. It has been suggested that surface impregnators will generally have a useful life of approximately 10 years or more (Bijen (Ed.) 1989), based on European climate conditions. As the estimate for the useful life of surface impregnators was based on the European climate, the direct application of the estimate to South Africa would be inappropriate. For the purposes of comparison among the repair alternatives in this work however it will be assumed that, where surface impregnators are used to prevent the ingress of contaminants, they will need to be replaced (or re-applied) every 10 years. The use of surface coatings will also be assumed to have a 10 year life (for the purposes of discussion in this work) at which point replacement will be necessary. Individual surface treatment compounds will clearly vary in effectiveness and life. Specific information, where available, should be used to form the basis of comparison. Upon replacement of the surface protection it may be necessary to clean the concrete surface and remove any of the old coating or surface deposits before the application of the new surface protection system.

For the purposes of comparison of various repair and design options, the use of a surface protection material will imply the surface treatment is being used as the primary means of protecting the reinforcing steel and the concrete cover will be based on the minimum code requirements for that situation. The use of surface treatments for protection of concrete will be compared to other repair and maintenance options later in this chapter.

Practically, surface protection should be used to enhance the performance of concrete and not as a replacement for high quality concrete. To assume that a relatively thin coating applied to the surface of concrete has the ability to prevent the corrosion of steel seems a bit wishful. The

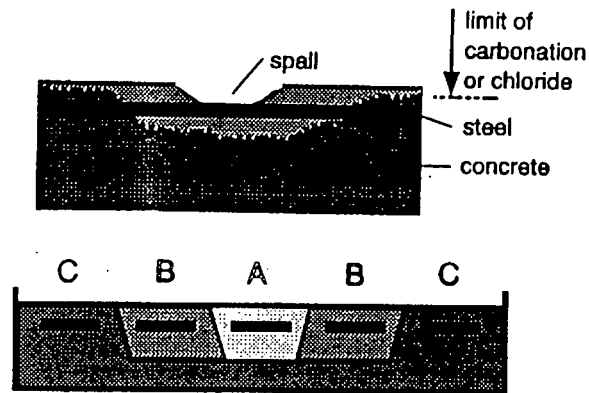
cracking of concrete, abrasion and possible ultraviolet damage after the application of the surface treatment could seriously affect the integrity of the coating and its ability to enhance the durability of the concrete. Furthermore, the effectiveness of applying a surface treatment after the reconstruction of a damaged area must also be questioned. It is quite likely that where chloride corrosion has occurred and a patch repair initiated there will still be sufficient moisture, oxygen and chloride content in that member to maintain reinforcing corrosion even with the application of a surface treatment. The site of corrosion may shift but within a relatively short period of time the signs of corrosion may become visible again. Once corrosion does resume, spalling and cracking will occur and the integrity of the surface treatment will be destroyed. Therefore it seems reasonable that if a surface coating is to be applied it should be done as a preventative measure before corrosion has initiated.

4.3.2 Reconstruction of Damaged Areas (Patch Repairs)

The reconstruction of damaged areas represents a fairly major and potentially expensive undertaking. A recent study conducted by Schiebl, Breit and Raupach (1994), investigated the effects of various repairs on the corrosion rates. The test was designed to simulate macro-corrosion conditions in which a portion of the concrete had a chloride concentration below the critical value, a section with the chloride content above the critical concentration but with no visible damage and a third section which had both a critical concentration of chlorides and visible damage. The visibly damaged section was repaired by breaking out the damaged section and replacing it with an alkaline repair mortar according to the "Guidelines for Protection and Repair of Concrete Components Part 1", as stated by the German Committee on Reinforced Concrete (Schiebl, Breit and Raupach 1994). The area of chloride-contaminated concrete without visible damage was not replaced to simulate conditions in which a local patch repair is conducted without removing all the contaminated concrete. Figure 4.2 clearly illustrates the three zones present in the experiment. The investigation was further developed to examine the effect of epoxy coating of reinforcement in the repaired sections.

The results of the experiment showed that corrosion was re-initiated in the region adjacent to the repaired section where chloride-contaminated concrete remained. Furthermore the effect

of coating the reinforcement may have slowed down the deterioration in the samples (by effectively removing a section which would otherwise have been cathodic) but in a real situation the repair would normally represent a minor portion of the total steel and thus the overall cathodic reaction would not be significantly affected by the application of a coating on the reinforcement. Thus the dangers associated with not removing the entire area of chloride-contaminated concrete (in excess of the critical level), have been clearly demonstrated as corrosion resumed shortly after the repairs were completed.



A - repaired area

B - chloride contaminated

C - undamaged area

Figure 4.2 (Schiebl, Breit and Raupach 1994): *Illustration of the situation in a concrete member which has been repaired using commonly employed patch techniques where chloride-contaminated concrete remains after the repair.*

Possible Estimates for Repair Life

From the preceding discussion it is clear that, for patching of damaged areas to be of any value, all the contaminated concrete (with a critical level of chlorides) in contact with the reinforcement should be removed. The removal of all contaminated concrete does not always happen however and thus it is important to be aware of the life of a patch repair under two scenarios:

1. Where all chloride-contaminated concrete at or above the threshold level has been removed from around the reinforcement

The removal of all concrete in which chlorides have reached or exceeded the threshold level in contact with the reinforcement could represent a sizeable portion of the total amount of cover

concrete. It is therefore important to have some estimates for the quantity of material which will have to be replaced and the approximate period when the repair will be required. It was previously noted that one method for estimating the time until repair was based on estimates of reinforcement distribution and the time until chlorides reached a certain percentage of the reinforcing. Once the concentration of chlorides at the reinforcement surface is sufficient, the time until cracks become visible can be fairly short. The same principle for estimating time to corrosion can also be applied to an assessment of repair life.

Once a repair has been completed and all the concrete has been replaced, corrosion would only initiate again once the threshold level of chlorides was reached in the surrounding concrete. Emmons (1994) has stated that an epoxy coating may be used to insulate the reinforcement from the surrounding concrete when a section of deteriorated reinforced concrete is repaired. There is some debate as to the effectiveness of epoxy coatings in preventing further damage to repaired areas but, for the purposes of numerical comparison of alternatives in this project, it will be assumed that corrosion does not re-initiate in the repaired region. Under this assumption corrosion of reinforcement would only initiate again once the chlorides have penetrated to a greater depth and in sufficient quantities in unrepaired areas. The time between repairs may therefore be estimated by defining acceptable bands of deterioration within the distribution of reinforcement. For example, assume that it has been deemed acceptable to allow for 15% of the surface to be cracked or spalled before repairs are undertaken. Once that region has been repaired, corrosion will again become visible and repairs required when the chlorides reach the next 15% of reinforcement lying in the next corresponding depth band.

Example:

Consider a 40 MPa OPC concrete column with a 60 mm cover under severe marine exposure conditions. According to table 4.1 (and assuming a 20% coefficient of variation in reinforcement depth distribution), 15 % of the reinforcement is at a depth of 48 mm or less. Using the chloride-penetrating model developed by Mackechnie the first 15 % of the reinforcement would be subject to potential corrosion conditions after approximately 20 years. If repairs were initiated at this stage the next set of repairs, associated with the

subsequent 15 % band, would be required once the chlorides penetrated the concrete to a depth of 54 mm. The time between the first and second repairs in this case would be 10 years.

In practice however there are numerous factors which will influence the longevity of the repair and integrity of the epoxy coating to the steel including: ease of access, removal of all corrosion products, and thorough application of the coating. Furthermore there may be some difficulties in applying an epoxy coating around the interior side of reinforcement even when the concrete is removed from behind the immediate repair site. The various practical limitations should be considered when assessing the likely life of a repair option and attempting to assign a particular value to it.

In a recent study of two parking structures by Bickley and Liscio (1997), two sets of repairs were conducted and their performance monitored over a number of years. The repairs consisted of removing all the delaminated concrete to a depth of 25 mm below the top mat of reinforcing, cleaning the reinforcement and applying an epoxy coating, and repairing the concrete with a 30 MPa air-entrained concrete. Approximately 33 % of the top surface was repaired and a surface treatment applied in 1988. The results and repair for the second structure were fairly similar and will not be discussed. By 1995 it was observed that roughly 8 % of the total top surface had delaminated and, based on extrapolations from the previous year's data, it was estimated that by 1998 approximately 37 % of the top surface would once again be delaminated. It was also determined that the majority of damaged areas lay outside the repaired region, and thus the repair itself was reasonably successful. It seems likely that there were still significant portions of the concrete with elevated chloride levels that were not removed at the time of initial repair which could have led to corrosion in areas not previously active. The structure would therefore require additional repairs after only 10 years, equal to greater than the quantity of the first repair. Thus the estimates for the repair life of structures presented in this chapter are only intended as a basic guide, and where more accurate forecast data is available those estimates should be used.

The interface between the replaced concrete and the original concrete represents an area of concern for a number of reasons. It is probable that the reinforcement adjacent to the repair

will be in the region where chlorides will reach a critical level next. There will already be elevated levels of contamination (though not critical) and the time to depassivation will therefore be shorter than for a region which is free of chloride contamination. Furthermore the physical and chemical difference between the repaired concrete and the original concrete may have an electro-chemical implication due to differences in resistivity and a corrosion cell may be quickly formed. It is quite likely that a portion of the initial repair will have to be replaced as expansive pressures from newly formed corrosion sites will exert an influence on the entire region around the 'localised' corrosion.

2. Where a portion of the chloride-contaminated concrete, above the threshold level, remains in contact with the reinforcement.

If only a portion of the chloride-contaminated concrete is removed, it is likely that an incipient anode will be established very quickly and the repair will have been of little value. After the addition of water to the experiment performed by Schiebl et al (1994), the corrosion resumed after a period of approximately 100 days. It is reasonable to suggest therefore that the time until the next repair (appearance of stain, cracking and spalling) may be approximated by the propagation time estimates for the original concrete. Schiebl et al (1994) have also suggested that repairs of this nature may in fact hasten corrosion in the unrepaired section, thereby further reducing the time until repairs once again become necessary. Variations in the resistivity of the concrete, chloride content, moisture and oxygen content may all lead to the rapid formation of macro-corrosion cells after repairs. If the concrete is permitted to dry while repairs take place, the corrosion rate will be influenced by the lower moisture content and thus the diffusion of water and oxygen through the concrete will also have to be considered. The addition of a surface treatment to the concrete may also have some effect but, as previously noted, it is unlikely that a surface coating will prevent the continued corrosion of the reinforcement or even delay its onset. Thus repairs where all the chloride-contaminated concrete in contact with reinforcement is not removed contribute very little to the life expectancy of a structure and may actually accelerate the entire corrosion process. Clearly this type of repair is to be avoided.

4.3.3 Cathodic Protection

It has been argued that cathodic protection is the only proven method for stopping corrosion of reinforcement once it has started (Bijen (Ed.) 1989). Cathodic protection can be used in either a preventative manner or in response to degradation and corrosion which is occurring. The discussion in this work will focus on the use of cathodic protection once corrosion has begun. There are a number of components to the overall cathodic protection system including:

- DC power source
- anode system (conductive overlays to act as anode)
- conductive electrolyte (concrete)
- cathodic system (the reinforcing itself must have electrical continuity)
- electrical connection cables
- monitoring devices (such as reference electrodes).

Of primary importance to the assessment of life expectancy of a cathodic protection system is the durability of the anode overlay and the connecting cables which link the reinforcement to the power source and the anodic area. Bijen (Ed.) (1989) has suggested a minimum service life for the anodic system to be 20 years or more. The design and selection of the cables and connection system should be consistent with the requirements of the overall cathodic protection system. Therefore using a cable with an estimated service life of 20 years when the design life of the anode and other components is 50 years would be inappropriate. The durability of the system is very much dependant upon the current densities: excessive current densities will cause the anode to degrade more quickly than expected and at very high current densities hydrogen embrittlement of the steel is possible (Bijen (Ed.) 1989). The reported lives of the anode overlay vary considerably. A titanium mesh for instance can last from 25 to 100 years (Wyatt 1995). It has been suggested by Clarke (1993) that the cathodic protection system should be costed over a 40 year period. When assigning a life to cathodic protection it is important to determine the type of anode which is to be used and any specific information available from the manufacturer and test data. As cathodic protection of reinforced concrete structures has not been available for an extended period of time, it is unlikely that specific long-term test data is available. In the absence of other information and for the purposes of illustration to allow for numerical comparison of alternative durability

strategies in this work it will be assumed that cathodic protection has a service life of 40 years as suggested by Clarke (1993) at which point the anode and connections must be replaced, or corrosion of the concrete will proceed.

Table 4.3: Summary of the useful life of various repair options

<i>Repair Methods</i>	<i>Possible Useful Life</i>
Surface Treatment	approximately 10 years (based on European data)
Reconstruction of Damaged Areas	variable, depends on rate of penetration of contaminants <ul style="list-style-type: none"> • complete removal of contaminated concrete - 10 years or more • partial removal of contaminated concrete - fairly short (a few years)
Cathodic Protection	variable, depends on components of system a minimum of 20 years

Table 4.3 provides a brief summary of the possible useful life of various repair options. The service life of repairs is highly variable and it is essential to have appropriate product information from the manufacturer, contractor and other sources.

4.4 APPROACHES TO THE REPAIR AND MAINTENANCE OF REINFORCED CONCRETE STRUCTURES

There are two general approaches to the planning and implementation of maintenance alternatives which will be considered. The first approach seeks to make repairs to the structure according to a routine schedule. The degree of damage and hence magnitude of repairs may vary but the intervals between repairs are the same. The second alternative considers there to be an acceptable level of deterioration at which point repairs are initiated. In this case the time between repairs may vary but the magnitude of repairs should be relatively constant. For

example, it might be considered appropriate that 15% of the surface of the structure is either cracked or spalled before repairs are undertaken and then subsequently repaired every time another 15% becomes visible.

The two approaches are similar in that both make use of the various repair alternatives previously discussed and have the same goal of maintaining the serviceability of the structure. The differentiation in alternatives is essentially to accommodate the various administrative or planning demands of the organisation responsible for the serviceability of the structure. The regular-interval-approach (RIA), for instance, might be appropriate when employing the surface protection/prevention strategy with fairly routine requirements for treatment and renewal. The RIA may also be of use when trying to allocate budgets for repair and maintenance. This approach allows for the establishment of regular payment intervals and lends itself well to various discounting of cash flow approaches. With the RIA it is likely that the magnitude of the repairs, and thus cost, will increase with time as more of the reinforcement becomes depassivated and subject to corrosion conditions (based on the assumptions for distribution of reinforcement and time to depassivation as stated earlier in this chapter). The increasing quantity of repairs and cost can be accounted for by applying a factor to accommodate the potential increase in damage.

The second approach, the constant percentage method (CPM), may be appropriate when a repair strategy of patch repairs of damaged sections is used. The CPM is useful in that it permits a maximum state of deterioration before repair and is more sensitive to the actual rehabilitation requirements of the structure. Regardless of which approach is used, the set of underlying assumptions and data requirements are very similar. Ultimately the selection of maintenance intervals and amount of degradation which is acceptable before repair should be at the discretion of the owners or managers, provided those decisions do not adversely impact upon the safe operation of the structure. The two approaches are best illustrated by an example which will be presented in section 4.4.1 of this chapter.

4.4.1 Specific Examples of Repair Strategies

A number of the possible repair strategies for reinforced concrete structures have already been presented. The choice of a particular repair strategy and approach to maintenance planning is up to the discretion of the owners or operators. This section will present a comparison of a number of specific options for repair of structures. As previously noted there are numerous factors influencing the decision to repair and the following example is based on simplifications and assumptions previously stated in this work. The options outlined in this section will be subsequently discussed in chapter seven in the context of the economic considerations presented in chapters five and six. An illustration of the economic optimisation of designing for durability and selection of repair strategies will then be presented in a numerical example.

The selection of acceptable degradation and repair intervals is to some degree subjective. It is one of the objectives of this work, however, to provide a rational economic basis for repair decisions and thereby remove some of this subjectivity. The values suggested in this example are for illustrative purposes and should not necessarily be considered as recommended values. The selection of an acceptable degree of degradation and repair intervals should be left to the individual conducting the investigation subject to sound judgement and a rational approach. For instance, the selection of a repair interval of 40 years would probably be excessive while 2 years may be too short. A number of repair intervals should be considered and the one found to be the most economically viable chosen.

Option 1: Application of protective coating to concrete

As previously discussed the application of a protective coating should be more of an early preventative measure than a repair method. It is assumed that the protective covering will need to be replaced every 10 years, and the following maintenance required:

- high pressure water-sand jet cleaning of the surface to remove any previous coatings, growth or loose concrete
- filling of non-structural cracks and surface blemishes
- application of a surface coating, either a barrier coating or surface impregnator.

Option 2: Permit 15% spalling of surface before repair

The second option is essentially the repair of damaged areas when 15% of the surface is either cracked or spalled. The determination of percentage spalled would normally be based on a visual assessment of the surface but, as previously noted for the purposes of this example, the relationship between visual cracking and the distribution of reinforcement will be considered a valid indicator. The repair of damaged areas is assumed to entail (Strohmeier 1994):

- removal of all contaminated concrete which is in contact with reinforcing, up to a depth of 20 mm behind the reinforcing (or to below threshold level of chloride contamination)
- high pressure water-sand jet cleaning of the surface to remove any previous coatings, growth or loose concrete
- high pressure grit blasting to remove all iron oxides from the steel
- application of anti-corrosive coating to reinforcing
- application of bond agent to spalled area to ensure adequate bond
- patching of spalled area
- application of surface finish to fill any small cracks or holes
- application of protective surface coating.

Option 3: Permit 30% spalling of surface before repair

The third option is very similar to the second, except 30% of the surface is permitted to exhibit spalling or cracking before repairs are initiated. The repair follows an identical process to that of option 2. The difference is the greater volume of material which must be removed and patched.

Option 4: Cathodic protection

The use of cathodic protection will be assumed to take place once 35% of the surface has exhibited either spalling or cracking. If repairs to the structure were not initiated at this point it is possible that there would be substantial reductions in the cross-sectional area of the reinforcement and the load carrying capacity of the structure. It was previously stated that anode and cable system will have a useful life of 40 years. Thus after 40 years the system will either have to be replaced or the structure allowed to follow the normal course of degradation.

A titanium mesh is assumed as the anode and all civil and patch work conducted in a similar manner as previously discussed.

As noted earlier in this section an example will be presented in chapter seven which will illustrate the relationship between the various repair options and cost over the life of the structure.

4.5 CONCLUSION

Accurate forecasting of repair and rehabilitation requirements of structures is of fundamental importance to validity of service life predictions and financial planning and evaluation. A number of possible repair strategies and approaches to maintenance planning have been outlined in this chapter. The accuracy of the prediction models however is not entirely satisfactory and further research is clearly needed in this area. A number of suggestions have been made which allow for the simplification of the prediction process and attempt to provide a practical approach to the problem. These simplifications include:

- a direct linear relationship between percentage of reinforcement in contaminated concrete and the percentage of the surface cracked or spalled
- a normal distribution of reinforcement about the design value with a coefficient of variation of 20 %
- assumption of service life of repair options as noted in table 4.3

Where more precise or accurate information is available, such information should be used. The predictions for repair and rehabilitation of structures represents the greatest component of inaccuracy of the entire analysis in this work. Four repair options were outlined in section 4.4.1. These options will be compared in chapter seven to other design criteria, such as a 'maintenance free' structure where the chlorides (at a critical level) reach the reinforcement coincident with the end of the service life. The various design and repair alternatives are evaluated according to economic principles and will allow for more informed decision making with respect to the durability and design of reinforced concrete structures.

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5 ECONOMIC PRINCIPLES OF CONSTRUCTION AND PROJECT EVALUATION

The principles and approaches governing capital investment decisions and capital intensive projects in general are vast and a comprehensive review is well beyond the scope of this project. It is important, however, to be aware of some of the fundamental concepts in investment decisions and the impact that various real world events such as inflation, taxes and risk have upon determining the success of any particular project. Engineers are not isolated from the economic world and the decisions taken at the design and development stage have a fundamental impact upon the overall cost of the project. As Hetherington et al (1976) have stated, the role of economic analysis as applied to engineering is to assess the real cost of using resources in order to establish priorities between competing proposals. The concept of comparison between engineering options is one of the underlying premises of this work which should be kept in mind.

Ahuja and Walsh (1983) have outlined three components which are considered to be essential for economic evaluation:

1. Forecasting
2. Capital project evaluation methods
3. Risk and uncertainty analysis.

The three components mentioned are essential if an analysis is to be thorough enough to allow for informed decision making.

The basis of economic decision making is derived from the use of models, whether for the forecasting of future inflation figures or the discounting of some future cost. Models are essentially attempts to mimic the real world in some way, thereby allowing for the prediction of future events. Any model is a simplification and generalisation which implies there is a certain limited region over which the model is valid. A step outside that region will cause the model to produce misleading results (Wahlstrom 1994). For the results to be of any value it is

therefore necessary to have a clear understanding of the underlying assumptions. There are four general categories of models:

- *Static* - implies no time dependence. There is an instantaneous transfer of information between cause and effect.
- *Dynamic* - time dependence is involved. Time constants are required.
- *Deterministic* - an identical output will always be produced when a specific input is applied.
- *Stochastic* - a mechanism of chance is involved. Stochastic models can be used to estimate probability distributions by repeated simulations.

The four model categories have a number of implications which determine both the ease of use and, to some degree, the limits of the model.

5.1 FORECASTING AND ESTIMATING

Forecasting is concerned with making predictions about future events based on a set of assumptions. Should it be proven at some stage that the assumptions are invalid then it is very likely that any forecast or predictions (no matter how good the model) based on those assumptions will be inaccurate. Forecasting remains an important tool in the planning of any project and can be used, for instance, to make predictions about the future cost of repairs. If construction costs increase at 10 % per annum but the average level of price increase in the economy is 5 % per annum and only the general inflation rate (5 %) is used, that simplified assessment of 'inflation' would seriously underestimate the true cost associated with repairs at some future date. The reduction in the estimated costs associated with the repair of the structure would thereby influence the initial design of a structure (assuming it was derived on a life cycle cost basis). Thus accurate forecasting is essential for engineers concerned with the development and management of projects. There are numerous models and methodologies in use for estimating future events. Ahuja and Walsh (1983) identified four main concerns or focuses in forecasting; market trends, market analysis, organisational analysis and the business environment.

Market Trends

Ahuja and Walsh (1983) have defined market trends as those events which are considered to be beyond the control of the individual company or organisation undertaking the analysis. Market trends refer to general patterns in society governed by the economic, sociological, political and technological environments within which the organisation operates. The construction industry, for instance, is not normally subject to sudden technological changes and designs are generally based on the requirements of established standards (Ahuja and Walsh 1983). While technological changes are a major concern in the communications or computer industry their effects impact less quickly and drastically upon the construction industry.

The construction industry is an important sector of the economy with annual concrete production alone estimated at over one ton for every man, woman and child on earth (Hansson 1995). In times of recession or government down-sizing and expenditure reductions, infrastructure development and large capital projects may be one of the first areas to go. It is important therefore to have some idea of the primary environments which should be monitored (economic and political for construction related industries) and the general direction and trends in society which form a basic level for predictions about which variations may occur.

Market Analysis

Market analysis is used to establish and examine the immediate environment surrounding the organisation. For a business to operate effectively it is necessary to have a well defined knowledge of the organisation and its position in the market, whether that be as a market leader known for its innovative approaches to design and construction or as an efficient low cost supplier. Regardless of where the organisation is situated, an objective view of its position in the market is essential. The major relationships which must be established relate to the competition in the industry for labour, resources and the nature of the organisation's target market. Such information is vital when examining the effect of certain market trends or events. If it is difficult for an organisation to attract workmen when the economy is sluggish, it will be that much harder when there is greater competition for those resources during boom times. An examination of the specific differences in opportunities, markets and ability to react to change

between organisations is crucial when evaluating an individual firm's likely growth and not simply that of the market in general. The results of organisational specific market analysis can greatly improve the accuracy and reliability of forecast data to be employed in the decision making process of a project.

Organisational Analysis

Organisational analysis is important from the perspective of being able to take advantage of the various changes in the market. The organisation must be such that it is capable of managing change, both advantageous and detrimental. Organisational analysis includes such areas as: organisational structure, management ability, physical resources and financial performance and structure. A predicted company growth rate of 10 % to 15 % p.a. (based on past data) could be considered quite acceptable but there may be organisational problems which will seriously impede growth once a certain level is reached. Furthermore limitations in the availability of physical resources or capital may prevent a company from acting on possible opportunities. Thus the potential growth present in the market in general may not be realised by an individual organisation. The ability of an organisation to adapt to market changes is crucial if it is to survive and prosper.

Business Environment

The business environment represents the sum of knowledge relating to the organisation and the factors affecting it. The preparation of bid proposals for various projects requires knowledge of not only the organisation's strengths and weaknesses but also those of possible rivals. The particular 'business environment' of the time may have a significant impact upon points of emphasis in the project which would be considered important; for instance, rapid construction may be considered more important at the time than simply lowest cost. The business environment is created by analysing the predictions and results obtained from the examination of market trends, market analysis and organisational analysis and combining them in such a way that it is possible to evaluate the current business situation (strengths, weaknesses and opportunities). The forecast data is then used to produce specific Rand figures for the analysis of various business opportunities or projects. The business environment

represents the sum of available knowledge and provides the context within which decisions are made.

There are numerous methods available for making predictions and estimates about future events. The intricacy of the method and degree of effort required to obtain useable results must be compared to the expected monetary savings obtained from the method's use, and the importance of the project. There is little value in going to tremendous lengths to obtain accurate forecast data for a project which is of minor consequence both economically and practically. Three groups of quantitative estimating techniques which are commonly employed are (Canada, Sullivan and White 1996):

1. *Time series techniques* such as linear regression or exponential smoothing are particularly useful for revenues or costs which are dependent on time. This is one of the most useful and generally employed groups of techniques for determining estimates based on financial data.
2. *Subjective estimating techniques* includes the Delphi method and technology forecasting. Both of these techniques use expert judgement and are highly effective when coupled with time series methods.
3. *Cost engineering techniques* are used to identify various cost items or processes and assign values to the components. They are particularly useful, for example, when examining operating costs of a machine based on its power consumption.

Each of the techniques mentioned have their own advantages and are useful under various circumstances. Apart from individual analyses conducted by the firm, there are various organisations which perform regular analyses on both general market trends and industry specific issues. The Bureau of Economic Research (Stellenbosch), for instance, is one such organisation which can provide long-term forecast of various economic indicators for use in capital project evaluations.

The forecasting and estimating component of project evaluation is critical to the entire exercise of optimal alternative evaluation. Forecasts of economic growth, labour productivity, technological advancements and cost increases are subject to considerable variation and it is

very unlikely that predictions made for 10 years let alone 50 years (as may be required for infrastructure projects) will be entirely valid. **What is important, however, is that the prediction represents a reasonable estimate based on currently available data to form a basis of comparison against competing options.** There are numerous ways of accounting for variability of results and determining the impact of changes to the predicted values. Issues such as sensitivity analysis and uncertainty are further discussed in a section 5.6 of this chapter.

The overall method recommended for determining estimates and forecast data involves a careful analysis of the organisation, the role of the organisation in the market (with the requirements as previously identified) and a forecast of general market trends using one or a combination of the evaluation techniques mentioned. The proper integration of the various data components is necessary in order to determine the true opportunities facing the organisation and the potential for capitalising on them. Only with accurate data appropriate to the level of the decision is it possible to provide for meaningful alternative evaluation.

5.2 TIME VALUE OF MONEY

The time value of money refers to the concept that the value or worth of a given sum of money will vary depending on the time of its utilisation (Lumby 1984). The time value of money is of fundamental importance when assessing the viability of a project over its lifetime. The question of lifetime is in itself an important issue but for the purposes of the present discussion the period of study for a particular structure will be defined simply as the evaluation life. The driving force behind the time-related value of money pertains to its ability to earn interest if invested. Other factors such as inflation and the uncertainty associated with receiving assets at some future point also contribute to the different values of money over time but are not taken into account in the inherent calculations - only in the amount of interest that is applied in the calculations. There are essentially two general forms of interest: simple and compound. Simple interest is not normally considered as a viable method for accommodating

the time value of money. Simple interest is presented, however, to form a basis upon which compound interest can be further developed.

Simple Interest

An example of the time value of money can be seen if R100 is put on deposit at the bank where it will receive interest at a rate of 10% per year. At the end of one year the money received would be R110. Therefore R100 received now has the same value as R110 received one year from now, *ceteris paribus*. The basic equation is given as:

$$S = P[1 + in] \quad \dots(5.1)$$

where:

S = future value

P = present value

i = interest rate per period

n = number of periods (normally given in years)

Compound Interest

Compound interest is the next logical extension in the time value of money. It represents a situation where the money obtained from the interest is re-invested at the same rate of interest thus contributing to the overall value of the investment being capable of earning further interest. It is important to note the number of times interest is calculated (converted) over a period. There are now two further types of interest which can be discussed:

- nominal (j) which refers to the interest stated per conversion periods
- effective (i) which is the equivalent annual rate of interest that accounts for the compounding effect.

There are two forms of the basic compound interest formula:

1. using the nominal interest rate j

$$S = P[1 + j / m]^{n.m} \quad \dots(5.2)$$

where:

m = number of conversions per period

2. using the effective interest 'i'

$$S = P[1+i]^n \quad \dots(5.3)$$

where:

$$[1+i]^n = [1+j/m]^{n.m} \quad \dots(5.4)$$

Continuously compounded interest is essentially a variation on normal compound interest. Under this situation growth is proportional to the amount of principal plus interest at each particular instant (Canada, Sullivan and White 1996). Under continuous compounding the number of conversions per year approaches infinity. The equation for continuous compounding is:

$$S = Pe^{j.n} \quad \dots(5.5)$$

Note: The nominal rate of interest is used in this situation.

Example:

R10 000 is invested at nominal rate of interest of 12% compounded monthly. The value (in Rands) of the investment in 10 years would be as follows;

Using equation 5.2 $S = P[1+j/m]^{n.m}$

$j = 0.12$ $n = 10$

$m = 12$

Value of Investment at end of year (Rand)

<u>Year</u>	<u>Compounded</u>	<u>Simple</u>
1	11 200	11 200
2	12 697	12 400
3	14 308	13 600
4	16 122	14 800
5	18 167	16 000
6	20 471	17 200
7	23 067	18 400
8	25 993	19 600
9	29 289	20 800
10	33 004	22 000

The effects of compounding with respect to interest and value of the investment are clearly substantial.

5.2.1 Inflation Effects

Inflation has a significant effect on not only the cost (or value) of money but also the future price of any commodity or service. Inflation will have a direct impact on forecasting and the cost of a structure as changes in the general level of prices will affect the construction industry thereby causing future prices to vary. As the value of money is affected by inflation, its worth will change and thus impact upon interest rates (Lumby 1984). There are three components of interest rates representing the latent time value of money, inflation, and a risk premium. Figure 5.1 graphically illustrates how the three factors combine to form the rate of interest to which a firm undertaking a project would be exposed.

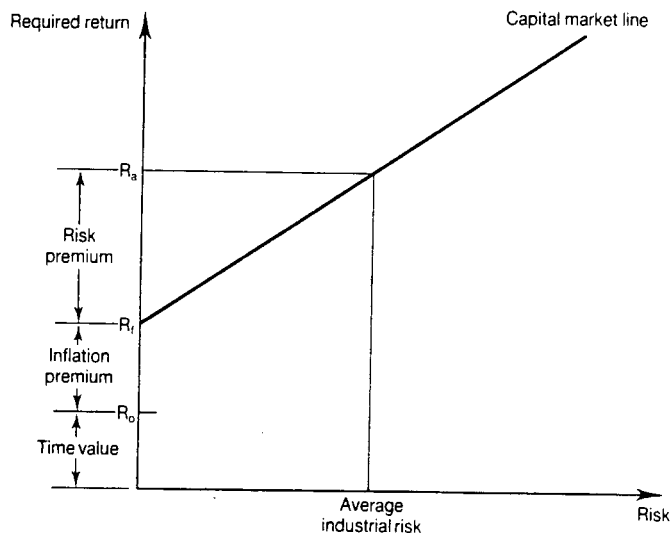


Figure 5.1 (Ferry and Flanagan 1991): *Relationship between interest rates, time, risk, and inflation. It is possible to determine the particular rate of interest to which a firm would be exposed based on its risk premium with respect to the capital market line. R_0 is the interest rate in the absence of both inflation and risk.*

The generally stated market interest rate contains both the real rate and inflationary effects. The real rate of interest is significant in that it removes the effect of inflation and allows for a uniform basis of comparison of the true (real) value of money over time. The real rate of interest as given by (Lumby 1984) is:

$$\text{Real Interest Rate} = \left(\frac{1 + \text{market interest}}{1 + \text{inflation rate}} \right) - 1 \quad \dots(5.6)$$

It is important when examining the time value of money that inflation be considered. In countries where inflation is very low the effects of inflation are fairly minor over the short to medium term period. Where inflation is high or even moderate the purchasing power (and value) of money can be quickly eroded unless it is protected appropriately. The greater the period of study the greater are the effects of inflation. The selection of appropriate interest and discount rates will be discussed in some detail in chapter six of this project.

A distinction must be drawn between particular cost indices and the general level of inflation. Various forecasting methods employ cost indices to help determine the future cost of a project. Cost indices (such as those used in the construction industry) are used to establish future rates for particular building components including materials, labour or equipment. The indices do not, however, take into account changes in productivity, construction methods or technical specifications. Ahuja and Walsh (1983) have suggested that indices tend to overinflate the costs during a given period. While their statement may be generally true it would be dangerous to assume that these indices necessarily overinflate costs in the current South African construction market. Policy directives such as labour intensive construction practices will have an impact upon efficiency and may erode some of the previous productivity gains associated with technological advancements. The effect of various policy directives and the current state of the construction industry should be considered in the forecasting of indices.

5.2.2 Tax Effects

Taxation effects have a profound impact upon project evaluations and can easily lead to the selection of one alternative over another. A comprehensive evaluation of all the possible tax effects is well beyond the scope of this work. The following discussion, however, attempts to provide a general overview of taxes and is based on general theory and principles and current tax law as applicable in South Africa in 1996. Tax incentives, programs and rates are subject to sudden changes and any optimal alternative evaluation should be based on current taxation information.

Income Tax

There are currently (as of 30th September 1995) five types of income tax applicable in South Africa: normal tax, non-resident shareholder's tax, donations tax, secondary tax on companies, and a transition levy. All of the various types of income tax will impact upon investment decisions and the available after-tax-income of a person (including companies). In a comprehensive evaluation of the true effect of income tax, all the components should be considered. For the purposes of discussion in this work only the 'normal' income tax is considered and the term income tax will be used to describe normal income tax, as defined in South Africa. Taxable income refers to "...the amount remaining after deducting from the income of any person all the amounts allowed under Part I of Chapter II to be deducted from or set off against such income;" (Huxham and Haupt 1996) according to section 1 of the Income Tax Act. Taxable income is approximately equal to the total income less expenses (except capital expenditures) less allowable deductions.

As interest is considered to be part of income, it is taxable and as such interest received represents a contribution to wealth and interest payable (for instance in the case of bonds) represents an expense. The value of money will therefore be affected by tax rates which in turn can be used to modify the effective rate of interest. Equation 5.3 can be modified by adding a (1-t) factor to the effective rate of interest, where t represent the income tax rate as given by Stevens (1996):

$$S = P[1 + i(1 - t)]^n \quad \dots(5.7)$$

Tax on interest income has the effect of reducing the effective rate of interest. With a tax rate of 35 % or 40 % this can have quite dramatic effects. Consider a pre-tax interest rate of 12%; once a 40 % tax is applied the effective interest rate is reduced to a mere 7.2%, a considerable reduction. The tax effect on interest is particularly important to owners of structures for determining the actual value of expenses at some future date and the present investment required to meet those obligations. Some of the basic concepts in project evaluation are expanded upon in section 5.3.

Capital Allowance

Capital allowances (also known as depreciation allowance) are another implication of taxes. The concept of capital allowance is fairly simple; an asset is deemed to have a certain value and over time the value of that asset is consumed as it contributes to the operations of the company. The loss in value can be considered a business expense and must therefore be accounted for in the financial records of the firm (Neil 1982). With respect to the financial accounting of depreciation there are a number of methods which may be used. The straight line method permits the value of the asset to be written off at a uniform rate over a period of time. If a machine costs R100 000 and has a life of 5 years then R20 000 is used as a yearly expense to offset the income of that period. Another method commonly employed is the declining balance. Under the declining balance approach, the depreciation is greatest in the first few years and then steadily decreased in the subsequent years until the salvage value (if applicable) is reached. The value of the asset is essentially steadily depreciated at a constant percentage (Canada, Sullivan and White 1996). One approximation for declining balance depreciation provided by Neil (1982), is given as:

$$\text{Depreciation} = (\text{factor}) \times \left(\frac{\text{Remaining Value}}{\text{Life of asset}} \right) \quad \dots (5.8)$$

where:

factor - a prescribed value by which the depreciation is calculated.

(a high factor implies larger initial depreciation allowances and smaller future allowances)

According to South African tax law, buildings erected between 1 July 1996 and 30 September 1999 and brought into use before 31 March 2000 will be written off at 10% per annum on a straight-line basis over 10 years. Those buildings which fall outside of the dates mentioned will be written off over a period of 20 years at 5% per annum on a straight line basis (Media Release June 1996). Depreciation is important from a tax perspective in that it reduces the taxable income of a firm and represents a negative expenditure. Furthermore the depreciation helps to equate the decline in value of an asset with general expenses thereby creating some parity in accounting.

It is important to note that depreciation allowances may not be claimed in all cases and the purpose of a structure will dictate the amount of depreciation allowance permitted. Structures associated with mining and farming for instance are treated differently from those associated with manufacturing. An organisation undertaking an economic analysis on a structure should obtain specific information of their tax situation and the requirements for depreciation of their structure.

Scrapping Allowance

The scrapping allowance of an asset will also have an impact upon the overall analysis of taxes and the time value of money. If an asset is scrapped at some future date before it is entirely written off then a scrapping allowance may be granted. The scrapping allowance is determined by subtracting the book value of the asset from its market value (proceeds of sale or scrapping). The book value is based on the initial cost of the asset less the depreciation to date at the time of scrapping. The market value is simply the proceeds at the time of scrapping (Huxham and Haupt 1996, Canada, Sullivan and White 1996). Once a scrapping allowance has been granted it can be used to offset the income of that period thereby reducing the effective taxable income.

There are a few notes with respect to scrapping which are worthy of mention. First, there is no exact definition of scrapping in the income tax act but results of various court cases have yielded the following guidelines (Huxham and Haupt 1996):

- a decision to scrap because the article is useless or redundant for the purposes of trade;
- followed by a cessation of use of the article;
- and this must be done in the normal course of business.

One of the important implications of the scrapping guideline is that the asset does not necessarily have to be sold or destroyed; it is sufficient simply to stop using the asset in the course of business. The next important aspect of scrapping allowance, as it pertains to buildings, states that an allowance is not claimable if the building is scrapped within 10 years of its erection or purchase. Under the current depreciation allowance mechanism (straight line 10 years) however, it is therefore effectively impossible to make a claim for a scrapping allowance.

Recoupment

Recoupment is very similar in concept to that of scrapping allowance. Recoupment essentially takes place when the sale of an asset which has been depreciated yields a greater market value than book value (capital gain).

$$\text{Recoupment} = \text{Market Value (proceeds)} - \text{Book Value (remaining tax value)}$$

Recoupment is limited to the amount of the capital allowance previously granted (Huxham and Haupt 1996) and represents an income of that period and as such is subject to tax.

Example:

Assume an asset was purchased for R50 000. After three years the total capital allowances (depreciation) were R30 000 at which point the asset was sold for R60 000. The amount of Recoupment can be determined as follows:

$$\begin{aligned} \text{Book Value} &= \text{Initial Cost} - \text{Capital Allowances} \\ &= \text{R50 000} - \text{30 000} = \text{R20 000} \end{aligned}$$

$$\text{Market Value} = \text{R60 000}$$

$$\text{Recoupment} = \text{Market Value} - \text{Book Value} = \text{R60 000} - \text{20 000} = \text{R40 000}$$

But the maximum recoupment is equal to that which has already been claimed in capital allowance (R30 000). Therefore the applicable recoupment would be R30 000, which would then be applied to the taxable income of that period.

5.3 CAPITAL PROJECT EVALUATION METHODS

The evaluation of any project requires an examination of both the cost and expected revenues associated with the project. The construction of a structure, installation of equipment and requirements for ongoing operations represents one side of the project investment decision: cost. The major focus of this dissertation, the economic optimisation of the design for reinforced concrete structures, is primarily concerned with the cost component of the engineering project. If the anticipated revenues or value of a project are less than its cost it is questionable whether that project will proceed. The emphasis of most evaluation techniques is on the final profitability of a project but, it is important to remember, there are two components. Any discussion on future (or even present) income must take into account revenue and cost. It is therefore necessary to present a general overview of some of the approaches commonly used in project evaluations.

5.3.1 Return on Investment

The return on investment (ROI) or return on capital employed, as it is sometimes called, is a relatively simple and widely used tool in capital project assessments. There are a number of variations to the model but the underlying concept is essentially the same: to determine the percentage profit a project can make on an annual basis relative to its capital outlay (Ahuja and Walsh 1983, Lumby 1984). ROI profits are usually calculated by accounting for the depreciation associated with the project but before any allowance for taxes are made. A modified version of ROI also has an advantage over some other techniques in that it accounts for the profits over the entire life of the project.

While profits are examined over the life of the project and the percentage average profits are compared, there is no account for the length of the project or the size of the financial benefit

(Lumby 1984). A project may have a ROI of 80 % but only have a one year duration and a profit of R2, compared to another project with a ROI of 'only' 50 %, 5 year duration and profits of R1 000. These two limitations, however, are fairly easily overcome by a simple examination of the investment data in non percentage terms. The major criticism of ROI is that it does not take into account the time value of money. There is no distinction between cash flows at the start of the project versus those at the end of the project. Despite its limitations the method does provide a fairly quick and simple way of initially evaluating a project and may be of use for relatively small, short duration projects where the time value of money is not significant. The use of ROI in evaluating the viability of various building design options nevertheless is limited at best. A structure will generally have a useful life requirement of many years and the repair costs associated with the structure may not be evident for 10 or 20 years.

5.3.2 Simple Payback Method

The simple payback method (SPM) is perhaps the most simplistic method currently in use for project evaluations. The idea of the SPM is to determine the length of time required to pay back the initial capital investment in a project from the revenues generated (Hawkins and Pearce 1971). The primary apparent advantage claimed by supporters of the SPM (aside from its simplicity) is its inherent adversity to risk. The SPM favours those projects which recoup the initial investment in the shortest time. A project which has a relatively short time period before the investment capital is recouped is in general less risky than a project where the revenues are spread over a longer period, *ceteris paribus*.

The major criticisms of the SPM include: not allowing for tax effects which, as noted earlier, can be substantial; no capital allowances; ignoring cash flows after the pay back period has been reached; and use of this method may in fact lead to greater risk in investments rather than less (Hawkins and Pearce 1971). The SPM makes no allowance for what happens to cash flows after the pay back period has been reached. One project may cost R100, with a payback period of two years but then only contribute an additional R10 throughout the rest of its life compared to another investment which has an initial cost of R100, a pay back period of three years but future earnings of another R100. Furthermore, as Hawkins and Pearce (1971) have noted, investments with a very short pay back period may be more risky than ones with longer

return times due to the nature of the investment “quick buck methods”. It is virtually impossible to estimate the degree of risk associated with a project by using the SPM alone.

5.3.3 Discounted Cash Flows

The next form of capital project evaluation techniques differs substantially from the first two in that it considers the time value of money. The purpose of discounting is to allow for the meaningful comparison of cash flows throughout the life of competing projects by determining the impact of time on the value of money. Generally, the objectives of discounted cash flow (DCF) models are to include virtually all effects of future cash flow (taxes, maintenance, and revenues to name a few) on the overall profitability of a project. The two most commonly used DCF techniques are the internal rate of return and net present value methods. Life Cycle Costing employs many of the techniques associated with DCF. The principles of Life Cycle Costing and additional elements of discounting theory will be expanded upon in chapter six.

Net Present Value

The principle of net present value (NPV) calculations involves the conversion of future cash flows into present day values by discounting at a rate which reflects the yield expected from an investment of similar risk and maturity (Lovejoy et al. 1989). Bull (1993) has stated that NPV is proposed by many as the best system for evaluating building related options and takes into account all the apparent variables which impact upon cash flows. Some of the time-value formulas which form the basis of NPV calculations have already been presented earlier in this chapter (for instance equations 5.2 and 5.7).

The investment decision with NPV appears relatively simple: accept any project which has a positive NPV. The idea is that any project which has a positive present value and is undertaken will contribute to the wealth of the organisation. One of the underlying assumptions of NPV calculations states there is no limit to the amount of capital which is available to an organisation. Practically this is not the case and as such projects must be evaluated for their ability to maximise wealth generation and not merely increase it. A further limitation to the NPV method is its sensitivity to variations in the discount rate (Heukensfeldt Jansen 1978). A

discount rate of 5 % may yield a profitable venture whereas a slightly higher rate of 7 % may make the project entirely inadvisable.

The effects of variation in the selected discount rate can be mitigated through the selection of a realistic rate based on the best available data and on sensitivity or uncertainty analysis. By providing for a number of possible discount rates it will be possible to determine the sensitivity of a particular project to fluctuations in the selected rate.

Internal Rate of Return

The internal rate of return (IRR) method is very similar to the NPV method. The IRR is used to determine the discount rate which would produce a present value of cash flows equal to zero. The normal criterion when using the IRR is that the project should produce an IRR which is greater than the minimum required return on capital (Hetherington et al. 1976). The IRR is normally calculated by trial and error through varying the rate until the present value of the project is equal to zero. Although the IRR method may be more attractive to business (consistency with return requirements and yields) than the NPV approach, there are nevertheless a number of problems with the IRR which leads to complications both practically and theoretically (Hawkins and Pearce 1971). The problems associated with the IRR include possible requirements for multiple IRR and variations in ranking preferences between IRR and NPV (Davis and Pinches 1991).

5.3.4 Cost Benefit Analysis

Cost benefit analysis is a means of more fully assessing the impact of a project not only to the individual (company) but also to society in general. Cost benefit analysis looks at the 'big picture' in an attempt to determine the value of a project. The evaluation includes assessing the project for each year to determine the total cost. Cost issues such as initial capital, operating, maintenance, and social costs (for instance the cost associated with the conversion of a park into an industrial site) should be included in the analysis. The costs of the project are then offset against the benefits which may include: revenues, effect of employment on the community (possibly lower crime) (Ahuja and Walsh 1983). Cost benefit analysis is closely related to that of value engineering which will be discussed in the following section.

5.4 VALUE ENGINEERING

When assessing the value of a project there are often issues which are considered to be intangible such as social good and the environment. These issues are also important in any analysis and must be considered in light of the project as a whole. The intangible issues can be loosely grouped under the heading of value engineering which attempts to integrate them as a real part of the decision making process. Values must be assigned to both the subjective and objective elements (Bull 1993). One of the main ideas in value engineering is the critical examination of the purpose and use of each particular element. The overall concept is to maximise the value obtained by a project at an acceptable minimum cost. Ahuja and Walsh (1983) have outlined three forms of value:

- *Cost Value* represents the amount of money required to produce a particular element. The question to be asked is whether a similar element is readily available and if so does the one being constructed represent value for what is being spent to produce it. In the case of a structure the assessment of cost value may involve an analysis of options such as the use of precast members or steel as a replacement for standard reinforced concrete.
- *Aesthetic Value* of a project or element is harder to define than the cost value. It is important to maintain a proper balance between the competing priorities of a project. Often there will be materials or components which are capable of performing the same function as others but at lower cost. A balance must be reached between the value associated with cost and that of appearance and prestige. When using value engineering it is essential to quantify aesthetics in some way and thereby assign a Rand value to them. The assigning of a rand value to aesthetics is not an easy task and by its very nature is subjective. If however reasonable effort is used at this stage in the project evaluation it will assist in the final selection of project options as the question of aesthetics will already have been addressed in a rational and quantifiable manner.
- *Use Value* is another important concept in the overall evaluation of a project. Use value is employed to establish the importance of an element to the project as a whole. It is likely that a particular element may have a low cost value associated with it but be an essential component in the project without which it would be impossible to operate effectively. Conversely, there may be an element in the project which has a very large cost value but

relatively minor use value; in such cases it may be advisable to re-evaluate that component of the project design and if possible remove that element or replace it with a more economical one.

Value engineering can be a very extensive undertaking and requires a careful assessment of its likely contribution to the effectiveness of the project. Value engineering is about asking questions in a rational manner and assigning worth appropriately. The six key questions pertaining to an element, as described by Ahuja and Walsh (1983) are:

1. What is it?
2. What does it do?
3. What does it cost?
4. What is the value of the function?
5. What else will perform the function?
6. What will that cost?

Once all the questions have been answered it should be possible to assign values to those issues which were previously thought of as merely intangibles and in so doing establish a more accurate picture of the cost and value of a project.

Value engineering may be particularly useful when assigning a cost or worth to the durability of a structure. In some cases the aesthetic value of facade panels or complicated structural designs may be offset by greater costs associated with repair and maintenance after a number of years of service.

Residual Value

The residual value of a structure has been discussed briefly with respect to tax implications (scrapping allowances and recoupment). The final disposal of an asset can occur in a number of ways and the intended method of disposal will have a significant impact upon design considerations. At the end of the evaluation period there are a number of options to be considered:

1. The structure may be sold (or evaluation life extended) with only minor repairs or maintenance required for continued use. If the structure is to be re-used by the organisation some value should be assigned to the structure for that use. There are a number of possibilities including replacement cost, and market value.
2. The disposal of the structure (sale or otherwise) may be accompanied by major rehabilitation if there is substantial deterioration.
3. Reconstruction and refurbishment may be required in order to achieve fitness for a newly intended use. This would imply the use of the structure has substantially changed so that modifications are necessary for the new operations.
4. Demolition of the old structure may be required in order that a new structure can be built in its place or the land used in a different manner. The structure would therefore have a negative value as there are clearly costs involved in its demolition.
5. In some cases there may be a requirement that the structure has to be demolished and the land restored to its former condition. There may be environmental concerns and possible contamination of the building materials which could seriously affect the cost of disposal.

The intended use of the structure after the evaluation period and the physical condition of structure at that time will determine whether the structure is to have a positive or negative salvage value. The demolition of a structure clearly represents a negative value whereas a structure which requires substantial repairs has both a positive value associated with the replacement cost of the structure and a negative value determined by the repair costs. The two must therefore be considered together when assessing the residual value of the structure. At the design stage it may be difficult to determine the value of the structure some 25 to 50 years later, but it is important for the purposes of comparison that some steps be taken to assign an appropriate value to the structure.

5.5 APPLICATION OF PROJECT EVALUATION TO THE PUBLIC SECTOR

The discussion on project evaluation has mainly focused on structures in the private sector. Many of the large projects such as infrastructure development which involve substantial

expenditure and commitments of society's resources, however, are conducted by government or various public organisations. The principles underlying the economic evaluation of projects are very similar to those employed in the private sector. As with 'private' economic analysis, cash flow estimates of costs and benefits, period of analyses and other forecast values should be required in public sector evaluations (Hetherington et al 1976).

One of the major difficulties in public sector analysis is the allocation of benefits and value to those items which cannot normally be bought or sold in the market (Hetherington et al 1976). Value engineering therefore plays a very important role in the assessment of public sector projects. Many of the funds for public projects are derived from taxes and it is important to realise that these projects are not financed free of charge. Had that money been left in individual hands it would have been subject to the various evaluation methods previously mentioned. It is therefore reasonable to expect that whatever evaluation methods are applied to the private sector (society) should also be applied to government (the representation of society) projects including the choice of an appropriate discount rate if required. Thus the models previously suggested may be used in project evaluation for both private and public structures.

The problem of adequate funding for repair and maintenance of structures is a serious issue faced by both public and private organisations. Often the allocation of funds is simply a budgeted item which does not adequately address the real maintenance needs of the structure. Funds for repair and maintenance clearly are not limitless and any plans for future construction must take account of maintenance requirements. By applying 'private sector' evaluation techniques to public projects a more realistic assessment of the cost and value are possible.

5.6 RISK AND UNCERTAINTY ANALYSIS

It has been shown in this chapter that there are a variety of techniques and procedures available for the forecasting of future events, whether they be estimates of the present value of some future cost or the service life of a building. The complexity and accuracy of the various

methods differ greatly and there is a general tendency towards more sophisticated computer simulations. “But however complete the records of the past may be, or however refined the methods of using them, it must be recognised that no amount of data will remove the fundamental uncertainties which surround any attempt to peer into the future” (Hetherington et al 1976). Although Hetherington’s comments regarding uncertainty are true, there are methods available which can be used to both analyse and manage the risk associated with project appraisal thereby allowing for more informed and effective decision making.

Risk analysis methods have been used for many years in areas of hazard assessment, the insurance industry, and nuclear power development to name but a few. Risk can simply be defined as “the potential realisation of unwanted consequences of an event” (Rowe 1987). There are essentially two components to risk: a) probability, which is associated with the likelihood of an event occurring, and b) the magnitude of the consequences if that event does occur. It is possible for two events to have the same degree of risk but with entirely different probabilities. If the probability of an event is great but the consequences are minimal then the risk associated with the event will probably be moderate. Similarly an event which has a low probability but serious consequences may also have a moderate level of risk attached to it.

Risk analysis has an important role to play in the evaluation of alternatives for the design of reinforced concrete structures. One of the methods for determining the likelihood of corrosion damage, as discussed in chapter four, used the distribution of reinforcement in concrete. The distribution of reinforcement in concrete is probabilistic in nature and the use of risk assessment would be of assistance in determining the exact degree of risk associated with the durability of structures. Variations in the assumed discounted cash flows for a given structure can also be accommodated using risk analysis.

5.6.1 Role of Risk Management

Risk analysis will play a pivotal role in the determination of whether or not a project should proceed. The type of risk analysis used at the project consideration stage is designed to determine the likelihood of success or profit from a given project or series of projects under review. There are two fundamental questions, both very subjective in nature, that must always

be considered: 1) does the return justify the risk? 2) what is the extent of loss if everything goes wrong? (Flanagan and Norman 1993). The idea of extent of loss when failure occurs is very relevant to the construction industry and should be given greater attention. Costs associated with substantial repairs to structures at an early age can be exorbitant and will significantly impact upon the viability of the associated project.

The risks associated with project selection generally fall into one of three categories: 1) failure to keep within cost, 2) failure to keep within a time frame, and 3) failure to meet technical standards. Risk analysis must be able to identify where the risks are and how and to what extent those risks will affect the three areas of concern (cost, time and standards). The primary area of study with respect to risk analysis in the current work for this dissertation focuses on the failure to achieve technical standards (or more correctly durability related issues). The two other forms of risk should not however be dismissed and when undertaking a complete project evaluation they should feature in that particular assessment. There are a number of steps involved in the risk management process and they are described as follows:

Step1: Identification and classification of risk

It is important that the list of possible failures is sufficiently extensive as to minimise the number of remaining unaccounted-for risks (Raafat 1983). Furthermore it is necessary to identify the potential effects of the risks. For simplicity and efficiency it is beneficial to break down the project into individual work units. The use of precedence networks or diagrams is useful for accomplishing this objective. Some examples of risk in construction projects include: inflation rising above the allowance in the estimates, unforeseen adverse ground conditions, exceptionally inclement weather, late delivery of crucial materials (for instance after a fire at a suppliers' works), incorrect design details such as the wrong size beams being shown on the drawing, insolvency of the main contractor, and lack of co-ordination (for example between the mechanical services contractors' drawings and the suspended ceiling specialist's drawings) (Flanagan and Norman 1993). Other concerns related to the durability of reinforced concrete structures are inadequate curing, insufficient compaction, failure to achieve prescribed reinforcement cover depths and excessive water to mention a few.

Step 2: Identification of various causes of the risk and assigning probabilities

The basis of the assigned probability generally takes one of two forms, historical data or expert judgement, although Rowe (1987) has identified a third approach to establishing probabilities which lies between the two. The assessment of probabilities is discussed in greater detail in section 5.6.2. If sufficient historical information is available for a particular event, frequencies can be determined and the necessary statistical data obtained. Most construction projects are considered to be somewhat unique and thus the availability of data from an 'identical' project is rather limited. It is therefore necessary to assign probabilities to components which are known and then determine the overall project probabilities through the combination of component probabilities.

Step 3: Analysis of consequences

The analysis of consequences of risk outlines the manner in which the risk may affect the overall system. Fault tree analysis is one method which can be used to determine the failures which would lead to critical events. The choice of critical events is based on the availability of information. An event tree diagram, for instance, can also be used to determine the consequences of a critical event (Tuler 1984).

Step 4: Evaluation of the consequences

The results of the various consequences are compared with certain criteria of acceptability as determined by the initial explicitly stated objectives in the project. In many cases the options will be ranked in some order. As has previously been stated, accurate quantitative information can be difficult to obtain but, by following a logical and consistent process of option comparison, reasonable decisions in the form of best alternative or highest likely degree of success may be taken.

5.6.2 Probability Assessment

Probability assessment is of fundamental importance to the entire field of risk and uncertainty analysis. It is necessary to assign probabilities to particular outcomes but it is often difficult to make predictions about the final outcome of an event as there are many factors which contribute to the ultimate result. It is therefore general practice to determine the probability of

individual components of the problem and the string of individual probabilities is then used to determine the overall probability. Rowe (1987) has stated that in practice any probability estimate involves a degree of belief and is therefore subjective by definition. He further states that there are three approaches to the establishment of probabilities:

- *Priori information* - prior knowledge about the behaviour of a system for which one has a degree of belief that similar behaviour can be expected to occur in the future.
- *Likelihood of occurrence* - the study of historical or experiential data to determine the behaviour of a system in order to evaluate its future behaviour.
- *Subjective estimates* - in the absence of historical data the use of any available information to estimate probabilities and subjectively evaluate the usefulness of the information.

The three concepts of probability estimates are useful in that they permit some degree of certainty over the probability of the event in question. Where there are clearly defined probabilities the results from an analysis can be treated with relative certainty. Estimates which are less certain must be treated accordingly and thus have a greater degree of risk (associated with the probability component).

If a reinforced concrete structure were built in a marine environment (or anywhere) there are a number of factors which would affect the durability of that structure including the environmental exposure conditions. If specific site condition data was not available, probability estimates would have to be determined based on extrapolations of data from similar sites or experiential subjective estimates. Where site-specific data on the exposure conditions is available this represents a less subjective estimate for the probability of certain durability related events occurring (such as chloride ingress) and should aid in the production of more durable structures.

5.6.3 Use of Models in Risk Analysis

Models, as previously stated, are essentially counterfeit realities which attempt to reproduce real world events. The major advantage of using models lies in their predictive ability for a variety of different situations. By changing the inputs to a model it is possible to get some idea of the variety of possible outcomes. Once again it is important to note that the accuracy of the

model's outcome is dependent upon the degree of closeness with which the model represents reality and the quality of the data and variables used in the model.

There are a number of model performance rules which have been established to help assess the value of a particular model, namely:

1. It must be repeatable. A model will be of little value if vastly different answers are obtained each time it is used (particularly when the inputs are the same). It should be noted that in a stochastic model, variations in outcome are expected, but the variations are used to produce a probability distribution and are a function of the model's design.
2. It must have predictive powers. A model is only useful in that it attempts to mimic reality thus allowing for the analysis of past information and making inferences about future results before an action is taken (Flanagan and Norman 1993).
3. It should be based on scientific consensus. Theories and models which are greatly contested may produce misleading results and not generate widespread credibility in the prediction.
4. Applied theories should be general, thus allowing for the widest possible application.
5. Used theories should not be contradictory. If a particular theory is employed in one section of the analysis, a theory which is in contradiction to the first one should not be used in a different section even though it may appear logical under those circumstances.
6. Minimal number of assumptions should be used. By minimising the number of assumptions a model can be produced which is closer to reality and has a wider degree of application (Wahlstrom 1994).

A model which is based on the six directives mentioned should yield useful information for the purposes of project evaluation.

5.6.4 Sensitivity Analysis

Sensitivity analysis is a deterministic modelling process which is used to assess the impact of changes in variables on a particular outcome. It is an important component of risk analysis in that it is used to identify those areas which are most subject to uncertainty and can therefore

be used as a decision-making tool among various project options (Flanagan and Norman 1993).

Sensitivity analysis is well suited to Life Cycle Cost (LCC) problems. As previously noted LCC involves predictions about the future. Usually variables such as interest rates and inflation have considerable uncertainty associated with them and sensitivity analysis can be used to assess their impact upon the cost of the project as a whole. If a structure was evaluated over its entire life, sensitivity analysis could be used to determine the effect of variations in reinforcement cover depth or the material properties of the concrete. The cost associated with a particular type of repair or material could also be varied and the effect on the overall cost of the structure determined.

Sensitivity analysis is particularly useful when presented in a graphical form which takes into account changes in a number of parameters. One of most powerful graphical methods is known as a spider diagram. The procedures for employing sensitivity analysis with a spider diagram are as follows (Flanagan and Norman 1993):

1. Calculate LCC using best estimate of parameters.
2. Identify the parameters subject to risk and uncertainty.
3. Select one risk parameter and recalculate the LCC by varying the parameter.
4. Plot results on spider diagram (a sample of a spider diagram is shown in Figure 5.2).
5. Repeat the steps for other risk parameters.

The usefulness of the spider diagram can be further enhanced through the incorporation of probabilities. It may be estimated that there is a certain probability that a parameter has values within a specific range. The range of probabilities can then be expressed by means of contours on the spider diagram (Flanagan and Norman 1993).

Sensitivity analysis can be used as a means of graphically distinguishing between alternatives with the aid of a probability modified spider diagram. Consider two project options with parameter variations plotted on the same graph. Probability contours are applied to the diagram and the likely range of possible outcomes of the alternatives can be seen. One of the

options may have a lower initial cost but, once the range of possible outcomes are examined (by varying the risk parameters) and it is revealed that at the 90 % confidence level there is considerable variation in the parameters, the alternative which has a lower sensitivity to variations (but not necessarily the lowest initial cost) may actually be the preferred option.

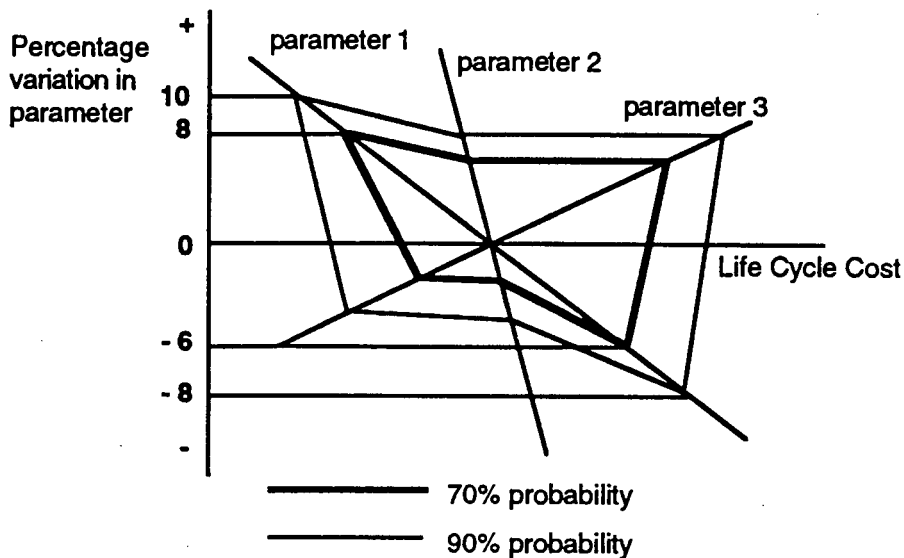


Figure 5.2 (Flanagan and Norman 1993): *Spider diagram plot with probability contours*

Despite its benefits there are limitations to the use of a spider diagram. The spider diagram can only be used to evaluate changes to each variable on an individual basis. It is not possible to examine the effect of simultaneous variations in the assumed values. Thus there are limitations to the use of spider diagrams as the sole means of sensitivity analysis.

Sensitivity analysis is of fundamental importance as a decision making aid to project managers, particularly if the risk analysis model does not take into account the distribution of possible values for given parameters. Even if an elaborate stochastic model is employed, sensitivity analysis can still be used to highlight those areas of potential concern which may impact negatively on the successful completion of the project.

5.7 CONCLUSION

A number of the principles outlining capital investment decisions have been presented in this chapter. Investment appraisals and project evaluations have been conducted for many years and in a wide variety of industries and settings. The use of appropriate long-term analysis in the construction industry however seems to have lagged behind. The 'low-bid syndrome', as stated by Rostam (1993), is responsible for much of the short-sighted approach to evaluation in the construction industry. Essentially the lowest bid is accepted due to the savings in immediate capital cost and the associated hidden costs of future maintenance and repair are not considered. By accepting the lowest bid there is little or no requirement to produce long-term estimates of maintenance costs or the various economic factors which will affect them.

The forecasting of business and economic data, coupled with appropriate allowance for the time value of money (including tax effects, inflation) is necessary if the evaluation of the structure is to allow for meaningful comparison among the competing options. Furthermore, value engineering (the assigning of value beyond the traditional economic boundaries for comparison) is an important process in examining the structure and its impact on a wider basis. Sensitivity analysis and risk management are further procedures which can be employed to allow for the evaluation of alternative proposals under a variety of conditions. Thus it is possible to determine the impact of various changes in the underlying predictions on the final outcome of a particular proposal and thereby determine its sensitivity to change. The following chapter will describe the manner in which the various economic tools, including life cycle costing, may be employed and provide some guidance as to the overall economic analysis of durability in reinforced concrete structures.

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6 ECONOMIC PREDICTION MODEL: PRINCIPLES AND PRACTICE

Much of the background information necessary for the development of an economic forecast model was presented in chapter five. Various options for the forecasting of future events and prices, analysis of variation, and capital evaluation techniques were discussed. The principle philosophy underlying the proposed forecast model to be employed is that of whole life costing (also known as Life Cycle Costing). The object is to determine those factors which will have an impact upon the cost (and benefit for optimal project evaluations) of the project, their probable time of occurrence, and express these in terms of a present value. Ferry and Flanagan (1991) have defined Life Cycle Costing (LCC) as “a technique which takes into account all the costs of acquiring, owning, operating, maintaining and disposing of an asset, with these costs reduced to a common base called the present cost”. LCC can be quite involved and requires a certain degree of effort and belief in the ultimate objectives of the procedure. LCC should be used where it is supported by the management of the company, is consistent with corporate strategy and is performed in an objective manner. In the case of public organisations, LCC should also be consistent with efforts to conserve public resources for the long-term.

The model discussed in this section is used to identify the major cost issues (relevant to the durability of reinforced concrete) involved in the construction components of projects and analyse the results based on generally accepted discounting theory. There will be additional costs and factors which have not been considered in this project such as variations in labour productivity and economy of scale effects. The various factors not explicitly discussed are by no means irrelevant but, when increasing the number of variables the complexity of the model also increases and the potential gains in the predictive ability of the model are offset by the additional effort required. Furthermore, given the nature of the economic uncertainty, the possibility of making precise predictions over one year let alone 20 or 50 years is virtually non-existent. The results must therefore be interpreted in the manner for which they were intended: to allow decisions and comparisons to be made in an informed manner based on the same set of assumptions and in a reasonably quantifiable manner. Specifically, the use of LCC should

allow for better evaluation of different construction and durability options. LCC will not make decisions in place of the manager, rather it is to be used in conjunction with expert judgement and as an aid to provide for greater awareness of the consequences associated with particular aspects of design and the long-term effects of durability on the project.

6.1 PRINCIPLES OF LIFE CYCLE COSTING

Society has only very recently become aware of the tremendous commitment of resources required after the initial capital investment in a project. Bull (1993) has stated that in most developed countries approximately 60 % (and as much as 80 %) of construction budgets is being spent on repair and maintenance of structures. The initial decisions taken during the design of a project will lead to continued and predominantly unavoidable expenditures over the life of the project. Once the project is underway or completed these early decisions can only be changed (if at all) with the expenditure of further money and possibly the suspension of activities in the facility (Bull 1993). Frequently, project decisions are based solely on initial capital cost with little or no concern for the future cash flow requirements. It should be recognised however that a trade-off does exist between cost and performance and that often constraints such as money or time are the dominating factors in the design of structures. The major considerations with respect to investment and capital project decisions include: the current available budget (perhaps the single most important governing factor), engineering constraints, capital grants, interest rates, and anticipated profits (Ahuja and Walsh 1983). Thus LCC must be seen within the context of the organisation (whether that be public or private) conducting the analysis and within its particular environment and constraints.

Ferry and Flanagan (1991) have been quite critical of LCC when applied to the analysis of operational and maintenance costs of buildings and other assets with relatively long lives and have presented a number of criticisms against LCC (with varying degrees of validity). Their two main points: 1) uncertainty over life expectancy and 2) uncertainty over economic conditions, are critiqued as follows.

Ferry and Flanagan (1991) claim that “nobody knows exactly what the service life of, for example, a modern steel-framed or concrete structure is likely to be” and they list uncertainties such as workmanship, material specifications and external protection. While it is true that there is uncertainty as to the exact service life of a structure (with the term service life being subjective in itself) there are numerous methods available for making reasonable predictions about the useful life of a structure as discussed in chapter three of this project. The methods discussed vary in complexity and predictive capabilities. The primary model used in the current analysis of chloride-induced corrosion, for instance, takes into account factors such as location (environmental conditions), material types, cover depth and quality of the concrete. This model and the ones proposed for carbonation-induced corrosion clearly are not exact and are valid only within a specific environmental range. As research in the field of concrete durability continues however so does the body of knowledge and ability to make more accurate predictions of service life. Furthermore the variability of the models can be accounted for, to some extent, through the use of sensitivity analysis. Consider for example the cover to reinforcement in a structure. Because of variability in the thickness of the concrete cover different parts of the reinforcement will be exposed to corrosion earlier than others. If the cover depth is assumed to be normally distributed, as previously stated, it becomes possible to vary this parameter and account for the effects of variation in workmanship in a quantifiable manner. Ferry and Flanagan’s criticism of uncertainty over life expectancy therefore is clearly no longer valid. Variability in the prediction models does exist but continued research in the field of durability of concrete structures will lessen the uncertainty and greatly contribute to the validity of Life Cycle Costing with respect to structures.

The second criticism presented by Ferry and Flanagan (1991) was the difficulty involved in predicting economic variables. The ability to accurately predict future economic or political events is certainly difficult if not impossible and Ferry and Flanagan (1991) are correct when they ask who could have predicted in 1970 the impending oil crisis, or ten years later the relative prosperity of the 1980’s? The answer to their question is clearly “no one” unless they were very lucky, had some degree of control over the situation, or were incredibly perceptive. Regardless, these events did occur and consequently impacted upon the economies of their time. But they are precisely that, events. They do not represent the economy over its entirety

or even over a period of 50 or 100 years. Economies are subject to fluctuations and shocks but there are general trends and premises which do persist. LCC (as applied to structural project assessment) represents a focus on long-term results. Because we cannot accurately predict the future does not mean that we should not plan for the future.

It is reasonable to suggest that taxes will remain with society for the indefinite future. The magnitude of the tax however is likely to vary and it is logical to say that the probability of effective taxes (in various forms) falling below say 20-30 % is quite unlikely. It is also reasonable to conclude that a tax rate in excess of 70 % or 80 % would be excessive and result in such serious disincentives to work and efficiency that the economy would cease to function properly. Somewhere between these two extremes there is a reasonable and probable long-term tax rate. It should be possible to look at historical data tempered with current political and economic trends to make predictions about future rates. Obviously those forecasts which are further away have a lower degree of validity or, more properly expressed, a higher probability of variation from the assumed value.

One possible method to account for the variation due to time effects is the use of different sets of predictive values depending on the time horizon. The process can be somewhat complicated and represents a substantial increase in required effort. Predictions which are for 5 years or less are assigned a certain probability while those at 15 years or less another and so on. While it might be considered appropriate to use different values for various time horizons, it is not employed in this thesis. It is important to note, however, that any comparison of alternatives should be based on the same set of criteria or assumptions (Ahuja and Walsh 1983). The underlying economic assumptions for one forecast should be the same as the assumptions for the other alternatives. Inflation, for instance, will affect the options in different ways but, provided the comparison is based on reasonable assumptions and appropriate sensitivity analysis is conducted, the effects of variations can be seen and a more informed investment decision taken.

Ahuja and Walsh (1983), have outlined five main cost groups in LCC: initial, operating, energy, maintenance and salvage. For the purposes of the current discussion in this dissertation

only the areas of initial, maintenance and salvage costs will be considered. It is unlikely that variations in the concrete properties, cover depth or other durability related considerations will significantly impact upon the operating or energy costs of the structure. The area of initial cost is further divided into a number of components as follows: research and development, acquisition including land, design of the facility, construction of the facility and installation of necessary plant and equipment, quality control and testing, commissioning and start up, recruitment and training of maintenance and operating staff, and auxiliary equipment to enable the facility to operate. The preceding list is quite extensive and while all the factors will contribute to the initial cost of the project, the primary area of study in this project is limited to the construction of the facility and possibly quality control and testing.

The costs associated with maintenance of a facility are also extensive but, while all the factors influencing maintenance cost should be considered, only those which are readily measurable and most significant have been examined. The maintenance and alteration costs are as follows: scheduled and un-scheduled repairs and replacement, downtime cost of lost production, cost of drop in performance due to ageing of components, capital cost of alterations, decoration, depreciation, and taxes. Salvage costs are the last area to be considered in the LCC analysis. These include: demolition and removal, dislocation of existing production capacity where applicable, reinstatement of site, and disposal of the physical asset and terminal wastes.

The trade-off between the various cost components is clearly illustrated in Figure 6.1. It can be seen that there are initially substantial savings in maintenance costs for fairly minor increases to the up-front capital costs. As the capital cost increases however the magnitude of the savings from the maintenance cost decreases. Thus there is an optimal point in the total Life Cycle Cost of the project which dictates how much capital should initially be invested (or expended). The optimal investment point however will vary as a result of the changes in factors such as inflation, interest, and tax rates.

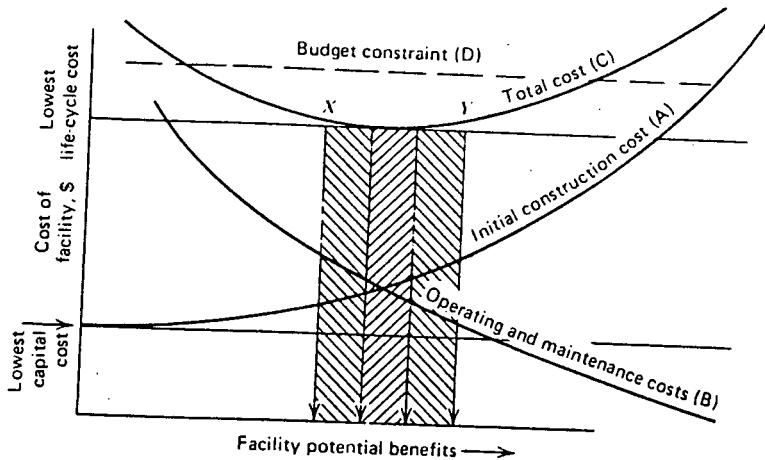


Figure 6.1 (Ahuja and Walsh 1983): *Comparison of variations in total cost with respect to maintenance and initial capital costs*

Ahuja and Walsh (1983) have stated that one of the major problems facing the acceptance of LCC is the divided interest through the stages of the project. The parties concerned with the design and building stage are very rarely the same ones that will be directly responsible for the running of the facility. Rostam (1993) outlines a number of requirements for co-operation between the various parties concerned with the design, production, and eventual operation of a structure:

- *Owner* - must define his present and foreseen future demands and wishes
- *Designer (engineers and architects)* - must prepare design specifications (including proposed quality control schemes) and conditions
- *Contractor* - must follow these intentions in his construction works. Very often sub-contractors are also involved
- *User* - is responsible for maintenance of the structure during the period of use.

When co-ordination does not exist between the various parties, it is difficult if not impossible to effectively employ LCC, and project evaluation based on lowest first cost will continue. Furthermore, financial controls even within a given organisation which owns, designs, and operates the structure, are often based on separate areas of interest, specifically capital expenditures versus normal income-related expenses (for instance maintenance). If the project manager can save money in the initial stage that is to his credit and it is unlikely he will be held

accountable at some 'distant' future date once the maintenance costs start to escalate. As noted earlier, LCC requires the proper environment (both public and private) for it to be treated seriously and have a chance of success.

6.2 SELECTION OF EVALUATION PERIODS

The selection of an appropriate evaluation period is the first step to be taken when undertaking LCC analysis. There are a number of possible lives when discussing life expectancy of an asset. Ferry and Flanagan (1991) have identified 5 components of an asset's evaluation life:

1. *Functional Life* - the period over which the need of the asset is anticipated.
2. *Physical Life* - the period of time over which the asset is expected to last physically; the period from installation until final disposal.
3. *Technological Life* - the period until technical obsolescence dictates the replacement due to technically superior alternatives.
4. *Social and legal life* - the period until human desire or legal requirements dictate replacement; the expiry of leasehold or substantial upgrades or disposal as required by law.
5. *Economic Life* - the period of time until economic obsolescence dictates replacement with a lower cost alternative.

Canada, Sullivan and White (1996), have identified a further life which is worthy of note:

6. *Ownership Life* - the period from time of installation until disposal by a particular owner.

The term "service life" has been used fairly extensively throughout this work and there are a number of interpretations of the exact meaning of service life. The general interpretation of service life, as previously stated, being the period of time over which the structure is to maintain serviceability is reasonably well accepted, but the determination of the time period is another matter. Ferry and Flanagan (1991) have essentially defined the service life as the shortest of the first five periods. Despite some variations in the definition of service life there is reasonable agreement in the literature that the period of study for use in LCC analysis should be the service life of the individual alternatives (Canada, Sullivan and White 1996, Ahuja and Walsh 1983). A fairly general estimate of the service life can be obtained by examining that

period which maximises the annual worth of the asset. The disposal of the asset is normally initiated when the annual worth of a possible new asset is greater than the worth of continuing to employ the existing asset. Essentially, once the asset in question can be employed in a more effective manner than is currently the case, the asset should be disposed of accordingly.

In the construction industry precisely defining the service life can be somewhat complex and may be considered as an integration of the five components as outlined by Ferry and Flanagan (1991) and not simply an individual component. The idea of economic obsolescence of a structure is obscure and difficult to measure. The limits of current technology and materials will influence the selection of a physical life and changes in demographics and use patterns will affect the functional life (particularly in bridge applications). When estimating the service life of a structure it is important to explicitly state the assumptions which have been made in the service life determination for the purpose of comparison among design alternatives.

There are two time periods which should be specified when evaluating a project. The first is the life of the project in general. How long is the entire project intended to be of economic value (service life of the project)? The second involves an analysis of the individual components of the project. In many cases the service life of the structure may be equal to or greater than the economically useful life of the project. Under such circumstances the appropriate evaluation life would be that of the project and a residual value assigned to the structure at that point. Alternatively, in some infrastructure projects, the functional or required life of the structure could almost be indefinite. There are few project construction options available which normally yield such a state, thus a reasonable evaluation period must be established. The conceptual design of a bridge may require a functional life nominally set at 120 years, but the alternative proposals for the actual life of the structure may have varying service lives, say 50, 60, 120 or even 150 years. Similarly, a project involving the production of 'widgets' may be viewed to be economically viable for 20 years with the service life requirements for the production facility of 20 years as well. Thus there are two points to consider: the period of evaluation of the project and the service life of the competing alternatives.

Circumstances may arise where the lives of competing proposals differ. It is essential when conducting a comparison of alternatives that the period of evaluation be the same. It is common practice to use a period of study either equal to the lowest common multiple of the life of the competing options or the length of time over which the alternatives will be needed, whichever is the shorter (Canada, Sullivan and White 1996). If the period of evaluation is less than the service life of alternative proposals, a residual value (or cost) is assigned to that asset at the end of the evaluation period.

If the lives of competing alternatives are three and four years, the lowest common multiple is twelve years to allow for a uniform comparison. If the evaluation period was nine years then three of the first asset and three of the second asset would be required. The second asset however would be assigned a residual value (or cost) for its remaining three years of potential service.

6.3 SELECTION OF DISCOUNT RATES

The selection of an appropriate discount rate is one of the most difficult and yet important operations in LCC. As noted earlier the present value of future costs is very sensitive to variations in the discount rate. A rate of 10 % may result in a profitable venture whereas a rate of 15 % could lead to substantial economic loss. It would be inappropriate to suggest that there is only one way of determining a discount rate and there is even considerable debate over the validity of many of the methods which are currently available. Therefore a number of the principles which underpin selection of the discount rate are discussed together with a few options for their determination.

The discounting of future cash flows can be performed in a number of ways. Two approaches as outlined by Lovejoy et al. (1989) are:

1. Apply a separate discount rate to the various parts of the cash flow. The separate cash flows can take the form of parts with low risk versus those which have a higher degree of

risk attached to them. Similarly the cash flows may be divided into time periods with different rates.

2. Separate the time value of money and discount for risk. This is accomplished by adjusting the cash flow of each period for risk and then discounting to the present value by a risk free rate.

Although the methods outlined by Lovejoy et al. (1989) seem reasonable and could lead to greater accuracy of predictions, such an approach would require substantially greater effort and for the purposes of the current discussion in this dissertation a single discounting factor is used in the LCC evaluation.

The principle of the discounting rate, as previously noted, is to convert the future value of some asset or expenditure (for instance maintenance costs) into a present value. There are uncertainties which relate to the risk involved in receiving the expected sum as well as the value associated with the time preference for money. The discount rate may also reflect the effect of inflation. Thus discounting can either be performed in real or monetary terms. It is important to note which method is being employed and not confuse the two. Where it is assumed that there is a general rate of inflation with little or no variation among the increase in commodity prices being considered, a real rate (net of inflation) can be used. This method does however create problems with respect to allowing for income tax which is based in monetary terms. If there is a variation in the increase of certain project components under consideration, then the particular inflationary effects should be taken into account (Ahuja and Walsh 1983).

There are a number of views as to what 'costs' the discount rate should reflect. The use of capital budgeting implies the assessment of alternative projects which will have an impact upon the value or wealth of the owners. It should be noted that capital budgeting decisions are also applicable to governments and their associated organisations. The selection of discount rates for public applications will be discussed in section 6.3.1. Two perspectives from which the discount rate should be considered are (Lovejoy et al. 1989):

- *Simulated Market Price* - Implies that the project should be discounted by the value the market would place on the investment given the same information and opportunities. The rate should reflect the investor's preference for risk and time and not necessarily that of the organisation undertaking the investment.
- *Opportunity Cost of Funds* - Represents the discounting of future cash flows in such a manner as to account for the alternative use of funds by the organisation. In other words if funds were used in the next best option what would be their yield? The concept of opportunity cost of funds implies the firm is restricted in its ability to raise capital from outside sources.

The principles underlying the selection of the discount rate should be consistent with the values of the firm or authority and the reality of the circumstances. If there are limits to an organisation's ability to raise capital or a desire to maintain a certain debt/equity ratio the opportunity cost of funds should be employed.

6.3.1 Selection of Discount Rates for Public Organisations

The selection of an appropriate discount rate for public projects raises potential problems. It is difficult to assign a cost to capital when the government has the ability to collect taxes. The question of how to assign these values has been answered by some governments through the imposition of an 'arbitrarily' set rate. The federal government of the United States of America, for instance, has stated its discount rate for capital project evaluations to be 10 % (Canada, Sullivan and White 1996). While this may be one approach it is surely not the best one. It can be reasonably well argued that one of the purposes of the government is to represent society and seek to raise the general economic level. If this approach is taken then the investment made by a government (which has taken money away from the individual) should ideally create a similar gain as would have been obtained if that money had been left in the hands of private individuals (Hetherington et al. 1976). Thus a reasonable discount rate for government investments should essentially be that of the equivalent market rate.

6.3.2 Options for the Selection of Discount Rates

There are a number of options which may be considered for the selection of an appropriate discount rate, five of which are discussed in this section. The first three (as stated by Lovejoy et al. (1989)) are fairly simple in concept and application:

1. Borrowing rate (long-term and short-term)
 - rate available to the organisation on unsecured debt for a similar term
 - or the rate on existing debt of the organisation.
2. Investment rate (long-term and short-term)
 - rate the organisation could earn on similar investments with similar terms
 - rate earned on the existing assets of the organisation.
3. Settlement rate
 - the market rate at the time of issue of liabilities.
4. Weighted Average Cost of Capital (WACC)
 - The WACC represents the cost to the organisation of employing capital. The two forms of capital employed are equity (from retained earnings) and debt. It is assumed that the current project will be financed in similar proportions to the firms existing debt/equity structures.

The equation is given as (Weston and Copeland 1992):

$$WACC = k_b(1-T)\left(\frac{B}{B+S}\right) + k_s\left(\frac{S}{B+S}\right) \quad \dots(6.1)$$

where:

$B/(B+S)$ - market value of debt to market value of firm

$S/(B+S)$ - market value of equity to market value of firm

k_b - before tax opportunity cost of debt

k_s - before and after tax return required by market on equity

Note : 1 - k_b and k_s are based on values obtained by the Capital Asset Pricing Model

2 - if using WACC with the proposed economic model, no allowance must be made for the tax as it will already have been considered in WACC.

5. Modigliani and Miller proposal

- The Modigliani and Miller (MM) model represents a counter to the WACC and other traditional methods. Modigliani and Miller have suggested that the cost of capital to a firm is not in fact dependant upon the proportion of debt to equity and that shareholders are indifferent as to whether the organisation proportions debt/equity or the individual investor proportions the debt/equity ratio (Hawkins and Pearce 1971).

The selection of an appropriate discount rate is clearly not an easy task but it is essential to the performance of any LCC analysis. The options presented for possible discount rates are merely a subset of alternatives which are available. The general principle of the opportunity cost of capital is nevertheless an important one and should figure in the analysis in some manner. According to Bull (1993) most net-of-inflation discount rates range from 2.5 % to 5 %, while the general discount rates, including inflation, are approximately 7-10 %. It should be noted that in the current South African market a value of 7-10 % would be below the cost of debt capital and thus not appropriate. A real rate of 2.5-5 % may however prove to be a good guideline for the comparison of alternatives.

6.4 DETERMINATION OF COSTS (PRESENT AND FUTURE)

The determination of both the initial cost and the final disposal costs of a structure should be based on expert judgement and be consistent with conventional cost-estimating practices. For the purposes of comparison in this dissertation it is assumed that the essential structural layout and design will be the same for the various design options. The focus of this exercise is an examination of the economics of various designs for achieving durability in reinforced concrete structures based on variations in cement type, content, cover and approaches to maintenance. The analysis is based on a materials perspective rather than a structural design approach. The costing for the various components of the project must therefore allow for a number of possible durability design options. Traditional methods of construction costing, such as the use of Quantity Surveyors, should be adequate for estimating the costs of the various options.

Where a project is constructed over a number of years, it may be advisable to set a baseline date at the completion of construction. For comparison purposes all expenditures and revenues would be discounted to that date. An additional option for determining the 'present value' of construction costs involves assigning the entire initial cost of the project to a single period of time which approximately middles the expenditures and then discount that value to the base line date that has been chosen. The choice of discounting rate and timings will ultimately rest with the organisation conducting the LCC exercise.

At the end of the LCC analysis period it may be necessary to assign a residual value to the structure under consideration. Based on the technical prediction models for deterioration of reinforced concrete structures it is possible to estimate the future physical state of the structure. The anticipated condition of the structure can then be compared to existing structures in similar conditions. A value or worth for the existing structure can be obtained and escalated to the anticipated date of disposal and at the end of the evaluation period the structure will have some value attached to it. The value of the structure will be either positive or negative depending on its possible uses and condition at the time of disposal. The escalated residual value will then be used in the economic calculations of the salvage value (or cost). Any recoupment in the form of taxes will be taken into account and the remaining value discounted to a present value. This method represents a fairly simple approach to estimating the future value of the structure. The principle behind the determination of costs is shown graphically in figure 6.2. Other issues involved in the establishment of a residual value such as land restoration, as discussed in section 5.4, should also be considered in the final assessment. Escalation rates may be obtained from a number of sources including the Bureau of Economic Research as previously noted. If no suitable escalation rates specific to structures can be found, the estimates for the general level of inflation may prove useful.

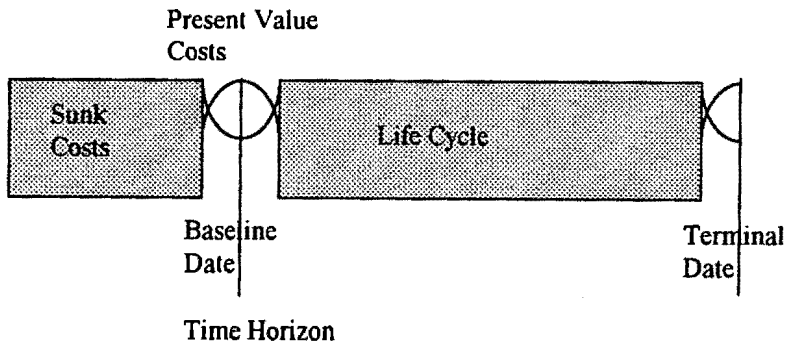


Figure 6.2 (Stevens 1996): *Relationship between present value and the time of occurrence of expenses. The sunk costs (for instance construction costs) are brought forward to the baseline and the future life cycle costs (such as maintenance) are discounted back to the baseline.*

6.5 DETERMINATION OF MAINTENANCE COSTS

The determination of maintenance costs follows a very similar premise to that used in estimating the future value of the asset, namely, that the magnitude and timings of the future repairs must be estimated from the model dealing with deterioration of reinforced concrete structures, and then related to the costs associated with conducting those repairs at the present. Once the current cost of conducting the repairs is established they can be escalated to their future time of occurrence and discounted accordingly.

Strohmeier (1994) has suggested that once a concrete structure is repaired the structure does not return to its initial condition and is in a worse state. The deterioration of the structure with repair, coupled with the distribution of reinforcement and increasing percentage of depassivated steel with depth, as previously discussed, implies maintenance (in whatever form chosen) must be conducted at successively shorter intervals. The rate of ingress of harmful agents such as chlorides however decreases with depth of the concrete. Thus the effects of a greater percentage of reinforcement per depth band (up to the centre of the distribution) may be offset by the slower rate of ingress with depth. While further research is needed to establish the true nature of this relationship it is assumed for the purpose of discussion in this work that maintenance on a structure is required at successively shorter intervals after each repair. The

work conducted by Bickley and Liscio (1997), as outlined in chapter four, appears to confirm this assumption as the first repair was conducted after approximately 15 years and a second repair, of similar magnitude, estimated to be required after only an additional 10 years. If the philosophy holds that the repaired structure has deteriorated from the original and it is the desire of management to undertake repairs at uniform intervals, successive repairs will require a greater degree of maintenance at that time to bring the structure back to a reasonable state (though not equal to the original or previous repair). Thus an additional factor, in excess of the normal financial escalation rate which accounts for the effective increase in the magnitude of repairs, must be used. By employing such an escalation rate it is possible to maintain uniform time series and greater ease of analysis in certain cases. The base escalation rate (financially motivated) can once again be determined by external organisations (such as the BER) or internally by examining trends and using the forecasting techniques previously discussed.

Maintenance costs are viewed as an expense and reduce the taxable income of an organisation (assuming it is a tax-paying enterprise). When assessing the true cost of maintenance to an organisation the taxation effects must therefore be considered. Thus the maintenance cost should be modified by a factor $(1-t)$ to obtain the effective cost. There are three factors (in addition to the discount rate) which should be determined for the calculation of maintenance costs:

1. economic escalation rate for the construction industry
2. physical repair escalation rate which accounts for the increasing magnitude of repairs with time
3. taxation effect of repairs, simply $(1-t)$.

When repairs are conducted on a regular interval basis the physical repair escalation factor is applicable. Where 'irregular' repairs are conducted specific estimates of damage for that time may be more practical. Nevertheless it is still reasonable to suggest that the repaired structure will have deteriorated somewhat from its original condition and that an additional repair factor may be required.

6.6 ECONOMIC PREDICTION MODEL

The model developed in this section is based on the principles established in the explanation of Life Cycle Costing and discounting. The current analysis is by no means a comprehensive model of every possibility which may arise throughout the life of a structure. It does however provide an aid to the decision maker based on the 'total' present costs of the four main areas affecting the project: initial capital investment, maintenance, depreciation (tax effect), and salvage value (including recoupment).

The general form of the equation is given as:

$$P = P_i + P_m - P_d - P_s \quad \dots(6.2)$$

where:

P - the present total cost of the structure(s) over its life cycle

P_i - the present value of the initial capital

P_m - the present value of maintenance

P_d - the present value of the tax savings associated with the depreciation of the structure

P_s - the present value associated with the disposal of the structure

For ease of computations an explanation of the calculations involved for each component is provided together with the appropriate charts and tables. Once the individual values are obtained the total life cycle cost of the project's structural component is simply the sum of the four present value components. It is recommended that sensitivity analysis, as outlined in chapter five, be performed in order to determine the effects of variations on the assumed values in the final outcome. A number of options can then be compared and evaluated.

6.6.1 Determination of P_i (Present Value of Initial Capital)

The calculation of P_i is one of the simplest in the life cycle costing exercise. As previously noted it represents the cost associated with the construction of the structure. Cost refers to materials, equipment and labour which can be directly attributed to the erection of the

structure. In this dissertation, the installation of services such as water or electricity or interior partitions, which are not structural in nature, are not considered in the overall initial cost of the structure. Where a particular item is included in one analysis, that item (if applicable to the other options) should be used in the LCC of the other options to ensure a uniform basis for comparison. In the report outlining the evaluation of the alternatives all costs which are considered should be expressly stated.

When the project's construction occurs over a substantial period of time, an allowance must be made for the escalation of cost during construction. All anticipated expenditures which are to be incurred in the construction phase of the project should be discounted to the established baseline date. A baseline date set at the end of the construction period may be reasonable for the comparison of alternatives. The escalation rates for construction should be based on the short-term anticipated increase in construction costs. The initial capital cost of the various design options may vary significantly due to differences in durability requirements. The use of different cement types, content, and reinforcing cover all contribute to variations in the initial cost of construction.

6.6.2 Determination of P_m (Present Value of Maintenance)

P_m represents the present value of the future maintenance costs over the life of the structure. It was noted that there are two approaches to maintenance which will be considered in this project. Where irregular maintenance intervals are used the projected costs at the various times of occurrence are simply discounted to the base time period. The general form of the present value of a single future maintenance cost is given as (Stevens 1996):

$$P = \frac{S}{(1 + i(1 - t))^n} (1 - t) \quad \dots(6.3)$$

where:

- P - present value of maintenance cost
- S - future value of maintenance cost
- i - discount rate
- t - tax rate

n - number of periods (usually years)

The future cost of maintenance 'S' can be easily determined by escalating the equivalent present cost of repairs to the future time of occurrence, thus (Strohmeier 1994):

$$S = P(1 + g)^n \quad \dots(6.4)$$

where:

g - the maintenance escalation rate as previously described in section 6.5

The general form of the expression for present value of a single future maintenance cost can therefore be given as:

$$P_m = \overline{P}_m(1-t) \left[\frac{(1+g)^n}{(1+i(1-t))^n} \right] \text{ or } \overline{P}_m(1-t) \left[\frac{1+g}{1+i(1-t)} \right]^n \quad \dots(6.5)$$

where:

P_m - present cost of future maintenance

\overline{P}_m - current cost of maintenance for a single period if performed at the base time period

The discount rate, as previously noted, is subject to the tax factor (1-t) which represents the reduction in interest income due to taxes, provided the organisation under consideration is subject to taxation. The actual cost of maintenance however is modified by the tax allowance (1-t) which represents the reduction in taxable income associated with repairs and maintenance. Once again the tax effects are applicable to tax paying enterprises. However the analysis of publicly funded projects or organisations should proceed in a similar manner to that of privately funded projects for the purpose of comparison among competing options. The basis for publicly funded evaluations was discussed in section 6.3.1.

Example:

A structure is to be repaired at irregular intervals with individual predictions for the magnitude of repairs. Given:

maintenance escalation rate = 5%
 discount rate = 10%
 tax_rate = 45%
 repairs at years 9 and 15.

The present cost of maintenance would be:

$$P_m = \overline{P}_{m1}(1 - 0.45) \left[\frac{(1 + 0.05)^9}{(1 + 0.1(1 - 0.45))^9} \right] + \overline{P}_{m2}(1 - 0.45) \left[\frac{(1 + 0.05)^{15}}{(1 + 0.1(1 - 0.45))^{15}} \right]$$

and

$$P_m = 0.527\overline{P}_{m1} + 0.513\overline{P}_{m2}$$

Note: \overline{P}_{m1} and \overline{P}_{m2} are simply the cost of the estimated repairs required in years 9 and 15 as if they were conducted today (at the base time period).

P_m represents the present cost of completing repairs to the structure in year 9 and 15. If $0.527\overline{P}_{m1} + 0.513\overline{P}_{m2}$ were invested now, under the economic conditions outlined in this example, it would provide sufficient money to pay for the future required repairs. Perhaps, more importantly, the present cost of repairs allows for a uniform basis of comparison among the competing durability options.

The second approach to repairs, as noted in chapter four, involves repairing the structure at uniform intervals. The choice of repair intervals is very important and influences the degree of maintenance to be performed at the particular time of repair. If the structure is maintained every five years (for instance the application of a protective coating) it is unlikely that damaging agents such as chlorides will have an opportunity to penetrate the structure to sufficient depth thereby causing corrosion of the reinforcement and substantial deterioration of the concrete. Under such conditions there may not be an increase in the magnitude of repairs required at each interval. Thus the maintenance escalation rate 'g' may be approximated by the purely economic component.

Where the maintenance interval is such that repairs to the reinforcement are required on an ongoing basis the physical deterioration effects should be considered. Thus the maintenance escalation rate 'g' has both an economic component 'g_e' and a physical component 'g_p'. Regardless of which escalation rate is used the present value of maintenance is simply the sum of the discounted individual costs over the evaluation life of the structure. The general form of the present value of uniform periods of maintenance is therefore given as:

$$P_m = \overline{P}_m(1-t) \sum \frac{(1+g)^n}{(1+i(1-t))^n} \quad \dots(6.6)$$

where:

$$g = g_e + g_p$$

The maintenance escalation factor 'g' and discount rate 'i' however can be replaced by a single variable 'W' which will be designated the modified discount factor. The modified form of the present value of maintenance can therefore be written as:

$$P_m = \overline{P}_m(1-t) \sum \frac{1}{(1+W(1-t))^n} \quad \dots(6.7)$$

where:

$$\sum = \text{sum of individual repairs occurring until time 'n'}$$

and,

$$W = \left(\frac{1+i(1-t)}{1+g} - 1 \right) \left(\frac{1}{1-t} \right) \quad \dots(6.8)$$

The modified discount rate W, as previously stated, is used to remove the individual effects of the general selected discount rate 'i' and the overall maintenance escalation rate 'g'. Therefore one value of W can represent a number of possible combinations of i and g in the present value calculations of the maintenance costs. W was derived from the progression between equation (6.6) and equation (6.7). A series of tables has been produced which allows for rapid determination of the maintenance discount factor. Provided there are no variations in the

maintenance escalation rate with time, the use of a single modified discount rate W for the calculation of the cumulative maintenance discount factor is acceptable. Individual calculations for the present value of repairs would have to be completed for each repair if the physical maintenance escalation rate ' g_p ' varies between repairs. If the increase in damage is uniform, as it is assumed in this dissertation, then a single maintenance escalation rate ' g ' (based on uniform physical maintenance escalation ' g_p ') and modified discount rate ' W ' are acceptable.

The general equation (6.7) is further simplified by combining the factors (including the effects of taxation) into cumulative maintenance discount factors (CMDf) and specific yearly discount factors (SYDF), yielding:

$$P_m = \bar{P}_m (CMDf) \quad \dots(6.9)$$

where:

$$CYDF = (1-t) \sum \frac{1}{(1+W(1-t))^n}$$

and,

$$P_m = \bar{P}_m (SYDF) \quad \dots(6.10)$$

where:

$$SYDF = (1-t) \frac{1}{(1+W(1-t))^n}$$

Equations (6.9) and (6.10) are essentially identical in concept and development. Equation (6.9) is based on a cumulative factor for repair intervals for periods of analysis up to 120 years (as provided in Appendix B). To determine P_m select the CMDf based on the current corporate tax rate (t), the repair intervals, and the modified discount rate (W) from the tables in Appendix B. The factor is then multiplied by the current cost of repair and the present cost of maintenance is obtained. To determine the present cost of repairs for a specific year turn to the appropriate SYDF table, select the year and use that value in equation (6.10). Tables have been prepared for the following situations and may be found in Appendix B:

tax rates 0, 0.3, 0.35, 0.4, 0.45, and 0.5

W values -0.04, -0.02, 0.0, 0.02, 0.04, 0.06, 0.08, and 0.12

repair intervals 1, 2, 5, 10, 15, 20, 30, 40, 60 years

There are two possible approaches with respect to the final repair of the structure at the end of the evaluation period. At the final date of analysis for the structure there is an option either to repair the structure for the last time or to leave it in its advanced state of deterioration. The option is entirely up to the organisation undertaking the analysis as to whether it should be scrapped or its use prolonged. For the purposes of comparison in this dissertation it is assumed that the structure will be sold at the end of the evaluation period and there should be little or no signs of corrosion at this point. Consider for instance an evaluation period of 50 years with repairs every 5 years. A 50 year CMDF would be selected so that the final repair to the structure would occur at year 50.

6.6.3 Determination of P_d (Present Value of Capital Allowances)

The calculation of the present value of the capital allowance (P_d) is fairly straight forward. Under the conditions specified in the income tax law the current ruling in South Africa, as noted, with respect to capital cost allowances provides for a straight line depreciation of the structure over a period of 10 years. As capital allowances are not allowed for all structures, specific tax information should be obtained for the structure under consideration. A set percentage (10 %) of the capital cost of the structure can be used to decrease the taxable income of that period. The value of the yearly savings can be easily determined and cash flows can then be discounted to the present and their worth determined. The equation for discounted capital allowance is given as:

$$P_d = \sum \frac{\bar{P}_i d}{(1+i(1-t))^n} (t) \quad \dots(6.11)$$

where:

d - yearly factor for capital allowance

<u>depreciated over</u>	<u>d - factor</u>
10 years	0.1
20 years	0.05

Tables have been prepared in Appendix C which provide the cumulative depreciation factor (CDF) from 1 to 30 years and for:

tax rates 0, 0.3, 0.35, 0.4, 0.45, and 0.5

discount rates 0, 0.02, 0.04, 0.06, 0.08, 0.1, 0.12, 0.14, 0.16, 0.18, 0.2

To determine the CDF select the appropriate tax rate, discount rate and the appropriate time period of analysis. For instance, if a 10 year discount period were chosen the d factor would be 0.1 and the CDF would be determined for a 10 year duration with an appropriately selected discount rate 'i'. The present value of the capital allowance is therefore given as:

$$P_d = \bar{P}_i d (CDF) \quad \dots(6.12)$$

Thus the present value of the capital allowance is readily determinable. The CDF's for the various taxation and depreciation rates can be found in the tables of Appendix C.

Example:

A structure is permitted a capital allowance of 10 % per annum on a straight line basis for 10 years. The initial capital cost of the structure is R 100 000. The present value of the total depreciation is as follows:

using equation 6.12: $P_d = \bar{P}_i d (CDF)$

$$\bar{P}_i = 100\,000$$

d = 0.1 - 10 year depreciation

CDF = 3.22 - taken from Appendix C

based on discount rate = 12 %

tax rate = 45 %

time = 10 years

$$P_d = 32,220$$

6.6.4 Determination of P_s (Present Residual of the Structure)

The final value to be determined is that of the cost (or revenue) associated with the disposal of the structure. There are three possibilities which must be considered in the discussion of

salvage value and its impact upon taxes and specifically recoupment. A scrapping allowance may be claimed, provided the structure is not disposed of before a 10 year period, if an asset is scrapped before it is entirely written off. No scrapping allowance can be claimed if the structure is scrapped before the ten year period. If the structure is scrapped before it is entirely written off (and after 10 years) the amount by which the original cost exceeds the sum of the tax allowances to date and the proceeds from the sale represents the scrapping allowance (Huxham and Haupt 1996). The scrapping allowance is then allowed as a deduction against the taxable income for that period. The third possibility is that the structure is scrapped and the proceeds from the sale of the asset are greater than its book (tax) value. Under this situation recoupment is equal to the proceeds in excess of the book value up to the sum of capital allowances previously granted and the recoupment value is then added to the taxable income of that period. In all cases the residual value achieved from the sale of the structure is added to the income of that period and thus subject to taxation. The components (residual value and recoupment) can then be determined to provide a present value. The equations for the periods can be summarised as follows:

1. Proceeds are Greater than Book Value (Recoupment)

($MV > BV$)

MV - market value, anticipated proceeds from the sale

BV - book value, initial cost of the asset less tax allowances

The general form of the recoupment equation is given as:

$$P_s = (MV(1-t) - (MV - BV)t) \frac{1}{(1+i(1-t))^n} \quad \dots(6.13)$$

Note:

$$MV = \overline{MV}(1+b)^n$$

$$BV = (P_i - P_i dn)$$

where:

the value for the MV-BV component can be a maximum of $P_i dn$

'n' with respect to the BV component can be a maximum of the time until the asset is fully written off (in the case of 10 year capital allowance $n \leq 10$)

\overline{MV} - current market value of structure in a similar state to the anticipated future condition of the structure.

b - escalation factor for the structure (the general inflation rate may be used if no other rate is available)

2. Proceeds are Less than Book Value (Scrapping Allowance)

- Scrapped with period less than 10 years

Where the asset is scrapped less than 10 years after erection no scrapping allowance is claimable. Hence the value of the asset is as follows:

$$P_s = MV(1-t) \frac{1}{(1+i(1-t))^n} \quad \dots(6.14)$$

No tax relief will be applicable under this situation.

- Scrapped with period greater than 10 years

Where the asset is scrapped after a period of 10 years and the proceeds from the sale are less than its book value a scrapping allowance is permitted and the effective proceeds are:

$$P_s = (MV(1-t) + (BV - MV)t) \frac{1}{(1+i(1-t))^n} \quad \dots(6.15)$$

where:

n can be a maximum of the time until the asset is fully written off (in the case of 10 year capital allowance $n \leq 10$).

To determine the anticipated present value of the disposal of the structure determine the appropriate situation (either 1 or 2) and calculate the values as indicated with equations 6.13, 6.14 or 6.15. General discount tables have been provided in Appendix D.

Once all the components of the costs (P_i , P_d , P_m , and P_s) have been determined the present value of the project can be estimated from equation 6.2.

6.6.5 Sensitivity Analysis Example

The following example illustrates the way in which sensitivity analysis can be used to evaluate the effect of variations in estimated values. Assume a structure is to be built with an initial capital cost of R 1 000 000 and a service life of 40 years, repairs of equal magnitude are to be conducted on the structure in years 20 and 30. The current cost of one repair is estimated at R 200 000. A straight line depreciation of 10 % per annum over 10 years is used to estimate the capital allowance. At the end of the 40 years the structure is to be sold and the current value of a structure which is in a similar condition to that anticipated at the time of disposal is R300 000.

The following rates have been assumed:

discount rate	'i'	= 12 %
maintenance escalation rate	'g'	= 8 %
tax rate	't'	= 45 %
escalation factor for structures 'b'		= 6 %

The total present cost of the structure $P = P_i + P_m - P_d - P_s$

- Calculation of P_i

$$P_i = 1\,000\,000$$

- Calculation of P_m

$$W = \left(\frac{1+i(1-t)}{1+g} - 1 \right) \left(\frac{1}{1-t} \right)$$

$$= -0.023 \text{ or } -2.3 \%$$

from Appendix B the SYDF for $t = 45 \%$

$$\text{year 20} = 0.686$$

$$\text{year 30} = 0.766$$

$$P_m = 0.686 \times 200\,000 + 0.766 \times 200\,000$$

$$= 290\,400$$

- Calculation of P_d

$$P_d = \overline{P}_i d(CDF)$$

where:

$$d = 0.1$$

CDF from Appendix C with year 10 and $i = 12\%$, $t = 45\%$

$$\text{CDF} = 3.22$$

$$\begin{aligned} P_d &= 1\,000\,000 \times 0.1 \times 3.22 \\ &= 322\,000 \end{aligned}$$

- Calculation of P_s
after 40 years the $BV = 0$

Therefore the proceeds from the sale of the asset are greater than the book value which implies case 1 as outlined in section 6.6.4.

$$MV = \overline{MV}(1+b)^n$$

where:

$$\overline{MV} = 300\,000 \quad b = 0.06$$

$$MV = 3\,085\,715$$

$$\begin{aligned} P_s &= (MV(1-t) - (MV - BV)t) \frac{1}{(1+i(1-t))^n} \\ &= 96\,745 \end{aligned}$$

- Total present cost

$$\begin{aligned} P &= P_i + P_m - P_d - P_s \\ &= 1\,000\,000 + 290\,400 - 322\,000 - 96\,745 \\ &= R\,871\,655 \end{aligned}$$

Sensitivity analysis involves varying the assumed parameters to determine their effect on the overall cost of the structure. For illustration purposes a new tax rate of 30% is assumed. The calculations are repeated but for the new rate.

- Calculation of P_i

$$P_i = 1\,000\,000$$

- Calculation of P_m

$$W = \left(\frac{1+i(1-t)}{1+g} - 1 \right) \left(\frac{1}{1-t} \right)$$

$$= 0.0053 \text{ or } 0.5 \%$$

from Appendix B the SYDF for $t = 30 \%$

$$\text{year 20} = 0.66$$

$$\text{year 30} = 0.64$$

$$\begin{aligned} P_m &= 0.66 \times 200\,000 + 0.64 \times 200\,000 \\ &= 260\,000 \end{aligned}$$

- Calculation of P_d

$$P_d = \bar{P}_i d(CDF)$$

where:

$$d = 0.1$$

CDF from Appendix C with year 10 and $i = 12 \%$, $t = 30 \%$

$$CDF = 1.977$$

$$\begin{aligned} Pd &= 1\,000\,000 \times 0.1 \times 1.977 \\ &= 197\,700 \end{aligned}$$

- Calculation of P_s

after 40 years the $BV = 0$

Therefore the proceeds from the sale of the asset are greater than the book value which implies case 1 as outlined in section 6.6.4.

$$MV = 3\,085\,715$$

$$\begin{aligned} P_s &= (MV(1-t) - (MV - BV)t) \frac{1}{(1+i(1-t))^n} \\ &= 73\,848 \end{aligned}$$

- Total present cost

$$\begin{aligned} P &= P_i + P_m - P_d - P_s \\ &= 1\,000\,000 + 260\,000 - 197\,700 - 73\,848 \\ &= R\,988\,452 \end{aligned}$$

From the sensitivity analysis it is evident that a decrease in the tax rate increases the present cost of the structure. A comprehensive sensitivity analysis would involve continuing this process but for a number of parameters thereby determining the sensitivity of the present cost of the design option to fluctuations in the assumed variables.

6.7 CONCLUSION

The principles of economic evaluation of structures presented in this chapter represent only one approach to estimating the full cost of a project. There are a number of areas however which have not been specifically addressed in this chapter. The principles of risk and sensitivity analysis, for instance, were discussed in chapter five of this project and, while a brief example of sensitivity analysis was presented in this chapter, a more thorough view of the ideas and principles should be employed in any meaningful evaluation to determine the affects of variations in the assumed values on the final outcome of the analysis.

The maintenance of reinforced concrete structures, as previously noted, can be very difficult to predict accurately, but it is essential to account for the future requirements of the structure at the design stage. The question of whether it is worth adding, say an extra 20 mm of cover to a reinforced concrete column to achieve a longer 'maintenance free' life will only truly be determined with time. The models and principles of deterioration prediction and life cycle costing analysis however do provide a uniform basis for the comparison of design options and allow for more informed and thorough decision making by the engineer and manager.

The following chapter outlines various interactions between the technical prediction models and the economic analysis model. A number of examples are provided in chapter seven which illustrate the intended use of the overall economic/durability model.

6.8 REFERENCES

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7 ECONOMIC OPTIMISATION MODEL FOR DURABLE DESIGN

Designing for durability in reinforced concrete structures has received considerable attention in published literature in recent years. It has become apparent that the old methods of design selection based on lowest first cost are no longer acceptable and that a broader approach to project evaluation and selection must be taken. A proposal which yields the lowest first cost for a structure may not be the most economical when evaluated over the entire design life of the project (Singh 1996). Hetherington et al. (1976) further state the comparison of various options must be based not only on technical merits of the particular design but also on their relative real cost of benefits to be secured. It would be of little value, for instance, to design a structure which will be 'free of maintenance' for 30 years when it is only to be used for 15 years at which point it will be replaced. Thus the evaluation of engineering projects must be based on the technical ability of the structure to achieve the purpose for which it was intended and the economic requirements of the structure (including projected maintenance) over the evaluation period.

Life Cycle Costing analysis has been suggested as one method of evaluating the true cost of a project over its entire life span. The federal government in the United States of America, for instance, requires LCC to be performed on all federally funded projects (Singh 1996). The United Kingdom has also taken steps to ensure LCC is performed and the Design Manual for Roads and Bridges (1992) vol. 1 sec. 2 specifically outlines the manner in which LCC is to be conducted together with various rates and values (for instance the test discount rate is stated to be 8 %). LCC is essentially used to evaluate the total worth of a project by analysing the initial cost and discounting future cash flows such as maintenance, reconstruction, rehabilitation, restoration, and resurfacing costs over the life of the project (Singh 1996).

A number of technical prediction models, as proposed by various authors, for carbonation and chloride-induced corrosion were identified in chapter three. Five maintenance strategies together with estimates for the time between repairs were then presented in chapter four. It is essential that the various technical options for achieving durability be evaluated in accordance with the principles of LCC analysis and their values compared to provide the necessary

background information for effective decision making. This chapter outlines one of the possible procedures and methodologies for conducting LCC analysis of a structure together with an example for illustrative purposes. It is important to note that the values given in this section are for the purposes of illustration only and should not be used to form the basis of other LCC project analyses. The various prediction models have a specific region of validity and attempts to use those models outside those stated regions is not recommended.

7.1 PROJECT EVALUATION PROCEDURES

There are a number of steps and procedures to evaluating the overall cost and benefit of a particular design option. This section identifies some of the concerns and presents a logical approach to dealing with the problems of LCC analysis. A number of simplifications and assumptions are used throughout this section. It was stated earlier that there is a point where the value associated with increasing the accuracy of a model is offset by its greater complexity, thus a balance between accurate prediction and ease of use must be reached. The overall evaluation model was developed in a modular or compartmental manner to allow for specific sections to be modified without affecting the value of the others. In an area where the simplifications are found to be too limiting, that section could simply be replaced by another which is broader in application (provided it is consistent with the overall approach present herein).

The overall project evaluation procedure consists of four subsections:

1. preliminary assessment
2. initial design selection
3. development of alternative designs (based on the five maintenance strategies as outlined in chapter four)
4. determination of the present value of durability options (initial capital cost, maintenance costs, capital allowances, salvage value).

It is important to reiterate that this is only one possible approach and the various principles previously outlined may be combined or used in a variety of other ways to evaluate the validity of the individual design options. For instance, the development of durability options may be coincident with the preliminary assessment where there is sufficient previous knowledge about a location and viable options for ensuring durability in that region.

7.1.1 Preliminary Assessment

The first stage in the assessment of durability in reinforced concrete structures should begin prior to the development of particular designs and figure prominently in setting the course for the rest of the project. If durability is paid only a courteous glance at this stage, it becomes increasingly difficult to integrate it later in the development of the project. The preliminary assessment of a project involves three areas of study: identification of the environment (physical and non-physical), determination of the evaluation periods, and integration of durability principles into the architectural and structural design.

1. Identification of the 'environment'

The objectives and aims of the project must be clearly stated in order for the design to be consistent with the overall approaches of the organisation undertaking the project. At this stage the various points of emphasis such as quality of construction, timing or cost must be identified. Included in this area is the identification of any weaknesses or hindrances in the organisation which may have an effect upon the successful completion of the project. This first stage essentially identifies the 'environment' in which the structure (or project) is to be completed and seeks to establish those items which may impact upon it. The identification of the overall environment must also include an assessment of the physical environment to which the structure will be exposed. The likely deterioration mechanisms and severity of exposure must be determined at this stage.

2. Determination of evaluation periods

At the time of the preliminary analysis it is crucial to identify the intended functional life of the project and its various components. The functional life of the project or structure represents the period of time over which there is a need for the asset (Ferry and Flanagan 1991). Once

the functional life of the project and its components has been determined it is then possible to establish the required service life. As previously noted the service life forms the basis of the evaluation period of the individual components both technically and economically. The determination of the service life, as outlined in section 6.2, should be based on current technical knowledge and be consistent with generally accepted approaches used in the market. In certain cases however an agency such as the government may explicitly dictate the service life. Singh (1996) for instance, suggests the service life for infrastructure along primary and secondary roads should be maintenance free for 50 years and relatively maintenance free for 100 years.

3. Integration of durability principles into the architectural and structural design

A final area of concern in the preliminary analysis is the possible conflict between structural (or architectural) design considerations and durability. The durability component of design can be generally be integrated with relative ease into the overall structural design. The general shape and appearance of the structure can remain essentially the same with the service life of the structure determined by the cement content, type and reinforcement cover. By varying the determinants of durability it may therefore be possible to achieve the desired service life of the structure while maintaining the architectural and structural design. The structural/durability design consideration must be an interactive process since strength of the concrete, for instance, will dictate the minimum dimensions of columns and beams. Furthermore, the detailing of the structure should be consistent with good practice for achieving durability. Areas of poor drainage, where water can pond, may lead to premature deterioration of the concrete. Other options to consider are the possible use of rounded corners. Where there are outside edges or corners, it is possible for the aggressive agents to penetrate the concrete from two directions leading to an area with elevated concentrations of contaminants (Rostam 1993). Thus there are a number of considerations which must be taken into account during the preliminary analysis of a project.

7.1.2 Initial Design Selection

The initial selection of materials and construction practices to be used in the structure is the next step in the overall analysis of the project. The selection of materials can be a very

involved and time consuming process in which 'all' the possible options are examined before the material is selected, or it may be a fairly short and simple procedure which examines only a subset of possible options. There are a number of evaluation and selection techniques available and the choice of the particular procedure will depend upon the implications of the effect of that decision. For instance, where the materials component represents a considerable expenditure it may be worth spending the extra time (and money) to fully examine a number of possible options. Where material costs are anticipated to be fairly low and the project not as important, the need for thorough analysis is not generally as great. The approach outlined in this section is a fairly simple one which can be quickly applied at the design stage for most projects. It is quite possible however that a more comprehensive analysis would yield a different result.

It was noted in chapter two that epoxy coated and galvanised reinforcing may also be used to ensure the durability of reinforced concrete structures. Long-term data for epoxy coated reinforcement (ECR) however is somewhat limited. Furthermore the application of ECR is limited by the careful handling requirements during construction. Due to the various limitations and uncertainty about the long term ability of ECR to provide protection it will not be presented in the analysis of options in this chapter. Galvanised reinforcement (GR) however has had an opportunity to prove itself in a number of applications, particularly where carbonation-induced corrosion is a concern. The focus of the evaluation and comparison in this chapter is primarily based on variations in the concrete, with the exception of the preventative surface application. Where the environment to which the structure will be exposed is sufficiently severe or there are certain architectural and design constraints, GR may be a requirement. In a more comprehensive evaluation the use of GR and possibly ECR should be presented as possible options. In such a case a similar evaluation method to the one suggested in this study could be followed but with the inclusion of reinforcement in the cost analysis. Additionally the requirements of the cover concrete may be somewhat lower both in terms of quantity (cover) and quality (use of extenders/cement content).

The initial design selection approach is given as follows:

1. Selection of trial cement type and content

The first step in the initial design selection is the identification of a number of possible cement types and contents. The three cement types/blends (OPC, FA and GGBS) together with three concrete strengths form the basis of comparison in this study. The selection of strengths should be considered in light of the particular requirements of the project. It would not be advisable to use a 20 MPa concrete in the marine extreme zone for instance. Options such as 30, 40 and 50 MPa concrete would be considered more appropriate. (Note that although strength is used here for convenience, specifiers should be encouraged to move away from specifying by strength for durability-sensitive structures).

2. Determination of penetration depth of contaminants

The depths of penetration of the contaminants may be obtained for the chosen cement types, strength (from step 1) and the appropriate service life and environmental conditions (identified in the preliminary assessment) as outlined in the relevant tables of Appendix A. Chlorides are used for the example in this chapter but the approach, with the addition of propagation effects, is equally applicable for carbonation-induced corrosion.

3. Determination of required cover depths

The appropriate cover depth can be obtained by matching the particular contaminant penetration depths (as determined in step 2) to those values in the 10 % column of Table 4.1. (Note: Table 4.1 may need future modification if steel depth variances differ greatly from the 20 % assumed, or it is shown that a normal distribution of steel is inappropriate). It is assumed, for the purpose of discussion in this chapter, that only 10 % of the reinforcement should be in contaminated concrete at the end of the structure's service life, hence the selection of the 10 % column of table 4.1. The 10 % exposure of reinforcement was chosen to allow for variation in the reinforcement placement, as occurs in practice, while minimising the degree of deterioration visible at the end of the structure's life. In other analyses it may be advisable that none of the reinforcement be exposed to contaminated concrete at the end of the evaluation period. The corresponding value in the design depth column of Table 4.1 represents the appropriate design cover. At this stage there should be nine options based on three cement types and three concrete strengths. The cover depths should be rounded up to the nearest 5 mm. The options may be easily viewed by setting up a simple table as follows:

Table 7.1: Initial Cover Depths

Strength (Mpa)	OPC	30 % FA	50 % GGBS
30	105	50	45
40	80	45	40
60	65	40	35

Note: These values are purely illustrative.

4. Elimination of inappropriate cover options

There may be certain engineering constraints which would exclude some of the options from further consideration. A cover in excesses of 80 to 100 mm would probably be considered excessive as cracking of the cover concrete becomes a greater problem. Consideration should also be given to the current code of practice which may prescribe certain minimum covers that would supersede the values identified in Table 7.1. Thus those options which are not feasible or realistic should be removed or adjusted to standards at this stage.

5. Selection of cost evaluation method

Varying the strength of the concrete has an effect on both the required cover depth and on the quantity of concrete required for structural purposes. As the strength of the concrete increases the required cover depth decreases to some extent as does the quantity of required structural concrete although for beams this effect is fairly minor. This is the stage where there is the greatest variation in the durability evaluation approach. There are a number of options to determine the cost depending on the various concrete mixes including: designing the structure for each of the remaining concrete mixes in table 7.1, selecting one type of cement for each strength category, or using a representative test member (such as a column) and determining the cost for the remaining options. In this work the test member option has been chosen as the basis for comparison. As previously noted the complete structural design approach may be used where conditions warrant.

Other variations in cost include quantity of formwork. Those options with the greater material requirements also require more formwork. The increase in formwork requirements however

may not be significant with respect to the overall cost and thus are not considered in this evaluation. The adequate curing of concrete and different requirements of the particular mix designs is a further area of concern. It has been suggested that FA and GGBS require concretes greater care in curing than OPC. While this may be true, Alexander and Krook (1996) point out that the curing of concrete in Cape Town by the construction industry may be considered inadequate and this might have led to the poor service performance of various concrete structures in the area. Thus proper curing is required for both OPC concrete and other concrete which contain cement extenders such as FA and GGBS. If curing is not conducted properly the anticipated gains associated with use of GGBS or FA will not be realised and their long term performance may actually be worse than OPC alone. The costs associated with the curing requirements of FA and GGBS are not considered in the current example. OPC concrete also requires sufficient curing if its durability properties are to be realised. The differences in the cost of curing among the various cement types may or may not be significant, but in a comprehensive project evaluation the specific curing costs should be considered. (These costs may, for example, also relate to longer stripping times and hence extra formwork costs).

Having selected an appropriate evaluation method it is now possible to determine the initial costs of the options. Other factors such as abrasion resistance and ease of placing should also be considered when selecting the appropriate mix design but for comparative purposes in this work the ultimate selection of the initial design is based on the lowest cost of equally durable options. All of the options being evaluated essentially afford the same degree of protection to the structure thus there are no anticipated service life gains by selecting one option over another.

6. Determination of material requirements

The selection of a concrete mix design and material requirements is based on the test member approach as previously outlined. The principle is to assume a certain load acting on a column and then determine the structural material requirements for the various mix design options. The various cover concrete requirements as determined in step 3 can be added on to the minimum structural requirements. For the purposes of discussion in this project the cover concrete is not considered in the determination of the load-carrying capacity of the column.

Normal practice in South Africa would be to include the cover concrete in the determination of the load-carrying capacity of the member. To allow for the effective economic comparison of durability options it is necessary to remove, or at least minimise, the structural influences on cost from the purely durability associated costs. Furthermore the examination of only the core concrete with respect to load carrying capacity is consistent with standard practice in other countries such as Canada. Pillai and Kirk (1988) have stated longitudinal structural reinforcing should consist of between 1 % and 8 % of the gross area. For the purposes of comparison the structural reinforcing is assumed to occupy 2 % of core area (excluding cover concrete). The following equation denotes the normal axial ultimate strength for a symmetrically loaded short column (Pillai and Kirk 1988):

$$P_{no} = 0.85f'_c(A_g - A_{st}) + f_y A_{st} \quad \dots(7.1)$$

where:

- P_{no} - normal axial ultimate strength (kN)
- f'_c - specified compressive strength of concrete (MPa)
- f_y - specified yield strength of reinforcing (MPa)
- A_g - gross area (mm²)
- A_{st} - area of steel (mm²)

It is assumed, for the purpose of illustration, that the normal ultimate axial required strength is 5 000 kN and, based on the assumption of 2 % reinforcing, the equation can be re-written to solve for the gross area as follows:

$$A_g = \frac{5}{0.83f'_c + 0.02f_y} \quad \dots(7.2)$$

and

A_g is expressed in m²

f'_c and f_y are expressed in (MPa)

It is further assumed that the column is square and the dimensions are therefore obtained by taking the square root of A_g . The final material requirements are determined by adding the previously calculated cover depths yielding:

$$w = \sqrt{A_g} + 2(\text{specific cover depth}) \quad \dots(7.3)$$

where:

w is the dimension of one side of the column (m)

The column is assumed to have a height of 1 m. Thus the comparison of the various options is based on a column of height 1 m, subject to a 5 000 kN load with the material requirements determined according to the equations as outlined. A simple spreadsheet program can be developed to determine the material requirements based on the mix design options.

7. Determination of unit cost of concrete

The next stage in the analysis is to determine the unit cost of the concrete for the various mix designs. The cost should be based on the method that will be used on site whether that be by batch plant or ready mix service.

8. Calculation of representative column cost

Finally the costs (per m^3) for the individual concrete mix designs are multiplied by the material requirements as determined in step 6 and the lowest capital cost of 'equally' durable options obtained. The total concrete requirement ($W \times W \times 1$ m) as stated in step 6 over-estimates the 'core' concrete requirement by 2% as the volume required by the reinforcement was not removed. In a more thorough evaluation (particularly if galvanised reinforcement was considered as an option) the appropriate quantity of concrete should be removed and the cost for the reinforcement included. As the comparison of options is based on assessments of the differences between the options, many of the normal costs, such as labour and curing, can be ignored at this stage without significantly affecting the analysis.

7.1.3 Development of Alternative Designs

The particular concrete design mix and cover to be used in the project evaluation was selected in the previous section. The initial design selected was based on the premise of no maintenance

over the life of the structure with the cover sufficiently large to limit the amount of contaminated concrete in contact with reinforcement to less than 10%. There are numerous ways, however, in which a structure can achieve its intended service life. The various other approaches generally involve some degree of maintenance, at either regular or irregular intervals as outlined in chapter four, and include: regular application of surface treatments, reconstruction of damaged areas, cathodic protection and replacement of damaged sections.

The objective of this section is to develop a number of possible options which can be used to ensure the serviceability of the structure over its evaluation period. The various options can then be compared on a life cycle cost basis to determine the least expensive option over the period of analysis. The selection of maintenance options should represent a cross-section of the alternatives available. The alternatives should be based on reasonable engineering judgement so that only those which are feasible are considered. Consider the case of a structure in the marine 'Very Severe' zone with an intended service life of 50 years: if the chosen mix design (as determined in the initial design selection section) was a 40 MPa 50% GGBS concrete, a 30 mm cover would clearly be inadequate as the threshold level of chlorides would be reached in 5 years or less (based on tables in Appendix A). Repairs to such a structure would be almost continuous and simply not practical.

When selecting various options for achieving the service life of the structure it might be reasonable to choose four options in addition to the 'maintenance free' approach. The approaches may include the following (based on a 50 year service life):

1. *cathodic protection* - The use of cathodic protection 20 years after construction might be reasonable at which time 35% spalling or cracking of the concrete surface would be considered acceptable.
2. *regular application of surface treatments to limit ingress of contaminants* - The concrete mix design would be the same one selected in the initial design but with the minimum allowable cover as prescribed by the building code. Where there is a conflict between the minimum standards prescribed by the code and the values determined from the various models the code requirements should be used in the analysis. The application intervals are subject to some uncertainty but refurbishment every 10 years might be appropriate.

3. & 4. *reconstruction of damaged areas* - The reconstruction of damaged areas can occur at almost any state of deterioration of the structure, thus a number of options might be considered appropriate. As previously noted substantial repairs every 5 years are probably not acceptable. Conversely, repairing the structure once at the end of 45 years could be considered too close to the initial maintenance free design option. Thus a reasonable timing for the first repair may be after 15 years with 25% cracking or spalling and then two further repairs over the remaining life. Another choice might be an initial repair after 20 years and a further one at some point over its remaining life. The choice of options is fairly arbitrary but the options should be diverse enough to allow for a reasonable comparison.

The determination of time between repairs for the maintenance options was discussed in chapter four. The procedure for determining repair intervals and an appropriate initial cover for the options, as previously outlined, is very similar to the initial design selection approach. It was assumed, for the purposes of comparison, that those areas of reinforcement which had been repaired would not corrode again. Thus the estimates for the propagation of corrosion would be based on the movement of contaminants through the concrete and the distribution of reinforcement in the concrete. An estimate can be made either for the magnitude of the repair based on chosen time periods or on the timings of the repair based on an accepted magnitude. An example will be provided in section 7.2 to clearly illustrate these principles.

7.1.4 Determination of the Present Value of Durability Options

When evaluating the economic merits of the particular options it is important to focus on those issues which can be used to differentiate the alternatives. As with the selection of the appropriate mix design, there are a number of approaches which can be used to evaluate the economic validity of the various repair strategies for achieving the service life of the structure. The options range from complete costing for all the project designs selected to examining a sub-set of the costs of the maintenance strategies based on a simple member (such as the column approach previously employed). The representative column approach is once again used for the determination of optimal durability strategy in this project. A sufficiently large project may warrant closer examination in which case a more comprehensive economic evaluation would be appropriate. Regardless of the approach used, there remain four essential

cost groups which should be considered: initial capital cost, maintenance costs, capital allowances, and salvage value/cost. The methods of applying the economic analysis to the selection of the durability strategies is presented as follows:

1. Initial capital cost

The initial capital cost of a structure is comprised of numerous components including labour, materials, design and planning to name but a few. For the purposes of comparison the costs to be used in the determination of initial capital cost are generally those which lead to differences among the options. A certain amount of labour, for instance, is required to build the structure regardless of which durability approach is taken. The difference in labour requirement between a member with a 30 mm cover and one with a 60 mm cover will probably be very minor, and will not be considered here. Therefore in the determination of initial cost only the material costs (in this case only concrete costs) are considered. The material cost in this example will be based on the column of height 1 m with the mix design and cover as previously determined. The one exception to this is the surface treatment option. The surface treatment approach requires the application of a surface 'coating' after construction is completed. The application of an initial surface coating is clearly an expense which would not be incurred under the other durability approaches and must therefore be accounted for accordingly.

2. Maintenance costs

The cost of maintenance on a structure can be subject to considerable uncertainty. There is a significant difference in cost between maintenance which is conducted at ground level and that which is conducted at a height requiring scaffolding with awkward working conditions. Estimates for maintenance cost should include labour, materials and any other requirements necessary for the completion of the repair. The labour should be considered in the maintenance cost estimate, unlike the initial capital cost estimate, as it is a cost which will be incurred at different times and in different quantities depending on the durability approach chosen. When conducting a full estimate of maintenance cost, down time and possible decreased productivity due to the repairs should also be considered.

Strohmeier (1994) has identified a number of the requirements for the various maintenance options which should be considered when evaluating the anticipated cost of repairs:

Application of protective coating:

- high pressure water-sand jet cleaning of the surface to remove any previous coatings, growth or loose concrete,
- filling of non-structural cracks and blow holes,
- application of a surface coating, either a barrier coating or a surface impregnator.

Repair of damaged areas:

- removal of all contaminated concrete which is in contact with reinforcing, down to a depth of 20 mm behind the reinforcing (or to below threshold level of chloride contamination)
- high pressure water-sand jet cleaning of the surface to remove any previous coatings, growth or loose concrete,
- high pressure grit blasting to remove all iron oxides from the steel,
- application of anti-corrosive coating to reinforcing,
- application of bond agent to spalled area to ensure adequate bond,
- patching of spalled area
- application of surface finish to fill any small cracks or holes,
- application of protective surface coating.

Cathodic protection:

- DC power source,
- anode system (conductive overlays to act as anode),
- conductive electrolyte (concrete),
- cathodic system (the reinforcing must have electrical continuity),
- electrical connection cables,
- monitoring devices (such as reference electrodes).

It should be reasonably simple to obtain estimates for the repair requirements, and unlike the initial cost, these estimates should include labour and additional costs such as scaffolding and access. The maintenance requirements and timings were already determined in the preceding section. Thus the specific cost of the particular maintenance options can then be applied to the present value equations developed in chapter six. It was previously established that there must

be reasonable estimates for the discount factor and the anticipated escalation of maintenance cost. Where no other information is available the current interest rates and construction cost indices may be sufficient.

3. Capital allowance (depreciation)

The capital allowance is normally based on the total initial cost of the structure. Under the current analysis only material costs have been included in that initial cost estimate thus the capital allowance will be subject to the same constraints. For the purposes of comparison it is assumed that the structure is to be discounted at 10 % over a 10 year period. After 10 years no further capital allowances will be granted.

4. Salvage value

The salvage value is the final cost to be considered in the overall analysis of durability strategies. Normally the salvage value could be estimated by examining the current worth of a structure which is in the same condition as that anticipated for the structure at the time of disposal. The value can be escalated to the future time of disposal and then discounted to the present. For the purposes of comparison (in the following example) it will be assumed that there is a nominally stated salvage value associated with the structure regardless of which approach is chosen.

Clearly the representative column approach does not include all of the associated costs of the intended structure and a more comprehensive analysis may yield different results. It is important to note, however, that the purpose of this examination is to choose between a number of competing options and therefore the ranking of the options will form the basis for selection. When the final selection of a particular design is made there are numerous other less tangible items to consider such as social good (non-monetary value to society) and environmental effects, all of which should be considered in some manner before a decision is made. Value engineering, as outlined in chapter five, is one method of dealing with these considerations. A sensitivity analysis should also be performed by selecting various discount rates to determine if the final choice would be different under those conditions. Where there is no change in lowest life cycle cost the choice is reasonably clear. If the optimal outcome does

vary depending on discount and escalation rates the selection must be carefully considered in light of the most probable and potentially lower risk outcome. There may be situations in which greater initial capital is simply not available and the lowest initial capital cost approach is the only 'viable' option. If that is the case the organisation should still be fully aware of the implications of their action on the future cost requirements of that project.

7.2 PROJECT EVALUATION EXAMPLE

The overall procedures for selecting and evaluating the various durability design options were presented in section 7.1 of this chapter. It is now possible to present an example which clearly illustrates how the procedure may be used.

Situation

A privately funded marine structure is to be constructed in a sheltered area protected from wave action in the Western Cape. A concrete elevated structure supported on columns is required and should have a service life of 40 years at which point the project will be handed to the government. At the end of the service life the structure should have no more than 10 % spalling or cracking of the surface and a nominal payment of 1 Rand (future price) will be made to the organisation. The corporate tax rate is given as 45%. For the purposes of this example, the organisation undertaking the project is known as New Harbour Management (NHM).

7.2.1 Preliminary Assessment

The structure is clearly in a marine environment and, as it is in sheltered location, the specific environment would be classified as very severe (Table 3.2) with a general environmental classification in the Coastal Severe Zone (Table 3.3)

The period of design and evaluation should be set as the service life which has been stated as 40 years. It is assumed that quality of the end product is of primary importance with the selection based on the option with the lowest LCC over the 40 years. It is also assumed that

the company financing the project and commissioning the design will be the same one that is responsible for operating and maintaining the structure. If the design and construction of the structure is being put to tender, NHM should be aware of the particular skills and weaknesses of the competing organisations. For instance, a company which constantly completes projects ahead of schedule might be viewed more favourably where time is the critical issue. For this example, it is assumed that NHM will conduct the design and construction themselves.

7.2.2 Initial Design Selection

1. Selection of trial cement types and content

The selection of the initial design and evaluation of durability is based on the representative column approach previously discussed in this chapter. The three cement/extender types to be considered are OPC, FA and GGBS, with concrete strengths of 30, 40 and 60 MPa.

2. Determination of penetration depths of contaminants

The determination of penetration depths of chlorides was based on the CSZ climate region - chloride ingress - Very Severe, tables found in Appendix A. For a 40 year period the chloride penetration depths at a concentration of 0.4% are as follows:

Penetration depth of chlorides (mm)

<i>Strength (MPa)</i>	<i>OPC</i>	<i>30 % FA</i>	<i>50 % GGBS</i>
30	131	54	51
40	99	48	41
60	75	40	39

3. Determination of required cover depths

Selection of the initial cover depths is based on 10 % of reinforcement in contact with contaminated concrete at 40 years. The design depth was determined from the comparison with the penetration depths under the 10% column of Table 4.1:

Initial cover depths (mm)

<i>Strength (MPa)</i>	<i>OPC</i>	<i>30 % FA</i>	<i>50 % GGBS</i>
30	NA (>100)	75	70
40	NA (>100)	65	60
60	100	55	55

4. Elimination of inappropriate cover depth options

A 100 mm cover would be considered excessive particularly where a 60 MPa concrete is being used, but for the purposes of comparison it will remain in the evaluation at this stage.

5. Selection of cost evaluation method

It was previously noted that the representative column evaluation approach will be used for the selection of the mix design. As the structure is in a sheltered location heavy abrasion is not a significant factor, thus the six FA and GGBS mixes and one OPC mix will be evaluated.

6. Determination of material requirements

The determination of the required material content was based on an assumed load of 5 000 kN and is calculated based on equation 7.2. The yield strength for the reinforcing is assumed to be 400 MPa. Thus the core cross-sectional areas (m²) of the columns are:

OPC: 60 MPa \cong 0.099 m² \cong 315 x 315 mm

FA and GGBS:

30 MPa \cong 0.195 m² \cong 440 x 440 mm

40 MPa \cong 0.147 m² \cong 385 x 385 mm

60 MPa \cong 0.099 m² \cong 315 x 315 mm

The total quantity of concrete required can be determined by adding the cover depths to the appropriate structural requirements. It should be noted in the overall calculation of the concrete cross-sectional area that the area of the steel was not removed, thus there is approximately 2% more core concrete than would normally be required. This represents a

fairly minor variation and should not significantly affect the final comparison. The overall dimensions of the particular columns are:

OPC: 60 MPa = 515 x 515 mm = 0.265 m²

FA: 30 MPa = 590 x 590 mm = 0.348 m²

40 MPa = 515 x 515 mm = 0.265 m²

60 MPa = 425 x 425 mm = 0.181 m²

GGBS: 30 MPa = 580 x 580 mm = 0.336 m²

40 MPa = 505 x 505 mm = 0.255 m²

60 MPa = 425 x 425 mm = 0.181 m²

7. Determination of the unit cost of concrete

The cost estimates used in this example are based on figures obtain from Ready Mix Materials for deliveries in the Cape Town area. Figures were provided for 20, 40 and 60 MPa concrete with 19 mm aggregate. A 30 MPa mix was estimated by interpolating between the 20 and 40 MPa concrete. The price for a 30 % FA mix is approximately R5 more per cubic meter and for a 50 % GGBS about R8 more per cubic meter. The delivery costs per m³ are therefore:

Cost estimates per cubic meter of concrete (Rand)

<i>Strength (MPa)</i>	<i>OPC</i>	<i>30 % FA</i>	<i>50 % GGBS</i>
20	339	344	347
30	365	370	373
40	391	396	399
60	461	466	469

8. Calculation of representative column cost

Finally the initial capital cost of the various options can be obtained as follows:

Initial Capital Cost Table (Rands/metre of column)

<i>Strength</i>	<i>OPC</i>	<i>30 % FA</i>	<i>50 % GGBS</i>
30	NA	129	125
40	NA	105	102
60	122	84	85

It is clear from the initial cost estimate that there are significant savings by opting for the higher strength concrete. The preferred options therefore would be either a 60 MPa FA or GGBS concrete. The price differential is fairly minor between the two and either one could be chosen. As the FA is R1 lower per cubic meter it has been selected for illustrative purposes. Thus the chosen mix design is a 60 MPa 30 % FA concrete.

7.2.3 Development of Alternative Designs

It is now possible to examine the various options for achieving durability in the structure based on a concrete mix design of 60 MPa with 30% FA. The evaluation of options is achieved using the representative column approach and the four suggested repair options, as presented in section 7.1, form an alternative to the 'maintenance free' options. The five durability options (including the maintenance free approach) are outlined as follows:

Option 1

The initial design selection with a cover depth of 55 mm. No maintenance is expected until after the end of the evaluation period.

Option 2

Application of protective coatings at regular intervals. It is assumed that the regular application of a surface treatment (with a 30 mm cover) provides sufficient protection for the reinforcing to avoid corrosion damage. A nominal cover of 30 mm has been chosen to ensure adequate bond development between the reinforcement and the concrete and ensure the distribution of reinforcement was not excessively close to the concrete surface. Surface

treatments will be applied at the time of construction and at the 10, 20 and 30 year marks and no final application is required at the end of the 40 year period.

Option 3

An alternative cover depth must be estimated which will allow for corrosion of the reinforcement (and thus requirements for repair) over the life of the structure. The selection of cover should be sufficiently different from the 'maintenance free' requirement to allow for a reasonable comparison of options. For the purpose of comparison in this example a cover of 40 mm was chosen to provide an initial protection with the repair periods as follows:

- 1st - 10th year - 15% spalling or cracking
- 2nd - 20th year - 15% spalling or cracking
- 3rd - 35th year - 15% spalling or cracking

The calculations were based on a 40 mm design cover depth and repair increments of approximately 15 %. The penetration depths were determined using the distribution of reinforcement for intervals at 15, 30 and 45 %, for a 40 mm design depth according to Table 4.1. The times until corrosion were obtained from chloride-induced corrosion Tables in Appendix A for the chosen penetration depths. A breakdown of the exact repair procedures will be given in the following section on maintenance cost determinations.

Option 4

Option 4 is very similar to option 3 in that a 40 mm cover has been chosen. The timings for the repairs are as follows:

- 1st - 20th year - 30% spalling or cracking
- 2nd - 35th year - 15% spalling or cracking

The calculation of the timing and magnitude of the repairs follows the same procedure as outlined in option 3, but for 30 % and 45 % reinforcement distributions.

Option 5

The use of cathodic protection is the final option to be considered. A similar 40 mm cover was selected and the deterioration after 20 years was estimated to be 30 % at which time cathodic protection would be installed.

7.2.4 Determination of Present Value of Durability Options

Before the present value of the various options can be determined it is necessary to choose an appropriate discount and construction escalation rate. The building cost indices increased on average 10.46 % per year between 1990 and 1995 (Pretorius 1996). A reasonable estimate for future increases may therefore be taken as 10 % per year. During that same period, 1990 to 1995, the consumer price index rose an average 14.1 % per year (Pretorius 1996). The current general inflation rate however is down to approximately 8 % per year. For the purpose of comparison in this example a reasonable future estimate might be taken as 12 %. An appropriate discount rate should therefore be at least equal to the prime rate of interest and for this example a discount rate of 20 % is assumed. It is now possible to estimate the cost of the various durability options and determine the present value of the estimates. The costs are based on a column of height 1m, with a 315 x 315 mm core section and constructed with a 60 MPa 30 % FA concrete. The cost per cubic meter of concrete is R 466 (1996 prices).

Initial capital cost

Option 1: 55 mm cover

Volume 0.181 m³

initial cost R 84

Option 2: 30 mm cover + surface treatment

Volume 0.141 m³

initial cost R 66

The application of a protective coating will also be added to the initial cost of the structure as it represents an enhancement to the durability of the structure prior to the ingress of harmful compounds. Strohmeier (1994) has provided one estimate for the application of a surface treatment at R 25,33 /m² in 1994. The estimate was based on an average cost taken from a

number of contractors and included labour. The building cost indices in 1994 were given as 133.6 (based on 1990 being 100) and 169.3 for 1996 (Pretorius 1996). Therefore a reasonable estimate for present cost of applying a protective coating would be approximately R 32 /m². This cost estimate is only for the application of the protective coating itself. As the coating would be applied immediately after construction this a reasonable assumption.

Surface area 1.5 m²

Total initial cost R 114

Options 3, 4 and 5: 40 mm cover

Volume 0.156 m³

initial cost R 73

If the decision for building the structure was limited to the initial capital cost (as has often been the case) then options 3, 4 or 5 would have an equal chance of being selected as they represent the same initial design of the structure with the lowest cost. Option 1 is next with option 2 being the most expensive. No further expenses are expected from option 1 but further costs will clearly be required of the surface treatment options.

Maintenance costs

Option 1: 55 mm cover

Maintenance costs: None

Option 2: 30 mm cover + surface treatment

The calculation of maintenance cost is based on the following application:

- high pressure water-sand jet cleaning of the surface to remove any previous coatings, growth or loose concrete,
- filling of non-structural cracks and blow holes,
- application of a surface coating, either a barrier coating or preferably a surface impregnator.

The cost for the individual components are based on values provided by Strohmeier (1994) for a SIKA product. The values have been converted to the end of 1996 prices. The overall cost in 1996 could be estimated at approximately R 81 /m². Therefore the cost per 1 m of column

would be R121,50 (1996 prices). The effective cost must now be determined for 10, 20 and 30 year applications with a discount rate of 20 % and construction cost rate of 10 %. The modified discount rate 'W' (based on equation 6.8) is approximately 0.02. The cumulative maintenance discount factor (taken from the corresponding table in Appendix B) was determined to be 1.331. Therefore the present value of maintenance for option 2 would be:

$$= 1.331 \times R 121,50$$

$$\cong R 162$$

Option 3: 40 mm cover with 3 repairs

The calculations for maintenance costs are based on the requirements outlined in section 7.1 for reconstruction of damaged areas where 15 % of the surface is repaired in years 10, 20 and 35. The cost estimates are taken from Strohmeier's (1994) analysis and represent an average taken from various contractors and products. The cost estimate in 1996 prices is approximately R 187 /m². The surface area for 1 m of column is 1.58 m² thus the overall cost would be R 295. A modified discount rate 'W' of 0.02 is used to determine the specific discount factor for the years 10, 20 and 35, yielding 0.493, 0.442, and 0.375 respectively. The present value of maintenance costs is therefore:

$$= R 295 \times (0.493 + 0.442 + 0.375)$$

$$\cong R 386$$

Option 4: 40 mm cover with 2 repairs

The calculation of maintenance costs for the fourth option is essentially identical to that of option 3 except only two repairs are to be conducted. The first repair occurs at year 20 with 30 % replacement and the second at year 35 with 15 % replacement. The cost estimates are once again based on the work of Strohmeier (1994) with the requirements as outlined in section 7.1 being adopted. The cost estimate in 1996 prices for a surface with 30% spalling or cracking is approximately R 228 /m². The 15% repair option was already determined to be R 187 /m². Therefore for a 1m column with area 1.58 m² the cost of repairs would be R360 (for 30% spalling) and R 295 (for 15% spalling). The specific discount factors are 0.442 and 0.375 for years 20 and 35 respectively. Therefore the present value of maintenance:

$$= (R 360 \times 0.442) + (R 295 \times 0.375)$$

$$\cong R 270$$

Option 5: 40 mm cover with cathodic protection in 20 years

The cost of cathodic protection is based on the requirements outlined in section 7.1 with the cost derived from the work of Strohmeier (1994). Cathodic protection is to be installed in 20 years once 30 % of the surface has spalled or cracked. Strohmeier (1994) suggests a cost of R 500 /m² might be appropriate where 35 % of the surface is spalled. For the purposes of discussion in this chapter a value of R 450 /m² is assumed. The 1996 price for 1 m of column with an area of 1.58 m² would be approximately R 900. The specific discount factor for the 20th year is 0.442, yielding a present value of maintenance:

$$= R\ 900 \times 0.442$$

$$\cong R\ 398$$

Capital allowances (depreciation)

It was previously stated that the capital allowance would be allocated on a straight line basis of 10 % over 10 years. The determination of the present value of the capital allowances is based on equation (6.12) in conjunction with the relevant table in Appendix C. The discount rate is given as 20 % with a tax rate of 45 % which yields a cumulative discount factor of 2.65 over 10 years.

Option 1: 55 mm cover

initial cost	R 84
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Yearly depreciation	= 84 x 0.1
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Present value of

Capital allowance	8.4 x 2.65 = R 22
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Option 2: 30 mm cover + surface treatment

initial cost	R 114
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Yearly depreciation	= 114 x 0.1
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Present value of

Capital allowance	11.4 x 2.65 = R 30
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Options 3, 4 and 5: 40 mm cover

initial cost	R 73
--------------	------

Yearly depreciation	= 73 x 0.1
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Present value of

$$\text{Capital allowance} = 7.3 \times 2.65 = \mathbf{R\ 19}$$

The capital allowance represents a negative cost and therefore decreases the present cost of the various options by the amount indicated.

Salvage value

The salvage value of the structure is the same for all options. As R 1 is received at the end of the evaluation period, no escalation rate will be applied and the modified discount rate 'W' will be equal to the discount rate of 20 %. This represents the 'normal case' for salvage values as the market value (R 1) is less than the initial capital cost and greater than the book value (0). Furthermore the structure is being sold after all capital allowances have been claimed and therefore some recoupment is payable. The present value of the salvage is therefore given as:

$$P_s = [MV(1-t) - (MV - BV)t] GDF \quad \dots(7.4)$$

where:

GDF is the general discount factor (taken from Appendix d)

$$GDF = \frac{1}{(1+i(1-t))^n} \quad \dots(7.5)$$

P_s is the present salvage value

MV is market value

BV is book value

Therefore the GDF for 40 years was determined to be 0.015 and the resulting present salvage value:

$$\begin{aligned} &= [1(1-0.45) - (1 \times 0.45)] \times 0.015 \\ &\cong \mathbf{R\ 0.01} \end{aligned}$$

The salvage value represents a negative cost and thus can be used to offset the other costs in the final present value determination.

Summary of present costs of options

The present cost of the various options is the sum of the associated costs. Therefore the LCC for this example yields the following results:

Cost of durability options (Rand)

<i>Costs</i>	<i>Option 1</i>	<i>Option 2</i>	<i>Option 3</i>	<i>Option 4</i>	<i>Option 5</i>
Initial	84	114	73	73	73
Maintenance	0	162	386	270	398
Capital allowance	(22)	(30)	(19)	(19)	(19)
Salvage value	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Total (R)	62	246	440	324	452

It is evident from the summary of durability design option costs that the 'maintenance free' option is by far the least expensive over the life of the structure. The increase in initial capital is very minor compared to the present value of savings over the service life of the structure. It is important to realise that a number of costs have not been included in the initial cost component such as curing costs and labour. They were not included because the variation in labour costs for a 30 MPa concrete versus a 60 MPa concrete are likely to be very minor. The purpose of the comparison of options, as outlined in this dissertation, is to determine the effects that differences in durability design have on the overall economics of a structure. Thus cost items which are the same for all structures regardless of design can be ignored. When determining the actual present cost of a structure however all costs must be considered. For instance, secondary costs due to loss of access during repairs may be very significant. Furthermore in the current analysis the reinforcing costs were not considered. If the evaluation of durability options were to include galvanised or epoxy-coated reinforcement it would be necessary to include reinforcement in the cost estimates. Even in the current analysis there may be some differences in reinforcement requirements due to the core-area of structural concrete varying with strength of concrete. The summary of option costs clearly shows however the tremendous savings in resources (money) associated with ensuring durability of the structure at the design stage and avoiding unnecessary future maintenance.

7.3 CONCLUSION

The durability design and evaluation model presented in this chapter represents one approach to the selection of an appropriate concrete mix design and service life strategy. The method suggested in this chapter is fairly simple in both concept and application. There are other approaches, as mentioned, which might provide for greater accuracy in the predicted values but due to the increased data requirements they may not be as practical and their usefulness is offset by the greater complexity of the model. The four stages noted in the selection of an appropriate design are reasonably independent and represent replaceable components. The only area where there could be some difficulty is the link between the initial design selection (stage 2) and the development of alternative designs (stage 3). The mix design which formed the basis of evaluation in stage 3 was however developed in stage 2. Where a more thorough analysis is required, further mix designs could be selected and the various maintenance strategies evaluated in a similar manner to that already suggested.

The selection of maintenance strategies and determination of repair intervals was developed in chapter four of this project. As previously noted, the quantity of useful information relating to the life of repair options is limited and the values suggested in this project were provided for illustrative purposes only. Greater research into the effectiveness of repairing reinforced concrete structures would be of significant benefit to the accuracy of any forecast model. Where more applicable repair information is available that information should be used in overall analysis.

The example outlined in section 7.2 provided an illustration of how the durability design and evaluation model could be used. The principles described therein, were general and should have a broad region of validity. The outcome of that particular example clearly showed the value of incorporating the durability portion of the design at the construction stage of the project rather than later as a repair or maintenance option. The present value of the savings, over the life of the project, are quite substantial. It is also interesting to note that the option with the highest initial cost (surface treatment approach) had reduced maintenance costs over the life of the project, but insufficient to make this an attractive option. The alternative which

was designed to achieve the intended service life, based on quality and quantity of the cover concrete, was only marginally more expensive (approximately R10 per meter of column) at the construction stage than other options with a lower cover and yet resulted in savings (in 1996 Rands) of over R 250 compared to traditional repair methods and cathodic protection over the life of the project.

The model presented in this chapter cannot take into account every possible situation which may be required in the selection of various project options. The principles of Life Cycle Costing however and the development of the technical prediction models for the life of a reinforced concrete structure allow for a considerable improvement to the quality of information available to the decision maker. The compartmental approach to development outlined in this chapter and project in general have produced a model which should be capable of growth to suit the situation for which it is required.

7.4 REFERENCES

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8 RESULTS OF CONCRETE DURABILITY SURVEY

A survey was conducted of various consulting engineering firms, mainly in the Western Cape. The objective of the survey was to determine common perceptions of durability related issues and problems currently being faced in the South African context among those people who have a direct impact upon the design of structures. The questionnaires were posted in September 1996 and in general returned within one month. The target population was identified as those people in consulting engineering firms who are responsible for the design of reinforced concrete structures. Ideally the target population for which information is required and that which is surveyed should be identical but, where this is not possible, projections of the survey population may be made to the target population provided they are duly noted (Chakrapani and Deal 1992). In the current examination of durability issues it is believed that the target population was reached in the survey.

Another factor which affects the accuracy and valid range of the survey is the selection of a sampling method: based on probability or non-probability sampling. Probability sampling implies that each member of the chosen population has an equal chance of being questioned. Chakrapani and Deal (1992) have suggested that probability sampling 'provides a sound theoretical basis for projecting the results to the general population'. The form of sampling chosen in the current study however was that of a non-probability, purposive sample. The choice of eligible people was based on individual judgement as to who would best represent the current views of that particular organisation. It is important to realise therefore that the results obtained from the respondents in the various engineering firms for this survey may not necessarily represent the views or practices of everyone in that organisation. The accuracy of the sample depends upon the degree to which the respondents answered the questions in accordance with the normal practices of that organisation. Due to the constraints of limited time and budget, the choice of a purposive non-probability sample would appear to be quite reasonable. The organisations chosen varied in: size, from 2 engineers (in the structural department) to over 100 (total); location, with both local and national companies considered; and area of specialisation. A fairly broad spectrum of engineering companies was chosen which would provide a reasonable basis for the determination of general market views.

Despite the broad spectrum of organisations chosen, the quantity surveyed remained fairly small. Twenty questionnaires were sent out with 10 being returned yielding a relatively high return rate (50 %), but still limited quantities. It would be inadvisable therefore to apply the various percentages derived from this survey to the market as a whole with confidence. The results of the survey are useful however if they are viewed as general trends and in a more qualitative manner. A sample of the questionnaire can be found in Appendix E.

8.1 ANALYSIS OF RESULTS

This survey consisted of 20 questions and one case study. The survey is divided into five sections: company details (demographics of the organisation), role of client and consultant in achieving durability, cost issues, durability and the concrete code of practice, and a case study. Not all of the questions presented in the survey are explicitly addressed in this section. The demographic results, for instance, were essentially used to ensure a reasonable distribution of size and area of specialisation among the organisations and therefore those results which do not significantly contribute to the overall assessment are not presented in the analysis or discussion.

8.1.1 Company Details

Question 1: *How many engineers are currently employed in your organisation's structural department?*

The companies ranged in size from 2 to 10 engineers employed in the structural department (based on 9 responses) with a mean average of 6.3. Five of the respondents indicated they had 5 or 6 engineers employed in their structural department.

Question 3: *Does your company support continuing education for your employee engineers? If so how?*

When asked about support for continuing education eight out of ten stated they actively support continuing education for their employees, with the remaining two providing some limited degree of support. Support included: payment of fees and bursaries for courses, time off, SAICE training programs, Post Graduate studies, seminars and in-house training.

Question 5: *Sources of consulting work, (please give percentages) - public/private*

Question 5 sought to determine the distribution of consulting work between public and private projects. The minimum percentage of publicly sourced work was given as 5 % with a maximum of 80 % and the mean was determined to be approximately 37 % (based on 8 responses). The results of the survey are shown in table 8.1.

Table 8.1: Percentage of work sourced from public organisations

<i>Percentage sourced from public</i>	<i>Number of Respondents (8)</i>
0 - 25 %	4
26 -50 %	2
> 50 %	2

Question 6 and 7: *Sizes of average project (many small contracts, few large ones)?
Main types of work (please indicate)*

The size of projects in which companies were engaged usually consisted of many smaller projects and a few larger ones. Three out of eight respondents stated their projects were of mixed sizes. All the companies surveyed performed more than one type of engineering (for instance industrial infrastructure, marine works, and residential building) with eight out of ten involved in 4 or more areas.

8.1.2 Role of Client and Consultant in Achieving Durability

Question 1: *When requested to design a structure/project, are durability/longevity requirements usually stated by the client? If so how?*

Six of the respondents indicated that clients do not normally state durability requirements for the structures; one indicated that this is occasionally done, while two indicated that the client's durability requirements are stated through the code. Only one of the respondents said that clients usually state their durability requirements. Figure 8.1 shows the degree to which clients stated durability requirements.

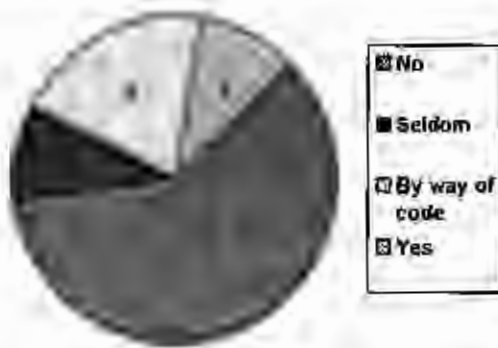


Figure 8.1: *Do Clients Specify Durability Requirements?*

Question 2: *What is the primary concern of most clients (please specify according to public and private sectors): time, quality, or cost?*

There were 8 responses to the public sector question and 9 responses to the private sector question. The respondents were not limited to indicating only one concern thus in many cases one respondent would include 2 or even 3 concerns. In the case of public clients, cost was identified as a primary concern by all eight respondents while only four stated that quality was also a concern. The issue of time was not addressed by the public sector clients. Cost was identified as an issue in 8 of 9 responses for the private sector. Only one respondent indicated that time was the primary concern but he also noted that cost was dependent upon time. A further four (of the eight) respondents indicated that time was also a significant factor and two respondents stated quality was a concern as well. Figure 8.2 illustrates the relationship between type of client and areas of concern.



Figure 8.2: Concerns of public and private clients. Note that there were 9 responses for the private client and 8 for public client questions.

Question 3: *How would you define durability in the context of concrete structural engineering? What would be your requirements for a durable concrete structure?*

The respondents were asked to provide a definition of durability in the context of concrete structural engineering. A number of responses were given as follows:

1. "...the ability of the concrete to protect the steel against corrosion."
2. "concrete that fulfils its structural and aesthetic role without further maintenance within an agreed time frame."
3. "the ability of the completed concrete work to provide a long period of service with minimal/little maintenance"
4. "the ability of a structure to perform its function in a given environment for its design life."

Question 4: *What would you view as various options for achieving durable concrete structures? Do you consider these options during design?*

The fourth question was concerned with establishing various options for achieving durability in concrete structures. There are numerous possible combinations of answers to this particular question. The options and number of respondents who indicated those particular options are found in Table 8.2.

Table 8.2: Options for achieving durability

<i>Option</i>	<i>Responses</i>	<i>Option</i>	<i>Responses</i>
curing	6	cement content	2
use of extenders	3	cover	7
max w/c ratio	3	design detailing	3
material specifications and properties	6	site supervision and construction	5

Other durability considerations included: density, workability, porosity, and coatings.

Questions 5 and 6: *How is 'durability' of the structure perceived by the client? Are clients aware of the various options mentioned in question (4) above? Do you in the ordinary course of events appraise the client of durability aspects of a design, and inform him of the various options for achieving durability?*

Question 5 dealt with client's awareness of the options for achieving durability. Question 6 was concerned with advising clients of durability options. There were 9 responses to these questions. Only one indicated that clients were aware of durability options and three stated in some circumstances clients were informed. Of those respondents who stated that clients were aware or somewhat aware, all further briefed the clients of durability-related issues. Only two out of the five that said clients were not initially aware of durability issues then appraised clients of various durability aspects. It should be noted however that a number of respondents who did brief clients stated that private sector developers were generally not interested or were unconcerned with durability issues. Figure 8.3 shows the proportion of respondents who stated clients were aware, some clients aware or clients not aware of durability issues.

One respondent suggested the clients were "often unaware - concrete is assumed to be as durable as a rock". This comment may well be indicative of the general state of clients' awareness of durability issues or their general lack of concern.

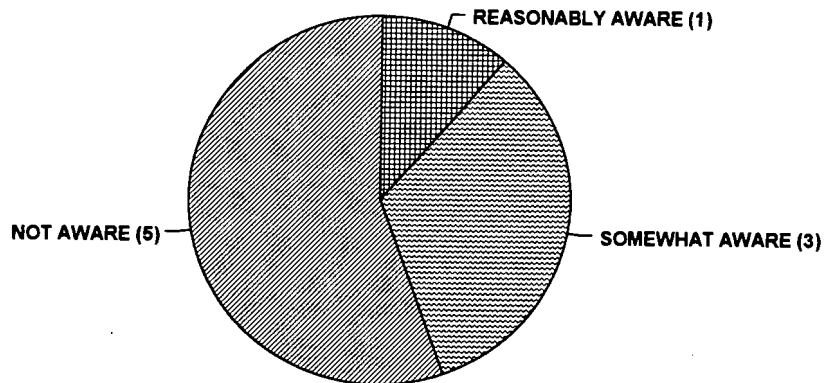


Figure 8.3: Client awareness of durability issues.

Question 7: *In the event of non-compliance with a durability specification (for example, minimum cover depth) how would you as an engineer handle the contractual failure and the cost of remedial work? Would you insist on remedial measures?*

Most of the respondents indicated they would require remedial work by the contractor in the event of non-compliance with specifications. One respondent indicated that it is often difficult to ascertain whether there has been a lack of compliance (for instance with respect to cover) due to the lack of continuous supervision. Generally the contractor would be responsible for remedial work at his own expense.

8.1.3 Cost Issues

Question 1 and 3: *When examining the cost of various options of achieving durability, is this done on a life cycle basis? (Life Cycle costing is taken to mean, but not limited to: examining not only the initial cost of the structure but also the expected life time cost associated with the maintenance and repair of the structure for a given design.) Have you ever carried out any studies into the most cost effective methods for achieving long-term durability in structures? If so what was the outcome?*

The question of life cycle costing and its use by clients was addressed in this question. Seven of the ten respondents stated life cycle costing was not currently used in the evaluation of durability options for concrete structures. Two stated life cycle costing was occasionally used, while one of the respondents said it was employed. It was also suggested by one respondent that life cycle costing, while not used in concrete structures, is used in steel structures.

Three of the respondents indicated that they had performed some studies on cost effective methods for achieving durability. Some suggestions included appropriate cover, curing, extenders and w/c ratio. A further respondent indicated the most economical method involved the incorporation of durability issues at the design and construction phase.

Question 2: *If it could be shown on the basis of life cycle costing, that the additional initial expense of producing a more durable structure is economically justifiable, would it be likely that your clients would adopt this?*

Question 2 dealt with the likelihood of a client accepting additional initial expenses for durability if it could be proven cheaper on a life cycle basis. Out of the 9 responses only one stated his clients would accept the greater initial expense. Six respondents indicated the clients might accept the greater initial expense but generally only the larger ones or public organisations. It was also noted that developers would not be interested in any additional expense. Two respondents indicated clients would not accept an additional initial cost associated with a more durable concrete structure. One respondent indicated "it is obvious that the small additional cost of achieving durability is economically justifiable". Figure 8.4 graphically illustrates the proportion of clients that would accept a higher additional cost, those that might and finally those that would not.



Figure 8.4: *Clients who would accept a higher initial cost for greater long term durability (based on LCC analysis).*

8.1.4 Durability and the Concrete Code of Practice

Question 2: *In your experience does the application of the requirements of the current concrete code result in adequately durable concrete structures, given the various environments within which structures operate (please elaborate as necessary)?*

Of the 10 individual responses only 1 stated the concrete code of practice was inadequate in that there were no provisions for local material quality or exposure conditions. The remaining 9 respondents indicate the code was adequate but with some qualification, such as whether the code was enforced. Also, poor site work and lack of quality control limit the code's effectiveness.

Question 3: *How would you like to see the code of practice changed in order to reflect the need for durable concrete construction (assuming you identify with such a need)?*

Despite the general satisfaction with the concrete code of practice the respondents provided a number of recommendations which reflect the need for durable concrete construction (where such a need was recognised). Five of the eight respondents indicated some changes would be helpful. Only three stated there was no need for change. Some of the suggestions included:

- requirements for site inspection and recording of results
- better definition of exposure conditions
- limit water demand of sands
- specify minimum cementitious content
- use of extenders
- simple empirical rules
- direct payment for curing

8.1.5 Case Study

The case study question consisted of two parts. The first part involved reviewing a former project where durability was a major issue. Of the five respondents, four stated they used an

extender in the mix design. In 3 of the cases a follow up study was conducted and the structures were found to be performing well.

In a hypothetical situation, if you were required to design a bridge column in the marine splash zone, what would you specify from a durability design point of view? (assuming 50 yr design life, 300 mm x 300 mm lightly loaded column)

The second part of the question was based on a hypothetical situation of designing a reinforced concrete column in the marine splash zone. All of the 9 responses stated the importance of adequate cover (40 mm or greater for those also specified) and eight of the nine respondents indicated an extender should be used. Six of the respondents indicated the use of special provisions such as galvanised reinforcement, adequate curing, and quality materials (for instance sand). Table 8.3 provides a summary of some of the recommendations for ensuring durability in the column.

Table 8.3: Recommendations for ensuring durability

<i>Option</i>	<i>Durability Requirements</i>
1	<ul style="list-style-type: none"> • 45 MPa, W/C ratio 0.5, extender (25% FA), 350 kg/m³ cement content • 40 mm cover
2	<ul style="list-style-type: none"> • max W/C ratio, extender, min cement content • cover, curing, sand quality
3	<ul style="list-style-type: none"> • 50 MPa, OPC • 70 mm cover, curing
4	<ul style="list-style-type: none"> • ideally use precast • mix design to ensure dense concrete with low permeability, extender MGBFS (blast furnace slag) • 50 - 60 mm cover, curing
5	<ul style="list-style-type: none"> • high strength, extender (CSF) • 50 - 60 mm cover, curing • use of galvanised reinforcing

8.2 DISCUSSION

The information on company details was used to confirm the existence of a reasonable distribution with respect to the size of organisations surveyed. The results indicated a range between 2 and 10 engineers employed within the structural departments. A further respondent indicated employment of over 100 engineers, spread through all the departments in the company. The majority (five of nine) of respondents indicated they employed either 5 or 6 engineers in their structural departments. The distribution of the organisational size therefore appears to be reasonable.

The consulting engineering companies surveyed, as previously mentioned, were generally supportive of continuing education for their employees. Many stated they provide some sort of financial compensation and time off to those who wish to further their studies. 'In house' training programs were also used by at least one of the respondents. Continuing education for employees is of particular concern from a durability perspective. Many of the concepts and suggestions relating to improvements in durability are fairly recent developments and it is possible that engineers who have not received some sort of continuing education training may not be aware of some of the newer durability approaches. Further questions relating to the exact nature of the training would assist in determining the degree to which the durability of concrete forms part of the continuing education. It appears from the analysis of the results however that most organisations are fairly progressive with respect to continued training and that some 'new ideas' should be returning to the office from which the employees were sent.

All of the companies surveyed indicated they had some degree of work from public sources. The amount varied considerably from a low of 5 % to a high of 80 % with a mean of approximately 37 %. The source of engineering work is important when related to the number of projects likely to be evaluated on a LCC basis. The respondents indicated that public organisations would be more likely to adopt LCC techniques and be willing to pay a little extra for initial durability than would private organisations. With only 37 % of contracts derived from public sources the extensive use of LCC as a basis for project evaluation does not appear

probable. The respondents also indicated that developers were the least likely to pay a higher initial cost as they only retain the structures for a short time before they are sold. Provided deterioration does not occur for the first few years the developers will be satisfied with their work. The lack of co-ordination between the various parties (developer, owner, engineer and consultant) over the life of the structure is clearly a major problem and one for which there is no easy solution.

The problem of co-ordination over the life of the structure is further compounded by a general lack of awareness or concern of durability issues on the part of the clients (both public and private). The vast majority of respondents indicated that clients were generally unaware of durability related issues and that only a few clients had some knowledge of durability problems. As one respondent indicated, clients are often unaware and 'concrete is assumed to be as durable as a rock'. Thus the lack of awareness of concrete durability issues by clients is another major problem facing the longevity of concrete structures. It appears however that the respondents themselves are generally informed of the requirements for achieving durability in reinforced concrete structures. The various durability definitions supplied in question 3 of section 2 (Role of the Client and Consultant in Achieving Durability) indicated a reasonable knowledge of the purpose and concept of durability while the results of question 4 (in the same section) demonstrated a good technical knowledge of the requirements for achieving durability (for instance: use of extenders, minimum cement content, and adequate cover).

One of the major reasons for failure with respect to the durability of a structure identified in this survey stemmed from poor construction and site practices. Half of the respondents indicated that quality of site work was inadequate and was probably the major cause of durability problems in reinforced concrete structures. The lack of adequate supervision was specifically cited by one respondent as the major reason for a lack of durability. The current concrete code of practice was found to be acceptable by most of the respondents. Only one indicated that it was inadequate as it did not make allowances for the effects of local material and environmental conditions. Despite the satisfaction with the code a few suggestions were made which could help to address some of the other problems (specifically site and

construction related) previously mentioned, namely: direct payment to the contractor for curing, requirements for site supervision and better definition of exposure conditions.

8.3 CONCLUSION

The results of the survey indicate that there are three main problems which must be addressed if durability is to be achieved at the design and construction stage.

1. The first problem is a lack of co-ordination and control over the life of the structure. In the private sector the developer, as previously noted, is satisfied provided the structure does not exhibit signs of deterioration during the time he has possession. Since this time period is fairly short, durability related problems are not likely to arise realistically until a few years after the developer has disposed of the particular structure. It is almost impossible for an 'ordinary' client (a new buyer or owner) to visually assess the future life of his newly acquired structure and the possible maintenance cost implications of his purchase. A 'durability audit' as a precondition to the purchase may however change that situation. A durability audit has a wide range of possible meanings but for the purposes of discussion here it refers to the assessment of a structure to determine: cover depths to reinforcement, chloride concentration and depth of penetration if appropriate (carbonation in other cases) and various material properties of the concrete. The durability audit would allow a prospective purchaser to be more informed about the true value and future costs of the structure under consideration. It is unlikely however that there will be greater consistency in control over the service life of a structure as developers will continue to have an important and vital role in the construction of new facilities. The integration of design and serviceability requirements among the key players (engineers, owners, developers and contractors) and knowledge base with respect to structures can be significantly improved through a more precise definition of the structure and its expected future life.

2. The concept of durability audits and co-ordination over the life of a structure relates to the next major problem, the public's (client's) general lack of knowledge with respect to durability related issues. The concept of a durability audit may be fine but if the future client is unaware of the potential of a problem he would see no reason to request such an audit. Until the client becomes more informed of the problems related to durability and the true cost of those problems, the situation will not improve without direct legislative action. One possibility would be the legislation of LCC in all projects, but such a step would involve serious infringements upon the individual and there may be considerable difficulties enforcing such a law. Other problems include the assigning of appropriate discount and escalation rates and the time period for analysis. Even if LCC were voluntarily employed by the developer he still has a very short period of analysis over which time no maintenance or repairs are likely. The pressure on the developer must therefore come from the individual (or organisation) who will be paying for the future maintenance. It is the LCC of the client which is important and should in turn have an effect upon the price a developer can charge. A structure which will require maintenance every 5 years is clearly less valuable than one which is 'maintenance free' for the same period of analysis, *ceteris paribus*. A marketing awareness campaign directed at potential clients in which both the cement companies and certain government agencies take part to inform them of durability issues may have a greater chance of success than legislation. Consulting engineers could also be of assistance by advising all clients of durability-related issues where such a concern is warranted. One form of legislation which could be valuable however is the requirement for durability audits on sale or re-purchase. Such legislation would ensure the purchaser is aware of the true nature of his investment and what durability-related problems he is likely to face in the future. The marketing awareness campaign together with the legislation of durability audits could significantly improve the situation currently being faced with the premature deterioration of reinforced concrete structures.
3. The final problem is that of the quality of site work and construction related activities. It is almost impossible to determine by visual inspection (after completion) whether the

specified covers have been achieved or various other requirements fulfilled. Suggestions such as better site supervision and direct payment for curing would certainly assist in correcting this problem. The contractors, as with the clients, must be made aware of the importance of achieving sufficient cover and curing (particularly where extenders are used). The use of durability index tests, as suggested by Alexander (1997), could be a significant aid in ensuring the quality of site work and standards for achieving long-term durability. The use of index tests correlated with real long-term durability data would allow for the more accurate prediction of the durability performance of a structure over its service life from a set of tests conducted at an early age. Alexander (1997) has identified three tests in particular which could be used for assessing the long-term durability of structures: oxygen permeability, water sorptivity and chloride conductivity. If payment to the contractor was contingent upon some sort of post construction durability audit (including the use of index tests) it is likely that previously ignored requirements would now receive considerable attention. Contractors could be left to 'police' themselves without legislative requirements or interference from other sources. Quality-contingent payment based on a post-construction assessment appears to provide the best solution for ensuring the future durability of reinforced concrete structures.

8.4 REFERENCES

Alexander, M. (1997). 'An indexing approach to achieving durability in concrete structures', The Concrete Way to Development, *FIP Symposium, Sandton, South Africa, March*, Concrete Society of Southern Africa, pp. 571-576.

Chakrapani, C. and Deal, K. (1992), *Marketing Research Methods and Canadian Practice*, Scarborough: Prentice-Hall Canada Inc.

9 CONCLUSION AND RECOMMENDATIONS

The deterioration of reinforced concrete structures has been established as one of the most serious problems faced by civil engineers today. Browne (1986) has estimated that 40 percent of construction efforts in the United Kingdom alone are devoted to the repair and reconstruction of deteriorated structures. This figure, coupled with that of Bull (1993) who states that up to 80 percent of the total cost of a structure may be spent during the service life, clearly indicates that a very serious burden exists on the already limited resources of society. There are a variety of reasons for the almost epidemic deterioration of reinforced concrete structures. Browne (1986) has provided a list of a number of the major causes which he feels are responsible for the current deterioration problems:

- Problems with accounting methods and the emphasis on initial capital outlay with little concern for future maintenance costs.
- Many commercial products have little or no long term performance data for unusual environmental conditions.
- Poor quality of construction practices, due to emphasis on speed of construction.
- A lack of thorough understanding of the mechanisms of deterioration and influences of environmental factors.

The last-mentioned factor identified by Browne has improved recently as continued research in the field of concrete durability has expanded the current knowledge of concrete and the impact of the environment.

A number of properties relevant to the durability of concrete were presented in this dissertation. The effects of extenders such as Fly Ash and Ground Granulated Blastfurnace Slag on the properties of concrete were examined and it was determined that there are considerable benefits associated with their use for promoting durability in reinforced concrete structures. FA and GGBS for instance both result in a finer pore structure for hardened concrete and have improved chloride-binding characteristics compared with OPC. The major limitation of these extenders however is the need for adequate curing of the concrete. Although there are many reasons for the deterioration of concrete, chloride-induced corrosion

of reinforcement appears to be the major cause of deterioration in modern reinforced concrete structures (Mangat and Molloy 1994). The integrity of the reinforcement, and thus durability of the structure, can be maintained either by using the properties of the concrete itself to prevent the ingress of harmful substances such as moisture, oxygen and chlorides or using other materials to isolate the reinforcement. There are a number of options for ensuring the durability of reinforced concrete structures including:

- adequate cover
- sufficient cement content
- use of extenders
- limiting w/c ratio
- adequate curing and compaction
- application of protective coatings
- use of galvanised, epoxy coated or even stainless steel reinforcing.

Even with the many options available for ensuring durability there are still numerous problems facing the design and construction of modern buildings and structures. It would not be practical, for instance, to design every building for 120 years of maintenance free service life as the commitment of materials and resources in such a venture would be enormous. There must be a reasonable estimate of both the required service life of the structure and what will become of the structure at the end of the evaluation period. If a building is to be demolished after 30 or 40 years then some degree of deterioration would probably be acceptable at the end of its service life. There is a requirement therefore not just to produce a 'durable' structure but also one which is durable for a particular time period. Mangat and Molloy (1994) have stated the need for accurate predictions of the initiation and propagation of reinforcement corrosion. With such predictions it is possible to optimise the repair and maintenance schedules and ensure the serviceability of the structure.

A number of prediction models were outlined for both carbonation and chloride-induced corrosion. The models varied somewhat in their approach and methodology for estimating the initiation period of corrosion. Generally the models were based on the calibration of accelerated laboratory tests with real in-situ data and structures. The carbonation prediction

models developed by Ballim and Lampacher and Watkins and Jones however were derived solely on the correlation of data from real structures in Johannesburg and Hong Kong respectively. The model developed by Dhir, Hewlett and Chan is particularly useful in concept, in that it employs the intrinsic properties of the material (concrete), which can be measured using various index tests and correlated with real data from a variety of environmental exposure conditions. Although their model is only directly applicable to the environmental conditions of Dundee, Scotland, their premise is useful for further study.

The primary limitation of the prediction models lies in the calibration of laboratory data to real site-specific events and conditions. Furthermore the environmental conditions in one area are often very different from those in another location even within a fairly limited locality. Thus models developed for European coastal conditions, for instance, cannot be directly applied to the Western Cape. The models may however provide a reasonable outline of procedures to be followed and with local site-specific data could be very useful for predicting the ingress of harmful materials through concrete. Nagataki, Nireki and Tomosawa (1993), have stated that one of the roles of the engineer is to tailor the concrete composition to suit the specific environment to which a structure will be exposed. Furthermore it was mentioned that too much emphasis is placed on the structural requirements with little regard to the environmental characteristics.

Once corrosion has occurred there are a number of options for the repair of the structure. Five major maintenance strategies were presented as follows:

- Do nothing and apply structural propping as required
- Application of surface treatments
- Reconstruction of damaged area
- Cathodic protection
- Complete replacement of damaged member.

The various repair strategies were discussed and some estimates of repair life given. There was generally little information in the literature as to reasonable estimates for the life of repairs, and therefore the values suggested in this thesis are for illustrative purposes and should not be

used without careful analysis. The lack of useful repair data has been cited as one of the major limitations of the current research but with future developments in the predictions of the repair life of various options, the overall accuracy of the durability design model should improve markedly.

It has been established that life cycle costing (LCC) can offer an effective means for addressing the concerns of deterioration in reinforced concrete structures. The use of life cycle costing allows for the evaluation of the total cost of a project over its anticipated life. There are numerous costs which could be included in a comprehensive LCC study. When evaluating the economic effectiveness of various options for ensuring the durability of reinforced concrete structures the emphasis should be on those items which can be used to differentiate between competing proposals. It was therefore determined that the costs to be considered in the proposed durability evaluation model should include: maintenance costs, initial capital costs (limited to structural and material considerations), residual value at the end of the service life and the effects of depreciation over the life of the structure. The various future costs can be discounted to the present for the purpose of comparison. By examining all the costs associated with a structure and presenting them at the time of project evaluation it is possible for managers and engineers to make more informed decisions. There is no longer any excuse for an owner of a structure to be surprised when 'unexpected' maintenance costs start to appear after a relatively short period of time if the selection of design alternatives was based on lowest initial cost. Life cycle costing offers an effective means of comparison and if employed will allow the decision-maker greater flexibility in his choice of options.

The durability design model as outlined in chapter seven offers one approach to selection of durable reinforced concrete designs. The method is by no means perfect and as noted there are numerous simplifications and assumptions which have been made. The concept presented for the integration of the technical prediction model and economic evaluation approaches (LCC) represent a realistic approach to the selection and evaluation of design alternatives. The compartmental approach should allow specific sections of the model to be modified and enhanced as progress is made in those particular fields of research. The durability design example outlined in chapter seven illustrated the tremendous cost savings (due to lower

maintenance requirements) over the life of the structure associated with a relatively minor increase in the initial cost of ensuring durability. Under the conditions outlined in the example a R10/m of column increase in the initial cost resulted in a savings of over R250 compared to traditional repair methods over the life of the structure. Clearly the requirements for durability of reinforced concrete structures must be given more attention at the design stage as they will significantly impact upon the future operating costs of the structure.

Many of the principal players, namely: developers, engineers, contractors, and owners, are likely to blame each other for the various failures being experienced, but this would not be entirely correct. Each of these groups must share some degree of the responsibility. Ultimately the engineer must give approval for a design and where it is known, or at least suspected, that the contractor will not meet the requirements some allowances should be provided. The developer in his quest for quick profits is probably the underlying cause for most of the durability problems being experienced. The developer however would not be permitted to do this if it were not for a generally ill-informed public. The perception, as shown by the results of the survey, indicates that clients are normally unaware of the durability aspects of concrete. As previously stated 'concrete is assumed to be as durable as a rock'. Why then would someone bother to pay a higher initial price for something that is already durable? People who are willing to pay for car insurance against theft or damage to a motor vehicle, at the same time are not willing to take out similar insurance (improved protection characteristics of concrete) for their much larger capital purchases, specifically reinforced concrete structures. Clearly some sort of market awareness campaign is needed. The contractor is by no means free of wrong-doing either. Where specified cover depths or adequate compaction of the concrete are not achieved, durability problems are bound to become a major issue. The contractor must ensure the specifications are met. The possible use of durability audits employing various index tests and quality-contingent payment for work, as outlined in chapter eight, may be of significant help in ensuring the durability of concrete structures.

If the suggestions or models presented in this thesis are to be effectively utilised, however, there must be greater co-operation among the various participants in the design, construction

and operation of structures. Coupled with the concept of co-operation is the need to improve the client's awareness of durability-related issues. If durability in reinforced concrete construction is to become a reality there must be:

- improvements in the forecasting of the repair life and the propagation period of corrosion
- greater co-operation among the affected parties associated with the structure
- greater public awareness of durability issues related to reinforced concrete structures.

The overall requirements for achieving durability in reinforced concrete structures and optimisation model developed in this thesis are graphically illustrated in figure 9.1. The ability to design, produce and operate durable structures is a reality. It requires a commitment to follow the principle of life cycle costing and expand the forecast horizon beyond merely the immediate future. The limited nature of resources and requirements for longer in-service use of infrastructure demands a response.

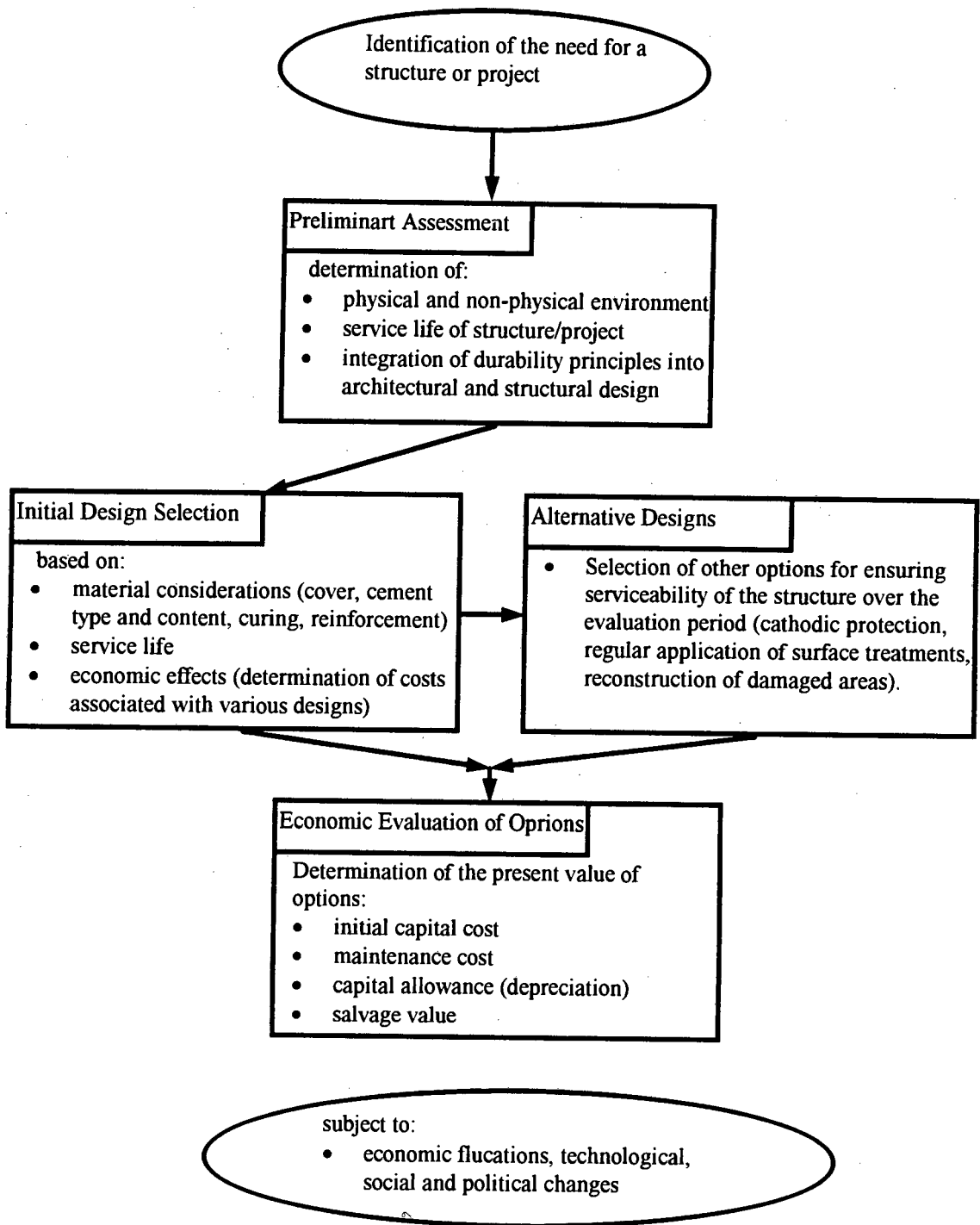


Figure 9.1: *Component requirements and interactions for determining a cost effective design in reinforced concrete structures.*

9.1 RECOMMENDATIONS FOR FURTHER WORK

A number of suggestions and recommendations for ensuring the durability of reinforced concrete structures have been presented in this thesis. While this work represents a step forward there are still many areas in which further research is required. The recommendations for further research include:

- develop more accurate prediction methods for the life of repairs, specifically, the useful life of surface treatments, patch repairs and cathodic protection components.
- examine the existing prediction models for carbonation and chloride-induced corrosion to determine the probabilities associated with the ingress of harmful substances.
- develop a data base of real site-specific information in South Africa to be used for calibrating the various prediction models to local conditions.
- determine the true nature and form of the probability distribution of reinforcement in concrete.

9.2 REFERENCES

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APPENDIX A

PREDICTIONS for CHLORIDE PENETRATION and CARBONATION of CONCRETE

Based on:

- Cement Type
(OPC, 30% FA, 50% GGBS)
- Strength
(20, 30, 40, 50 60 MPa)
- Environmental exposure
Regions:
(Coastal, Interior Moderate)
Marine Exposures:
(Extreme, Very Severe, Severe)

**MIX DESIGNS for CONCRETE USED in the DETERMINATION
of the CHLORIDE PENETRATION PREDICTION MODEL**

<i>Concrete Type</i>	<i>Concrete Materials</i>	<i>Grade 20 MPa (kg/m³)</i>	<i>Grade 40 MPa (kg/m³)</i>	<i>Grade 60 MPa (kg/m³)</i>
OPC ONLY	Cement	240	346	515
	Sand	862	794	637
	Stone	1050	1050	1050
	Water	200	192	198
	W/C ratio	0.83	0.56	0.38
30% FIY Ash CONCRETE	Cement	173	253	370
	Fly Ash	74	108	158
	Sand	843	762	580
	Stone	1102	1102	1102
	Water	177	168	179
	W/C ratio	0.71	0.46	0.34
50% GGBS CONCRETE	Cement	116	176	269
	GGBS	116	176	269
	Sand	872	782	596
	Stone	1080	1080	1080
	Water	185	180	189
	W/C ratio	0.80	0.51	0.35

(Mackechnie 1996)

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Extreme
Cement Type: OPC

Marine Exposure: Very Severe
Cement Type: OPC

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	176	107	59	52	44
10	225	137	76	66	56
15	259	158	88	76	64
20	287	175	97	84	71
25	311	189	105	91	77
30	332	202	112	97	82
35	351	213	119	103	87
40	368	223	124	108	91
45	383	233	130	112	95
50	398	242	135	117	99
55	412	250	139	121	102
60	424	258	144	125	105
65	437	265	148	128	108
70	448	272	152	132	111
75	459	279	155	135	114
80	470	286	159	138	117
85	480	292	162	141	119
90	490	298	166	144	122
95	500	304	169	147	124
100	509	309	172	149	126
105	518	315	175	152	128
110	526	320	178	154	130
115	535	325	181	157	133
120	543	330	184	159	135

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	87	63	47	40	36
10	111	80	60	51	46
15	129	93	70	59	53
20	143	103	77	65	59
25	154	111	83	70	64
30	165	119	89	75	68
35	174	125	94	79	72
40	182	131	99	83	75
45	190	137	103	87	79
50	197	142	107	90	82
55	204	147	110	93	84
60	211	152	114	96	87
65	217	156	117	99	90
70	222	160	120	101	92
75	228	164	123	104	94
80	233	168	126	106	96
85	238	172	129	108	99
90	243	175	132	111	101
95	248	179	134	113	103
100	252	182	137	115	104
105	257	185	139	117	106
110	261	188	141	119	108
115	265	191	144	121	110
120	269	194	146	123	111

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Severe
 Cement Type: OPC

Strength (MPa)

<i>Time (yr)</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>50</i>	<i>60</i>
0	0	0	0	0	0
5	46	36	29	25	23
10	59	46	37	33	29
15	68	53	42	38	34
20	75	59	47	42	38
25	82	64	51	45	41
30	87	68	54	48	43
35	92	72	57	51	46
40	96	75	60	53	48
45	100	78	63	55	50
50	104	81	65	58	52
55	108	84	67	60	54
60	111	87	69	61	56
65	114	89	71	63	57
70	118	92	73	65	59
75	120	94	75	66	60
80	123	96	77	68	62
85	126	98	78	69	63
90	129	100	80	71	64
95	131	102	82	72	65
100	133	104	83	74	67
105	136	106	84	75	68
110	138	108	86	76	69
115	140	109	87	77	70
120	142	111	89	79	71

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Extreme
Cement Type: 30% FA

Marine Exposure: Very Severe
Cement Type: 30% FA

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	63	50	41	36	33
10	71	56	46	40	37
15	75	60	49	43	39
20	79	63	51	45	41
25	82	65	53	47	42
30	84	67	55	48	44
35	86	68	56	49	45
40	88	70	58	51	46
45	90	71	59	51	46
50	91	72	60	52	47
55	93	74	61	53	48
60	94	75	61	54	49
65	95	76	62	55	49
70	96	76	63	55	50
75	97	77	64	56	50
80	98	78	64	56	51
85	99	79	65	57	51
90	100	80	65	58	52
95	101	80	66	58	52
100	102	81	67	59	53
105	103	82	67	59	53
110	104	82	68	59	54
115	104	83	68	60	54
120	105	83	69	60	54

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	44	39	34	31	29
10	49	43	38	35	32
15	53	46	41	37	34
20	55	48	43	39	36
25	57	50	44	40	37
30	59	52	45	42	38
35	60	53	47	43	39
40	61	54	48	43	40
45	63	55	49	44	41
50	64	56	49	45	42
55	65	57	50	46	42
60	66	58	51	46	43
65	66	59	51	47	43
70	67	59	52	48	44
75	68	60	53	48	44
80	69	60	53	49	45
85	69	61	54	49	45
90	70	62	54	50	46
95	71	62	55	50	46
100	71	63	55	50	46
105	72	63	56	51	47
110	72	64	56	51	47
115	73	64	56	51	47
120	73	65	57	52	48

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Severe
 Cement Type: 30% FA

Strength (MPa)

<i>Time (yr)</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>50</i>	<i>60</i>
0	0	0	0	0	0
5	30	27	24	22	22
10	33	30	26	25	24
15	35	32	28	27	26
20	37	33	30	28	27
25	38	35	31	29	28
30	39	36	32	30	29
35	40	37	32	30	29
40	41	37	33	31	30
45	42	38	34	32	31
50	43	39	34	32	31
55	43	39	35	33	32
60	44	40	35	33	32
65	44	40	36	34	33
70	45	41	36	34	33
75	46	41	37	34	33
80	46	42	37	35	34
85	46	42	37	35	34
90	47	42	38	35	34
95	47	43	38	36	35
100	48	43	38	36	35
105	48	44	39	36	35
110	48	44	39	37	35
115	49	44	39	37	36
120	49	44	39	37	36

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Extreme
Cement Type: 50% GGBS

Marine Exposure: Very Severe
Cement Type: 50% GGBS

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	59	45	35	32	30
10	66	50	39	36	33
15	71	54	41	38	35
20	74	56	43	40	37
25	77	58	45	42	38
30	79	60	46	43	40
35	81	61	47	44	41
40	83	63	48	45	41
45	85	64	49	46	42
50	86	65	50	47	43
55	87	66	51	47	44
60	89	67	51	48	44
65	90	68	52	49	45
70	91	69	53	49	45
75	92	69	53	50	46
80	93	70	54	50	46
85	94	71	54	51	47
90	94	71	55	51	47
95	95	72	55	52	48
100	96	73	56	52	48
105	97	73	56	52	48
110	98	74	57	53	49
115	98	74	57	53	49
120	99	75	57	54	49

Strength (MPa)

<i>Time (yr)</i>	20	30	40	50	60
0	0	0	0	0	0
5	43	37	30	29	28
10	48	41	33	32	31
15	52	44	35	34	33
20	54	46	37	36	35
25	56	47	38	37	36
30	58	49	40	38	37
35	59	50	41	39	38
40	60	51	41	40	39
45	61	52	42	41	40
50	62	53	43	42	40
55	63	54	44	42	41
60	64	55	44	43	41
65	65	55	45	43	42
70	66	56	45	44	43
75	67	57	46	44	43
80	67	57	46	45	43
85	68	58	47	45	44
90	69	58	47	46	44
95	69	59	48	46	45
100	70	59	48	47	45
105	70	60	48	47	45
110	71	60	49	47	46
115	71	61	49	48	46
120	72	61	49	48	46

PENETRATION DEPTHS (mm) for CHLORIDES at 0.4%

Marine Exposure: Severe
 Cement Type: 50% GGBS

Strength (MPa)

<i>Time (yr)</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>50</i>	<i>60</i>
0	0	0	0	0	0
5	29	26	23	22	22
10	33	29	26	25	24
15	35	31	27	27	26
20	37	32	29	28	27
25	38	33	30	29	28
30	39	34	31	30	29
35	40	35	31	30	29
40	41	36	32	31	30
45	42	37	33	32	31
50	42	37	33	32	31
55	43	38	34	33	32
60	44	38	34	33	32
65	44	39	35	34	32
70	45	39	35	34	33
75	45	40	36	34	33
80	46	40	36	35	34
85	46	40	36	35	34
90	47	41	37	35	34
95	47	41	37	36	34
100	47	42	37	36	35
105	48	42	37	36	35
110	48	42	38	36	35
115	48	42	38	37	36
120	49	43	38	37	36

CARBONATION DEPTHS (mm) for CONCRETE (Initiation Period)

Climate Region: Coastal Severe
(Greater than 1 km from the sea)
Relative Humidity: Approximately 70 - 80 %

Time (yrs)	Strength (MPa)															
	Watkins and Jones '93 (based on Hong Kong)			Dhir et al '89 (based on Dundee Scotland)					Micro- Silica	GGBS	Parrott '94					
	←	OPC											FA 27%	(8%)	(25%)	OPC
	20	30	40	30	35	45	55	65	45	45	45	45	45	55		
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
5	16	11	8	17	14	9	8	6	9	8	8	8	6	4		
10	24	17	13	22	18	13	11	9	12	12	11	11	9	5		
15	30	21	16	26	21	16	14	11	15	15	13	13	10	6		
20	35	25	19	29	24	18	16	12	17	17	15	15	12	7		
25	40	29	22	32	26	20	17	14	19	19	17	17	13	8		
30	45	32	25	34	28	22	19	15	21	21	18	18	14	9		
35	49	35	27	37	30	24	21	16	23	22	19	19	15	9		
40	53	38	30	39	31	26	22	17	24	24	20	20	16	10		
45	56	41	32	41	33	27	23	18	26	25	21	21	17	10		
50	60	43	34	42	34	29	25	19	27	26	22	22	18	11		
55	63	46	36	44	36	30	26	20	29	28	23	23	18	11		
60	66	48	38	45	37	32	27	21	30	29	24	24	19	12		
65	69	51	40	47	38	33	28	22	31	30	25	25	20	12		
70	72	53	42	48	39	34	29	23	32	31	26	26	20	12		
75	75	55	43	50	40	35	30	24	33	32	27	27	21	13		
80	78	57	45	51	42	37	31	24	35	34	28	28	22	13		
85	81	59	47	52	43	38	32	25	36	35	28	28	22	14		
90	84	61	49	53	44	39	33	26	37	36	29	29	23	14		
95	86	63	50	55	44	40	34	27	38	37	30	30	23	14		
100	89	65	52	56	45	41	35	27	39	37	30	30	24	15		
105	91	67	53	57	46	42	36	28	40	38	31	31	24	15		
110	94	69	55	58	47	43	37	29	41	39	32	32	25	15		
115	96	71	57	59	48	44	37	29	41	40	32	32	25	15		
120	98	73	58	60	49	45	38	30	42	41	33	33	26	16		

Note: wet cured for 3 days (Dhir et al.)
Parrott's work based on European environment
($a = 64$, $RH = 77\%$)

PROPAGATION PREDICTIONS

Time to cracking (years) from
depassivation

Climate: Coastal Severe
Exposure: Sheltered from rain
Corrosion rate: 1.5 $\mu\text{m}/\text{year}$

Exposure: Exposed to rain
Corrosion rate: 6.0 $\mu\text{m}/\text{year}$

Reinforcing Bar Diameter (mm)

Cover (mm)	15	20	25	30
10	36	27	21	18
15	53	40	32	27
20	71	53	43	36
25	89	67	53	44
30	107	80	64	53
35	124	93	75	62
40	142	107	85	71
45	160	120	96	80
50	178	133	107	89
55	196	147	117	98
60	213	160	128	107
70	249	187	149	124
80	284	213	171	142

Reinforcing Bar Diameter (mm)

Cover (mm)	15	20	25	30
10	9	7	5	4
15	13	10	8	7
20	18	13	11	9
25	22	17	13	11
30	27	20	16	13
35	31	23	19	16
40	36	27	21	18
45	40	30	24	20
50	44	33	27	22
55	49	37	29	24
60	53	40	32	27
70	62	47	37	31
80	71	53	43	36

CARBONATION DEPTHS (mm) for CONCRETE (Initiation Period)

Climate Region: Interior Moderate
Relative Humidity: Approximately 60 %

Time (yrs)	Strength (MPa)			
	Ballim and Lampacher '96	Parrott '94		GGBS 25%
	← OPC →	45	55	45
0	0	0	0	0
5	8	9	6	12
10	12	13	8	17
15	14	16	10	21
20	17	19	11	24
25	19	21	13	26
30	20	23	14	29
35	22	25	15	31
40	23	26	16	34
45	25	28	17	36
50	26	29	18	37
55	27	31	19	39
60	29	32	20	41
65	30	34	20	43
70	31	35	21	44
75	32	36	22	46
80	33	37	23	47
85	34	38	23	49
90	35	40	24	50
95	36	41	25	52
100	37	42	25	53
105	38	43	26	54
110	39	44	27	56
115	40	45	27	57
120	41	46	28	58

Note: Parrott's model correlated with exposed European data
(a = 64, RH = 60 %)
Ballim and Lampacher '96 based on Johannesburg
site data

PROPAGATION PREDICTIONS

Time to cracking (years) from
depassivation

Climate: Interior Moderate
Exposure: Sheltered from rain
Corrosion rate: 0.05 $\mu\text{m}/\text{year}$

Exposure: Exposed to rain
Corrosion rate: 1.5 $\mu\text{m}/\text{year}$

Reinforcing Bar Diameter (mm)

Cover (mm)	15	20	25	30
10	1067	800	640	533
15	1600	1200	960	800
20	2133	1600	1280	1067
25	2667	2000	1600	1333
30	3200	2400	1920	1600
35	3733	2800	2240	1867
40	4267	3200	2560	2133
45	4800	3600	2880	2400
50	5333	4000	3200	2667
55	5867	4400	3520	2933
60	6400	4800	3840	3200
70	7467	5600	4480	3733
80	8533	6400	5120	4267

Reinforcing Bar Diameter (mm)

Cover (mm)	15	20	25	30
10	36	27	21	18
15	53	40	32	27
20	71	53	43	36
25	89	67	53	44
30	107	80	64	53
35	124	93	75	62
40	142	107	85	71
45	160	120	96	80
50	178	133	107	89
55	196	147	117	98
60	213	160	128	107
70	249	187	149	124
80	284	213	171	142

APPENDIX B**SPECIFIC and CUMULATIVE YEARLY
DISCOUNT FACTORS for MAINTENANCE**

$$SYDF = (1-t) \frac{1}{(1+W(1-t))^n}$$

$$CYDF = (1-t) \sum \frac{1}{(1+W(1-t))^n}$$

for Tax Rates: 0, 30, 35, 40, 45, 50 %

and Maintenance Intervals: 1, 2, 5, 10, 15, 20, 30, 40, 60 years

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 0 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	1.042	1.020	1.000	0.980	0.962	0.943	0.926	0.893
2	1.085	1.041	1.000	0.961	0.925	0.890	0.857	0.797
3	1.130	1.062	1.000	0.942	0.889	0.840	0.794	0.712
4	1.177	1.084	1.000	0.924	0.855	0.792	0.735	0.636
5	1.226	1.106	1.000	0.906	0.822	0.747	0.681	0.567
6	1.278	1.129	1.000	0.888	0.790	0.705	0.630	0.507
7	1.331	1.152	1.000	0.871	0.760	0.665	0.583	0.452
8	1.386	1.175	1.000	0.853	0.731	0.627	0.540	0.404
9	1.444	1.199	1.000	0.837	0.703	0.592	0.500	0.361
10	1.504	1.224	1.000	0.820	0.676	0.558	0.463	0.322
11	1.567	1.249	1.000	0.804	0.650	0.527	0.429	0.287
12	1.632	1.274	1.000	0.788	0.625	0.497	0.397	0.257
13	1.700	1.300	1.000	0.773	0.601	0.469	0.368	0.229
14	1.771	1.327	1.000	0.758	0.577	0.442	0.340	0.205
15	1.845	1.354	1.000	0.743	0.555	0.417	0.315	0.183
16	1.922	1.382	1.000	0.728	0.534	0.394	0.292	0.163
17	2.002	1.410	1.000	0.714	0.513	0.371	0.270	0.146
18	2.085	1.439	1.000	0.700	0.494	0.350	0.250	0.130
19	2.172	1.468	1.000	0.686	0.475	0.331	0.232	0.116
20	2.262	1.498	1.000	0.673	0.456	0.312	0.215	0.104
21	2.357	1.528	1.000	0.660	0.439	0.294	0.199	0.093
22	2.455	1.560	1.000	0.647	0.422	0.278	0.184	0.083
23	2.557	1.591	1.000	0.634	0.406	0.262	0.170	0.074
24	2.664	1.624	1.000	0.622	0.390	0.247	0.158	0.066
25	2.775	1.657	1.000	0.610	0.375	0.233	0.146	0.059
26	2.890	1.691	1.000	0.598	0.361	0.220	0.135	0.053
27	3.011	1.725	1.000	0.586	0.347	0.207	0.125	0.047
28	3.136	1.761	1.000	0.574	0.333	0.196	0.116	0.042
29	3.267	1.797	1.000	0.563	0.321	0.185	0.107	0.037
30	3.403	1.833	1.000	0.552	0.308	0.174	0.099	0.033
31	3.545	1.871	1.000	0.541	0.296	0.164	0.092	0.030
32	3.693	1.909	1.000	0.531	0.285	0.155	0.085	0.027
33	3.846	1.948	1.000	0.520	0.274	0.146	0.079	0.024
34	4.007	1.988	1.000	0.510	0.264	0.138	0.073	0.021
35	4.174	2.028	1.000	0.500	0.253	0.130	0.068	0.019
36	4.347	2.069	1.000	0.490	0.244	0.123	0.063	0.017
37	4.529	2.112	1.000	0.481	0.234	0.116	0.058	0.015
38	4.717	2.155	1.000	0.471	0.225	0.109	0.054	0.013
39	4.914	2.199	1.000	0.462	0.217	0.103	0.050	0.012
40	5.119	2.244	1.000	0.453	0.208	0.097	0.046	0.011
41	5.332	2.289	1.000	0.444	0.200	0.092	0.043	0.010
42	5.554	2.336	1.000	0.435	0.193	0.087	0.039	0.009
43	5.785	2.384	1.000	0.427	0.185	0.082	0.037	0.008
44	6.027	2.432	1.000	0.418	0.178	0.077	0.034	0.007
45	6.278	2.482	1.000	0.410	0.171	0.073	0.031	0.006
46	6.539	2.533	1.000	0.402	0.165	0.069	0.029	0.005
47	6.812	2.584	1.000	0.394	0.158	0.065	0.027	0.005
48	7.095	2.637	1.000	0.387	0.152	0.061	0.025	0.004
49	7.391	2.691	1.000	0.379	0.146	0.058	0.023	0.004
50	7.699	2.746	1.000	0.372	0.141	0.054	0.021	0.003
51	8.020	2.802	1.000	0.364	0.135	0.051	0.020	0.003
52	8.354	2.859	1.000	0.357	0.130	0.048	0.018	0.003
53	8.702	2.918	1.000	0.350	0.125	0.046	0.017	0.002
54	9.065	2.977	1.000	0.343	0.120	0.043	0.016	0.002
55	9.442	3.038	1.000	0.337	0.116	0.041	0.015	0.002
56	9.836	3.100	1.000	0.330	0.111	0.038	0.013	0.002
57	10.246	3.163	1.000	0.323	0.107	0.036	0.012	0.002
58	10.673	3.228	1.000	0.317	0.103	0.034	0.012	0.001
59	11.117	3.294	1.000	0.311	0.099	0.032	0.011	0.001
60	11.580	3.361	1.000	0.305	0.095	0.030	0.010	0.001

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	12.063	3.429	1.000	0.299	0.091	0.029	0.009	0.001
62	12.566	3.499	1.000	0.293	0.088	0.027	0.008	0.001
63	13.089	3.571	1.000	0.287	0.085	0.025	0.008	0.001
64	13.635	3.644	1.000	0.282	0.081	0.024	0.007	0.001
65	14.203	3.718	1.000	0.276	0.078	0.023	0.007	0.001
66	14.794	3.794	1.000	0.271	0.075	0.021	0.006	0.001
67	15.411	3.871	1.000	0.265	0.072	0.020	0.006	0.001
68	16.053	3.950	1.000	0.260	0.069	0.019	0.005	0.000
69	16.722	4.031	1.000	0.255	0.067	0.018	0.005	0.000
70	17.419	4.113	1.000	0.250	0.064	0.017	0.005	0.000
71	18.144	4.197	1.000	0.245	0.062	0.016	0.004	0.000
72	18.900	4.283	1.000	0.240	0.059	0.015	0.004	0.000
73	19.688	4.370	1.000	0.236	0.057	0.014	0.004	0.000
74	20.508	4.459	1.000	0.231	0.055	0.013	0.003	0.000
75	21.363	4.550	1.000	0.226	0.053	0.013	0.003	0.000
76	22.253	4.643	1.000	0.222	0.051	0.012	0.003	0.000
77	23.180	4.738	1.000	0.218	0.049	0.011	0.003	0.000
78	24.146	4.835	1.000	0.213	0.047	0.011	0.002	0.000
79	25.152	4.933	1.000	0.209	0.045	0.010	0.002	0.000
80	26.200	5.034	1.000	0.205	0.043	0.009	0.002	0.000
81	27.292	5.137	1.000	0.201	0.042	0.009	0.002	0.000
82	28.429	5.242	1.000	0.197	0.040	0.008	0.002	0.000
83	29.613	5.349	1.000	0.193	0.039	0.008	0.002	0.000
84	30.847	5.458	1.000	0.189	0.037	0.007	0.002	0.000
85	32.133	5.569	1.000	0.186	0.036	0.007	0.001	0.000
86	33.471	5.683	1.000	0.182	0.034	0.007	0.001	0.000
87	34.866	5.799	1.000	0.179	0.033	0.006	0.001	0.000
88	36.319	5.917	1.000	0.175	0.032	0.006	0.001	0.000
89	37.832	6.038	1.000	0.172	0.030	0.006	0.001	0.000
90	39.408	6.161	1.000	0.168	0.029	0.005	0.001	0.000
91	41.050	6.287	1.000	0.165	0.028	0.005	0.001	0.000
92	42.761	6.415	1.000	0.162	0.027	0.005	0.001	0.000
93	44.543	6.546	1.000	0.159	0.026	0.004	0.001	0.000
94	46.399	6.680	1.000	0.155	0.025	0.004	0.001	0.000
95	48.332	6.816	1.000	0.152	0.024	0.004	0.001	0.000
96	50.346	6.955	1.000	0.149	0.023	0.004	0.001	0.000
97	52.443	7.097	1.000	0.146	0.022	0.004	0.001	0.000
98	54.628	7.242	1.000	0.144	0.021	0.003	0.001	0.000
99	56.905	7.390	1.000	0.141	0.021	0.003	0.000	0.000
100	59.276	7.540	1.000	0.138	0.020	0.003	0.000	0.000
101	61.746	7.694	1.000	0.135	0.019	0.003	0.000	0.000
102	64.318	7.851	1.000	0.133	0.018	0.003	0.000	0.000
103	66.998	8.012	1.000	0.130	0.018	0.002	0.000	0.000
104	69.790	8.175	1.000	0.128	0.017	0.002	0.000	0.000
105	72.698	8.342	1.000	0.125	0.016	0.002	0.000	0.000
106	75.727	8.512	1.000	0.123	0.016	0.002	0.000	0.000
107	78.882	8.686	1.000	0.120	0.015	0.002	0.000	0.000
108	82.169	8.863	1.000	0.118	0.014	0.002	0.000	0.000
109	85.592	9.044	1.000	0.115	0.014	0.002	0.000	0.000
110	89.159	9.229	1.000	0.113	0.013	0.002	0.000	0.000
111	92.874	9.417	1.000	0.111	0.013	0.002	0.000	0.000
112	96.744	9.609	1.000	0.109	0.012	0.001	0.000	0.000
113	100.775	9.805	1.000	0.107	0.012	0.001	0.000	0.000
114	104.973	10.005	1.000	0.105	0.011	0.001	0.000	0.000
115	109.347	10.209	1.000	0.103	0.011	0.001	0.000	0.000
116	113.903	10.418	1.000	0.101	0.011	0.001	0.000	0.000
117	118.649	10.630	1.000	0.099	0.010	0.001	0.000	0.000
118	123.593	10.847	1.000	0.097	0.010	0.001	0.000	0.000
119	128.743	11.069	1.000	0.095	0.009	0.001	0.000	0.000
120	134.107	11.295	1.000	0.093	0.009	0.001	0.000	0.000

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 30 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.720	0.710	0.700	0.690	0.681	0.672	0.663	0.646
2	0.741	0.720	0.700	0.681	0.662	0.645	0.628	0.596
3	0.762	0.730	0.700	0.671	0.644	0.619	0.594	0.550
4	0.784	0.741	0.700	0.662	0.627	0.594	0.563	0.507
5	0.807	0.751	0.700	0.653	0.610	0.570	0.533	0.468
6	0.830	0.762	0.700	0.644	0.593	0.547	0.505	0.431
7	0.854	0.773	0.700	0.635	0.577	0.525	0.478	0.398
8	0.879	0.784	0.700	0.626	0.561	0.504	0.453	0.367
9	0.904	0.795	0.700	0.618	0.546	0.483	0.429	0.339
10	0.930	0.806	0.700	0.609	0.531	0.464	0.406	0.312
11	0.957	0.817	0.700	0.601	0.517	0.445	0.384	0.288
12	0.984	0.829	0.700	0.592	0.503	0.427	0.364	0.266
13	1.013	0.841	0.700	0.584	0.489	0.410	0.345	0.245
14	1.042	0.853	0.700	0.576	0.476	0.394	0.326	0.226
15	1.072	0.865	0.700	0.568	0.463	0.378	0.309	0.209
16	1.103	0.877	0.700	0.560	0.450	0.362	0.293	0.193
17	1.134	0.890	0.700	0.553	0.438	0.348	0.277	0.178
18	1.167	0.902	0.700	0.545	0.426	0.334	0.263	0.164
19	1.201	0.915	0.700	0.537	0.414	0.320	0.249	0.151
20	1.235	0.928	0.700	0.530	0.403	0.307	0.235	0.139
21	1.271	0.941	0.700	0.523	0.392	0.295	0.223	0.129
22	1.307	0.955	0.700	0.516	0.381	0.283	0.211	0.119
23	1.345	0.968	0.700	0.508	0.371	0.272	0.200	0.110
24	1.384	0.982	0.700	0.501	0.361	0.261	0.189	0.101
25	1.424	0.996	0.700	0.494	0.351	0.250	0.179	0.093
26	1.465	1.010	0.700	0.488	0.341	0.240	0.170	0.086
27	1.507	1.024	0.700	0.481	0.332	0.230	0.161	0.079
28	1.550	1.039	0.700	0.474	0.323	0.221	0.152	0.073
29	1.595	1.054	0.700	0.468	0.314	0.212	0.144	0.067
30	1.641	1.069	0.700	0.461	0.306	0.204	0.137	0.062
31	1.688	1.084	0.700	0.455	0.297	0.196	0.129	0.057
32	1.737	1.099	0.700	0.449	0.289	0.188	0.122	0.053
33	1.787	1.115	0.700	0.442	0.281	0.180	0.116	0.049
34	1.838	1.131	0.700	0.436	0.274	0.173	0.110	0.045
35	1.891	1.147	0.700	0.430	0.266	0.166	0.104	0.042
36	1.946	1.163	0.700	0.424	0.259	0.159	0.098	0.038
37	2.002	1.179	0.700	0.418	0.252	0.153	0.093	0.035
38	2.060	1.196	0.700	0.413	0.245	0.147	0.088	0.033
39	2.119	1.213	0.700	0.407	0.238	0.141	0.084	0.030
40	2.180	1.230	0.700	0.401	0.232	0.135	0.079	0.028
41	2.243	1.248	0.700	0.396	0.226	0.130	0.075	0.026
42	2.307	1.266	0.700	0.390	0.219	0.124	0.071	0.024
43	2.374	1.283	0.700	0.385	0.213	0.119	0.067	0.022
44	2.442	1.302	0.700	0.380	0.208	0.115	0.064	0.020
45	2.513	1.320	0.700	0.374	0.202	0.110	0.060	0.019
46	2.585	1.339	0.700	0.369	0.197	0.105	0.057	0.017
47	2.659	1.358	0.700	0.364	0.191	0.101	0.054	0.016
48	2.736	1.377	0.700	0.359	0.186	0.097	0.051	0.015
49	2.815	1.397	0.700	0.354	0.181	0.093	0.048	0.013
50	2.896	1.417	0.700	0.349	0.176	0.089	0.046	0.012
51	2.979	1.437	0.700	0.344	0.171	0.086	0.043	0.011
52	3.065	1.457	0.700	0.340	0.167	0.082	0.041	0.011
53	3.153	1.478	0.700	0.335	0.162	0.079	0.039	0.010
54	3.244	1.499	0.700	0.330	0.158	0.076	0.037	0.009
55	3.338	1.520	0.700	0.326	0.153	0.073	0.035	0.008
56	3.434	1.542	0.700	0.321	0.149	0.070	0.033	0.008
57	3.533	1.564	0.700	0.317	0.145	0.067	0.031	0.007
58	3.635	1.586	0.700	0.313	0.141	0.064	0.030	0.007
59	3.739	1.608	0.700	0.308	0.137	0.062	0.028	0.006
60	3.847	1.631	0.700	0.304	0.134	0.059	0.027	0.006

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	3.958	1.654	0.700	0.300	0.130	0.057	0.025	0.005
62	4.072	1.678	0.700	0.296	0.126	0.055	0.024	0.005
63	4.189	1.702	0.700	0.292	0.123	0.052	0.023	0.004
64	4.310	1.726	0.700	0.288	0.120	0.050	0.021	0.004
65	4.434	1.750	0.700	0.284	0.116	0.048	0.020	0.004
66	4.562	1.775	0.700	0.280	0.113	0.046	0.019	0.003
67	4.693	1.800	0.700	0.276	0.110	0.044	0.018	0.003
68	4.828	1.826	0.700	0.272	0.107	0.043	0.017	0.003
69	4.967	1.852	0.700	0.268	0.104	0.041	0.016	0.003
70	5.110	1.878	0.700	0.265	0.101	0.039	0.015	0.002
71	5.258	1.905	0.700	0.261	0.099	0.038	0.015	0.002
72	5.409	1.932	0.700	0.257	0.096	0.036	0.014	0.002
73	5.565	1.959	0.700	0.254	0.093	0.035	0.013	0.002
74	5.725	1.987	0.700	0.250	0.091	0.033	0.012	0.002
75	5.890	2.015	0.700	0.247	0.088	0.032	0.012	0.002
76	6.060	2.044	0.700	0.243	0.086	0.031	0.011	0.002
77	6.234	2.073	0.700	0.240	0.083	0.029	0.011	0.001
78	6.414	2.102	0.700	0.237	0.081	0.028	0.010	0.001
79	6.599	2.132	0.700	0.233	0.079	0.027	0.009	0.001
80	6.789	2.162	0.700	0.230	0.077	0.026	0.009	0.001
81	6.984	2.193	0.700	0.227	0.075	0.025	0.008	0.001
82	7.186	2.224	0.700	0.224	0.073	0.024	0.008	0.001
83	7.393	2.256	0.700	0.221	0.071	0.023	0.008	0.001
84	7.606	2.288	0.700	0.218	0.069	0.022	0.007	0.001
85	7.825	2.320	0.700	0.215	0.067	0.021	0.007	0.001
86	8.050	2.353	0.700	0.212	0.065	0.020	0.006	0.001
87	8.282	2.387	0.700	0.209	0.063	0.020	0.006	0.001
88	8.521	2.421	0.700	0.206	0.062	0.019	0.006	0.001
89	8.766	2.455	0.700	0.203	0.060	0.018	0.005	0.001
90	9.018	2.490	0.700	0.200	0.058	0.017	0.005	0.000
91	9.278	2.525	0.700	0.198	0.057	0.017	0.005	0.000
92	9.546	2.561	0.700	0.195	0.055	0.016	0.005	0.000
93	9.821	2.597	0.700	0.192	0.054	0.015	0.004	0.000
94	10.103	2.634	0.700	0.189	0.052	0.015	0.004	0.000
95	10.394	2.672	0.700	0.187	0.051	0.014	0.004	0.000
96	10.694	2.710	0.700	0.184	0.049	0.013	0.004	0.000
97	11.002	2.748	0.700	0.182	0.048	0.013	0.004	0.000
98	11.319	2.787	0.700	0.179	0.047	0.012	0.003	0.000
99	11.645	2.827	0.700	0.177	0.045	0.012	0.003	0.000
100	11.980	2.867	0.700	0.174	0.044	0.011	0.003	0.000
101	12.326	2.908	0.700	0.172	0.043	0.011	0.003	0.000
102	12.681	2.949	0.700	0.170	0.042	0.011	0.003	0.000
103	13.046	2.991	0.700	0.167	0.041	0.010	0.003	0.000
104	13.422	3.033	0.700	0.165	0.040	0.010	0.002	0.000
105	13.808	3.076	0.700	0.163	0.039	0.009	0.002	0.000
106	14.206	3.120	0.700	0.160	0.037	0.009	0.002	0.000
107	14.615	3.164	0.700	0.158	0.036	0.009	0.002	0.000
108	15.036	3.209	0.700	0.156	0.035	0.008	0.002	0.000
109	15.469	3.255	0.700	0.154	0.035	0.008	0.002	0.000
110	15.915	3.301	0.700	0.152	0.034	0.008	0.002	0.000
111	16.374	3.348	0.700	0.150	0.033	0.007	0.002	0.000
112	16.845	3.395	0.700	0.148	0.032	0.007	0.002	0.000
113	17.330	3.444	0.700	0.145	0.031	0.007	0.001	0.000
114	17.830	3.492	0.700	0.143	0.030	0.006	0.001	0.000
115	18.343	3.542	0.700	0.141	0.029	0.006	0.001	0.000
116	18.872	3.592	0.700	0.140	0.028	0.006	0.001	0.000
117	19.415	3.643	0.700	0.138	0.028	0.006	0.001	0.000
118	19.975	3.695	0.700	0.136	0.027	0.005	0.001	0.000
119	20.550	3.748	0.700	0.134	0.026	0.005	0.001	0.000
120	21.142	3.801	0.700	0.132	0.025	0.005	0.001	0.000

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 35 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.667	0.659	0.650	0.642	0.634	0.626	0.618	0.603
2	0.685	0.667	0.650	0.633	0.617	0.602	0.587	0.559
3	0.703	0.676	0.650	0.625	0.602	0.580	0.558	0.519
4	0.722	0.685	0.650	0.617	0.587	0.558	0.531	0.481
5	0.742	0.694	0.650	0.609	0.572	0.537	0.504	0.446
6	0.761	0.703	0.650	0.602	0.557	0.517	0.480	0.414
7	0.782	0.712	0.650	0.594	0.543	0.497	0.456	0.384
8	0.802	0.722	0.650	0.586	0.529	0.479	0.433	0.356
9	0.824	0.731	0.650	0.579	0.516	0.461	0.412	0.331
10	0.846	0.741	0.650	0.571	0.503	0.443	0.392	0.307
11	0.868	0.751	0.650	0.564	0.490	0.427	0.372	0.285
12	0.892	0.761	0.650	0.557	0.478	0.411	0.354	0.264
13	0.915	0.771	0.650	0.550	0.466	0.395	0.336	0.245
14	0.940	0.781	0.650	0.542	0.454	0.380	0.320	0.227
15	0.965	0.791	0.650	0.536	0.442	0.366	0.304	0.211
16	0.991	0.801	0.650	0.529	0.431	0.352	0.289	0.195
17	1.017	0.812	0.650	0.522	0.420	0.339	0.275	0.181
18	1.044	0.823	0.650	0.515	0.410	0.326	0.261	0.168
19	1.072	0.833	0.650	0.509	0.399	0.314	0.248	0.156
20	1.101	0.844	0.650	0.502	0.389	0.302	0.236	0.145
21	1.130	0.856	0.650	0.496	0.379	0.291	0.224	0.134
22	1.160	0.867	0.650	0.489	0.370	0.280	0.213	0.125
23	1.191	0.878	0.650	0.483	0.360	0.270	0.203	0.116
24	1.223	0.890	0.650	0.477	0.351	0.260	0.193	0.107
25	1.256	0.902	0.650	0.471	0.342	0.250	0.183	0.099
26	1.289	0.913	0.650	0.465	0.333	0.240	0.174	0.092
27	1.324	0.925	0.650	0.459	0.325	0.231	0.165	0.086
28	1.359	0.938	0.650	0.453	0.317	0.223	0.157	0.079
29	1.395	0.950	0.650	0.447	0.309	0.214	0.149	0.074
30	1.433	0.962	0.650	0.441	0.301	0.206	0.142	0.068
31	1.471	0.975	0.650	0.436	0.293	0.199	0.135	0.063
32	1.510	0.988	0.650	0.430	0.286	0.191	0.128	0.059
33	1.550	1.001	0.650	0.424	0.279	0.184	0.122	0.055
34	1.592	1.014	0.650	0.419	0.272	0.177	0.116	0.051
35	1.634	1.028	0.650	0.414	0.265	0.170	0.110	0.047
36	1.678	1.041	0.650	0.408	0.258	0.164	0.105	0.044
37	1.723	1.055	0.650	0.403	0.251	0.158	0.100	0.040
38	1.769	1.069	0.650	0.398	0.245	0.152	0.095	0.037
39	1.816	1.083	0.650	0.393	0.239	0.146	0.090	0.035
40	1.864	1.097	0.650	0.388	0.233	0.141	0.086	0.032
41	1.914	1.112	0.650	0.383	0.227	0.135	0.081	0.030
42	1.965	1.126	0.650	0.378	0.221	0.130	0.077	0.028
43	2.018	1.141	0.650	0.373	0.216	0.125	0.073	0.026
44	2.072	1.156	0.650	0.368	0.210	0.121	0.070	0.024
45	2.127	1.171	0.650	0.363	0.205	0.116	0.066	0.022
46	2.184	1.187	0.650	0.359	0.200	0.112	0.063	0.021
47	2.242	1.202	0.650	0.354	0.195	0.108	0.060	0.019
48	2.302	1.218	0.650	0.350	0.190	0.104	0.057	0.018
49	2.363	1.234	0.650	0.345	0.185	0.100	0.054	0.016
50	2.426	1.250	0.650	0.341	0.180	0.096	0.052	0.015
51	2.491	1.267	0.650	0.336	0.176	0.092	0.049	0.014
52	2.558	1.284	0.650	0.332	0.171	0.089	0.047	0.013
53	2.626	1.300	0.650	0.328	0.167	0.086	0.044	0.012
54	2.696	1.318	0.650	0.324	0.163	0.082	0.042	0.011
55	2.768	1.335	0.650	0.319	0.158	0.079	0.040	0.010
56	2.842	1.353	0.650	0.315	0.154	0.076	0.038	0.010
57	2.918	1.370	0.650	0.311	0.150	0.073	0.036	0.009
58	2.996	1.388	0.650	0.307	0.147	0.071	0.034	0.008
59	3.076	1.407	0.650	0.303	0.143	0.068	0.033	0.008
60	3.158	1.425	0.650	0.299	0.139	0.065	0.031	0.007

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	3.242	1.444	0.650	0.296	0.136	0.063	0.030	0.007
62	3.329	1.463	0.650	0.292	0.132	0.061	0.028	0.006
63	3.417	1.482	0.650	0.288	0.129	0.058	0.027	0.006
64	3.509	1.502	0.650	0.284	0.126	0.056	0.025	0.005
65	3.602	1.522	0.650	0.281	0.123	0.054	0.024	0.005
66	3.698	1.542	0.650	0.277	0.119	0.052	0.023	0.005
67	3.797	1.562	0.650	0.274	0.116	0.050	0.022	0.004
68	3.899	1.583	0.650	0.270	0.113	0.048	0.021	0.004
69	4.003	1.603	0.650	0.267	0.111	0.046	0.020	0.004
70	4.109	1.624	0.650	0.263	0.108	0.045	0.019	0.003
71	4.219	1.646	0.650	0.260	0.105	0.043	0.018	0.003
72	4.332	1.668	0.650	0.256	0.102	0.041	0.017	0.003
73	4.447	1.690	0.650	0.253	0.100	0.040	0.016	0.003
74	4.566	1.712	0.650	0.250	0.097	0.038	0.015	0.003
75	4.688	1.734	0.650	0.247	0.095	0.037	0.015	0.002
76	4.813	1.757	0.650	0.244	0.092	0.035	0.014	0.002
77	4.942	1.780	0.650	0.240	0.090	0.034	0.013	0.002
78	5.074	1.804	0.650	0.237	0.088	0.033	0.012	0.002
79	5.209	1.828	0.650	0.234	0.086	0.032	0.012	0.002
80	5.348	1.852	0.650	0.231	0.083	0.030	0.011	0.002
81	5.491	1.876	0.650	0.228	0.081	0.029	0.011	0.001
82	5.637	1.901	0.650	0.225	0.079	0.028	0.010	0.001
83	5.788	1.926	0.650	0.222	0.077	0.027	0.010	0.001
84	5.942	1.951	0.650	0.220	0.075	0.026	0.009	0.001
85	6.101	1.977	0.650	0.217	0.073	0.025	0.009	0.001
86	6.264	2.003	0.650	0.214	0.071	0.024	0.008	0.001
87	6.431	2.029	0.650	0.211	0.070	0.023	0.008	0.001
88	6.603	2.056	0.650	0.209	0.068	0.022	0.008	0.001
89	6.779	2.083	0.650	0.206	0.066	0.022	0.007	0.001
90	6.960	2.110	0.650	0.203	0.065	0.021	0.007	0.001
91	7.146	2.138	0.650	0.201	0.063	0.020	0.006	0.001
92	7.337	2.166	0.650	0.198	0.061	0.019	0.006	0.001
93	7.532	2.195	0.650	0.196	0.060	0.019	0.006	0.001
94	7.733	2.224	0.650	0.193	0.058	0.018	0.006	0.001
95	7.940	2.253	0.650	0.191	0.057	0.017	0.005	0.001
96	8.152	2.283	0.650	0.188	0.055	0.017	0.005	0.000
97	8.369	2.313	0.650	0.186	0.054	0.016	0.005	0.000
98	8.593	2.343	0.650	0.183	0.053	0.015	0.005	0.000
99	8.822	2.374	0.650	0.181	0.051	0.015	0.004	0.000
100	9.058	2.405	0.650	0.179	0.050	0.014	0.004	0.000
101	9.299	2.437	0.650	0.176	0.049	0.014	0.004	0.000
102	9.548	2.469	0.650	0.174	0.047	0.013	0.004	0.000
103	9.803	2.502	0.650	0.172	0.046	0.013	0.004	0.000
104	10.064	2.535	0.650	0.170	0.045	0.012	0.003	0.000
105	10.333	2.568	0.650	0.167	0.044	0.012	0.003	0.000
106	10.609	2.602	0.650	0.165	0.043	0.011	0.003	0.000
107	10.892	2.636	0.650	0.163	0.042	0.011	0.003	0.000
108	11.183	2.671	0.650	0.161	0.041	0.010	0.003	0.000
109	11.481	2.706	0.650	0.159	0.040	0.010	0.003	0.000
110	11.788	2.742	0.650	0.157	0.039	0.010	0.002	0.000
111	12.102	2.778	0.650	0.155	0.038	0.009	0.002	0.000
112	12.425	2.814	0.650	0.153	0.037	0.009	0.002	0.000
113	12.757	2.852	0.650	0.151	0.036	0.009	0.002	0.000
114	13.098	2.889	0.650	0.149	0.035	0.008	0.002	0.000
115	13.447	2.927	0.650	0.147	0.034	0.008	0.002	0.000
116	13.806	2.966	0.650	0.145	0.033	0.008	0.002	0.000
117	14.175	3.005	0.650	0.143	0.032	0.007	0.002	0.000
118	14.553	3.044	0.650	0.142	0.031	0.007	0.002	0.000
119	14.942	3.084	0.650	0.140	0.031	0.007	0.002	0.000
120	15.340	3.125	0.650	0.138	0.030	0.007	0.001	0.000

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 40 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.615	0.607	0.600	0.593	0.586	0.579	0.573	0.560
2	0.630	0.615	0.600	0.586	0.572	0.559	0.546	0.522
3	0.645	0.622	0.600	0.579	0.559	0.540	0.521	0.487
4	0.661	0.630	0.600	0.572	0.546	0.521	0.497	0.454
5	0.677	0.637	0.600	0.565	0.533	0.503	0.475	0.424
6	0.694	0.645	0.600	0.559	0.520	0.485	0.453	0.395
7	0.711	0.653	0.600	0.552	0.508	0.468	0.432	0.369
8	0.729	0.661	0.600	0.545	0.496	0.452	0.412	0.344
9	0.747	0.669	0.600	0.539	0.485	0.436	0.393	0.321
10	0.765	0.677	0.600	0.533	0.473	0.421	0.375	0.299
11	0.784	0.685	0.600	0.526	0.462	0.407	0.358	0.279
12	0.803	0.694	0.600	0.520	0.451	0.392	0.342	0.261
13	0.823	0.702	0.600	0.514	0.441	0.379	0.326	0.243
14	0.843	0.710	0.600	0.508	0.430	0.366	0.311	0.227
15	0.864	0.719	0.600	0.502	0.420	0.353	0.297	0.211
16	0.885	0.728	0.600	0.496	0.411	0.341	0.283	0.197
17	0.907	0.737	0.600	0.490	0.401	0.329	0.270	0.184
18	0.929	0.746	0.600	0.484	0.392	0.317	0.258	0.172
19	0.952	0.755	0.600	0.478	0.382	0.306	0.246	0.160
20	0.975	0.764	0.600	0.473	0.373	0.296	0.235	0.149
21	0.999	0.773	0.600	0.467	0.365	0.285	0.224	0.139
22	1.024	0.783	0.600	0.462	0.356	0.276	0.214	0.130
23	1.049	0.792	0.600	0.456	0.348	0.266	0.204	0.121
24	1.075	0.802	0.600	0.451	0.340	0.257	0.195	0.113
25	1.101	0.811	0.600	0.445	0.332	0.248	0.186	0.106
26	1.128	0.821	0.600	0.440	0.324	0.239	0.177	0.098
27	1.156	0.831	0.600	0.435	0.316	0.231	0.169	0.092
28	1.185	0.841	0.600	0.430	0.309	0.223	0.161	0.086
29	1.214	0.852	0.600	0.425	0.302	0.215	0.154	0.080
30	1.244	0.862	0.600	0.420	0.295	0.208	0.147	0.075
31	1.274	0.872	0.600	0.415	0.288	0.200	0.140	0.070
32	1.305	0.883	0.600	0.410	0.281	0.193	0.134	0.065
33	1.338	0.894	0.600	0.405	0.274	0.187	0.128	0.060
34	1.370	0.905	0.600	0.400	0.268	0.180	0.122	0.056
35	1.404	0.915	0.600	0.395	0.262	0.174	0.116	0.053
36	1.439	0.927	0.600	0.391	0.255	0.168	0.111	0.049
37	1.474	0.938	0.600	0.386	0.249	0.162	0.106	0.046
38	1.510	0.949	0.600	0.381	0.244	0.156	0.101	0.043
39	1.547	0.961	0.600	0.377	0.238	0.151	0.096	0.040
40	1.585	0.972	0.600	0.372	0.232	0.146	0.092	0.037
41	1.624	0.984	0.600	0.368	0.227	0.141	0.088	0.035
42	1.664	0.996	0.600	0.364	0.222	0.136	0.084	0.032
43	1.705	1.008	0.600	0.359	0.216	0.131	0.080	0.030
44	1.747	1.021	0.600	0.355	0.211	0.127	0.076	0.028
45	1.790	1.033	0.600	0.351	0.206	0.122	0.073	0.026
46	1.834	1.046	0.600	0.347	0.202	0.118	0.069	0.025
47	1.879	1.058	0.600	0.343	0.197	0.114	0.066	0.023
48	1.926	1.071	0.600	0.338	0.192	0.110	0.063	0.021
49	1.973	1.084	0.600	0.334	0.188	0.106	0.060	0.020
50	2.021	1.097	0.600	0.330	0.183	0.102	0.058	0.019
51	2.071	1.111	0.600	0.327	0.179	0.099	0.055	0.017
52	2.122	1.124	0.600	0.323	0.175	0.095	0.052	0.016
53	2.174	1.138	0.600	0.319	0.171	0.092	0.050	0.015
54	2.228	1.152	0.600	0.315	0.167	0.089	0.048	0.014
55	2.283	1.166	0.600	0.311	0.163	0.086	0.046	0.013
56	2.339	1.180	0.600	0.308	0.159	0.083	0.043	0.012
57	2.396	1.194	0.600	0.304	0.155	0.080	0.041	0.011
58	2.455	1.209	0.600	0.300	0.152	0.077	0.040	0.011
59	2.515	1.223	0.600	0.297	0.148	0.074	0.038	0.010
60	2.577	1.238	0.600	0.293	0.145	0.072	0.036	0.009

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	2.641	1.253	0.600	0.290	0.141	0.069	0.034	0.009
62	2.706	1.268	0.600	0.286	0.138	0.067	0.033	0.008
63	2.772	1.284	0.600	0.283	0.135	0.065	0.031	0.008
64	2.840	1.299	0.600	0.280	0.132	0.062	0.030	0.007
65	2.910	1.315	0.600	0.276	0.128	0.060	0.028	0.007
66	2.982	1.331	0.600	0.273	0.125	0.058	0.027	0.006
67	3.055	1.347	0.600	0.270	0.122	0.056	0.026	0.006
68	3.130	1.364	0.600	0.267	0.120	0.054	0.025	0.005
69	3.207	1.380	0.600	0.263	0.117	0.052	0.024	0.005
70	3.286	1.397	0.600	0.260	0.114	0.050	0.023	0.005
71	3.367	1.414	0.600	0.257	0.111	0.049	0.022	0.004
72	3.450	1.431	0.600	0.254	0.109	0.047	0.021	0.004
73	3.534	1.448	0.600	0.251	0.106	0.045	0.020	0.004
74	3.621	1.466	0.600	0.248	0.104	0.044	0.019	0.003
75	3.710	1.484	0.600	0.245	0.101	0.042	0.018	0.003
76	3.802	1.502	0.600	0.242	0.099	0.041	0.017	0.003
77	3.895	1.520	0.600	0.239	0.097	0.039	0.016	0.003
78	3.991	1.539	0.600	0.237	0.094	0.038	0.015	0.003
79	4.089	1.557	0.600	0.234	0.092	0.037	0.015	0.002
80	4.190	1.576	0.600	0.231	0.090	0.035	0.014	0.002
81	4.293	1.595	0.600	0.228	0.088	0.034	0.013	0.002
82	4.398	1.615	0.600	0.226	0.086	0.033	0.013	0.002
83	4.506	1.634	0.600	0.223	0.084	0.032	0.012	0.002
84	4.617	1.654	0.600	0.220	0.082	0.031	0.012	0.002
85	4.731	1.674	0.600	0.218	0.080	0.030	0.011	0.002
86	4.847	1.695	0.600	0.215	0.078	0.029	0.011	0.002
87	4.966	1.715	0.600	0.213	0.076	0.028	0.010	0.001
88	5.088	1.736	0.600	0.210	0.074	0.027	0.010	0.001
89	5.213	1.757	0.600	0.208	0.073	0.026	0.009	0.001
90	5.342	1.778	0.600	0.205	0.071	0.025	0.009	0.001
91	5.473	1.800	0.600	0.203	0.069	0.024	0.008	0.001
92	5.607	1.822	0.600	0.200	0.068	0.023	0.008	0.001
93	5.745	1.844	0.600	0.198	0.066	0.022	0.008	0.001
94	5.887	1.866	0.600	0.196	0.065	0.022	0.007	0.001
95	6.031	1.889	0.600	0.193	0.063	0.021	0.007	0.001
96	6.180	1.912	0.600	0.191	0.062	0.020	0.007	0.001
97	6.332	1.935	0.600	0.189	0.060	0.019	0.006	0.001
98	6.487	1.959	0.600	0.186	0.059	0.019	0.006	0.001
99	6.647	1.983	0.600	0.184	0.057	0.018	0.006	0.001
100	6.810	2.007	0.600	0.182	0.056	0.017	0.006	0.001
101	6.978	2.031	0.600	0.180	0.055	0.017	0.005	0.001
102	7.149	2.056	0.600	0.178	0.053	0.016	0.005	0.000
103	7.325	2.081	0.600	0.176	0.052	0.016	0.005	0.000
104	7.505	2.106	0.600	0.174	0.051	0.015	0.005	0.000
105	7.690	2.131	0.600	0.171	0.050	0.015	0.004	0.000
106	7.879	2.157	0.600	0.169	0.049	0.014	0.004	0.000
107	8.073	2.184	0.600	0.167	0.047	0.014	0.004	0.000
108	8.271	2.210	0.600	0.165	0.046	0.013	0.004	0.000
109	8.475	2.237	0.600	0.163	0.045	0.013	0.004	0.000
110	8.683	2.264	0.600	0.162	0.044	0.012	0.003	0.000
111	8.897	2.292	0.600	0.160	0.043	0.012	0.003	0.000
112	9.115	2.319	0.600	0.158	0.042	0.011	0.003	0.000
113	9.339	2.348	0.600	0.156	0.041	0.011	0.003	0.000
114	9.569	2.376	0.600	0.154	0.040	0.011	0.003	0.000
115	9.804	2.405	0.600	0.152	0.039	0.010	0.003	0.000
116	10.046	2.434	0.600	0.150	0.038	0.010	0.003	0.000
117	10.293	2.464	0.600	0.149	0.037	0.010	0.002	0.000
118	10.546	2.494	0.600	0.147	0.037	0.009	0.002	0.000
119	10.805	2.524	0.600	0.145	0.036	0.009	0.002	0.000
120	11.071	2.555	0.600	0.143	0.035	0.009	0.002	0.000

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 45 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.562	0.556	0.550	0.544	0.538	0.532	0.527	0.516
2	0.575	0.562	0.550	0.538	0.527	0.515	0.505	0.484
3	0.588	0.569	0.550	0.532	0.515	0.499	0.483	0.454
4	0.601	0.575	0.550	0.526	0.504	0.483	0.463	0.426
5	0.615	0.581	0.550	0.521	0.493	0.468	0.443	0.400
6	0.629	0.588	0.550	0.515	0.483	0.453	0.425	0.375
7	0.643	0.594	0.550	0.509	0.472	0.438	0.407	0.352
8	0.657	0.601	0.550	0.504	0.462	0.424	0.390	0.330
9	0.672	0.608	0.550	0.498	0.452	0.411	0.373	0.309
10	0.687	0.614	0.550	0.493	0.442	0.398	0.358	0.290
11	0.702	0.621	0.550	0.488	0.433	0.385	0.342	0.272
12	0.718	0.628	0.550	0.482	0.424	0.373	0.328	0.255
13	0.734	0.635	0.550	0.477	0.414	0.361	0.314	0.240
14	0.751	0.642	0.550	0.472	0.406	0.349	0.301	0.225
15	0.768	0.649	0.550	0.467	0.397	0.338	0.288	0.211
16	0.785	0.656	0.550	0.462	0.388	0.327	0.276	0.198
17	0.803	0.664	0.550	0.457	0.380	0.317	0.265	0.186
18	0.821	0.671	0.550	0.452	0.372	0.307	0.253	0.174
19	0.839	0.679	0.550	0.447	0.364	0.297	0.243	0.163
20	0.858	0.686	0.550	0.442	0.356	0.287	0.232	0.153
21	0.877	0.694	0.550	0.437	0.348	0.278	0.223	0.144
22	0.897	0.702	0.550	0.432	0.341	0.269	0.213	0.135
23	0.917	0.709	0.550	0.428	0.333	0.261	0.204	0.126
24	0.938	0.717	0.550	0.423	0.326	0.252	0.196	0.119
25	0.959	0.725	0.550	0.418	0.319	0.244	0.187	0.111
26	0.981	0.733	0.550	0.414	0.312	0.236	0.180	0.104
27	1.003	0.741	0.550	0.409	0.306	0.229	0.172	0.098
28	1.025	0.750	0.550	0.405	0.299	0.222	0.165	0.092
29	1.048	0.758	0.550	0.400	0.293	0.215	0.158	0.086
30	1.072	0.766	0.550	0.396	0.286	0.208	0.151	0.081
31	1.096	0.775	0.550	0.392	0.280	0.201	0.145	0.076
32	1.121	0.784	0.550	0.388	0.274	0.195	0.139	0.071
33	1.146	0.792	0.550	0.383	0.268	0.188	0.133	0.067
34	1.172	0.801	0.550	0.379	0.262	0.182	0.127	0.063
35	1.198	0.810	0.550	0.375	0.257	0.177	0.122	0.059
36	1.225	0.819	0.550	0.371	0.251	0.171	0.117	0.055
37	1.253	0.828	0.550	0.367	0.246	0.165	0.112	0.052
38	1.281	0.837	0.550	0.363	0.241	0.160	0.107	0.048
39	1.310	0.847	0.550	0.359	0.235	0.155	0.103	0.045
40	1.339	0.856	0.550	0.355	0.230	0.150	0.098	0.043
41	1.369	0.866	0.550	0.351	0.225	0.145	0.094	0.040
42	1.400	0.875	0.550	0.347	0.221	0.141	0.090	0.038
43	1.432	0.885	0.550	0.344	0.216	0.136	0.086	0.035
44	1.464	0.895	0.550	0.340	0.211	0.132	0.083	0.033
45	1.497	0.905	0.550	0.336	0.207	0.128	0.079	0.031
46	1.530	0.915	0.550	0.333	0.202	0.124	0.076	0.029
47	1.565	0.925	0.550	0.329	0.198	0.120	0.073	0.027
48	1.600	0.935	0.550	0.325	0.194	0.116	0.070	0.026
49	1.636	0.946	0.550	0.322	0.189	0.112	0.067	0.024
50	1.673	0.956	0.550	0.318	0.185	0.108	0.064	0.023
51	1.710	0.967	0.550	0.315	0.181	0.105	0.061	0.021
52	1.749	0.978	0.550	0.311	0.177	0.102	0.059	0.020
53	1.788	0.988	0.550	0.308	0.174	0.098	0.056	0.019
54	1.828	0.999	0.550	0.305	0.170	0.095	0.054	0.017
55	1.870	1.011	0.550	0.301	0.166	0.092	0.052	0.016
56	1.912	1.022	0.550	0.298	0.163	0.089	0.049	0.015
57	1.955	1.033	0.550	0.295	0.159	0.086	0.047	0.014
58	1.999	1.045	0.550	0.292	0.156	0.084	0.045	0.014
59	2.043	1.056	0.550	0.288	0.152	0.081	0.043	0.013
60	2.089	1.068	0.550	0.285	0.149	0.078	0.042	0.012

Modified Discount Rate 'W'

<i>Year</i>	<i>-0.04</i>	<i>-0.02</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.12</i>
61	2.136	1.080	0.550	0.282	0.146	0.076	0.040	0.011
62	2.185	1.092	0.550	0.279	0.143	0.073	0.038	0.010
63	2.234	1.104	0.550	0.276	0.140	0.071	0.036	0.010
64	2.284	1.116	0.550	0.273	0.137	0.069	0.035	0.009
65	2.335	1.129	0.550	0.270	0.134	0.067	0.033	0.009
66	2.388	1.141	0.550	0.267	0.131	0.065	0.032	0.008
67	2.442	1.154	0.550	0.264	0.128	0.062	0.031	0.008
68	2.496	1.167	0.550	0.261	0.125	0.060	0.029	0.007
69	2.553	1.180	0.550	0.259	0.123	0.059	0.028	0.007
70	2.610	1.193	0.550	0.256	0.120	0.057	0.027	0.006
71	2.669	1.206	0.550	0.253	0.117	0.055	0.026	0.006
72	2.729	1.220	0.550	0.250	0.115	0.053	0.025	0.006
73	2.790	1.233	0.550	0.247	0.112	0.051	0.024	0.005
74	2.853	1.247	0.550	0.245	0.110	0.050	0.023	0.005
75	2.917	1.261	0.550	0.242	0.108	0.048	0.022	0.005
76	2.983	1.275	0.550	0.239	0.105	0.047	0.021	0.004
77	3.050	1.289	0.550	0.237	0.103	0.045	0.020	0.004
78	3.118	1.303	0.550	0.234	0.101	0.044	0.019	0.004
79	3.189	1.318	0.550	0.232	0.099	0.042	0.018	0.004
80	3.260	1.332	0.550	0.229	0.096	0.041	0.018	0.003
81	3.334	1.347	0.550	0.227	0.094	0.040	0.017	0.003
82	3.409	1.362	0.550	0.224	0.092	0.038	0.016	0.003
83	3.485	1.377	0.550	0.222	0.090	0.037	0.015	0.003
84	3.564	1.393	0.550	0.219	0.088	0.036	0.015	0.003
85	3.644	1.408	0.550	0.217	0.087	0.035	0.014	0.002
86	3.726	1.424	0.550	0.215	0.085	0.034	0.014	0.002
87	3.810	1.440	0.550	0.212	0.083	0.033	0.013	0.002
88	3.895	1.456	0.550	0.210	0.081	0.032	0.012	0.002
89	3.983	1.472	0.550	0.208	0.079	0.031	0.012	0.002
90	4.073	1.488	0.550	0.205	0.078	0.030	0.011	0.002
91	4.164	1.505	0.550	0.203	0.076	0.029	0.011	0.002
92	4.258	1.522	0.550	0.201	0.074	0.028	0.010	0.002
93	4.354	1.539	0.550	0.199	0.073	0.027	0.010	0.001
94	4.452	1.556	0.550	0.197	0.071	0.026	0.010	0.001
95	4.552	1.573	0.550	0.195	0.070	0.025	0.009	0.001
96	4.654	1.590	0.550	0.192	0.068	0.024	0.009	0.001
97	4.759	1.608	0.550	0.190	0.067	0.024	0.008	0.001
98	4.866	1.626	0.550	0.188	0.065	0.023	0.008	0.001
99	4.975	1.644	0.550	0.186	0.064	0.022	0.008	0.001
100	5.087	1.662	0.550	0.184	0.062	0.021	0.007	0.001
101	5.202	1.681	0.550	0.182	0.061	0.021	0.007	0.001
102	5.319	1.700	0.550	0.180	0.060	0.020	0.007	0.001
103	5.438	1.718	0.550	0.178	0.058	0.019	0.007	0.001
104	5.561	1.738	0.550	0.176	0.057	0.019	0.006	0.001
105	5.686	1.757	0.550	0.174	0.056	0.018	0.006	0.001
106	5.814	1.776	0.550	0.172	0.055	0.018	0.006	0.001
107	5.944	1.796	0.550	0.171	0.054	0.017	0.005	0.001
108	6.078	1.816	0.550	0.169	0.052	0.017	0.005	0.001
109	6.215	1.836	0.550	0.167	0.051	0.016	0.005	0.001
110	6.355	1.857	0.550	0.165	0.050	0.015	0.005	0.000
111	6.498	1.877	0.550	0.163	0.049	0.015	0.005	0.000
112	6.644	1.898	0.550	0.162	0.048	0.014	0.004	0.000
113	6.793	1.919	0.550	0.160	0.047	0.014	0.004	0.000
114	6.946	1.941	0.550	0.158	0.046	0.014	0.004	0.000
115	7.102	1.962	0.550	0.156	0.045	0.013	0.004	0.000
116	7.262	1.984	0.550	0.155	0.044	0.013	0.004	0.000
117	7.425	2.006	0.550	0.153	0.043	0.012	0.004	0.000
118	7.592	2.029	0.550	0.151	0.042	0.012	0.003	0.000
119	7.763	2.051	0.550	0.150	0.041	0.012	0.003	0.000
120	7.938	2.074	0.550	0.148	0.040	0.011	0.003	0.000

SPECIFIC YEARLY DISCOUNT FACTOR

Tax Rate = 50 %

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.510	0.505	0.500	0.495	0.490	0.485	0.481	0.472
2	0.521	0.510	0.500	0.490	0.481	0.471	0.462	0.445
3	0.531	0.515	0.500	0.485	0.471	0.458	0.444	0.420
4	0.542	0.521	0.500	0.480	0.462	0.444	0.427	0.396
5	0.553	0.526	0.500	0.476	0.453	0.431	0.411	0.374
6	0.564	0.531	0.500	0.471	0.444	0.419	0.395	0.352
7	0.576	0.536	0.500	0.466	0.435	0.407	0.380	0.333
8	0.588	0.542	0.500	0.462	0.427	0.395	0.365	0.314
9	0.600	0.547	0.500	0.457	0.418	0.383	0.351	0.296
10	0.612	0.553	0.500	0.453	0.410	0.372	0.338	0.279
11	0.624	0.558	0.500	0.448	0.402	0.361	0.325	0.263
12	0.637	0.564	0.500	0.444	0.394	0.351	0.312	0.248
13	0.650	0.570	0.500	0.439	0.387	0.340	0.300	0.234
14	0.663	0.576	0.500	0.435	0.379	0.331	0.289	0.221
15	0.677	0.581	0.500	0.431	0.372	0.321	0.278	0.209
16	0.691	0.587	0.500	0.426	0.364	0.312	0.267	0.197
17	0.705	0.593	0.500	0.422	0.357	0.303	0.257	0.186
18	0.719	0.599	0.500	0.418	0.350	0.294	0.247	0.175
19	0.734	0.605	0.500	0.414	0.343	0.285	0.237	0.165
20	0.749	0.611	0.500	0.410	0.336	0.277	0.228	0.156
21	0.764	0.617	0.500	0.406	0.330	0.269	0.219	0.147
22	0.780	0.624	0.500	0.402	0.323	0.261	0.211	0.139
23	0.796	0.630	0.500	0.398	0.317	0.253	0.203	0.131
24	0.812	0.636	0.500	0.394	0.311	0.246	0.195	0.123
25	0.829	0.643	0.500	0.390	0.305	0.239	0.188	0.116
26	0.845	0.649	0.500	0.386	0.299	0.232	0.180	0.110
27	0.863	0.656	0.500	0.382	0.293	0.225	0.173	0.104
28	0.880	0.662	0.500	0.378	0.287	0.219	0.167	0.098
29	0.898	0.669	0.500	0.375	0.282	0.212	0.160	0.092
30	0.917	0.676	0.500	0.371	0.276	0.206	0.154	0.087
31	0.935	0.683	0.500	0.367	0.271	0.200	0.148	0.082
32	0.954	0.690	0.500	0.364	0.265	0.194	0.143	0.077
33	0.974	0.697	0.500	0.360	0.260	0.189	0.137	0.073
34	0.994	0.704	0.500	0.356	0.255	0.183	0.132	0.069
35	1.014	0.711	0.500	0.353	0.250	0.178	0.127	0.065
36	1.035	0.718	0.500	0.349	0.245	0.173	0.122	0.061
37	1.056	0.725	0.500	0.346	0.240	0.167	0.117	0.058
38	1.077	0.733	0.500	0.343	0.236	0.163	0.113	0.055
39	1.099	0.740	0.500	0.339	0.231	0.158	0.108	0.052
40	1.122	0.747	0.500	0.336	0.226	0.153	0.104	0.049
41	1.145	0.755	0.500	0.333	0.222	0.149	0.100	0.046
42	1.168	0.763	0.500	0.329	0.218	0.144	0.096	0.043
43	1.192	0.770	0.500	0.326	0.213	0.140	0.093	0.041
44	1.216	0.778	0.500	0.323	0.209	0.136	0.089	0.039
45	1.241	0.786	0.500	0.320	0.205	0.132	0.086	0.036
46	1.266	0.794	0.500	0.316	0.201	0.128	0.082	0.034
47	1.292	0.802	0.500	0.313	0.197	0.125	0.079	0.032
48	1.319	0.810	0.500	0.310	0.193	0.121	0.076	0.030
49	1.346	0.818	0.500	0.307	0.189	0.117	0.073	0.029
50	1.373	0.826	0.500	0.304	0.186	0.114	0.070	0.027
51	1.401	0.835	0.500	0.301	0.182	0.111	0.068	0.026
52	1.430	0.843	0.500	0.298	0.179	0.108	0.065	0.024
53	1.459	0.852	0.500	0.295	0.175	0.104	0.063	0.023
54	1.489	0.860	0.500	0.292	0.172	0.101	0.060	0.022
55	1.519	0.869	0.500	0.289	0.168	0.098	0.058	0.020
56	1.550	0.878	0.500	0.286	0.165	0.096	0.056	0.019
57	1.582	0.887	0.500	0.284	0.162	0.093	0.053	0.018
58	1.614	0.896	0.500	0.281	0.159	0.090	0.051	0.017
59	1.647	0.905	0.500	0.278	0.155	0.087	0.049	0.016
60	1.680	0.914	0.500	0.275	0.152	0.085	0.048	0.015

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	1.715	0.923	0.500	0.272	0.149	0.082	0.046	0.014
62	1.750	0.932	0.500	0.270	0.146	0.080	0.044	0.013
63	1.785	0.942	0.500	0.267	0.144	0.078	0.042	0.013
64	1.822	0.951	0.500	0.264	0.141	0.075	0.041	0.012
65	1.859	0.961	0.500	0.262	0.138	0.073	0.039	0.011
66	1.897	0.971	0.500	0.259	0.135	0.071	0.038	0.011
67	1.936	0.980	0.500	0.257	0.133	0.069	0.036	0.010
68	1.975	0.990	0.500	0.254	0.130	0.067	0.035	0.010
69	2.015	1.000	0.500	0.252	0.128	0.065	0.033	0.009
70	2.057	1.010	0.500	0.249	0.125	0.063	0.032	0.008
71	2.099	1.021	0.500	0.247	0.123	0.061	0.031	0.008
72	2.141	1.031	0.500	0.244	0.120	0.060	0.030	0.008
73	2.185	1.041	0.500	0.242	0.118	0.058	0.029	0.007
74	2.230	1.052	0.500	0.239	0.115	0.056	0.027	0.007
75	2.275	1.063	0.500	0.237	0.113	0.054	0.026	0.006
76	2.322	1.073	0.500	0.235	0.111	0.053	0.025	0.006
77	2.369	1.084	0.500	0.232	0.109	0.051	0.024	0.006
78	2.417	1.095	0.500	0.230	0.107	0.050	0.023	0.005
79	2.467	1.106	0.500	0.228	0.105	0.048	0.023	0.005
80	2.517	1.117	0.500	0.226	0.103	0.047	0.022	0.005
81	2.568	1.129	0.500	0.223	0.101	0.046	0.021	0.004
82	2.621	1.140	0.500	0.221	0.099	0.044	0.020	0.004
83	2.674	1.151	0.500	0.219	0.097	0.043	0.019	0.004
84	2.729	1.163	0.500	0.217	0.095	0.042	0.019	0.004
85	2.785	1.175	0.500	0.215	0.093	0.041	0.018	0.004
86	2.841	1.187	0.500	0.212	0.091	0.039	0.017	0.003
87	2.899	1.199	0.500	0.210	0.089	0.038	0.016	0.003
88	2.959	1.211	0.500	0.208	0.088	0.037	0.016	0.003
89	3.019	1.223	0.500	0.206	0.086	0.036	0.015	0.003
90	3.081	1.235	0.500	0.204	0.084	0.035	0.015	0.003
91	3.143	1.248	0.500	0.202	0.082	0.034	0.014	0.002
92	3.208	1.260	0.500	0.200	0.081	0.033	0.014	0.002
93	3.273	1.273	0.500	0.198	0.079	0.032	0.013	0.002
94	3.340	1.286	0.500	0.196	0.078	0.031	0.013	0.002
95	3.408	1.299	0.500	0.194	0.076	0.030	0.012	0.002
96	3.477	1.312	0.500	0.192	0.075	0.029	0.012	0.002
97	3.548	1.325	0.500	0.190	0.073	0.028	0.011	0.002
98	3.621	1.339	0.500	0.189	0.072	0.028	0.011	0.002
99	3.695	1.352	0.500	0.187	0.070	0.027	0.010	0.002
100	3.770	1.366	0.500	0.185	0.069	0.026	0.010	0.001
101	3.847	1.380	0.500	0.183	0.068	0.025	0.010	0.001
102	3.926	1.394	0.500	0.181	0.066	0.025	0.009	0.001
103	4.006	1.408	0.500	0.179	0.065	0.024	0.009	0.001
104	4.088	1.422	0.500	0.178	0.064	0.023	0.008	0.001
105	4.171	1.436	0.500	0.176	0.063	0.022	0.008	0.001
106	4.256	1.451	0.500	0.174	0.061	0.022	0.008	0.001
107	4.343	1.466	0.500	0.172	0.060	0.021	0.008	0.001
108	4.432	1.480	0.500	0.171	0.059	0.021	0.007	0.001
109	4.522	1.495	0.500	0.169	0.058	0.020	0.007	0.001
110	4.614	1.510	0.500	0.167	0.057	0.019	0.007	0.001
111	4.708	1.526	0.500	0.166	0.056	0.019	0.006	0.001
112	4.805	1.541	0.500	0.164	0.054	0.018	0.006	0.001
113	4.903	1.557	0.500	0.162	0.053	0.018	0.006	0.001
114	5.003	1.572	0.500	0.161	0.052	0.017	0.006	0.001
115	5.105	1.588	0.500	0.159	0.051	0.017	0.005	0.001
116	5.209	1.604	0.500	0.158	0.050	0.016	0.005	0.001
117	5.315	1.621	0.500	0.156	0.049	0.016	0.005	0.001
118	5.424	1.637	0.500	0.155	0.048	0.015	0.005	0.001
119	5.534	1.653	0.500	0.153	0.047	0.015	0.005	0.000
120	5.647	1.670	0.500	0.151	0.046	0.014	0.005	0.000

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 0 %

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	1.042	1.020	1.000	0.980	0.962	0.943	0.926	0.893
2	2.127	2.062	2.000	1.942	1.886	1.833	1.783	1.690
3	3.257	3.124	3.000	2.884	2.775	2.673	2.577	2.402
4	4.434	4.208	4.000	3.808	3.630	3.465	3.312	3.037
5	5.661	5.315	5.000	4.713	4.452	4.212	3.993	3.605
6	6.938	6.443	6.000	5.601	5.242	4.917	4.623	4.111
7	8.269	7.595	7.000	6.472	6.002	5.582	5.206	4.564
8	9.655	8.771	8.000	7.325	6.733	6.210	5.747	4.968
9	11.099	9.970	9.000	8.162	7.435	6.802	6.247	5.328
10	12.603	11.194	10.000	8.983	8.111	7.360	6.710	5.650
11	14.170	12.443	11.000	9.787	8.760	7.887	7.139	5.938
12	15.802	13.717	12.000	10.575	9.385	8.384	7.536	6.194
13	17.502	15.018	13.000	11.348	9.986	8.853	7.904	6.424
14	19.273	16.345	14.000	12.106	10.563	9.295	8.244	6.628
15	21.118	17.698	15.000	12.849	11.118	9.712	8.559	6.811
16	23.040	19.080	16.000	13.578	11.652	10.106	8.851	6.974
17	25.041	20.490	17.000	14.292	12.166	10.477	9.122	7.120
18	27.126	21.928	18.000	14.992	12.659	10.828	9.372	7.250
19	29.298	23.396	19.000	15.678	13.134	11.158	9.604	7.366
20	31.561	24.894	20.000	16.351	13.590	11.470	9.818	7.469
21	33.917	26.423	21.000	17.011	14.029	11.764	10.017	7.562
22	36.372	27.982	22.000	17.658	14.451	12.042	10.201	7.645
23	38.930	29.574	23.000	18.292	14.857	12.303	10.371	7.718
24	41.593	31.198	24.000	18.914	15.247	12.550	10.529	7.784
25	44.368	32.855	25.000	19.523	15.622	12.783	10.675	7.843
26	47.258	34.546	26.000	20.121	15.983	13.003	10.810	7.896
27	50.269	36.271	27.000	20.707	16.330	13.211	10.935	7.943
28	53.405	38.032	28.000	21.281	16.663	13.406	11.051	7.984
29	56.672	39.828	29.000	21.844	16.984	13.591	11.158	8.022
30	60.075	41.662	30.000	22.396	17.292	13.765	11.258	8.055
31	63.620	43.532	31.000	22.938	17.588	13.929	11.350	8.085
32	67.313	45.441	32.000	23.468	17.874	14.084	11.435	8.112
33	71.159	47.389	33.000	23.989	18.148	14.230	11.514	8.135
34	75.165	49.376	34.000	24.499	18.411	14.368	11.587	8.157
35	79.339	51.405	35.000	24.999	18.665	14.498	11.655	8.176
36	83.687	53.474	36.000	25.489	18.908	14.621	11.717	8.192
37	88.215	55.586	37.000	25.969	19.143	14.737	11.775	8.208
38	92.932	57.741	38.000	26.441	19.368	14.846	11.829	8.221
39	97.846	59.939	39.000	26.903	19.584	14.949	11.879	8.233
40	102.965	62.183	40.000	27.355	19.793	15.046	11.925	8.244
41	108.297	64.472	41.000	27.799	19.993	15.138	11.967	8.253
42	113.851	66.809	42.000	28.235	20.186	15.225	12.007	8.262
43	119.636	69.192	43.000	28.662	20.371	15.306	12.043	8.270
44	125.663	71.625	44.000	29.080	20.549	15.383	12.077	8.276
45	131.940	74.107	45.000	29.490	20.720	15.456	12.108	8.283
46	138.479	76.640	46.000	29.892	20.885	15.524	12.137	8.288
47	145.291	79.224	47.000	30.287	21.043	15.589	12.164	8.293
48	152.387	81.862	48.000	30.673	21.195	15.650	12.189	8.297
49	159.778	84.553	49.000	31.052	21.341	15.708	12.212	8.301
50	167.477	87.299	50.000	31.424	21.482	15.762	12.233	8.304
51	175.497	90.101	51.000	31.788	21.617	15.813	12.253	8.308
52	183.851	92.960	52.000	32.145	21.748	15.861	12.272	8.310
53	192.553	95.877	53.000	32.495	21.873	15.907	12.288	8.313
54	201.617	98.854	54.000	32.838	21.993	15.950	12.304	8.315
55	211.060	101.892	55.000	33.175	22.109	15.991	12.319	8.317
56	220.896	104.992	56.000	33.505	22.220	16.029	12.332	8.319
57	231.141	108.155	57.000	33.828	22.327	16.065	12.344	8.320
58	241.814	111.383	58.000	34.145	22.430	16.099	12.356	8.322
59	252.931	114.676	59.000	34.456	22.528	16.131	12.367	8.323
60	264.512	118.037	60.000	34.761	22.623	16.161	12.377	8.324

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	276.575	121.467	61.000	35.060	22.715	16.190	12.386	8.325
62	289.140	124.966	62.000	35.353	22.803	16.217	12.394	8.326
63	302.229	128.537	63.000	35.640	22.887	16.242	12.402	8.327
64	315.864	132.180	64.000	35.921	22.969	16.266	12.409	8.327
65	330.067	135.898	65.000	36.197	23.047	16.289	12.416	8.328
66	344.861	139.692	66.000	36.468	23.122	16.310	12.422	8.329
67	360.272	143.563	67.000	36.733	23.194	16.331	12.428	8.329
68	376.325	147.514	68.000	36.994	23.264	16.350	12.433	8.330
69	393.047	151.544	69.000	37.249	23.330	16.368	12.438	8.330
70	410.465	155.658	70.000	37.499	23.395	16.385	12.443	8.330
71	428.610	159.855	71.000	37.744	23.456	16.401	12.447	8.331
72	447.510	164.137	72.000	37.984	23.516	16.416	12.451	8.331
73	467.198	168.508	73.000	38.220	23.573	16.430	12.455	8.331
74	487.706	172.967	74.000	38.451	23.628	16.443	12.458	8.331
75	509.069	177.517	75.000	38.677	23.680	16.456	12.461	8.332
76	531.322	182.160	76.000	38.899	23.731	16.468	12.464	8.332
77	554.502	186.898	77.000	39.117	23.780	16.479	12.467	8.332
78	578.648	191.733	78.000	39.330	23.827	16.490	12.469	8.332
79	603.800	196.666	79.000	39.539	23.872	16.500	12.471	8.332
80	630.000	201.700	80.000	39.745	23.915	16.509	12.474	8.332
81	657.292	206.837	81.000	39.946	23.957	16.518	12.475	8.332
82	685.721	212.079	82.000	40.143	23.997	16.526	12.477	8.333
83	715.334	217.427	83.000	40.336	24.036	16.534	12.479	8.333
84	746.181	222.885	84.000	40.526	24.073	16.542	12.481	8.333
85	778.314	228.454	85.000	40.711	24.109	16.549	12.482	8.333
86	811.785	234.137	86.000	40.893	24.143	16.556	12.483	8.333
87	846.651	239.936	87.000	41.072	24.176	16.562	12.485	8.333
88	882.970	245.853	88.000	41.247	24.207	16.568	12.486	8.333
89	920.802	251.890	89.000	41.419	24.238	16.573	12.487	8.333
90	960.211	258.051	90.000	41.587	24.267	16.579	12.488	8.333
91	1001.261	264.338	91.000	41.752	24.295	16.584	12.489	8.333
92	1044.022	270.753	92.000	41.914	24.323	16.588	12.489	8.333
93	1088.564	277.299	93.000	42.072	24.349	16.593	12.490	8.333
94	1134.963	283.979	94.000	42.228	24.374	16.597	12.491	8.333
95	1183.295	290.795	95.000	42.380	24.398	16.601	12.492	8.333
96	1233.640	297.750	96.000	42.529	24.421	16.605	12.492	8.333
97	1286.084	304.847	97.000	42.676	24.443	16.608	12.493	8.333
98	1340.712	312.088	98.000	42.820	24.465	16.611	12.493	8.333
99	1397.617	319.478	99.000	42.960	24.485	16.615	12.494	8.333
100	1456.893	327.018	100.000	43.098	24.505	16.618	12.494	8.333
101	1518.638	334.713	101.000	43.234	24.524	16.620	12.495	8.333
102	1582.956	342.564	102.000	43.366	24.542	16.623	12.495	8.333
103	1649.954	350.575	103.000	43.496	24.560	16.625	12.495	8.333
104	1719.744	358.750	104.000	43.624	24.577	16.628	12.496	8.333
105	1792.442	367.092	105.000	43.749	24.593	16.630	12.496	8.333
106	1868.169	375.604	106.000	43.872	24.609	16.632	12.496	8.333
107	1947.051	384.290	107.000	43.992	24.624	16.634	12.497	8.333
108	2029.219	393.153	108.000	44.110	24.638	16.636	12.497	8.333
109	2114.812	402.197	109.000	44.225	24.652	16.638	12.497	8.333
110	2203.971	411.426	110.000	44.338	24.666	16.639	12.497	8.333
111	2296.845	420.842	111.000	44.449	24.678	16.641	12.498	8.333
112	2393.588	430.451	112.000	44.558	24.691	16.642	12.498	8.333
113	2494.363	440.257	113.000	44.665	24.703	16.644	12.498	8.333
114	2599.336	450.262	114.000	44.769	24.714	16.645	12.498	8.333
115	2708.683	460.471	115.000	44.872	24.725	16.646	12.498	8.333
116	2822.587	470.889	116.000	44.973	24.736	16.647	12.498	8.333
117	2941.236	481.519	117.000	45.071	24.746	16.648	12.498	8.333
118	3064.829	492.367	118.000	45.168	24.756	16.649	12.499	8.333
119	3193.572	503.435	119.000	45.262	24.765	16.650	12.499	8.333
120	3327.680	514.730	120.000	45.355	24.774	16.651	12.499	8.333

Tax Rate = 0 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	1.085	1.041	1.000	0.961	0.925	0.890	0.857	0.797
4	2.262	2.125	2.000	1.885	1.779	1.682	1.592	1.433
6	3.540	3.254	3.000	2.773	2.570	2.387	2.223	1.939
8	4.926	4.430	4.000	3.626	3.300	3.014	2.763	2.343
10	6.430	5.654	5.000	4.447	3.976	3.573	3.226	2.665
12	8.062	6.928	6.000	5.235	4.601	4.070	3.623	2.922
14	9.833	8.255	7.000	5.993	5.178	4.512	3.964	3.126
16	11.755	9.636	8.000	6.722	5.712	4.906	4.255	3.290
18	13.840	11.075	9.000	7.422	6.206	5.256	4.506	3.420
20	16.102	12.573	10.000	8.095	6.662	5.568	4.720	3.523
22	18.557	14.133	11.000	8.742	7.084	5.845	4.904	3.606
24	21.221	15.756	12.000	9.363	7.474	6.092	5.062	3.672
26	24.111	17.447	13.000	9.961	7.835	6.312	5.197	3.724
28	27.248	19.208	14.000	10.535	8.168	6.508	5.313	3.766
30	30.651	21.041	15.000	11.087	8.476	6.682	5.412	3.800
32	34.343	22.950	16.000	11.618	8.762	6.837	5.498	3.826
34	38.350	24.938	17.000	12.128	9.025	6.975	5.571	3.847
36	42.697	27.007	18.000	12.618	9.269	7.098	5.633	3.864
38	47.414	29.162	19.000	13.089	9.494	7.207	5.687	3.878
40	52.533	31.406	20.000	13.542	9.702	7.304	5.733	3.889
42	58.087	33.742	21.000	13.978	9.895	7.391	5.772	3.897
44	64.114	36.174	22.000	14.396	10.073	7.468	5.806	3.904
46	70.653	38.707	23.000	14.798	10.238	7.536	5.835	3.909
48	77.748	41.344	24.000	15.185	10.390	7.597	5.860	3.914
50	85.447	44.090	25.000	15.556	10.530	7.651	5.881	3.917
52	93.801	46.949	26.000	15.913	10.661	7.700	5.900	3.920
54	102.866	49.927	27.000	16.257	10.781	7.743	5.915	3.922
56	112.702	53.026	28.000	16.586	10.892	7.781	5.929	3.924
58	123.374	56.254	29.000	16.904	10.995	7.815	5.940	3.925
60	134.955	59.615	30.000	17.208	11.090	7.845	5.950	3.926
62	147.521	63.114	31.000	17.501	11.178	7.872	5.959	3.927
64	161.155	66.758	32.000	17.783	11.259	7.896	5.966	3.928
66	175.950	70.552	33.000	18.054	11.334	7.918	5.972	3.929
68	192.003	74.502	34.000	18.314	11.404	7.937	5.978	3.929
70	209.421	78.615	35.000	18.564	11.468	7.954	5.982	3.929
72	228.322	82.898	36.000	18.804	11.527	7.969	5.986	3.930
74	248.830	87.357	37.000	19.035	11.582	7.982	5.989	3.930
76	271.083	92.000	38.000	19.257	11.633	7.994	5.992	3.930
78	295.229	96.835	39.000	19.470	11.680	8.005	5.995	3.930
80	321.429	101.869	40.000	19.676	11.723	8.014	5.997	3.930
82	349.857	107.110	41.000	19.873	11.763	8.023	5.999	3.930
84	380.705	112.568	42.000	20.062	11.800	8.030	6.000	3.931
86	414.176	118.251	43.000	20.244	11.835	8.037	6.002	3.931
88	450.495	124.168	44.000	20.419	11.866	8.043	6.003	3.931
90	489.903	130.329	45.000	20.588	11.896	8.048	6.004	3.931
92	532.664	136.744	46.000	20.749	11.923	8.053	6.005	3.931
94	579.063	143.424	47.000	20.905	11.948	8.057	6.005	3.931
96	629.408	150.379	48.000	21.054	11.971	8.061	6.006	3.931
98	684.037	157.620	49.000	21.198	11.992	8.064	6.006	3.931
100	743.313	165.161	50.000	21.336	12.012	8.067	6.007	3.931
102	807.631	173.012	51.000	21.468	12.031	8.069	6.007	3.931
104	877.421	181.187	52.000	21.596	12.047	8.072	6.008	3.931
106	953.147	189.699	53.000	21.719	12.063	8.074	6.008	3.931
108	1035.316	198.562	54.000	21.836	12.078	8.076	6.008	3.931
110	1124.475	207.791	55.000	21.950	12.091	8.077	6.008	3.931
112	1221.218	217.400	56.000	22.058	12.103	8.079	6.009	3.931
114	1326.192	227.405	57.000	22.163	12.115	8.080	6.009	3.931
116	1440.095	237.823	58.000	22.264	12.125	8.081	6.009	3.931
118	1563.689	248.670	59.000	22.360	12.135	8.082	6.009	3.931
120	1697.796	259.965	60.000	22.453	12.144	8.083	6.009	3.931

Tax Rate = 0 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	1.226	1.106	1.000	0.906	0.822	0.747	0.681	0.567
10	2.731	2.330	2.000	1.726	1.497	1.306	1.144	0.889
15	4.575	3.684	3.000	2.469	2.053	1.723	1.459	1.072
20	6.838	5.182	4.000	3.142	2.509	2.035	1.674	1.176
25	9.612	6.839	5.000	3.752	2.884	2.268	1.820	1.235
30	13.015	8.672	6.000	4.304	3.193	2.442	1.919	1.268
35	17.189	10.700	7.000	4.804	3.446	2.572	1.987	1.287
40	22.308	12.944	8.000	5.257	3.654	2.669	2.033	1.298
45	28.585	15.426	9.000	5.667	3.825	2.742	2.064	1.304
50	36.284	18.172	10.000	6.038	3.966	2.796	2.085	1.307
55	45.727	21.210	11.000	6.375	4.082	2.837	2.100	1.309
60	57.307	24.571	12.000	6.680	4.177	2.867	2.110	1.310
65	71.510	28.289	13.000	6.956	4.255	2.890	2.116	1.311
70	88.928	32.402	14.000	7.206	4.319	2.907	2.121	1.311
75	110.291	36.952	15.000	7.432	4.372	2.919	2.124	1.311
80	136.491	41.986	16.000	7.637	4.415	2.929	2.126	1.312
85	168.624	47.555	17.000	7.823	4.451	2.936	2.128	1.312
90	208.032	53.716	18.000	7.991	4.480	2.941	2.129	1.312
95	256.364	60.532	19.000	8.144	4.504	2.945	2.129	1.312
100	315.640	68.073	20.000	8.282	4.524	2.948	2.130	1.312
105	388.337	76.414	21.000	8.407	4.541	2.950	2.130	1.312
110	477.496	85.643	22.000	8.520	4.554	2.952	2.130	1.312
115	586.844	95.852	23.000	8.623	4.565	2.953	2.130	1.312
120	720.951	107.147	24.000	8.715	4.574	2.954	2.130	1.312

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	1.504	1.224	1.000	0.820	0.676	0.558	0.463	0.322
20	3.767	2.722	2.000	1.493	1.132	0.870	0.678	0.426
30	7.170	4.555	3.000	2.045	1.440	1.044	0.777	0.459
40	12.288	6.799	4.000	2.498	1.649	1.142	0.823	0.470
50	19.987	9.545	5.000	2.870	1.789	1.196	0.844	0.473
60	31.568	12.905	6.000	3.175	1.884	1.226	0.854	0.474
70	48.986	17.019	7.000	3.425	1.949	1.243	0.859	0.475
80	75.186	22.053	8.000	3.630	1.992	1.253	0.861	0.475
90	114.595	28.214	9.000	3.798	2.021	1.258	0.862	0.475
100	173.870	35.754	10.000	3.936	2.041	1.261	0.862	0.475
110	263.029	44.982	11.000	4.049	2.054	1.262	0.863	0.475
120	397.136	56.277	12.000	4.142	2.063	1.263	0.863	0.475

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year \ W	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	1.845	1.354	1.000	0.743	0.555	0.417	0.315	0.183
30	5.248	3.187	2.000	1.295	0.864	0.591	0.415	0.216
45	11.525	5.669	3.000	1.705	1.035	0.664	0.446	0.222
60	23.106	9.030	4.000	2.010	1.130	0.694	0.456	0.223
75	44.469	13.580	5.000	2.237	1.183	0.707	0.459	0.223
90	83.877	19.741	6.000	2.405	1.212	0.712	0.460	0.224
105	156.575	28.083	7.000	2.530	1.228	0.714	0.460	0.224
120	290.682	39.378	8.000	2.623	1.237	0.715	0.460	0.224

Tax Rate = 0 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	2.262	1.498	1.000	0.673	0.456	0.312	0.215	0.104
40	7.381	3.742	2.000	1.126	0.665	0.409	0.261	0.114
60	18.961	7.102	3.000	1.431	0.760	0.439	0.270	0.116
80	45.161	12.136	4.000	1.636	0.803	0.449	0.273	0.116
100	104.437	19.677	5.000	1.774	0.823	0.452	0.273	0.116
120	238.544	30.971	6.000	1.867	0.832	0.453	0.273	0.116

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	3.403	1.833	1.000	0.552	0.308	0.174	0.099	0.033
60	14.983	5.194	2.000	0.857	0.403	0.204	0.109	0.034
90	54.392	11.355	3.000	1.025	0.433	0.210	0.110	0.035
120	188.499	22.650	4.000	1.118	0.442	0.211	0.110	0.035

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	5.119	2.244	1.000	0.453	0.208	0.097	0.046	0.011
80	31.319	7.278	2.000	0.658	0.252	0.107	0.048	0.011
120	165.426	18.572	3.000	0.751	0.261	0.108	0.048	0.011

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	11.580	3.361	1.000	0.305	0.095	0.030	0.010	0.001
120	145.688	14.655	2.000	0.398	0.104	0.031	0.010	0.001

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 30 %

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.720	0.710	0.700	0.690	0.681	0.672	0.663	0.646
2	1.461	1.430	1.400	1.371	1.343	1.316	1.291	1.241
3	2.223	2.160	2.100	2.043	1.988	1.935	1.885	1.791
4	3.008	2.901	2.800	2.705	2.614	2.529	2.448	2.298
5	3.814	3.652	3.500	3.358	3.224	3.099	2.981	2.766
6	4.644	4.414	4.200	4.002	3.817	3.646	3.486	3.197
7	5.498	5.186	4.900	4.637	4.394	4.171	3.964	3.595
8	6.377	5.970	5.600	5.263	4.956	4.674	4.417	3.962
9	7.281	6.765	6.300	5.881	5.501	5.158	4.845	4.301
10	8.211	7.571	7.000	6.490	6.033	5.622	5.251	4.613
11	9.167	8.388	7.700	7.091	6.549	6.067	5.636	4.902
12	10.152	9.217	8.400	7.683	7.052	6.494	6.000	5.168
13	11.164	10.058	9.100	8.267	7.541	6.904	6.344	5.413
14	12.206	10.911	9.800	8.843	8.016	7.298	6.671	5.639
15	13.278	11.776	10.500	9.412	8.479	7.675	6.980	5.848
16	14.380	12.653	11.200	9.972	8.929	8.038	7.273	6.041
17	15.515	13.542	11.900	10.525	9.366	8.385	7.550	6.218
18	16.682	14.444	12.600	11.070	9.792	8.719	7.812	6.382
19	17.883	15.359	13.300	11.607	10.207	9.040	8.061	6.533
20	19.118	16.288	14.000	12.137	10.609	9.347	8.296	6.673
21	20.389	17.229	14.700	12.660	11.001	9.642	8.519	6.802
22	21.696	18.183	15.400	13.176	11.383	9.925	8.730	6.920
23	23.041	19.151	16.100	13.684	11.754	10.197	8.930	7.030
24	24.425	20.133	16.800	14.185	12.114	10.458	9.120	7.131
25	25.849	21.129	17.500	14.680	12.465	10.708	9.299	7.224
26	27.314	22.139	18.200	15.168	12.807	10.948	9.469	7.310
27	28.821	23.163	18.900	15.649	13.139	11.179	9.629	7.389
28	30.371	24.202	19.600	16.123	13.462	11.400	9.782	7.462
29	31.966	25.256	20.300	16.591	13.776	11.612	9.926	7.530
30	33.607	26.324	21.000	17.052	14.082	11.816	10.062	7.592
31	35.296	27.408	21.700	17.507	14.379	12.011	10.192	7.650
32	37.033	28.507	22.400	17.955	14.669	12.199	10.314	7.703
33	38.819	29.622	23.100	18.398	14.950	12.379	10.430	7.751
34	40.658	30.752	23.800	18.834	15.224	12.552	10.540	7.797
35	42.549	31.899	24.500	19.264	15.490	12.718	10.644	7.838
36	44.495	33.062	25.200	19.689	15.749	12.877	10.742	7.876
37	46.497	34.241	25.900	20.107	16.001	13.030	10.835	7.912
38	48.557	35.437	26.600	20.520	16.246	13.176	10.924	7.945
39	50.676	36.650	27.300	20.927	16.485	13.317	11.007	7.975
40	52.856	37.881	28.000	21.328	16.716	13.452	11.086	8.002
41	55.098	39.128	28.700	21.724	16.942	13.582	11.161	8.028
42	57.406	40.394	29.400	22.115	17.162	13.706	11.232	8.052
43	59.779	41.677	30.100	22.500	17.375	13.825	11.300	8.074
44	62.222	42.979	30.800	22.879	17.583	13.940	11.363	8.094
45	64.734	44.299	31.500	23.254	17.785	14.050	11.423	8.112
46	67.319	45.638	32.200	23.623	17.981	14.155	11.481	8.129
47	69.979	46.996	32.900	23.987	18.172	14.256	11.535	8.145
48	72.715	48.373	33.600	24.346	18.358	14.354	11.586	8.160
49	75.529	49.770	34.300	24.701	18.539	14.447	11.634	8.173
50	78.425	51.187	35.000	25.050	18.715	14.536	11.680	8.186
51	81.405	52.624	35.700	25.394	18.886	14.622	11.724	8.197
52	84.470	54.081	36.400	25.734	19.053	14.705	11.765	8.208
53	87.623	55.559	37.100	26.069	19.215	14.784	11.804	8.217
54	90.868	57.057	37.800	26.400	19.373	14.860	11.841	8.226
55	94.205	58.577	38.500	26.725	19.526	14.932	11.876	8.235
56	97.639	60.119	39.200	27.047	19.675	15.002	11.909	8.242
57	101.172	61.683	39.900	27.364	19.820	15.069	11.940	8.249
58	104.807	63.268	40.600	27.676	19.961	15.134	11.970	8.256
59	108.546	64.877	41.300	27.984	20.098	15.196	11.998	8.262
60	112.393	66.508	42.000	28.288	20.232	15.255	12.025	8.267

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	116.351	68.162	42.700	28.588	20.362	15.312	12.050	8.273
62	120.422	69.840	43.400	28.884	20.488	15.366	12.074	8.277
63	124.612	71.541	44.100	29.175	20.611	15.419	12.096	8.282
64	128.921	73.267	44.800	29.463	20.730	15.469	12.118	8.286
65	133.355	75.017	45.500	29.746	20.847	15.517	12.138	8.289
66	137.917	76.793	46.200	30.026	20.960	15.564	12.157	8.293
67	142.610	78.593	46.900	30.302	21.070	15.608	12.175	8.296
68	147.438	80.419	47.600	30.574	21.177	15.651	12.193	8.299
69	152.406	82.270	48.300	30.842	21.281	15.692	12.209	8.301
70	157.516	84.149	49.000	31.106	21.382	15.731	12.224	8.304
71	162.774	86.053	49.700	31.367	21.481	15.769	12.239	8.306
72	168.183	87.985	50.400	31.625	21.577	15.805	12.253	8.308
73	173.748	89.944	51.100	31.878	21.670	15.840	12.266	8.310
74	179.473	91.931	51.800	32.128	21.761	15.873	12.278	8.312
75	185.363	93.947	52.500	32.375	21.849	15.905	12.290	8.314
76	191.423	95.990	53.200	32.619	21.935	15.936	12.301	8.315
77	197.658	98.063	53.900	32.859	22.018	15.965	12.312	8.317
78	204.072	100.166	54.600	33.095	22.099	15.993	12.322	8.318
79	210.670	102.298	55.300	33.329	22.178	16.021	12.331	8.319
80	217.459	104.460	56.000	33.559	22.255	16.047	12.340	8.320
81	224.444	106.653	56.700	33.786	22.330	16.072	12.349	8.321
82	231.629	108.878	57.400	34.010	22.403	16.096	12.357	8.322
83	239.022	111.134	58.100	34.230	22.474	16.119	12.364	8.323
84	246.628	113.421	58.800	34.448	22.542	16.141	12.371	8.324
85	254.452	115.742	59.500	34.663	22.609	16.162	12.378	8.325
86	262.502	118.095	60.200	34.875	22.674	16.182	12.385	8.325
87	270.784	120.482	60.900	35.083	22.738	16.202	12.391	8.326
88	279.305	122.903	61.600	35.289	22.799	16.221	12.397	8.326
89	288.071	125.358	62.300	35.493	22.859	16.238	12.402	8.327
90	297.089	127.847	63.000	35.693	22.918	16.256	12.407	8.327
91	306.367	130.373	63.700	35.890	22.974	16.272	12.412	8.328
92	315.913	132.934	64.400	36.085	23.030	16.288	12.417	8.328
93	325.734	135.531	65.100	36.277	23.083	16.303	12.421	8.329
94	335.837	138.166	65.800	36.467	23.135	16.318	12.425	8.329
95	346.232	140.837	66.500	36.654	23.186	16.332	12.429	8.329
96	356.925	143.547	67.200	36.838	23.236	16.346	12.433	8.330
97	367.927	146.295	67.900	37.020	23.284	16.359	12.437	8.330
98	379.246	149.082	68.600	37.199	23.330	16.371	12.440	8.330
99	390.891	151.909	69.300	37.376	23.376	16.383	12.443	8.330
100	402.872	154.776	70.000	37.550	23.420	16.394	12.446	8.331
101	415.197	157.683	70.700	37.722	23.463	16.405	12.449	8.331
102	427.878	160.632	71.400	37.891	23.505	16.416	12.452	8.331
103	440.924	163.623	72.100	38.058	23.546	16.426	12.454	8.331
104	454.345	166.656	72.800	38.223	23.585	16.436	12.457	8.331
105	468.154	169.732	73.500	38.386	23.624	16.445	12.459	8.332
106	482.360	172.852	74.200	38.546	23.661	16.454	12.461	8.332
107	496.975	176.016	74.900	38.704	23.698	16.462	12.463	8.332
108	512.011	179.226	75.600	38.860	23.733	16.471	12.465	8.332
109	527.481	182.480	76.300	39.014	23.768	16.479	12.467	8.332
110	543.396	185.781	77.000	39.166	23.801	16.486	12.469	8.332
111	559.769	189.129	77.700	39.315	23.834	16.493	12.470	8.332
112	576.615	192.524	78.400	39.463	23.866	16.500	12.472	8.332
113	593.945	195.968	79.100	39.608	23.897	16.507	12.474	8.332
114	611.775	199.460	79.800	39.752	23.927	16.514	12.475	8.332
115	630.118	203.002	80.500	39.893	23.956	16.520	12.476	8.333
116	648.990	206.595	81.200	40.033	23.984	16.526	12.478	8.333
117	668.405	210.238	81.900	40.171	24.012	16.531	12.479	8.333
118	688.380	213.933	82.600	40.306	24.039	16.537	12.480	8.333
119	708.930	217.681	83.300	40.440	24.065	16.542	12.481	8.333
120	730.072	221.481	84.000	40.572	24.091	16.547	12.482	8.333

Tax Rate = 30 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	0.741	0.720	0.700	0.681	0.662	0.645	0.628	0.596
4	1.525	1.461	1.400	1.343	1.289	1.238	1.191	1.103
6	2.355	2.222	2.100	1.987	1.882	1.785	1.695	1.534
8	3.234	3.006	2.800	2.613	2.444	2.289	2.148	1.901
10	4.164	3.812	3.500	3.222	2.975	2.753	2.554	2.214
12	5.148	4.641	4.200	3.815	3.477	3.180	2.918	2.480
14	6.190	5.494	4.900	4.391	3.953	3.574	3.245	2.706
16	7.292	6.371	5.600	4.951	4.403	3.936	3.537	2.899
18	8.459	7.273	6.300	5.496	4.829	4.270	3.800	3.062
20	9.695	8.201	7.000	6.026	5.231	4.577	4.035	3.202
22	11.002	9.156	7.700	6.542	5.613	4.860	4.246	3.321
24	12.386	10.138	8.400	7.043	5.974	5.121	4.436	3.422
26	13.851	11.148	9.100	7.531	6.315	5.361	4.605	3.508
28	15.401	12.186	9.800	8.005	6.638	5.583	4.758	3.581
30	17.042	13.255	10.500	8.467	6.944	5.786	4.894	3.643
32	18.779	14.354	11.200	8.915	7.233	5.974	5.017	3.696
34	20.618	15.485	11.900	9.352	7.507	6.147	5.126	3.741
36	22.563	16.647	12.600	9.776	7.766	6.306	5.225	3.780
38	24.623	17.844	13.300	10.189	8.011	6.453	5.313	3.812
40	26.803	19.074	14.000	10.590	8.243	6.588	5.392	3.840
42	29.110	20.339	14.700	10.980	8.462	6.712	5.463	3.864
44	31.553	21.641	15.400	11.360	8.670	6.827	5.527	3.884
46	34.138	22.980	16.100	11.729	8.867	6.932	5.584	3.901
48	36.874	24.357	16.800	12.089	9.052	7.029	5.635	3.915
50	39.769	25.774	17.500	12.438	9.228	7.119	5.681	3.928
52	42.835	27.231	18.200	12.778	9.395	7.201	5.722	3.938
54	46.079	28.730	18.900	13.108	9.553	7.277	5.759	3.947
56	49.513	30.271	19.600	13.429	9.702	7.347	5.792	3.955
58	53.147	31.857	20.300	13.742	9.843	7.411	5.822	3.962
60	56.994	33.488	21.000	14.046	9.976	7.471	5.849	3.967
62	61.066	35.166	21.700	14.341	10.103	7.525	5.872	3.972
64	65.376	36.892	22.400	14.629	10.222	7.575	5.894	3.976
66	69.938	38.667	23.100	14.909	10.335	7.622	5.913	3.979
68	74.766	40.493	23.800	15.181	10.442	7.664	5.930	3.982
70	79.876	42.371	24.500	15.445	10.544	7.704	5.946	3.985
72	85.286	44.303	25.200	15.702	10.639	7.740	5.960	3.987
74	91.011	46.290	25.900	15.953	10.730	7.773	5.972	3.988
76	97.071	48.334	26.600	16.196	10.816	7.804	5.983	3.990
78	103.485	50.436	27.300	16.433	10.897	7.832	5.993	3.991
80	110.273	52.598	28.000	16.663	10.974	7.858	6.002	3.992
82	117.459	54.823	28.700	16.887	11.047	7.882	6.010	3.993
84	125.065	57.111	29.400	17.104	11.116	7.904	6.017	3.994
86	133.115	59.464	30.100	17.316	11.181	7.925	6.024	3.995
88	141.635	61.884	30.800	17.522	11.242	7.943	6.029	3.995
90	150.654	64.374	31.500	17.722	11.301	7.961	6.035	3.996
92	160.199	66.935	32.200	17.917	11.356	7.977	6.039	3.996
94	170.303	69.570	32.900	18.107	11.408	7.991	6.044	3.997
96	180.997	72.279	33.600	18.291	11.457	8.005	6.047	3.997
98	192.316	75.067	34.300	18.470	11.504	8.017	6.051	3.997
100	204.296	77.933	35.000	18.644	11.548	8.029	6.054	3.997
102	216.977	80.882	35.700	18.814	11.590	8.039	6.056	3.998
104	230.398	83.915	36.400	18.979	11.630	8.049	6.059	3.998
106	244.604	87.035	37.100	19.139	11.667	8.058	6.061	3.998
108	259.641	90.245	37.800	19.295	11.703	8.066	6.063	3.998
110	275.556	93.545	38.500	19.447	11.736	8.074	6.065	3.998
112	292.401	96.941	39.200	19.594	11.768	8.081	6.066	3.998
114	310.231	100.433	39.900	19.738	11.798	8.087	6.068	3.998
116	329.102	104.026	40.600	19.877	11.827	8.093	6.069	3.998
118	349.077	107.721	41.300	20.013	11.854	8.098	6.070	3.998
120	370.219	111.521	42.000	20.145	11.879	8.103	6.071	3.998

Tax Rate = 30 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	0.807	0.751	0.700	0.653	0.610	0.570	0.533	0.468
10	1.737	1.557	1.400	1.262	1.141	1.034	0.939	0.780
15	2.808	2.422	2.100	1.830	1.603	1.411	1.248	0.989
20	4.044	3.350	2.800	2.360	2.006	1.719	1.484	1.128
25	5.468	4.346	3.500	2.855	2.357	1.969	1.663	1.222
30	7.109	5.414	4.200	3.316	2.663	2.173	1.799	1.284
35	9.000	6.561	4.900	3.747	2.929	2.339	1.903	1.325
40	11.180	7.791	5.600	4.148	3.161	2.474	1.982	1.353
45	13.692	9.111	6.300	4.522	3.363	2.584	2.043	1.372
50	16.588	10.528	7.000	4.872	3.539	2.673	2.089	1.384
55	19.926	12.048	7.700	5.197	3.693	2.746	2.124	1.393
60	23.773	13.679	8.400	5.501	3.826	2.805	2.150	1.398
65	28.207	15.430	9.100	5.785	3.942	2.853	2.170	1.402
70	33.318	17.308	9.800	6.050	4.044	2.893	2.186	1.404
75	39.208	19.323	10.500	6.296	4.132	2.925	2.198	1.406
80	45.997	21.485	11.200	6.526	4.209	2.951	2.207	1.407
85	53.821	23.806	11.900	6.741	4.276	2.972	2.213	1.408
90	62.840	26.296	12.600	6.941	4.334	2.989	2.219	1.408
95	73.234	28.967	13.300	7.128	4.385	3.003	2.223	1.409
100	85.215	31.834	14.000	7.303	4.429	3.015	2.226	1.409
105	99.023	34.910	14.700	7.465	4.467	3.024	2.228	1.409
110	114.938	38.211	15.400	7.617	4.501	3.032	2.230	1.409
115	133.281	41.753	16.100	7.758	4.530	3.038	2.231	1.409
120	154.423	45.554	16.800	7.890	4.556	3.043	2.232	1.409

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	0.930	0.806	0.700	0.609	0.531	0.464	0.406	0.312
20	2.165	1.734	1.400	1.139	0.934	0.771	0.641	0.452
30	3.806	2.803	2.100	1.600	1.240	0.975	0.778	0.514
40	5.986	4.033	2.800	2.002	1.472	1.110	0.857	0.542
50	8.882	5.449	3.500	2.351	1.648	1.200	0.903	0.554
60	12.729	7.081	4.200	2.655	1.781	1.259	0.930	0.560
70	17.840	8.959	4.900	2.920	1.882	1.298	0.945	0.562
80	24.628	11.121	5.600	3.150	1.959	1.324	0.954	0.564
90	33.647	13.611	6.300	3.350	2.018	1.341	0.959	0.564
100	45.627	16.478	7.000	3.524	2.062	1.353	0.962	0.564
110	61.542	19.779	7.700	3.676	2.095	1.360	0.964	0.564
120	82.684	23.580	8.400	3.808	2.121	1.365	0.965	0.564

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	1.072	0.865	0.700	0.568	0.463	0.378	0.309	0.209
30	2.713	1.933	1.400	1.030	0.768	0.581	0.446	0.271
45	5.225	3.254	2.100	1.404	0.970	0.691	0.506	0.290
60	9.072	4.885	2.800	1.708	1.104	0.751	0.533	0.295
75	14.963	6.900	3.500	1.955	1.192	0.783	0.544	0.297
90	23.981	9.390	4.200	2.155	1.250	0.800	0.550	0.297
105	37.789	12.466	4.900	2.318	1.289	0.809	0.552	0.297
120	58.931	16.267	5.600	2.450	1.314	0.814	0.553	0.297

Tax Rate = 30 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	1.235	0.928	0.700	0.530	0.403	0.307	0.235	0.139
40	3.415	2.158	1.400	0.931	0.635	0.442	0.315	0.167
60	7.262	3.789	2.100	1.235	0.768	0.502	0.341	0.173
80	14.051	5.952	2.800	1.466	0.845	0.528	0.350	0.174
100	26.032	8.819	3.500	1.640	0.889	0.539	0.353	0.174
120	47.174	12.620	4.200	1.772	0.915	0.544	0.354	0.174

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	1.641	1.069	0.700	0.461	0.306	0.204	0.137	0.062
60	5.488	2.700	1.400	0.765	0.439	0.263	0.163	0.068
90	14.507	5.190	2.100	0.966	0.498	0.280	0.168	0.068
120	35.649	8.990	2.800	1.098	0.523	0.285	0.169	0.068

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	2.180	1.230	0.700	0.401	0.232	0.135	0.079	0.028
80	8.969	3.393	1.400	0.632	0.309	0.161	0.088	0.029
120	30.111	7.194	2.100	0.764	0.334	0.166	0.089	0.029

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	3.847	1.631	0.700	0.304	0.134	0.059	0.027	0.006
120	24.989	5.432	1.400	0.436	0.159	0.064	0.028	0.006

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 35 %

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.667	0.659	0.650	0.642	0.634	0.626	0.618	0.603
2	1.353	1.326	1.300	1.275	1.251	1.228	1.205	1.162
3	2.056	2.002	1.950	1.900	1.853	1.807	1.763	1.681
4	2.778	2.687	2.600	2.518	2.439	2.365	2.294	2.163
5	3.520	3.381	3.250	3.127	3.011	2.902	2.799	2.609
6	4.281	4.084	3.900	3.729	3.568	3.419	3.278	3.023
7	5.063	4.796	4.550	4.322	4.111	3.916	3.734	3.407
8	5.865	5.518	5.200	4.909	4.641	4.394	4.167	3.764
9	6.689	6.249	5.850	5.487	5.157	4.855	4.579	4.094
10	7.535	6.990	6.500	6.058	5.660	5.298	4.971	4.401
11	8.403	7.741	7.150	6.622	6.150	5.725	5.343	4.686
12	9.295	8.501	7.800	7.179	6.627	6.136	5.697	4.950
13	10.211	9.272	8.450	7.729	7.093	6.531	6.033	5.194
14	11.151	10.052	9.100	8.271	7.547	6.912	6.353	5.422
15	12.116	10.843	9.750	8.807	7.989	7.278	6.656	5.632
16	13.106	11.645	10.400	9.335	8.420	7.630	6.945	5.828
17	14.124	12.457	11.050	9.857	8.840	7.969	7.220	6.009
18	15.168	13.279	11.700	10.372	9.250	8.296	7.481	6.177
19	16.240	14.113	12.350	10.881	9.649	8.610	7.729	6.333
20	17.341	14.957	13.000	11.383	10.038	8.912	7.965	6.478
21	18.471	15.813	13.650	11.878	10.417	9.204	8.189	6.612
22	19.632	16.680	14.300	12.368	10.787	9.484	8.402	6.737
23	20.823	17.558	14.950	12.851	11.147	9.753	8.605	6.852
24	22.046	18.448	15.600	13.327	11.498	10.013	8.797	6.959
25	23.302	19.349	16.250	13.798	11.840	10.263	8.980	7.059
26	24.591	20.263	16.900	14.262	12.173	10.503	9.154	7.151
27	25.915	21.188	17.550	14.721	12.499	10.734	9.320	7.237
28	27.274	22.126	18.200	15.174	12.815	10.957	9.477	7.316
29	28.670	23.076	18.850	15.621	13.124	11.171	9.626	7.390
30	30.102	24.038	19.500	16.062	13.425	11.378	9.768	7.458
31	31.573	25.013	20.150	16.498	13.718	11.576	9.903	7.521
32	33.084	26.001	20.800	16.927	14.004	11.767	10.032	7.580
33	34.634	27.002	21.450	17.352	14.283	11.951	10.154	7.634
34	36.226	28.017	22.100	17.771	14.554	12.128	10.270	7.685
35	37.860	29.044	22.750	18.184	14.819	12.298	10.380	7.732
36	39.538	30.085	23.400	18.593	15.077	12.462	10.485	7.775
37	41.261	31.140	24.050	18.996	15.329	12.620	10.584	7.816
38	43.030	32.209	24.700	19.394	15.574	12.772	10.679	7.853
39	44.846	33.292	25.350	19.786	15.813	12.918	10.769	7.888
40	46.710	34.389	26.000	20.174	16.045	13.059	10.855	7.920
41	48.625	35.500	26.650	20.557	16.272	13.194	10.936	7.950
42	50.590	36.626	27.300	20.935	16.494	13.325	11.013	7.978
43	52.608	37.767	27.950	21.308	16.709	13.450	11.087	8.004
44	54.679	38.923	28.600	21.676	16.919	13.571	11.157	8.027
45	56.806	40.094	29.250	22.039	17.124	13.687	11.223	8.050
46	58.990	41.281	29.900	22.398	17.324	13.799	11.286	8.070
47	61.232	42.483	30.550	22.753	17.518	13.907	11.346	8.089
48	63.534	43.702	31.200	23.102	17.708	14.010	11.403	8.107
49	65.897	44.936	31.850	23.447	17.892	14.110	11.457	8.123
50	68.324	46.186	32.500	23.788	18.073	14.206	11.509	8.138
51	70.815	47.453	33.150	24.125	18.248	14.298	11.558	8.153
52	73.373	48.737	33.800	24.457	18.419	14.387	11.604	8.166
53	75.999	50.037	34.450	24.784	18.586	14.473	11.649	8.178
54	78.695	51.355	35.100	25.108	18.749	14.555	11.691	8.189
55	81.463	52.690	35.750	25.427	18.907	14.634	11.731	8.199
56	84.305	54.042	36.400	25.743	19.061	14.711	11.769	8.209
57	87.222	55.413	37.050	26.054	19.212	14.784	11.805	8.218
58	90.218	56.801	37.700	26.361	19.359	14.855	11.839	8.226
59	93.294	58.208	38.350	26.665	19.501	14.923	11.872	8.234
60	96.451	59.633	39.000	26.964	19.641	14.988	11.903	8.241

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	99.693	61.077	39.650	27.260	19.777	15.051	11.933	8.248
62	103.022	62.540	40.300	27.552	19.909	15.112	11.961	8.254
63	106.439	64.022	40.950	27.840	20.038	15.170	11.987	8.260
64	109.948	65.524	41.600	28.124	20.164	15.226	12.013	8.265
65	113.550	67.046	42.250	28.405	20.286	15.280	12.037	8.270
66	117.249	68.587	42.900	28.682	20.406	15.332	12.060	8.275
67	121.046	70.149	43.550	28.956	20.522	15.383	12.081	8.279
68	124.945	71.732	44.200	29.226	20.636	15.431	12.102	8.283
69	128.947	73.335	44.850	29.492	20.746	15.477	12.122	8.287
70	133.057	74.960	45.500	29.755	20.854	15.522	12.140	8.290
71	137.276	76.605	46.150	30.015	20.959	15.565	12.158	8.293
72	141.608	78.273	46.800	30.272	21.062	15.606	12.175	8.296
73	146.055	79.962	47.450	30.525	21.161	15.646	12.191	8.299
74	150.621	81.674	48.100	30.775	21.259	15.684	12.206	8.301
75	155.309	83.409	48.750	31.022	21.353	15.721	12.221	8.304
76	160.123	85.166	49.400	31.265	21.446	15.757	12.235	8.306
77	165.064	86.946	50.050	31.505	21.536	15.791	12.248	8.308
78	170.138	88.750	50.700	31.743	21.624	15.824	12.260	8.310
79	175.347	90.577	51.350	31.977	21.709	15.855	12.272	8.311
80	180.695	92.429	52.000	32.208	21.793	15.886	12.283	8.313
81	186.186	94.305	52.650	32.437	21.874	15.915	12.294	8.314
82	191.823	96.205	53.300	32.662	21.953	15.943	12.304	8.316
83	197.611	98.131	53.950	32.885	22.030	15.970	12.314	8.317
84	203.553	100.082	54.600	33.104	22.106	15.997	12.323	8.318
85	209.654	102.059	55.250	33.321	22.179	16.022	12.332	8.319
86	215.918	104.062	55.900	33.535	22.250	16.046	12.340	8.320
87	222.349	106.091	56.550	33.746	22.320	16.069	12.348	8.321
88	228.952	108.147	57.200	33.955	22.388	16.092	12.356	8.322
89	235.731	110.230	57.850	34.161	22.454	16.113	12.363	8.323
90	242.691	112.340	58.500	34.364	22.519	16.134	12.370	8.324
91	249.837	114.478	59.150	34.565	22.582	16.154	12.376	8.324
92	257.173	116.645	59.800	34.763	22.643	16.173	12.382	8.325
93	264.706	118.840	60.450	34.958	22.703	16.192	12.388	8.326
94	272.439	121.064	61.100	35.152	22.761	16.210	12.393	8.326
95	280.379	123.317	61.750	35.342	22.818	16.227	12.399	8.327
96	288.531	125.600	62.400	35.530	22.873	16.243	12.404	8.327
97	296.900	127.912	63.050	35.716	22.927	16.259	12.409	8.328
98	305.493	130.256	63.700	35.899	22.979	16.274	12.413	8.328
99	314.315	132.630	64.350	36.080	23.031	16.289	12.417	8.328
100	323.373	135.035	65.000	36.259	23.080	16.303	12.421	8.329
101	332.672	137.473	65.650	36.435	23.129	16.317	12.425	8.329
102	342.220	139.942	66.300	36.609	23.176	16.330	12.429	8.329
103	352.023	142.444	66.950	36.781	23.223	16.343	12.433	8.330
104	362.087	144.978	67.600	36.951	23.268	16.355	12.436	8.330
105	372.420	147.546	68.250	37.118	23.312	16.367	12.439	8.330
106	383.029	150.148	68.900	37.283	23.354	16.378	12.442	8.330
107	393.921	152.784	69.550	37.447	23.396	16.389	12.445	8.331
108	405.103	155.455	70.200	37.608	23.437	16.399	12.448	8.331
109	416.584	158.161	70.850	37.767	23.476	16.409	12.450	8.331
110	428.372	160.903	71.500	37.924	23.515	16.419	12.453	8.331
111	440.474	163.681	72.150	38.079	23.553	16.428	12.455	8.331
112	452.900	166.496	72.800	38.232	23.589	16.437	12.457	8.331
113	465.657	169.347	73.450	38.383	23.625	16.446	12.459	8.332
114	478.754	172.236	74.100	38.532	23.660	16.454	12.461	8.332
115	492.202	175.163	74.750	38.679	23.694	16.462	12.463	8.332
116	506.008	178.129	75.400	38.824	23.727	16.470	12.465	8.332
117	520.183	181.134	76.050	38.968	23.759	16.477	12.467	8.332
118	534.736	184.178	76.700	39.109	23.791	16.484	12.468	8.332
119	549.677	187.262	77.350	39.249	23.821	16.491	12.470	8.332
120	565.018	190.387	78.000	39.387	23.851	16.498	12.471	8.332

Tax Rate = 35 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	0.685	0.667	0.650	0.633	0.617	0.602	0.587	0.559
4	1.407	1.352	1.300	1.251	1.204	1.160	1.118	1.041
6	2.169	2.055	1.950	1.852	1.761	1.677	1.598	1.455
8	2.971	2.777	2.600	2.438	2.291	2.155	2.031	1.811
10	3.817	3.518	3.250	3.010	2.793	2.599	2.422	2.118
12	4.709	4.278	3.900	3.566	3.271	3.009	2.776	2.382
14	5.649	5.059	4.550	4.109	3.725	3.390	3.096	2.609
16	6.639	5.860	5.200	4.637	4.156	3.742	3.385	2.804
18	7.684	6.683	5.850	5.153	4.566	4.069	3.646	2.973
20	8.785	7.528	6.500	5.655	4.955	4.371	3.881	3.117
22	9.945	8.394	7.150	6.144	5.324	4.651	4.095	3.242
24	11.168	9.284	7.800	6.621	5.675	4.911	4.287	3.349
26	12.458	10.198	8.450	7.085	6.009	5.151	4.461	3.441
28	13.817	11.135	9.100	7.538	6.325	5.374	4.618	3.521
30	15.249	12.098	9.750	7.979	6.626	5.580	4.760	3.589
32	16.760	13.086	10.400	8.409	6.912	5.771	4.889	3.648
34	18.352	14.100	11.050	8.828	7.184	5.948	5.005	3.698
36	20.030	15.141	11.700	9.236	7.442	6.112	5.109	3.742
38	21.798	16.210	12.350	9.634	7.687	6.264	5.204	3.779
40	23.663	17.307	13.000	10.022	7.920	6.405	5.290	3.811
42	25.628	18.433	13.650	10.400	8.141	6.535	5.367	3.839
44	27.700	19.589	14.300	10.768	8.351	6.656	5.437	3.863
46	29.884	20.776	14.950	11.127	8.551	6.768	5.500	3.884
48	32.185	21.994	15.600	11.477	8.740	6.871	5.557	3.901
50	34.612	23.244	16.250	11.817	8.920	6.967	5.609	3.916
52	37.170	24.528	16.900	12.149	9.091	7.056	5.655	3.930
54	39.866	25.845	17.550	12.473	9.254	7.138	5.697	3.941
56	42.707	27.198	18.200	12.788	9.408	7.215	5.735	3.950
58	45.703	28.586	18.850	13.096	9.555	7.285	5.770	3.959
60	48.861	30.012	19.500	13.395	9.694	7.351	5.801	3.966
62	52.189	31.475	20.150	13.687	9.827	7.411	5.829	3.972
64	55.698	32.976	20.800	13.971	9.952	7.468	5.854	3.977
66	59.397	34.518	21.450	14.248	10.072	7.520	5.877	3.982
68	63.295	36.100	22.100	14.518	10.185	7.568	5.898	3.986
70	67.405	37.725	22.750	14.782	10.293	7.612	5.916	3.989
72	71.736	39.393	23.400	15.038	10.396	7.654	5.933	3.992
74	76.303	41.104	24.050	15.288	10.493	7.692	5.949	3.995
76	81.116	42.861	24.700	15.532	10.585	7.728	5.962	3.997
78	86.189	44.665	25.350	15.769	10.673	7.760	5.975	3.999
80	91.537	46.517	26.000	16.000	10.756	7.791	5.986	4.000
82	97.175	48.417	26.650	16.226	10.836	7.819	5.996	4.002
84	103.117	50.368	27.300	16.445	10.911	7.845	6.005	4.003
86	109.381	52.371	27.950	16.659	10.982	7.870	6.014	4.004
88	115.984	54.427	28.600	16.868	11.050	7.892	6.021	4.005
90	122.944	56.538	29.250	17.071	11.115	7.913	6.028	4.006
92	130.280	58.704	29.900	17.269	11.176	7.932	6.034	4.006
94	138.014	60.928	30.550	17.462	11.234	7.950	6.040	4.007
96	146.166	63.211	31.200	17.650	11.290	7.966	6.045	4.007
98	154.758	65.554	31.850	17.834	11.342	7.982	6.049	4.008
100	163.816	67.959	32.500	18.012	11.392	7.996	6.053	4.008
102	173.364	70.429	33.150	18.186	11.440	8.009	6.057	4.008
104	183.428	72.963	33.800	18.356	11.485	8.021	6.060	4.009
106	194.037	75.565	34.450	18.521	11.527	8.032	6.063	4.009
108	205.219	78.236	35.100	18.682	11.568	8.043	6.066	4.009
110	217.007	80.978	35.750	18.839	11.607	8.052	6.069	4.009
112	229.433	83.792	36.400	18.992	11.643	8.061	6.071	4.009
114	242.530	86.681	37.050	19.142	11.678	8.070	6.073	4.009
116	256.336	89.647	37.700	19.287	11.711	8.077	6.075	4.010
118	270.889	92.691	38.350	19.428	11.743	8.084	6.076	4.010
120	286.230	95.817	39.000	19.566	11.773	8.091	6.078	4.010

Tax Rate = 35 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	0.742	0.694	0.650	0.609	0.572	0.537	0.504	0.446
10	1.587	1.435	1.300	1.181	1.075	0.980	0.896	0.753
15	2.552	2.226	1.950	1.716	1.517	1.346	1.200	0.964
20	3.653	3.070	2.600	2.218	1.906	1.649	1.436	1.109
25	4.909	3.972	3.250	2.689	2.248	1.899	1.619	1.208
30	6.342	4.934	3.900	3.130	2.549	2.105	1.761	1.276
35	7.976	5.962	4.550	3.544	2.814	2.275	1.871	1.323
40	9.841	7.059	5.200	3.931	3.046	2.416	1.957	1.355
45	11.968	8.230	5.850	4.295	3.251	2.532	2.023	1.378
50	14.394	9.481	6.500	4.636	3.431	2.628	2.075	1.393
55	17.162	10.815	7.150	4.955	3.590	2.707	2.115	1.403
60	20.320	12.241	7.800	5.254	3.729	2.773	2.146	1.410
65	23.922	13.762	8.450	5.535	3.852	2.827	2.170	1.415
70	28.032	15.387	9.100	5.798	3.959	2.871	2.188	1.419
75	32.720	17.121	9.750	6.045	4.054	2.908	2.203	1.421
80	38.068	18.973	10.400	6.276	4.138	2.939	2.214	1.423
85	44.169	20.949	11.050	6.493	4.211	2.964	2.223	1.424
90	51.129	23.060	11.700	6.696	4.276	2.985	2.230	1.424
95	59.069	25.313	12.350	6.887	4.332	3.002	2.235	1.425
100	68.126	27.718	13.000	7.066	4.382	3.016	2.239	1.425
105	78.459	30.287	13.650	7.233	4.426	3.028	2.242	1.426
110	90.247	33.028	14.300	7.390	4.465	3.037	2.245	1.426
115	103.694	35.955	14.950	7.537	4.499	3.045	2.247	1.426
120	119.035	39.080	15.600	7.675	4.529	3.052	2.248	1.426

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	0.846	0.741	0.650	0.571	0.503	0.443	0.392	0.307
20	1.947	1.585	1.300	1.073	0.892	0.746	0.627	0.451
30	3.379	2.548	1.950	1.514	1.193	0.952	0.769	0.520
40	5.244	3.645	2.600	1.902	1.426	1.093	0.855	0.552
50	7.670	4.895	3.250	2.243	1.606	1.189	0.907	0.567
60	10.828	6.321	3.900	2.542	1.745	1.254	0.938	0.574
70	14.938	7.945	4.550	2.806	1.853	1.299	0.956	0.578
80	20.286	9.797	5.200	3.037	1.936	1.329	0.968	0.579
90	27.246	11.907	5.850	3.240	2.001	1.350	0.974	0.580
100	36.303	14.312	6.500	3.419	2.051	1.364	0.978	0.580
110	48.091	17.054	7.150	3.576	2.089	1.374	0.981	0.581
120	63.431	20.179	7.800	3.714	2.119	1.380	0.982	0.581

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	0.965	0.791	0.650	0.536	0.442	0.366	0.304	0.211
30	2.398	1.753	1.300	0.977	0.743	0.572	0.446	0.279
45	4.525	2.925	1.950	1.340	0.948	0.689	0.512	0.301
60	7.682	4.350	2.600	1.640	1.087	0.754	0.543	0.308
75	12.370	6.084	3.250	1.886	1.182	0.791	0.558	0.311
90	19.330	8.195	3.900	2.090	1.247	0.812	0.565	0.311
105	29.663	10.763	4.550	2.257	1.291	0.823	0.568	0.312
120	45.004	13.888	5.200	2.395	1.320	0.830	0.569	0.312

Tax Rate = 35 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	1.101	0.844	0.650	0.502	0.389	0.302	0.236	0.145
40	2.965	1.941	1.300	0.890	0.622	0.443	0.321	0.177
60	6.123	3.367	1.950	1.189	0.761	0.509	0.352	0.184
80	11.471	5.218	2.600	1.421	0.845	0.539	0.364	0.186
100	20.529	7.624	3.250	1.599	0.894	0.553	0.368	0.186
120	35.869	10.749	3.900	1.737	0.924	0.560	0.369	0.186

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	1.433	0.962	0.650	0.441	0.301	0.206	0.142	0.068
60	4.590	2.388	1.300	0.741	0.440	0.272	0.173	0.075
90	11.550	4.498	1.950	0.944	0.505	0.293	0.180	0.076
120	26.891	7.623	2.600	1.082	0.535	0.299	0.181	0.076

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	1.864	1.097	0.650	0.388	0.233	0.141	0.086	0.032
80	7.213	2.949	1.300	0.619	0.316	0.171	0.097	0.034
120	22.553	6.074	1.950	0.757	0.346	0.178	0.098	0.034

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	3.158	1.425	0.650	0.299	0.139	0.065	0.031	0.007
120	18.498	4.550	1.300	0.437	0.169	0.072	0.033	0.007

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 40 %

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.615	0.607	0.600	0.593	0.586	0.579	0.573	0.560
2	1.245	1.222	1.200	1.179	1.158	1.138	1.119	1.082
3	1.890	1.844	1.800	1.758	1.717	1.678	1.640	1.569
4	2.551	2.474	2.400	2.330	2.263	2.199	2.137	2.023
5	3.229	3.111	3.000	2.895	2.796	2.701	2.612	2.447
6	3.923	3.756	3.600	3.454	3.316	3.187	3.065	2.842
7	4.634	4.409	4.200	4.005	3.824	3.655	3.497	3.211
8	5.363	5.070	4.800	4.551	4.320	4.107	3.909	3.555
9	6.109	5.739	5.400	5.090	4.805	4.544	4.303	3.876
10	6.874	6.416	6.000	5.622	5.278	4.965	4.678	4.175
11	7.658	7.101	6.600	6.149	5.741	5.372	5.037	4.455
12	8.461	7.795	7.200	6.668	6.192	5.764	5.378	4.715
13	9.284	8.496	7.800	7.182	6.633	6.143	5.705	4.958
14	10.127	9.207	8.400	7.690	7.063	6.509	6.016	5.185
15	10.991	9.926	9.000	8.192	7.484	6.862	6.313	5.396
16	11.876	10.654	9.600	8.687	7.894	7.202	6.596	5.594
17	12.783	11.391	10.200	9.177	8.295	7.531	6.867	5.778
18	13.712	12.136	10.800	9.661	8.687	7.849	7.125	5.949
19	14.664	12.891	11.400	10.140	9.069	8.155	7.371	6.109
20	15.639	13.655	12.000	10.612	9.442	8.451	7.606	6.259
21	16.638	14.428	12.600	11.079	9.807	8.736	7.830	6.398
22	17.662	15.210	13.200	11.541	10.163	9.012	8.044	6.528
23	18.711	16.002	13.800	11.997	10.511	9.278	8.248	6.649
24	19.786	16.804	14.400	12.448	10.851	9.535	8.443	6.762
25	20.888	17.616	15.000	12.893	11.182	9.782	8.629	6.868
26	22.016	18.437	15.600	13.333	11.506	10.022	8.806	6.966
27	23.172	19.268	16.200	13.768	11.822	10.253	8.975	7.058
28	24.357	20.109	16.800	14.197	12.131	10.475	9.136	7.144
29	25.570	20.961	17.400	14.622	12.433	10.691	9.291	7.224
30	26.814	21.823	18.000	15.041	12.727	10.898	9.438	7.298
31	28.088	22.695	18.600	15.456	13.015	11.099	9.578	7.368
32	29.393	23.578	19.200	15.865	13.296	11.292	9.712	7.433
33	30.731	24.472	19.800	16.270	13.570	11.479	9.839	7.493
34	32.101	25.376	20.400	16.670	13.838	11.659	9.961	7.550
35	33.505	26.292	21.000	17.065	14.100	11.833	10.077	7.602
36	34.944	27.218	21.600	17.456	14.355	12.001	10.188	7.651
37	36.418	28.156	22.200	17.842	14.605	12.163	10.294	7.697
38	37.928	29.105	22.800	18.223	14.848	12.320	10.395	7.740
39	39.476	30.066	23.400	18.600	15.086	12.471	10.492	7.780
40	41.061	31.039	24.000	18.972	15.319	12.617	10.584	7.817
41	42.686	32.023	24.600	19.340	15.545	12.757	10.671	7.852
42	44.350	33.019	25.200	19.704	15.767	12.893	10.755	7.884
43	46.056	34.027	25.800	20.063	15.983	13.024	10.835	7.914
44	47.803	35.048	26.400	20.418	16.195	13.151	10.911	7.942
45	49.593	36.081	27.000	20.769	16.401	13.273	10.984	7.969
46	51.427	37.127	27.600	21.115	16.603	13.391	11.054	7.993
47	53.307	38.185	28.200	21.458	16.799	13.505	11.120	8.016
48	55.232	39.256	28.800	21.796	16.992	13.615	11.183	8.037
49	57.205	40.340	29.400	22.131	17.179	13.721	11.243	8.057
50	59.227	41.437	30.000	22.461	17.363	13.823	11.301	8.076
51	61.298	42.548	30.600	22.788	17.542	13.922	11.356	8.093
52	63.420	43.672	31.200	23.110	17.716	14.017	11.408	8.109
53	65.594	44.810	31.800	23.429	17.887	14.109	11.458	8.124
54	67.822	45.961	32.400	23.744	18.054	14.198	11.506	8.138
55	70.104	47.127	33.000	24.056	18.217	14.284	11.551	8.151
56	72.443	48.306	33.600	24.363	18.376	14.367	11.595	8.164
57	74.839	49.500	34.200	24.667	18.531	14.447	11.636	8.175
58	77.294	50.709	34.800	24.968	18.683	14.524	11.676	8.186
59	79.810	51.932	35.400	25.265	18.831	14.598	11.714	8.196
60	82.387	53.170	36.000	25.558	18.975	14.670	11.750	8.205

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	85.027	54.423	36.600	25.848	19.116	14.740	11.784	8.213
62	87.733	55.691	37.200	26.134	19.254	14.807	11.817	8.221
63	90.505	56.975	37.800	26.417	19.389	14.871	11.848	8.229
64	93.345	58.274	38.400	26.697	19.520	14.934	11.878	8.236
65	96.256	59.589	39.000	26.973	19.649	14.994	11.906	8.243
66	99.237	60.920	39.600	27.246	19.774	15.052	11.934	8.249
67	102.292	62.268	40.200	27.516	19.897	15.108	11.960	8.254
68	105.422	63.631	40.800	27.783	20.016	15.162	11.984	8.260
69	108.630	65.011	41.400	28.046	20.133	15.214	12.008	8.265
70	111.916	66.408	42.000	28.306	20.247	15.265	12.031	8.269
71	115.282	67.822	42.600	28.564	20.359	15.314	12.052	8.273
72	118.732	69.253	43.200	28.818	20.467	15.361	12.073	8.278
73	122.266	70.702	43.800	29.069	20.574	15.406	12.092	8.281
74	125.888	72.168	44.400	29.317	20.677	15.450	12.111	8.285
75	129.598	73.651	45.000	29.562	20.779	15.492	12.129	8.288
76	133.400	75.153	45.600	29.805	20.878	15.533	12.146	8.291
77	137.295	76.673	46.200	30.044	20.974	15.572	12.162	8.294
78	141.285	78.212	46.800	30.281	21.069	15.610	12.177	8.297
79	145.374	79.769	47.400	30.515	21.161	15.647	12.192	8.299
80	149.564	81.345	48.000	30.746	21.251	15.683	12.206	8.301
81	153.857	82.941	48.600	30.974	21.339	15.717	12.220	8.303
82	158.255	84.555	49.200	31.200	21.424	15.750	12.233	8.305
83	162.761	86.189	49.800	31.422	21.508	15.782	12.245	8.307
84	167.378	87.844	50.400	31.643	21.590	15.812	12.256	8.309
85	172.109	89.518	51.000	31.860	21.670	15.842	12.268	8.311
86	176.956	91.212	51.600	32.076	21.748	15.871	12.278	8.312
87	181.922	92.928	52.200	32.288	21.824	15.898	12.288	8.314
88	187.010	94.663	52.800	32.498	21.899	15.925	12.298	8.315
89	192.223	96.421	53.400	32.706	21.971	15.951	12.307	8.316
90	197.565	98.199	54.000	32.911	22.042	15.976	12.316	8.317
91	203.038	99.999	54.600	33.113	22.112	16.000	12.325	8.318
92	208.645	101.821	55.200	33.314	22.179	16.023	12.333	8.319
93	214.391	103.665	55.800	33.511	22.245	16.045	12.340	8.320
94	220.277	105.531	56.400	33.707	22.310	16.067	12.348	8.321
95	226.309	107.420	57.000	33.900	22.373	16.088	12.355	8.322
96	232.488	109.332	57.600	34.091	22.435	16.108	12.361	8.323
97	238.820	111.267	58.200	34.280	22.495	16.127	12.368	8.324
98	245.307	113.226	58.800	34.466	22.554	16.146	12.374	8.324
99	251.954	115.209	59.400	34.650	22.611	16.164	12.379	8.325
100	258.765	117.215	60.000	34.832	22.667	16.182	12.385	8.325
101	265.742	119.246	60.600	35.012	22.722	16.198	12.390	8.326
102	272.892	121.302	61.200	35.190	22.775	16.215	12.395	8.326
103	280.217	123.382	61.800	35.366	22.827	16.230	12.400	8.327
104	287.722	125.488	62.400	35.539	22.878	16.246	12.405	8.327
105	295.412	127.620	63.000	35.711	22.928	16.260	12.409	8.328
106	303.291	129.777	63.600	35.880	22.976	16.274	12.413	8.328
107	311.364	131.960	64.200	36.047	23.024	16.288	12.417	8.328
108	319.635	134.170	64.800	36.213	23.070	16.301	12.421	8.329
109	328.110	136.407	65.400	36.376	23.115	16.314	12.425	8.329
110	336.793	138.671	66.000	36.538	23.159	16.326	12.428	8.329
111	345.689	140.963	66.600	36.698	23.203	16.338	12.431	8.330
112	354.805	143.282	67.200	36.855	23.245	16.349	12.434	8.330
113	364.144	145.630	67.800	37.011	23.286	16.360	12.437	8.330
114	373.713	148.006	68.400	37.165	23.326	16.371	12.440	8.330
115	383.518	150.411	69.000	37.317	23.365	16.381	12.443	8.331
116	393.563	152.845	69.600	37.468	23.404	16.391	12.446	8.331
117	403.856	155.309	70.200	37.616	23.441	16.401	12.448	8.331
118	414.401	157.802	70.800	37.763	23.478	16.410	12.451	8.331
119	425.206	160.326	71.400	37.908	23.513	16.419	12.453	8.331
120	436.277	162.881	72.000	38.052	23.548	16.428	12.455	8.331

Tax Rate = 40 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	0.630	0.615	0.600	0.586	0.572	0.559	0.546	0.522
4	1.291	1.244	1.200	1.158	1.118	1.080	1.044	0.976
6	1.985	1.889	1.800	1.716	1.638	1.565	1.497	1.372
8	2.714	2.550	2.400	2.262	2.135	2.017	1.909	1.716
10	3.479	3.227	3.000	2.794	2.608	2.439	2.284	2.015
12	4.282	3.921	3.600	3.314	3.059	2.831	2.626	2.276
14	5.125	4.631	4.200	3.822	3.490	3.197	2.937	2.502
16	6.010	5.359	4.800	4.318	3.900	3.537	3.221	2.700
18	6.939	6.105	5.400	4.802	4.292	3.855	3.479	2.871
20	7.915	6.869	6.000	5.275	4.665	4.151	3.714	3.021
22	8.938	7.651	6.600	5.736	5.021	4.426	3.928	3.151
24	10.013	8.453	7.200	6.187	5.361	4.683	4.122	3.264
26	11.142	9.274	7.800	6.627	5.685	4.922	4.300	3.362
28	12.326	10.115	8.400	7.056	5.994	5.145	4.461	3.448
30	13.570	10.977	9.000	7.476	6.288	5.353	4.608	3.522
32	14.875	11.860	9.600	7.885	6.569	5.546	4.742	3.587
34	16.246	12.765	10.200	8.285	6.837	5.727	4.864	3.644
36	17.684	13.691	10.800	8.676	7.092	5.894	4.975	3.693
38	19.195	14.641	11.400	9.057	7.336	6.051	5.076	3.735
40	20.780	15.613	12.000	9.430	7.568	6.197	5.168	3.773
42	22.444	16.609	12.600	9.793	7.790	6.333	5.252	3.805
44	24.192	17.630	13.200	10.148	8.001	6.459	5.328	3.833
46	26.026	18.675	13.800	10.495	8.203	6.577	5.397	3.858
48	27.952	19.746	14.400	10.833	8.395	6.687	5.460	3.879
50	29.973	20.844	15.000	11.164	8.578	6.789	5.518	3.898
52	32.095	21.968	15.600	11.486	8.753	6.885	5.570	3.914
54	34.323	23.119	16.200	11.801	8.920	6.974	5.618	3.928
56	36.661	24.299	16.800	12.109	9.079	7.056	5.662	3.940
58	39.116	25.507	17.400	12.409	9.231	7.134	5.701	3.951
60	41.694	26.745	18.000	12.703	9.375	7.205	5.737	3.960
62	44.399	28.014	18.600	12.989	9.513	7.272	5.770	3.968
64	47.240	29.313	19.200	13.269	9.645	7.335	5.800	3.975
66	50.221	30.644	19.800	13.542	9.770	7.393	5.827	3.981
68	53.351	32.008	20.400	13.808	9.890	7.447	5.852	3.986
70	56.637	33.405	21.000	14.069	10.004	7.498	5.874	3.991
72	60.087	34.836	21.600	14.323	10.112	7.545	5.895	3.995
74	63.708	36.302	22.200	14.571	10.216	7.588	5.913	3.998
76	67.510	37.803	22.800	14.813	10.315	7.629	5.930	4.001
78	71.501	39.342	23.400	15.050	10.409	7.667	5.946	4.004
80	75.690	40.918	24.000	15.281	10.499	7.703	5.960	4.006
82	80.088	42.533	24.600	15.507	10.585	7.736	5.973	4.008
84	84.705	44.187	25.200	15.727	10.667	7.766	5.985	4.010
86	89.552	45.881	25.800	15.942	10.745	7.795	5.995	4.012
88	94.641	47.617	26.400	16.152	10.820	7.822	6.005	4.013
90	99.982	49.396	27.000	16.357	10.890	7.847	6.014	4.014
92	105.590	51.218	27.600	16.557	10.958	7.870	6.022	4.015
94	111.476	53.084	28.200	16.753	11.023	7.891	6.029	4.016
96	117.656	54.996	28.800	16.944	11.084	7.911	6.036	4.017
98	124.143	56.955	29.400	17.130	11.143	7.930	6.042	4.017
100	130.954	58.961	30.000	17.312	11.199	7.948	6.047	4.018
102	138.103	61.017	30.600	17.490	11.252	7.964	6.052	4.019
104	145.608	63.123	31.200	17.664	11.303	7.979	6.057	4.019
106	153.487	65.280	31.800	17.833	11.352	7.993	6.061	4.019
108	161.759	67.490	32.400	17.998	11.398	8.006	6.065	4.020
110	170.442	69.754	33.000	18.160	11.442	8.019	6.068	4.020
112	179.557	72.074	33.600	18.318	11.485	8.030	6.072	4.020
114	189.126	74.450	34.200	18.472	11.525	8.041	6.074	4.020
116	199.172	76.884	34.800	18.622	11.563	8.051	6.077	4.021
118	209.717	79.377	35.400	18.769	11.600	8.060	6.079	4.021
120	220.788	81.932	36.000	18.912	11.634	8.069	6.082	4.021

Tax Rate = 40 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	0.677	0.637	0.600	0.565	0.533	0.503	0.475	0.424
10	1.442	1.314	1.200	1.098	1.006	0.924	0.850	0.723
15	2.306	2.033	1.800	1.599	1.427	1.277	1.147	0.935
20	3.282	2.797	2.400	2.072	1.800	1.573	1.382	1.084
25	4.383	3.609	3.000	2.517	2.132	1.821	1.568	1.190
30	5.626	4.471	3.600	2.937	2.426	2.028	1.715	1.264
35	7.031	5.386	4.200	3.332	2.688	2.202	1.831	1.317
40	8.616	6.359	4.800	3.704	2.920	2.348	1.923	1.354
45	10.406	7.391	5.400	4.055	3.127	2.470	1.996	1.380
50	12.428	8.489	6.000	4.386	3.310	2.573	2.053	1.399
55	14.710	9.654	6.600	4.697	3.473	2.658	2.099	1.412
60	17.287	10.892	7.200	4.990	3.617	2.730	2.135	1.421
65	20.198	12.207	7.800	5.267	3.746	2.790	2.163	1.428
70	23.484	13.604	8.400	5.527	3.860	2.841	2.186	1.432
75	27.194	15.088	9.000	5.772	3.961	2.883	2.204	1.435
80	31.383	16.664	9.600	6.003	4.051	2.919	2.218	1.438
85	36.114	18.338	10.200	6.221	4.131	2.948	2.229	1.439
90	41.456	20.117	10.800	6.426	4.202	2.973	2.238	1.441
95	47.487	22.006	11.400	6.619	4.265	2.994	2.245	1.441
100	54.297	24.012	12.000	6.801	4.321	3.012	2.250	1.442
105	61.987	26.144	12.600	6.973	4.371	3.026	2.255	1.442
110	70.670	28.408	13.200	7.134	4.415	3.038	2.258	1.443
115	80.475	30.813	13.800	7.286	4.454	3.049	2.261	1.443
120	91.545	33.367	14.400	7.430	4.489	3.057	2.263	1.443

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	0.765	0.677	0.600	0.533	0.473	0.421	0.375	0.299
20	1.740	1.441	1.200	1.005	0.847	0.717	0.610	0.449
30	2.984	2.303	1.800	1.425	1.141	0.925	0.757	0.523
40	4.569	3.275	2.400	1.797	1.374	1.070	0.849	0.560
50	6.591	4.372	3.000	2.127	1.557	1.173	0.907	0.579
60	9.168	5.610	3.600	2.421	1.701	1.245	0.943	0.588
70	12.454	7.007	4.200	2.681	1.816	1.295	0.965	0.593
80	16.644	8.584	4.800	2.912	1.906	1.331	0.980	0.595
90	21.985	10.362	5.400	3.117	1.977	1.356	0.988	0.596
100	28.795	12.368	6.000	3.299	2.033	1.373	0.994	0.597
110	37.478	14.633	6.600	3.461	2.077	1.385	0.997	0.597
120	48.549	17.187	7.200	3.604	2.112	1.394	1.000	0.597

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	0.864	0.719	0.600	0.502	0.420	0.353	0.297	0.211
30	2.107	1.581	1.200	0.921	0.715	0.561	0.444	0.286
45	3.898	2.614	1.800	1.272	0.921	0.683	0.517	0.312
60	6.475	3.852	2.400	1.565	1.066	0.755	0.553	0.322
75	10.185	5.336	3.000	1.811	1.167	0.797	0.571	0.325
90	15.527	7.114	3.600	2.016	1.238	0.822	0.579	0.326
105	23.217	9.246	4.200	2.187	1.288	0.836	0.584	0.326
120	34.287	11.800	4.800	2.330	1.323	0.845	0.586	0.326

Tax Rate = 40 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	0.975	0.764	0.600	0.473	0.373	0.296	0.235	0.149
40	2.561	1.736	1.200	0.845	0.606	0.442	0.327	0.187
60	5.138	2.974	1.800	1.138	0.750	0.513	0.363	0.196
80	9.328	4.551	2.400	1.369	0.840	0.549	0.377	0.198
100	16.138	6.557	3.000	1.551	0.896	0.566	0.383	0.199
120	27.209	9.112	3.600	1.695	0.931	0.575	0.385	0.199

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	1.244	0.862	0.600	0.420	0.295	0.208	0.147	0.075
60	3.821	2.100	1.200	0.713	0.439	0.280	0.183	0.084
90	9.162	3.878	1.800	0.918	0.510	0.304	0.192	0.085
120	20.233	6.433	2.400	1.061	0.545	0.313	0.194	0.085

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	1.585	0.972	0.600	0.372	0.232	0.146	0.092	0.037
80	5.775	2.549	1.200	0.603	0.322	0.181	0.106	0.039
120	16.846	5.103	1.800	0.747	0.357	0.190	0.108	0.040

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	2.577	1.238	0.600	0.293	0.145	0.072	0.036	0.009
120	13.648	3.793	1.200	0.437	0.179	0.080	0.038	0.009

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 45 %
 Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.562	0.556	0.550	0.544	0.538	0.532	0.527	0.516
2	1.137	1.118	1.100	1.082	1.065	1.048	1.031	1.000
3	1.725	1.687	1.650	1.614	1.580	1.547	1.515	1.454
4	2.327	2.262	2.200	2.141	2.084	2.030	1.978	1.880
5	2.941	2.843	2.750	2.662	2.577	2.497	2.421	2.279
6	3.570	3.431	3.300	3.177	3.060	2.950	2.846	2.654
7	4.212	4.025	3.850	3.686	3.532	3.388	3.253	3.006
8	4.870	4.626	4.400	4.190	3.995	3.812	3.643	3.336
9	5.541	5.234	4.950	4.688	4.447	4.223	4.016	3.645
10	6.229	5.848	5.500	5.181	4.889	4.621	4.373	3.935
11	6.931	6.469	6.050	5.669	5.322	5.005	4.716	4.208
12	7.649	7.097	6.600	6.151	5.746	5.378	5.044	4.463
13	8.384	7.732	7.150	6.628	6.160	5.739	5.358	4.703
14	9.135	8.374	7.700	7.100	6.566	6.088	5.659	4.928
15	9.903	9.024	8.250	7.567	6.962	6.426	5.948	5.138
16	10.688	9.680	8.800	8.029	7.351	6.753	6.224	5.336
17	11.490	10.344	9.350	8.485	7.731	7.069	6.488	5.522
18	12.311	11.015	9.900	8.937	8.102	7.376	6.742	5.696
19	13.151	11.694	10.450	9.384	8.466	7.673	6.984	5.859
20	14.009	12.380	11.000	9.826	8.822	7.960	7.217	6.012
21	14.886	13.074	11.550	10.263	9.170	8.238	7.439	6.156
22	15.784	13.775	12.100	10.695	9.511	8.508	7.653	6.291
23	16.701	14.484	12.650	11.123	9.845	8.768	7.857	6.417
24	17.639	15.202	13.200	11.546	10.171	9.021	8.053	6.536
25	18.598	15.927	13.750	11.964	10.490	9.265	8.240	6.647
26	19.579	16.660	14.300	12.378	10.802	9.501	8.420	6.752
27	20.582	17.402	14.850	12.788	11.108	9.730	8.592	6.850
28	21.607	18.151	15.400	13.192	11.407	9.952	8.756	6.941
29	22.656	18.909	15.950	13.593	11.700	10.166	8.914	7.028
30	23.728	19.676	16.500	13.989	11.986	10.374	9.065	7.108
31	24.824	20.451	17.050	14.381	12.266	10.575	9.210	7.184
32	25.944	21.234	17.600	14.768	12.540	10.770	9.349	7.255
33	27.090	22.027	18.150	15.152	12.808	10.958	9.481	7.322
34	28.262	22.828	18.700	15.531	13.071	11.140	9.609	7.385
35	29.460	23.638	19.250	15.906	13.328	11.317	9.731	7.443
36	30.685	24.457	19.800	16.277	13.579	11.488	9.847	7.499
37	31.938	25.285	20.350	16.644	13.825	11.653	9.959	7.550
38	33.219	26.122	20.900	17.007	14.065	11.813	10.066	7.599
39	34.528	26.969	21.450	17.366	14.301	11.968	10.169	7.644
40	35.868	27.825	22.000	17.721	14.531	12.119	10.267	7.687
41	37.237	28.690	22.550	18.072	14.756	12.264	10.361	7.727
42	38.637	29.566	23.100	18.419	14.977	12.404	10.451	7.764
43	40.068	30.451	23.650	18.763	15.193	12.541	10.538	7.800
44	41.532	31.345	24.200	19.103	15.404	12.672	10.620	7.833
45	43.029	32.250	24.750	19.439	15.610	12.800	10.700	7.864
46	44.559	33.165	25.300	19.771	15.812	12.924	10.775	7.893
47	46.124	34.090	25.850	20.100	16.010	13.043	10.848	7.920
48	47.724	35.025	26.400	20.426	16.204	13.159	10.918	7.946
49	49.359	35.971	26.950	20.747	16.393	13.271	10.984	7.970
50	51.032	36.927	27.500	21.066	16.578	13.379	11.048	7.992
51	52.742	37.894	28.050	21.381	16.760	13.484	11.109	8.013
52	54.491	38.872	28.600	21.692	16.937	13.586	11.168	8.033
53	56.279	39.860	29.150	22.000	17.111	13.685	11.224	8.052
54	58.108	40.859	29.700	22.305	17.280	13.780	11.278	8.069
55	59.977	41.870	30.250	22.606	17.447	13.872	11.329	8.085
56	61.889	42.892	30.800	22.904	17.609	13.961	11.379	8.101
57	63.843	43.925	31.350	23.199	17.768	14.048	11.426	8.115
58	65.842	44.970	31.900	23.490	17.924	14.131	11.471	8.129
59	67.885	46.026	32.450	23.779	18.076	14.212	11.515	8.141
60	69.975	47.094	33.000	24.064	18.225	14.291	11.556	8.153

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	72.111	48.174	33.550	24.346	18.371	14.367	11.596	8.164
62	74.296	49.266	34.100	24.625	18.514	14.440	11.634	8.175
63	76.529	50.370	34.650	24.902	18.654	14.511	11.671	8.185
64	78.813	51.486	35.200	25.175	18.790	14.580	11.706	8.194
65	81.149	52.615	35.750	25.445	18.924	14.647	11.739	8.203
66	83.536	53.756	36.300	25.712	19.055	14.711	11.771	8.211
67	85.978	54.910	36.850	25.976	19.183	14.774	11.802	8.218
68	88.474	56.077	37.400	26.238	19.308	14.834	11.831	8.225
69	91.027	57.257	37.950	26.496	19.430	14.893	11.859	8.232
70	93.637	58.450	38.500	26.752	19.550	14.949	11.886	8.238
71	96.306	59.656	39.050	27.005	19.668	15.004	11.912	8.244
72	99.034	60.876	39.600	27.255	19.782	15.057	11.937	8.250
73	101.825	62.109	40.150	27.502	19.895	15.109	11.961	8.255
74	104.678	63.356	40.700	27.747	20.005	15.159	11.983	8.260
75	107.595	64.617	41.250	27.989	20.112	15.207	12.005	8.264
76	110.577	65.892	41.800	28.229	20.217	15.253	12.026	8.269
77	113.627	67.181	42.350	28.466	20.320	15.299	12.046	8.273
78	116.746	68.484	42.900	28.700	20.421	15.342	12.065	8.276
79	119.934	69.802	43.450	28.932	20.520	15.385	12.084	8.280
80	123.194	71.134	44.000	29.161	20.616	15.426	12.101	8.283
81	126.528	72.481	44.550	29.388	20.710	15.465	12.118	8.286
82	129.937	73.844	45.100	29.612	20.803	15.504	12.134	8.289
83	133.422	75.221	45.650	29.834	20.893	15.541	12.149	8.292
84	136.986	76.614	46.200	30.053	20.981	15.577	12.164	8.294
85	140.629	78.022	46.750	30.270	21.068	15.611	12.178	8.297
86	144.355	79.446	47.300	30.485	21.153	15.645	12.192	8.299
87	148.165	80.886	47.850	30.697	21.235	15.678	12.205	8.301
88	152.060	82.342	48.400	30.907	21.316	15.709	12.217	8.303
89	156.043	83.814	48.950	31.115	21.396	15.740	12.229	8.305
90	160.116	85.302	49.500	31.320	21.473	15.770	12.241	8.307
91	164.280	86.807	50.050	31.524	21.549	15.798	12.252	8.309
92	168.538	88.328	50.600	31.725	21.624	15.826	12.262	8.310
93	172.891	89.867	51.150	31.924	21.696	15.853	12.272	8.311
94	177.343	91.423	51.700	32.120	21.767	15.879	12.282	8.313
95	181.894	92.995	52.250	32.315	21.837	15.904	12.291	8.314
96	186.548	94.586	52.800	32.507	21.905	15.928	12.300	8.315
97	191.307	96.194	53.350	32.698	21.972	15.952	12.308	8.316
98	196.173	97.820	53.900	32.886	22.037	15.975	12.316	8.317
99	201.148	99.464	54.450	33.072	22.101	15.997	12.324	8.318
100	206.236	101.127	55.000	33.256	22.163	16.018	12.331	8.319
101	211.437	102.807	55.550	33.438	22.224	16.039	12.339	8.320
102	216.756	104.507	56.100	33.619	22.284	16.059	12.345	8.321
103	222.194	106.226	56.650	33.797	22.342	16.078	12.352	8.322
104	227.755	107.963	57.200	33.973	22.400	16.097	12.358	8.323
105	233.440	109.720	57.750	34.147	22.456	16.115	12.364	8.323
106	239.254	111.496	58.300	34.320	22.510	16.133	12.370	8.324
107	245.198	113.293	58.850	34.491	22.564	16.150	12.375	8.324
108	251.276	115.109	59.400	34.659	22.616	16.167	12.381	8.325
109	257.491	116.945	59.950	34.826	22.668	16.183	12.386	8.325
110	263.846	118.802	60.500	34.991	22.718	16.198	12.390	8.326
111	270.343	120.680	61.050	35.155	22.767	16.213	12.395	8.326
112	276.987	122.578	61.600	35.316	22.815	16.228	12.399	8.327
113	283.780	124.497	62.150	35.476	22.862	16.242	12.404	8.327
114	290.726	126.438	62.700	35.634	22.908	16.255	12.408	8.328
115	297.828	128.401	63.250	35.790	22.953	16.268	12.412	8.328
116	305.090	130.385	63.800	35.945	22.997	16.281	12.415	8.328
117	312.516	132.391	64.350	36.098	23.040	16.293	12.419	8.329
118	320.108	134.420	64.900	36.249	23.083	16.305	12.422	8.329
119	327.871	136.471	65.450	36.399	23.124	16.317	12.426	8.329
120	335.809	138.545	66.000	36.547	23.164	16.328	12.429	8.329

Tax Rate = 45 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	0.575	0.562	0.550	0.538	0.527	0.515	0.505	0.484
4	1.176	1.137	1.100	1.065	1.031	0.998	0.968	0.910
6	1.805	1.725	1.650	1.580	1.513	1.451	1.392	1.285
8	2.462	2.326	2.200	2.084	1.976	1.875	1.782	1.615
10	3.149	2.940	2.750	2.577	2.418	2.273	2.140	1.905
12	3.867	3.568	3.300	3.059	2.842	2.645	2.468	2.160
14	4.618	4.210	3.850	3.531	3.247	2.994	2.769	2.385
16	5.403	4.867	4.400	3.992	3.635	3.322	3.045	2.583
18	6.224	5.538	4.950	4.444	4.007	3.628	3.298	2.757
20	7.082	6.224	5.500	4.886	4.363	3.915	3.531	2.910
22	7.980	6.926	6.050	5.318	4.704	4.185	3.744	3.045
24	8.918	7.643	6.600	5.741	5.030	4.437	3.940	3.164
26	9.898	8.376	7.150	6.155	5.342	4.674	4.119	3.268
28	10.924	9.126	7.700	6.560	5.641	4.895	4.284	3.360
30	11.996	9.892	8.250	6.956	5.928	5.103	4.435	3.441
32	13.116	10.676	8.800	7.344	6.202	5.297	4.574	3.512
34	14.288	11.477	9.350	7.723	6.464	5.480	4.701	3.574
36	15.513	12.296	9.900	8.094	6.716	5.651	4.818	3.630
38	16.794	13.133	10.450	8.457	6.956	5.811	4.925	3.678
40	18.133	13.989	11.000	8.812	7.186	5.961	5.023	3.721
42	19.533	14.865	11.550	9.159	7.407	6.102	5.113	3.758
44	20.997	15.759	12.100	9.499	7.618	6.233	5.196	3.791
46	22.527	16.674	12.650	9.832	7.820	6.357	5.272	3.820
48	24.127	17.609	13.200	10.157	8.014	6.473	5.341	3.846
50	25.800	18.566	13.750	10.475	8.199	6.581	5.405	3.868
52	27.549	19.543	14.300	10.787	8.376	6.683	5.464	3.888
54	29.377	20.543	14.850	11.091	8.546	6.778	5.518	3.906
56	31.289	21.565	15.400	11.389	8.709	6.867	5.567	3.921
58	33.287	22.609	15.950	11.681	8.864	6.951	5.612	3.935
60	35.377	23.677	16.500	11.966	9.014	7.029	5.654	3.946
62	37.561	24.769	17.050	12.245	9.156	7.103	5.692	3.957
64	39.845	25.866	17.600	12.518	9.293	7.172	5.727	3.966
66	42.233	27.027	18.150	12.786	9.424	7.236	5.759	3.974
68	44.729	28.194	18.700	13.047	9.549	7.297	5.788	3.981
70	47.339	29.387	19.250	13.303	9.669	7.353	5.815	3.988
72	50.068	30.606	19.800	13.553	9.784	7.406	5.840	3.993
74	52.921	31.853	20.350	13.798	9.893	7.456	5.863	3.998
76	55.904	33.128	20.900	14.037	9.999	7.503	5.884	4.002
78	59.022	34.431	21.450	14.272	10.099	7.547	5.903	4.006
80	62.282	35.764	22.000	14.501	10.196	7.588	5.920	4.009
82	65.691	37.126	22.550	14.725	10.288	7.626	5.936	4.012
84	69.255	38.519	23.100	14.944	10.377	7.662	5.951	4.015
86	72.980	39.943	23.650	15.159	10.461	7.696	5.965	4.017
88	76.876	41.398	24.200	15.369	10.542	7.727	5.977	4.019
90	80.948	42.887	24.750	15.575	10.620	7.757	5.989	4.021
92	85.206	44.408	25.300	15.776	10.694	7.785	5.999	4.022
94	89.658	45.964	25.850	15.972	10.765	7.811	6.009	4.024
96	94.312	47.555	26.400	16.165	10.833	7.835	6.017	4.025
98	99.177	49.181	26.950	16.353	10.899	7.858	6.026	4.026
100	104.265	50.843	27.500	16.537	10.961	7.879	6.033	4.027
102	109.583	52.543	28.050	16.717	11.021	7.899	6.040	4.028
104	115.144	54.280	28.600	16.894	11.078	7.918	6.046	4.028
106	120.957	56.057	29.150	17.066	11.133	7.936	6.052	4.029
108	127.036	57.873	29.700	17.235	11.185	7.952	6.057	4.030
110	133.390	59.730	30.250	17.400	11.235	7.968	6.062	4.030
112	140.034	61.628	30.800	17.561	11.283	7.982	6.066	4.030
114	146.980	63.569	31.350	17.720	11.329	7.996	6.070	4.031
116	154.242	65.553	31.900	17.874	11.373	8.008	6.074	4.031
118	161.834	67.582	32.450	18.025	11.416	8.020	6.077	4.031
120	169.772	69.656	33.000	18.173	11.456	8.031	6.081	4.032

Tax Rate = 45 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	0.615	0.581	0.550	0.521	0.493	0.468	0.443	0.400
10	1.302	1.196	1.100	1.014	0.936	0.865	0.801	0.690
15	2.070	1.845	1.650	1.480	1.333	1.203	1.089	0.901
20	2.928	2.531	2.200	1.922	1.688	1.490	1.322	1.054
25	3.887	3.256	2.750	2.341	2.008	1.735	1.509	1.165
30	4.959	4.023	3.300	2.737	2.294	1.942	1.660	1.246
35	6.157	4.833	3.850	3.112	2.551	2.119	1.782	1.305
40	7.496	5.689	4.400	3.467	2.781	2.269	1.880	1.347
45	8.993	6.594	4.950	3.803	2.988	2.397	1.960	1.378
50	10.666	7.550	5.500	4.121	3.173	2.505	2.024	1.401
55	12.535	8.560	6.050	4.423	3.339	2.597	2.075	1.417
60	14.624	9.628	6.600	4.708	3.488	2.676	2.117	1.429
65	16.960	10.757	7.150	4.978	3.622	2.742	2.150	1.438
70	19.570	11.950	7.700	5.234	3.742	2.799	2.177	1.444
75	22.487	13.211	8.250	5.476	3.849	2.847	2.199	1.449
80	25.747	14.543	8.800	5.705	3.946	2.888	2.216	1.452
85	29.391	15.952	9.350	5.922	4.032	2.923	2.231	1.454
90	33.463	17.440	9.900	6.128	4.110	2.953	2.242	1.456
95	38.015	19.013	10.450	6.322	4.179	2.978	2.251	1.457
100	43.102	20.675	11.000	6.507	4.242	2.999	2.259	1.458
105	48.788	22.432	11.550	6.681	4.298	3.017	2.265	1.459
110	55.143	24.289	12.100	6.846	4.348	3.033	2.269	1.459
115	62.245	26.251	12.650	7.002	4.393	3.046	2.273	1.460
120	70.183	28.325	13.200	7.150	4.433	3.057	2.276	1.460

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	0.687	0.614	0.550	0.493	0.442	0.398	0.358	0.290
20	1.545	1.301	1.100	0.935	0.798	0.685	0.590	0.443
30	2.617	2.067	1.650	1.331	1.085	0.892	0.741	0.524
40	3.956	2.923	2.200	1.686	1.315	1.043	0.839	0.567
50	5.629	3.879	2.750	2.004	1.500	1.151	0.903	0.589
60	7.718	4.947	3.300	2.290	1.649	1.229	0.945	0.601
70	10.328	6.140	3.850	2.545	1.769	1.286	0.972	0.608
80	13.589	7.473	4.400	2.775	1.866	1.327	0.989	0.611
90	17.661	8.961	4.950	2.980	1.943	1.357	1.001	0.613
100	22.748	10.623	5.500	3.164	2.006	1.378	1.008	0.614
110	29.103	12.480	6.050	3.329	2.056	1.394	1.013	0.614
120	37.041	14.554	6.600	3.477	2.096	1.405	1.016	0.614

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	0.768	0.649	0.550	0.467	0.397	0.338	0.288	0.211
30	1.840	1.416	1.100	0.863	0.683	0.546	0.439	0.292
45	3.336	2.320	1.650	1.199	0.890	0.673	0.519	0.323
60	5.426	3.388	2.200	1.484	1.039	0.752	0.560	0.335
75	8.343	4.649	2.750	1.726	1.146	0.800	0.582	0.339
90	12.416	6.138	3.300	1.932	1.224	0.829	0.593	0.341
105	18.101	7.895	3.850	2.106	1.280	0.848	0.599	0.342
120	26.039	9.968	4.400	2.254	1.320	0.859	0.602	0.342

Tax Rate = 45 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	0.858	0.686	0.550	0.442	0.356	0.287	0.232	0.153
40	2.197	1.542	1.100	0.797	0.586	0.437	0.331	0.196
60	4.287	2.610	1.650	1.082	0.735	0.516	0.372	0.208
80	7.547	3.943	2.200	1.312	0.832	0.557	0.390	0.211
100	12.634	5.605	2.750	1.496	0.894	0.578	0.397	0.212
120	20.572	7.679	3.300	1.644	0.935	0.589	0.400	0.212

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	1.072	0.766	0.550	0.396	0.286	0.208	0.151	0.081
60	3.161	1.834	1.100	0.681	0.435	0.286	0.193	0.093
90	7.234	3.323	1.650	0.887	0.513	0.316	0.204	0.094
120	15.172	5.397	2.200	1.035	0.553	0.327	0.207	0.095

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	1.339	0.856	0.550	0.355	0.230	0.150	0.098	0.043
80	4.599	2.189	1.100	0.584	0.327	0.191	0.116	0.046
120	12.537	4.263	1.650	0.732	0.367	0.202	0.119	0.046

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	2.089	1.068	0.550	0.285	0.149	0.078	0.042	0.012
120	10.027	3.142	1.100	0.433	0.189	0.090	0.045	0.012

CUMULATIVE MAINTENANCE DISCOUNT FACTOR

Tax Rate = 50 %

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
1	0.510	0.505	0.500	0.495	0.490	0.485	0.481	0.472
2	1.031	1.015	1.000	0.985	0.971	0.957	0.943	0.917
3	1.562	1.531	1.500	1.470	1.442	1.414	1.388	1.337
4	2.104	2.051	2.000	1.951	1.904	1.859	1.815	1.733
5	2.657	2.577	2.500	2.427	2.357	2.290	2.226	2.106
6	3.222	3.108	3.000	2.898	2.801	2.709	2.621	2.459
7	3.798	3.644	3.500	3.364	3.236	3.115	3.001	2.791
8	4.385	4.186	4.000	3.826	3.663	3.510	3.366	3.105
9	4.985	4.734	4.500	4.283	4.081	3.893	3.718	3.401
10	5.597	5.286	5.000	4.736	4.491	4.265	4.055	3.680
11	6.221	5.845	5.500	5.184	4.893	4.626	4.380	3.943
12	6.859	6.409	6.000	5.628	5.288	4.977	4.693	4.192
13	7.509	6.979	6.500	6.067	5.674	5.317	4.993	4.426
14	8.172	7.554	7.000	6.502	6.053	5.648	5.282	4.647
15	8.849	8.136	7.500	6.933	6.425	5.969	5.559	4.856
16	9.540	8.723	8.000	7.359	6.789	6.281	5.826	5.053
17	10.245	9.316	8.500	7.781	7.146	6.583	6.083	5.239
18	10.964	9.915	9.000	8.199	7.496	6.877	6.330	5.414
19	11.698	10.520	9.500	8.613	7.839	7.162	6.567	5.579
20	12.447	11.132	10.000	9.023	8.176	7.439	6.795	5.735
21	13.211	11.749	10.500	9.428	8.506	7.708	7.015	5.882
22	13.991	12.373	11.000	9.830	8.829	7.968	7.226	6.021
23	14.787	13.003	11.500	10.228	9.146	8.222	7.428	6.152
24	15.599	13.639	12.000	10.622	9.457	8.468	7.623	6.275
25	16.427	14.282	12.500	11.012	9.762	8.707	7.811	6.392
26	17.273	14.931	13.000	11.398	10.061	8.938	7.991	6.502
27	18.136	15.587	13.500	11.780	10.353	9.164	8.165	6.605
28	19.016	16.250	14.000	12.158	10.641	9.382	8.332	6.703
29	19.914	16.919	14.500	12.533	10.922	9.594	8.492	6.795
30	20.831	17.595	15.000	12.904	11.198	9.800	8.646	6.882
31	21.766	18.278	15.500	13.271	11.469	10.000	8.794	6.965
32	22.721	18.967	16.000	13.635	11.734	10.194	8.937	7.042
33	23.694	19.664	16.500	13.995	11.994	10.383	9.074	7.115
34	24.688	20.368	17.000	14.351	12.249	10.566	9.206	7.184
35	25.702	21.078	17.500	14.704	12.499	10.744	9.332	7.249
36	26.737	21.796	18.000	15.054	12.744	10.916	9.454	7.310
37	27.793	22.522	18.500	15.400	12.985	11.084	9.571	7.368
38	28.870	23.254	19.000	15.742	13.220	11.246	9.684	7.423
39	29.970	23.994	19.500	16.082	13.451	11.404	9.792	7.475
40	31.091	24.742	20.000	16.417	13.678	11.557	9.896	7.523
41	32.236	25.497	20.500	16.750	13.900	11.706	9.997	7.569
42	33.404	26.259	21.000	17.079	14.117	11.851	10.093	7.612
43	34.596	27.029	21.500	17.405	14.331	11.991	10.185	7.653
44	35.812	27.807	22.000	17.728	14.540	12.127	10.274	7.692
45	37.054	28.593	22.500	18.047	14.745	12.259	10.360	7.728
46	38.320	29.387	23.000	18.364	14.946	12.388	10.442	7.762
47	39.612	30.189	23.500	18.677	15.143	12.512	10.521	7.795
48	40.931	30.999	24.000	18.987	15.337	12.633	10.598	7.825
49	42.276	31.817	24.500	19.294	15.526	12.751	10.671	7.854
50	43.649	32.644	25.000	19.598	15.712	12.865	10.741	7.881
51	45.050	33.479	25.500	19.899	15.894	12.976	10.809	7.907
52	46.480	34.322	26.000	20.197	16.072	13.083	10.874	7.931
53	47.939	35.174	26.500	20.492	16.248	13.187	10.936	7.953
54	49.427	36.034	27.000	20.784	16.419	13.289	10.996	7.975
55	50.946	36.903	27.500	21.074	16.587	13.387	11.054	7.995
56	52.496	37.781	28.000	21.360	16.752	13.483	11.110	8.014
57	54.078	38.667	28.500	21.644	16.914	13.575	11.163	8.032
58	55.691	39.563	29.000	21.924	17.073	13.666	11.215	8.049
59	57.338	40.468	29.500	22.202	17.228	13.753	11.264	8.066
60	59.019	41.382	30.000	22.478	17.380	13.838	11.312	8.081

Maintenance Interval = 1 year

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
61	60.733	42.305	30.500	22.750	17.530	13.920	11.357	8.095
62	62.483	43.237	31.000	23.020	17.676	14.000	11.401	8.109
63	64.268	44.179	31.500	23.287	17.820	14.078	11.444	8.121
64	66.090	45.130	32.000	23.551	17.961	14.153	11.484	8.133
65	67.949	46.091	32.500	23.813	18.099	14.226	11.523	8.145
66	69.846	47.062	33.000	24.073	18.234	14.298	11.561	8.155
67	71.782	48.042	33.500	24.329	18.367	14.367	11.597	8.165
68	73.757	49.032	34.000	24.583	18.497	14.434	11.632	8.175
69	75.772	50.033	34.500	24.835	18.624	14.499	11.665	8.184
70	77.829	51.043	35.000	25.084	18.749	14.562	11.697	8.192
71	79.927	52.064	35.500	25.331	18.872	14.623	11.728	8.200
72	82.069	53.095	36.000	25.575	18.992	14.683	11.758	8.208
73	84.254	54.136	36.500	25.817	19.110	14.740	11.786	8.215
74	86.483	55.188	37.000	26.056	19.225	14.796	11.814	8.222
75	88.759	56.250	37.500	26.294	19.339	14.851	11.840	8.228
76	91.080	57.324	38.000	26.528	19.450	14.904	11.866	8.234
77	93.449	58.408	38.500	26.761	19.558	14.955	11.890	8.240
78	95.867	59.503	39.000	26.991	19.665	15.005	11.913	8.245
79	98.333	60.609	39.500	27.219	19.770	15.053	11.936	8.250
80	100.850	61.726	40.000	27.444	19.872	15.100	11.958	8.255
81	103.419	62.855	40.500	27.667	19.973	15.146	11.979	8.259
82	106.039	63.995	41.000	27.889	20.071	15.190	11.999	8.263
83	108.714	65.146	41.500	28.107	20.168	15.233	12.018	8.267
84	111.442	66.309	42.000	28.324	20.263	15.275	12.036	8.271
85	114.227	67.484	42.500	28.539	20.356	15.316	12.054	8.274
86	117.068	68.671	43.000	28.751	20.447	15.355	12.071	8.278
87	119.968	69.869	43.500	28.962	20.536	15.393	12.088	8.281
88	122.926	71.080	44.000	29.170	20.624	15.430	12.104	8.284
89	125.945	72.303	44.500	29.376	20.709	15.466	12.119	8.287
90	129.026	73.539	45.000	29.580	20.793	15.501	12.134	8.289
91	132.169	74.786	45.500	29.783	20.876	15.535	12.148	8.292
92	135.377	76.047	46.000	29.983	20.957	15.568	12.161	8.294
93	138.650	77.320	46.500	30.181	21.036	15.600	12.174	8.296
94	141.989	78.606	47.000	30.377	21.114	15.631	12.187	8.298
95	145.397	79.905	47.500	30.571	21.190	15.661	12.199	8.300
96	148.875	81.217	48.000	30.764	21.265	15.691	12.210	8.302
97	152.423	82.543	48.500	30.954	21.338	15.719	12.222	8.304
98	156.044	83.882	49.000	31.143	21.410	15.747	12.232	8.306
99	159.739	85.234	49.500	31.330	21.480	15.773	12.243	8.307
100	163.509	86.600	50.000	31.514	21.549	15.799	12.252	8.309
101	167.356	87.980	50.500	31.697	21.617	15.825	12.262	8.310
102	171.282	89.373	51.000	31.879	21.683	15.849	12.271	8.311
103	175.288	90.781	51.500	32.058	21.748	15.873	12.280	8.313
104	179.375	92.203	52.000	32.236	21.812	15.896	12.288	8.314
105	183.546	93.640	52.500	32.412	21.874	15.919	12.297	8.315
106	187.802	95.091	53.000	32.586	21.936	15.940	12.304	8.316
107	192.145	96.556	53.500	32.758	21.996	15.962	12.312	8.317
108	196.577	98.037	54.000	32.929	22.055	15.982	12.319	8.318
109	201.099	99.532	54.500	33.098	22.113	16.002	12.326	8.319
110	205.713	101.042	55.000	33.265	22.169	16.021	12.333	8.320
111	210.421	102.568	55.500	33.431	22.225	16.040	12.339	8.320
112	215.226	104.109	56.000	33.595	22.279	16.058	12.345	8.321
113	220.128	105.666	56.500	33.757	22.332	16.076	12.351	8.322
114	225.131	107.238	57.000	33.918	22.385	16.093	12.357	8.322
115	230.236	108.826	57.500	34.077	22.436	16.110	12.363	8.323
116	235.445	110.431	58.000	34.235	22.486	16.126	12.368	8.324
117	240.760	112.051	58.500	34.391	22.536	16.142	12.373	8.324
118	246.183	113.688	59.000	34.546	22.584	16.157	12.378	8.325
119	251.718	115.341	59.500	34.699	22.631	16.172	12.383	8.325
120	257.365	117.012	60.000	34.850	22.678	16.187	12.387	8.326

Tax Rate = 50 %
 Maintenance Interval = 2 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
2	0.521	0.510	0.500	0.490	0.481	0.471	0.462	0.445
4	1.063	1.031	1.000	0.971	0.943	0.916	0.890	0.841
6	1.627	1.562	1.500	1.442	1.386	1.334	1.285	1.194
8	2.215	2.104	2.000	1.903	1.813	1.729	1.650	1.507
10	2.827	2.656	2.500	2.356	2.223	2.101	1.988	1.786
12	3.464	3.221	3.000	2.800	2.618	2.452	2.300	2.035
14	4.127	3.796	3.500	3.235	2.997	2.782	2.589	2.256
16	4.818	4.383	4.000	3.661	3.361	3.094	2.856	2.453
18	5.537	4.982	4.500	4.079	3.711	3.388	3.103	2.628
20	6.286	5.594	5.000	4.489	4.047	3.664	3.331	2.784
22	7.066	6.218	5.500	4.891	4.371	3.925	3.542	2.923
24	7.878	6.854	6.000	5.284	4.682	4.171	3.737	3.046
26	8.724	7.503	6.500	5.670	4.980	4.403	3.917	3.156
28	9.604	8.166	7.000	6.049	5.268	4.622	4.084	3.254
30	10.521	8.842	7.500	6.420	5.544	4.828	4.238	3.341
32	11.475	9.531	8.000	6.783	5.809	5.022	4.381	3.418
34	12.469	10.235	8.500	7.140	6.064	5.205	4.513	3.487
36	13.504	10.953	9.000	7.489	6.309	5.377	4.634	3.549
38	14.581	11.686	9.500	7.832	6.545	5.540	4.747	3.603
40	15.703	12.433	10.000	8.168	6.771	5.693	4.851	3.652
42	16.871	13.196	10.500	8.497	6.989	5.838	4.947	3.695
44	18.087	13.974	11.000	8.820	7.198	5.974	5.036	3.734
46	19.354	14.767	11.500	9.136	7.399	6.102	5.119	3.768
48	20.672	15.577	12.000	9.446	7.592	6.223	5.195	3.799
50	22.045	16.404	12.500	9.750	7.778	6.337	5.265	3.826
52	23.475	17.247	13.000	10.048	7.957	6.445	5.330	3.850
54	24.963	18.107	13.500	10.340	8.128	6.546	5.390	3.871
56	26.513	18.985	14.000	10.627	8.293	6.642	5.446	3.890
58	28.127	19.881	14.500	10.908	8.452	6.732	5.497	3.908
60	29.807	20.795	15.000	11.183	8.604	6.817	5.545	3.923
62	31.557	21.727	15.500	11.453	8.751	6.897	5.589	3.936
64	33.379	22.678	16.000	11.717	8.891	6.972	5.630	3.948
66	35.276	23.649	16.500	11.976	9.027	7.043	5.667	3.959
68	37.251	24.639	17.000	12.231	9.157	7.110	5.702	3.968
70	39.307	25.650	17.500	12.480	9.282	7.173	5.734	3.977
72	41.449	26.681	18.000	12.724	9.402	7.233	5.764	3.984
74	43.679	27.733	18.500	12.963	9.517	7.289	5.791	3.991
76	46.000	28.806	19.000	13.198	9.628	7.342	5.816	3.997
78	48.417	29.901	19.500	13.428	9.735	7.392	5.840	4.002
80	50.934	31.018	20.000	13.654	9.838	7.439	5.862	4.007
82	53.555	32.158	20.500	13.875	9.936	7.483	5.882	4.011
84	56.284	33.321	21.000	14.092	10.031	7.525	5.900	4.015
86	59.125	34.508	21.500	14.304	10.122	7.564	5.917	4.018
88	62.084	35.719	22.000	14.512	10.210	7.601	5.933	4.021
90	65.164	36.954	22.500	14.717	10.294	7.636	5.948	4.024
92	68.372	38.215	23.000	14.917	10.375	7.669	5.961	4.026
94	71.712	39.501	23.500	15.113	10.452	7.700	5.974	4.028
96	75.189	40.813	24.000	15.305	10.527	7.729	5.986	4.030
98	78.810	42.152	24.500	15.494	10.599	7.757	5.996	4.032
100	82.580	43.518	25.000	15.679	10.668	7.783	6.006	4.033
102	86.506	44.911	25.500	15.860	10.734	7.808	6.015	4.035
104	90.594	46.333	26.000	16.038	10.798	7.831	6.024	4.036
106	94.850	47.784	26.500	16.212	10.859	7.852	6.032	4.037
108	99.281	49.265	27.000	16.383	10.918	7.873	6.039	4.038
110	103.895	50.775	27.500	16.550	10.975	7.892	6.045	4.039
112	108.700	52.316	28.000	16.714	11.029	7.911	6.052	4.039
114	113.702	53.888	28.500	16.875	11.082	7.928	6.057	4.040
116	118.911	55.493	29.000	17.032	11.132	7.944	6.063	4.041
118	124.335	57.130	29.500	17.187	11.180	7.959	6.068	4.041
120	129.982	58.800	30.000	17.338	11.227	7.974	6.072	4.042

Tax Rate = 50 %
 Maintenance Interval = 5 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
5	0.553	0.526	0.500	0.476	0.453	0.431	0.411	0.374
10	1.165	1.079	1.000	0.928	0.863	0.803	0.749	0.653
15	1.842	1.660	1.500	1.359	1.235	1.124	1.026	0.861
20	2.591	2.271	2.000	1.769	1.571	1.401	1.255	1.017
25	3.420	2.914	2.500	2.159	1.876	1.640	1.442	1.134
30	4.336	3.590	3.000	2.530	2.152	1.846	1.596	1.221
35	5.350	4.301	3.500	2.883	2.402	2.024	1.723	1.286
40	6.472	5.048	4.000	3.218	2.628	2.177	1.827	1.335
45	7.713	5.834	4.500	3.538	2.833	2.309	1.913	1.371
50	9.086	6.661	5.000	3.842	3.019	2.423	1.983	1.398
55	10.605	7.530	5.500	4.131	3.187	2.522	2.041	1.418
60	12.285	8.443	6.000	4.406	3.340	2.606	2.088	1.433
65	14.144	9.404	6.500	4.668	3.478	2.680	2.128	1.445
70	16.201	10.415	7.000	4.918	3.603	2.743	2.160	1.453
75	18.476	11.477	7.500	5.155	3.716	2.797	2.186	1.460
80	20.993	12.595	8.000	5.380	3.819	2.844	2.208	1.464
85	23.778	13.769	8.500	5.595	3.912	2.885	2.226	1.468
90	26.858	15.005	9.000	5.799	3.996	2.920	2.240	1.471
95	30.266	16.304	9.500	5.993	4.072	2.950	2.252	1.472
100	34.036	17.670	10.000	6.178	4.141	2.976	2.262	1.474
105	38.207	19.106	10.500	6.354	4.203	2.998	2.270	1.475
110	42.822	20.617	11.000	6.521	4.260	3.018	2.277	1.476
115	47.926	22.205	11.500	6.681	4.311	3.034	2.282	1.476
120	53.574	23.875	12.000	6.832	4.358	3.049	2.287	1.477

Maintenance Interval = 10 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
10	0.612	0.553	0.500	0.453	0.410	0.372	0.338	0.279
20	1.361	1.164	1.000	0.862	0.747	0.649	0.566	0.435
30	2.277	1.840	1.500	1.233	1.023	0.855	0.720	0.522
40	3.399	2.588	2.000	1.569	1.249	1.008	0.824	0.571
50	4.772	3.414	2.500	1.873	1.435	1.122	0.895	0.598
60	6.453	4.328	3.000	2.148	1.587	1.207	0.942	0.613
70	8.509	5.338	3.500	2.398	1.712	1.270	0.974	0.622
80	11.026	6.455	4.000	2.623	1.815	1.317	0.996	0.626
90	14.107	7.691	4.500	2.827	1.899	1.352	1.011	0.629
100	17.877	9.057	5.000	3.012	1.968	1.378	1.021	0.630
110	22.491	10.567	5.500	3.180	2.025	1.398	1.027	0.631
120	28.139	12.237	6.000	3.331	2.071	1.412	1.032	0.632

Maintenance Interval = 15 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
15	0.677	0.581	0.500	0.431	0.372	0.321	0.278	0.209
30	1.594	1.257	1.000	0.802	0.648	0.527	0.432	0.296
45	2.835	2.043	1.500	1.121	0.853	0.659	0.517	0.332
60	4.515	2.957	2.000	1.396	1.005	0.744	0.565	0.347
75	6.790	4.020	2.500	1.633	1.118	0.798	0.591	0.353
90	9.871	5.255	3.000	1.838	1.202	0.833	0.606	0.356
105	14.042	6.691	3.500	2.014	1.265	0.856	0.614	0.357
120	19.689	8.361	4.000	2.165	1.311	0.870	0.619	0.358

Tax Rate = 50 %
 Maintenance Interval = 20 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
20	0.749	0.611	0.500	0.410	0.336	0.277	0.228	0.156
40	1.871	1.359	1.000	0.746	0.563	0.430	0.332	0.205
60	3.551	2.273	1.500	1.021	0.715	0.515	0.380	0.220
80	6.068	3.390	2.000	1.246	0.818	0.562	0.402	0.224
100	9.838	4.756	2.500	1.431	0.887	0.588	0.411	0.226
120	15.486	6.426	3.000	1.583	0.933	0.602	0.416	0.226

Maintenance Interval = 30 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
30	0.917	0.676	0.500	0.371	0.276	0.206	0.154	0.087
60	2.597	1.590	1.000	0.646	0.428	0.291	0.202	0.102
90	5.678	2.825	1.500	0.850	0.513	0.326	0.216	0.105
120	11.325	4.495	2.000	1.002	0.559	0.340	0.221	0.105

Maintenance Interval = 40 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
40	1.122	0.747	0.500	0.336	0.226	0.153	0.104	0.049
80	3.639	1.865	1.000	0.561	0.329	0.200	0.126	0.053
120	9.286	3.535	1.500	0.713	0.375	0.215	0.130	0.054

Maintenance Interval = 60 years

Modified Discount Rate 'W'

Year	-0.04	-0.02	0	0.02	0.04	0.06	0.08	0.12
60	1.680	0.914	0.500	0.275	0.152	0.085	0.048	0.015
120	7.328	2.584	1.000	0.427	0.199	0.099	0.052	0.016

APPENDIX C
CUMULATIVE DEPRECIATION FACTORS

$$CDF = t \sum \frac{1}{(1+i(1-t))^n}$$

for Tax Rates: 30, 35, 40, 45, 50 %

CUMULATIVE DEPRECIATION FACTORS

Tax Rate = 30 %

Discount Rate 'i'

<i>Year</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.1</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.2</i>
1	0.300	0.296	0.292	0.288	0.284	0.280	0.277	0.273	0.270	0.266	0.263
2	0.600	0.588	0.576	0.564	0.553	0.542	0.532	0.522	0.512	0.503	0.494
3	0.900	0.875	0.852	0.829	0.808	0.787	0.768	0.749	0.731	0.713	0.696
4	1.200	1.159	1.120	1.084	1.049	1.016	0.985	0.955	0.927	0.900	0.874
5	1.500	1.439	1.382	1.328	1.278	1.230	1.185	1.143	1.103	1.066	1.030
6	1.800	1.715	1.636	1.562	1.494	1.430	1.370	1.314	1.262	1.213	1.167
7	2.100	1.987	1.883	1.787	1.699	1.617	1.541	1.470	1.405	1.343	1.286
8	2.400	2.256	2.124	2.003	1.893	1.791	1.698	1.612	1.533	1.460	1.392
9	2.700	2.520	2.358	2.210	2.077	1.955	1.843	1.742	1.648	1.563	1.484
10	3.000	2.781	2.585	2.409	2.250	2.107	1.977	1.859	1.752	1.654	1.565
11	3.300	3.039	2.807	2.600	2.415	2.250	2.101	1.967	1.845	1.736	1.636
12	3.600	3.293	3.022	2.783	2.571	2.383	2.215	2.064	1.929	1.808	1.698
13	3.900	3.543	3.232	2.959	2.719	2.507	2.320	2.153	2.005	1.872	1.753
14	4.200	3.790	3.435	3.128	2.859	2.624	2.417	2.234	2.073	1.929	1.801
15	4.500	4.034	3.634	3.289	2.991	2.732	2.506	2.308	2.134	1.979	1.843
16	4.800	4.274	3.827	3.445	3.117	2.834	2.589	2.375	2.189	2.024	1.880
17	5.100	4.511	4.014	3.594	3.236	2.929	2.665	2.437	2.238	2.064	1.912
18	5.400	4.744	4.197	3.737	3.348	3.018	2.735	2.492	2.282	2.100	1.940
19	5.700	4.975	4.374	3.874	3.455	3.101	2.800	2.543	2.322	2.131	1.965
20	6.000	5.202	4.547	4.006	3.556	3.178	2.860	2.589	2.358	2.159	1.987
21	6.300	5.426	4.715	4.132	3.651	3.251	2.915	2.631	2.390	2.184	2.006
22	6.600	5.647	4.878	4.254	3.742	3.318	2.966	2.670	2.419	2.206	2.023
23	6.900	5.865	5.037	4.370	3.827	3.382	3.013	2.705	2.445	2.226	2.038
24	7.200	6.079	5.192	4.482	3.908	3.441	3.056	2.737	2.469	2.243	2.051
25	7.500	6.291	5.342	4.589	3.985	3.496	3.096	2.766	2.490	2.258	2.062
26	7.800	6.500	5.489	4.692	4.058	3.548	3.133	2.792	2.509	2.272	2.072
27	8.100	6.707	5.631	4.791	4.127	3.596	3.167	2.816	2.526	2.284	2.081
28	8.400	6.910	5.769	4.886	4.192	3.641	3.198	2.838	2.541	2.295	2.088
29	8.700	7.110	5.904	4.977	4.254	3.683	3.227	2.858	2.555	2.305	2.095
30	9.000	7.308	6.035	5.064	4.312	3.723	3.254	2.876	2.568	2.313	2.101

CUMULATIVE DEPRECIATION FACTORS

Tax Rate = 35 %

Discount Rate 'i'

<i>Year</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.1</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.2</i>
1	0.350	0.346	0.341	0.337	0.333	0.329	0.325	0.321	0.317	0.313	0.310
2	0.700	0.687	0.674	0.661	0.649	0.637	0.626	0.615	0.604	0.594	0.584
3	1.050	1.023	0.998	0.973	0.950	0.927	0.905	0.884	0.864	0.845	0.826
4	1.400	1.356	1.314	1.273	1.235	1.199	1.164	1.131	1.100	1.070	1.041
5	1.750	1.684	1.621	1.563	1.507	1.454	1.405	1.358	1.313	1.271	1.231
6	2.100	2.008	1.921	1.841	1.765	1.694	1.628	1.565	1.507	1.451	1.399
7	2.450	2.327	2.214	2.109	2.011	1.920	1.835	1.756	1.682	1.613	1.548
8	2.800	2.643	2.499	2.366	2.244	2.131	2.027	1.930	1.840	1.757	1.680
9	3.150	2.955	2.777	2.614	2.466	2.330	2.205	2.090	1.984	1.886	1.796
10	3.500	3.262	3.047	2.853	2.677	2.516	2.370	2.236	2.114	2.002	1.899
11	3.850	3.566	3.311	3.083	2.877	2.691	2.523	2.371	2.232	2.106	1.990
12	4.200	3.866	3.569	3.304	3.067	2.856	2.665	2.494	2.339	2.199	2.071
13	4.550	4.162	3.819	3.517	3.249	3.010	2.797	2.606	2.435	2.282	2.143
14	4.900	4.454	4.064	3.722	3.421	3.155	2.919	2.710	2.523	2.356	2.206
15	5.250	4.742	4.302	3.919	3.584	3.291	3.033	2.805	2.602	2.422	2.262
16	5.600	5.027	4.534	4.109	3.740	3.419	3.138	2.892	2.674	2.482	2.311
17	5.950	5.308	4.760	4.291	3.888	3.539	3.236	2.971	2.739	2.535	2.355
18	6.300	5.585	4.981	4.467	4.028	3.651	3.326	3.044	2.798	2.583	2.394
19	6.650	5.859	5.196	4.636	4.162	3.757	3.410	3.111	2.852	2.626	2.428
20	7.000	6.129	5.405	4.799	4.289	3.856	3.488	3.172	2.900	2.664	2.459
21	7.350	6.396	5.609	4.956	4.409	3.950	3.560	3.229	2.944	2.699	2.486
22	7.700	6.659	5.808	5.107	4.524	4.037	3.627	3.280	2.984	2.729	2.509
23	8.050	6.920	6.002	5.252	4.633	4.120	3.690	3.327	3.020	2.757	2.530
24	8.400	7.176	6.191	5.391	4.737	4.197	3.747	3.371	3.052	2.781	2.549
25	8.750	7.430	6.375	5.526	4.835	4.269	3.801	3.410	3.082	2.803	2.565
26	9.100	7.680	6.555	5.655	4.929	4.337	3.851	3.447	3.108	2.823	2.580
27	9.450	7.927	6.730	5.780	5.018	4.401	3.897	3.480	3.133	2.841	2.593
28	9.800	8.171	6.901	5.900	5.103	4.461	3.939	3.510	3.155	2.856	2.604
29	10.150	8.411	7.067	6.015	5.183	4.518	3.979	3.538	3.174	2.871	2.615
30	10.500	8.649	7.229	6.126	5.260	4.571	4.016	3.564	3.192	2.883	2.623

CUMULATIVE DEPRECIATION FACTORS

Tax Rate = 40 %

Discount Rate 'i'

<i>Year</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.1</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.2</i>
1	0.400	0.395	0.391	0.386	0.382	0.377	0.373	0.369	0.365	0.361	0.357
2	0.800	0.786	0.772	0.759	0.746	0.733	0.721	0.709	0.698	0.687	0.676
3	1.200	1.172	1.145	1.119	1.093	1.069	1.046	1.023	1.002	0.981	0.961
4	1.600	1.553	1.508	1.466	1.425	1.386	1.349	1.313	1.279	1.246	1.215
5	2.000	1.930	1.864	1.801	1.741	1.685	1.631	1.580	1.532	1.486	1.442
6	2.400	2.302	2.211	2.124	2.043	1.967	1.895	1.827	1.763	1.702	1.645
7	2.800	2.670	2.549	2.437	2.331	2.233	2.141	2.054	1.973	1.897	1.826
8	3.200	3.034	2.880	2.738	2.606	2.484	2.370	2.264	2.165	2.073	1.987
9	3.600	3.393	3.203	3.029	2.869	2.721	2.584	2.458	2.341	2.232	2.131
10	4.000	3.748	3.519	3.310	3.119	2.944	2.784	2.636	2.501	2.376	2.260
11	4.400	4.099	3.827	3.581	3.358	3.155	2.970	2.801	2.647	2.505	2.375
12	4.800	4.446	4.128	3.843	3.586	3.354	3.143	2.953	2.780	2.622	2.478
13	5.200	4.788	4.422	4.095	3.803	3.541	3.305	3.093	2.901	2.727	2.569
14	5.600	5.127	4.709	4.339	4.011	3.718	3.457	3.222	3.012	2.822	2.651
15	6.000	5.461	4.989	4.574	4.209	3.885	3.598	3.342	3.113	2.908	2.724
16	6.400	5.792	5.263	4.802	4.397	4.042	3.729	3.452	3.205	2.986	2.790
17	6.800	6.118	5.530	5.021	4.578	4.191	3.852	3.553	3.290	3.056	2.848
18	7.200	6.441	5.791	5.232	4.750	4.331	3.966	3.647	3.366	3.119	2.900
19	7.600	6.760	6.046	5.437	4.914	4.463	4.073	3.733	3.437	3.176	2.946
20	8.000	7.075	6.295	5.634	5.071	4.588	4.173	3.813	3.501	3.227	2.988
21	8.400	7.386	6.538	5.824	5.220	4.706	4.265	3.887	3.559	3.274	3.025
22	8.800	7.694	6.775	6.008	5.363	4.817	4.352	3.954	3.612	3.316	3.058
23	9.200	7.998	7.007	6.185	5.499	4.921	4.433	4.017	3.661	3.354	3.087
24	9.600	8.298	7.234	6.356	5.628	5.020	4.508	4.075	3.705	3.388	3.114
25	10.000	8.595	7.455	6.522	5.752	5.113	4.579	4.128	3.745	3.419	3.137
26	10.400	8.889	7.671	6.681	5.871	5.201	4.644	4.177	3.782	3.446	3.158
27	10.800	9.178	7.882	6.835	5.983	5.284	4.705	4.222	3.816	3.471	3.177
28	11.200	9.465	8.087	6.984	6.091	5.362	4.763	4.264	3.847	3.494	3.194
29	11.600	9.748	8.288	7.127	6.194	5.436	4.816	4.303	3.875	3.514	3.209
30	12.000	10.028	8.485	7.266	6.292	5.506	4.866	4.338	3.900	3.533	3.222

CUMULATIVE DEPRECIATION FACTORS

Tax Rate = 45 %

Discount Rate 'i'

<i>Year</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.1</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.2</i>
1	0.450	0.445	0.440	0.436	0.431	0.427	0.422	0.418	0.414	0.409	0.405
2	0.900	0.885	0.871	0.857	0.844	0.831	0.818	0.806	0.794	0.782	0.771
3	1.350	1.321	1.293	1.266	1.239	1.214	1.190	1.166	1.143	1.121	1.100
4	1.800	1.752	1.705	1.661	1.618	1.577	1.538	1.500	1.464	1.430	1.396
5	2.250	2.178	2.109	2.043	1.981	1.922	1.865	1.811	1.759	1.710	1.663
6	2.700	2.599	2.504	2.414	2.329	2.248	2.172	2.099	2.031	1.966	1.904
7	3.150	3.016	2.890	2.772	2.661	2.557	2.459	2.367	2.280	2.198	2.120
8	3.600	3.428	3.268	3.119	2.980	2.851	2.729	2.616	2.509	2.409	2.316
9	4.050	3.836	3.638	3.455	3.286	3.128	2.982	2.847	2.720	2.602	2.492
10	4.500	4.239	4.000	3.780	3.578	3.392	3.220	3.061	2.914	2.777	2.650
11	4.950	4.638	4.354	4.095	3.859	3.642	3.443	3.260	3.091	2.936	2.793
12	5.400	5.033	4.701	4.400	4.127	3.878	3.652	3.445	3.255	3.081	2.922
13	5.850	5.423	5.040	4.695	4.384	4.103	3.848	3.616	3.405	3.213	3.037
14	6.300	5.809	5.372	4.981	4.630	4.315	4.032	3.775	3.544	3.333	3.142
15	6.750	6.191	5.697	5.257	4.866	4.517	4.204	3.923	3.671	3.442	3.236
16	7.200	6.569	6.014	5.525	5.092	4.708	4.366	4.061	3.787	3.542	3.321
17	7.650	6.943	6.325	5.784	5.309	4.889	4.518	4.188	3.895	3.632	3.397
18	8.100	7.312	6.629	6.035	5.516	5.061	4.660	4.307	3.993	3.714	3.466
19	8.550	7.678	6.927	6.278	5.714	5.223	4.794	4.417	4.084	3.789	3.528
20	9.000	8.039	7.218	6.513	5.905	5.378	4.919	4.519	4.167	3.857	3.583
21	9.450	8.397	7.503	6.740	6.087	5.524	5.037	4.613	4.244	3.919	3.634
22	9.900	8.751	7.782	6.961	6.261	5.662	5.147	4.701	4.314	3.976	3.679
23	10.350	9.101	8.055	7.174	6.428	5.794	5.251	4.783	4.379	4.027	3.720
24	10.800	9.447	8.322	7.380	6.589	5.918	5.348	4.859	4.438	4.074	3.757
25	11.250	9.789	8.583	7.580	6.742	6.036	5.439	4.929	4.493	4.116	3.790
26	11.700	10.128	8.838	7.774	6.889	6.148	5.524	4.995	4.543	4.155	3.820
27	12.150	10.463	9.088	7.961	7.030	6.254	5.604	5.055	4.589	4.190	3.847
28	12.600	10.794	9.333	8.142	7.164	6.355	5.679	5.112	4.632	4.222	3.871
29	13.050	11.121	9.572	8.318	7.293	6.450	5.750	5.164	4.671	4.251	3.893
30	13.500	11.446	9.807	8.488	7.417	6.540	5.816	5.213	4.706	4.278	3.912

CUMULATIVE DEPRECIATION FACTORS

Tax Rate = 50 %

Discount Rate 'i'

<i>Year</i>	<i>0</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.1</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.2</i>
1	0.500	0.495	0.490	0.485	0.481	0.476	0.472	0.467	0.463	0.459	0.455
2	1.000	0.985	0.971	0.957	0.943	0.930	0.917	0.904	0.892	0.880	0.868
3	1.500	1.470	1.442	1.414	1.388	1.362	1.337	1.312	1.289	1.266	1.243
4	2.000	1.951	1.904	1.859	1.815	1.773	1.733	1.694	1.656	1.620	1.585
5	2.500	2.427	2.357	2.290	2.226	2.165	2.106	2.050	1.996	1.945	1.895
6	3.000	2.898	2.801	2.709	2.621	2.538	2.459	2.383	2.311	2.243	2.178
7	3.500	3.364	3.236	3.115	3.001	2.893	2.791	2.695	2.603	2.516	2.434
8	4.000	3.826	3.663	3.510	3.366	3.232	3.105	2.986	2.873	2.767	2.667
9	4.500	4.283	4.081	3.893	3.718	3.554	3.401	3.258	3.123	2.998	2.880
10	5.000	4.736	4.491	4.265	4.055	3.861	3.680	3.512	3.355	3.209	3.072
11	5.500	5.184	4.893	4.626	4.380	4.153	3.943	3.749	3.569	3.403	3.248
12	6.000	5.628	5.288	4.977	4.693	4.432	4.192	3.971	3.768	3.580	3.407
13	6.500	6.067	5.674	5.317	4.993	4.697	4.426	4.179	3.952	3.743	3.552
14	7.000	6.502	6.053	5.648	5.282	4.949	4.647	4.373	4.122	3.893	3.683
15	7.500	6.933	6.425	5.969	5.559	5.190	4.856	4.554	4.280	4.030	3.803
16	8.000	7.359	6.789	6.281	5.826	5.419	5.053	4.723	4.426	4.156	3.912
17	8.500	7.781	7.146	6.583	6.083	5.637	5.239	4.882	4.561	4.272	4.011
18	9.000	8.199	7.496	6.877	6.330	5.845	5.414	5.030	4.686	4.378	4.101
19	9.500	8.613	7.839	7.162	6.567	6.043	5.579	5.168	4.802	4.475	4.182
20	10.000	9.023	8.176	7.439	6.795	6.231	5.735	5.297	4.909	4.564	4.257
21	10.500	9.428	8.506	7.708	7.015	6.411	5.882	5.418	5.008	4.646	4.324
22	11.000	9.830	8.829	7.968	7.226	6.582	6.021	5.531	5.100	4.721	4.386
23	11.500	10.228	9.146	8.222	7.428	6.744	6.152	5.636	5.186	4.790	4.442
24	12.000	10.622	9.457	8.468	7.623	6.899	6.275	5.735	5.264	4.853	4.492
25	12.500	11.012	9.762	8.707	7.811	7.047	6.392	5.827	5.337	4.911	4.539
26	13.000	11.398	10.061	8.938	7.991	7.188	6.502	5.913	5.405	4.964	4.580
27	13.500	11.780	10.353	9.164	8.165	7.322	6.605	5.993	5.468	5.013	4.619
28	14.000	12.158	10.641	9.382	8.332	7.449	6.703	6.069	5.526	5.058	4.653
29	14.500	12.533	10.922	9.594	8.492	7.571	6.795	6.139	5.579	5.099	4.685
30	15.000	12.904	11.198	9.800	8.646	7.686	6.882	6.205	5.629	5.137	4.713

APPENDIX D
GENERAL DISCOUNT FACTORS

$$GDF = \frac{1}{(1+i(1-t))^n}$$

for Tax Rates: 0, 30, 35, 40, 45, 50 %

GENERAL DISCOUNT FACTORS

Tax Rate = 0 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.980	0.962	0.943	0.926	0.909	0.893	0.877	0.862	0.847	0.833
2	0.961	0.925	0.890	0.857	0.826	0.797	0.769	0.743	0.718	0.694
3	0.942	0.889	0.840	0.794	0.751	0.712	0.675	0.641	0.609	0.579
4	0.924	0.855	0.792	0.735	0.683	0.636	0.592	0.552	0.516	0.482
5	0.906	0.822	0.747	0.681	0.621	0.567	0.519	0.476	0.437	0.402
6	0.888	0.790	0.705	0.630	0.564	0.507	0.456	0.410	0.370	0.335
7	0.871	0.760	0.665	0.583	0.513	0.452	0.400	0.354	0.314	0.279
8	0.853	0.731	0.627	0.540	0.467	0.404	0.351	0.305	0.266	0.233
9	0.837	0.703	0.592	0.500	0.424	0.361	0.308	0.263	0.225	0.194
10	0.820	0.676	0.558	0.463	0.386	0.322	0.270	0.227	0.191	0.162
11	0.804	0.650	0.527	0.429	0.350	0.287	0.237	0.195	0.162	0.135
12	0.788	0.625	0.497	0.397	0.319	0.257	0.208	0.168	0.137	0.112
13	0.773	0.601	0.469	0.368	0.290	0.229	0.182	0.145	0.116	0.093
14	0.758	0.577	0.442	0.340	0.263	0.205	0.160	0.125	0.099	0.078
15	0.743	0.555	0.417	0.315	0.239	0.183	0.140	0.108	0.084	0.065
16	0.728	0.534	0.394	0.292	0.218	0.163	0.123	0.093	0.071	0.054
17	0.714	0.513	0.371	0.270	0.198	0.146	0.108	0.080	0.060	0.045
18	0.700	0.494	0.350	0.250	0.180	0.130	0.095	0.069	0.051	0.038
19	0.686	0.475	0.331	0.232	0.164	0.116	0.083	0.060	0.043	0.031
20	0.673	0.456	0.312	0.215	0.149	0.104	0.073	0.051	0.037	0.026
21	0.660	0.439	0.294	0.199	0.135	0.093	0.064	0.044	0.031	0.022
22	0.647	0.422	0.278	0.184	0.123	0.083	0.056	0.038	0.026	0.018
23	0.634	0.406	0.262	0.170	0.112	0.074	0.049	0.033	0.022	0.015
24	0.622	0.390	0.247	0.158	0.102	0.066	0.043	0.028	0.019	0.013
25	0.610	0.375	0.233	0.146	0.092	0.059	0.038	0.024	0.016	0.010
26	0.598	0.361	0.220	0.135	0.084	0.053	0.033	0.021	0.014	0.009
27	0.586	0.347	0.207	0.125	0.076	0.047	0.029	0.018	0.011	0.007
28	0.574	0.333	0.196	0.116	0.069	0.042	0.026	0.016	0.010	0.006
29	0.563	0.321	0.185	0.107	0.063	0.037	0.022	0.014	0.008	0.005
30	0.552	0.308	0.174	0.099	0.057	0.033	0.020	0.012	0.007	0.004
31	0.541	0.296	0.164	0.092	0.052	0.030	0.017	0.010	0.006	0.004
32	0.531	0.285	0.155	0.085	0.047	0.027	0.015	0.009	0.005	0.003
33	0.520	0.274	0.146	0.079	0.043	0.024	0.013	0.007	0.004	0.002
34	0.510	0.264	0.138	0.073	0.039	0.021	0.012	0.006	0.004	0.002
35	0.500	0.253	0.130	0.068	0.036	0.019	0.010	0.006	0.003	0.002
36	0.490	0.244	0.123	0.063	0.032	0.017	0.009	0.005	0.003	0.001
37	0.481	0.234	0.116	0.058	0.029	0.015	0.008	0.004	0.002	0.001
38	0.471	0.225	0.109	0.054	0.027	0.013	0.007	0.004	0.002	0.001
39	0.462	0.217	0.103	0.050	0.024	0.012	0.006	0.003	0.002	0.001
40	0.453	0.208	0.097	0.046	0.022	0.011	0.005	0.003	0.001	0.001
41	0.444	0.200	0.092	0.043	0.020	0.010	0.005	0.002	0.001	0.001
42	0.435	0.193	0.087	0.039	0.018	0.009	0.004	0.002	0.001	0.000
43	0.427	0.185	0.082	0.037	0.017	0.008	0.004	0.002	0.001	0.000
44	0.418	0.178	0.077	0.034	0.015	0.007	0.003	0.001	0.001	0.000
45	0.410	0.171	0.073	0.031	0.014	0.006	0.003	0.001	0.001	0.000
46	0.402	0.165	0.069	0.029	0.012	0.005	0.002	0.001	0.000	0.000
47	0.394	0.158	0.065	0.027	0.011	0.005	0.002	0.001	0.000	0.000
48	0.387	0.152	0.061	0.025	0.010	0.004	0.002	0.001	0.000	0.000
49	0.379	0.146	0.058	0.023	0.009	0.004	0.002	0.001	0.000	0.000
50	0.372	0.141	0.054	0.021	0.009	0.003	0.001	0.001	0.000	0.000
51	0.364	0.135	0.051	0.020	0.008	0.003	0.001	0.001	0.000	0.000
52	0.357	0.130	0.048	0.018	0.007	0.003	0.001	0.000	0.000	0.000
53	0.350	0.125	0.046	0.017	0.006	0.002	0.001	0.000	0.000	0.000
54	0.343	0.120	0.043	0.016	0.006	0.002	0.001	0.000	0.000	0.000
55	0.337	0.116	0.041	0.015	0.005	0.002	0.001	0.000	0.000	0.000
56	0.330	0.111	0.038	0.013	0.005	0.002	0.001	0.000	0.000	0.000
57	0.323	0.107	0.036	0.012	0.004	0.002	0.001	0.000	0.000	0.000
58	0.317	0.103	0.034	0.012	0.004	0.001	0.001	0.000	0.000	0.000
59	0.311	0.099	0.032	0.011	0.004	0.001	0.000	0.000	0.000	0.000
60	0.305	0.095	0.030	0.010	0.003	0.001	0.000	0.000	0.000	0.000

GENERAL DISCOUNT FACTORS

Tax Rate = 30 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.986	0.973	0.960	0.947	0.935	0.923	0.911	0.899	0.888	0.877
2	0.973	0.946	0.921	0.897	0.873	0.851	0.829	0.809	0.789	0.769
3	0.959	0.920	0.884	0.849	0.816	0.785	0.755	0.727	0.700	0.675
4	0.946	0.895	0.848	0.804	0.763	0.724	0.688	0.654	0.622	0.592
5	0.933	0.871	0.814	0.762	0.713	0.668	0.627	0.588	0.552	0.519
6	0.920	0.847	0.781	0.721	0.666	0.616	0.571	0.529	0.491	0.456
7	0.907	0.824	0.750	0.683	0.623	0.569	0.520	0.476	0.436	0.400
8	0.895	0.802	0.720	0.647	0.582	0.525	0.473	0.428	0.387	0.351
9	0.882	0.780	0.691	0.612	0.544	0.484	0.431	0.385	0.344	0.308
10	0.870	0.759	0.663	0.580	0.508	0.446	0.393	0.346	0.305	0.270
11	0.858	0.738	0.636	0.549	0.475	0.412	0.358	0.311	0.271	0.237
12	0.846	0.718	0.610	0.520	0.444	0.380	0.326	0.280	0.241	0.208
13	0.835	0.698	0.586	0.492	0.415	0.350	0.297	0.252	0.214	0.182
14	0.823	0.679	0.562	0.466	0.388	0.323	0.270	0.226	0.190	0.160
15	0.812	0.661	0.539	0.442	0.362	0.298	0.246	0.203	0.169	0.140
16	0.801	0.643	0.518	0.418	0.339	0.275	0.224	0.183	0.150	0.123
17	0.790	0.625	0.497	0.396	0.317	0.254	0.204	0.165	0.133	0.108
18	0.779	0.608	0.477	0.375	0.296	0.234	0.186	0.148	0.118	0.095
19	0.768	0.592	0.458	0.355	0.277	0.216	0.169	0.133	0.105	0.083
20	0.757	0.576	0.439	0.336	0.258	0.199	0.154	0.120	0.093	0.073
21	0.747	0.560	0.421	0.318	0.242	0.184	0.140	0.108	0.083	0.064
22	0.736	0.545	0.404	0.302	0.226	0.170	0.128	0.097	0.073	0.056
23	0.726	0.530	0.388	0.286	0.211	0.156	0.116	0.087	0.065	0.049
24	0.716	0.515	0.373	0.270	0.197	0.144	0.106	0.078	0.058	0.043
25	0.706	0.501	0.358	0.256	0.184	0.133	0.097	0.070	0.051	0.038
26	0.697	0.488	0.343	0.243	0.172	0.123	0.088	0.063	0.046	0.033
27	0.687	0.474	0.329	0.230	0.161	0.113	0.080	0.057	0.041	0.029
28	0.678	0.462	0.316	0.217	0.150	0.105	0.073	0.051	0.036	0.026
29	0.668	0.449	0.303	0.206	0.141	0.096	0.066	0.046	0.032	0.022
30	0.659	0.437	0.291	0.195	0.131	0.089	0.061	0.041	0.028	0.020
31	0.650	0.425	0.279	0.185	0.123	0.082	0.055	0.037	0.025	0.017
32	0.641	0.413	0.268	0.175	0.115	0.076	0.050	0.033	0.022	0.015
33	0.632	0.402	0.257	0.166	0.107	0.070	0.046	0.030	0.020	0.013
34	0.623	0.391	0.247	0.157	0.100	0.064	0.042	0.027	0.018	0.012
35	0.615	0.380	0.237	0.149	0.094	0.059	0.038	0.024	0.016	0.010
36	0.606	0.370	0.227	0.141	0.088	0.055	0.035	0.022	0.014	0.009
37	0.598	0.360	0.218	0.133	0.082	0.051	0.031	0.020	0.012	0.008
38	0.590	0.350	0.209	0.126	0.076	0.047	0.029	0.018	0.011	0.007
39	0.581	0.341	0.201	0.119	0.071	0.043	0.026	0.016	0.010	0.006
40	0.573	0.331	0.193	0.113	0.067	0.040	0.024	0.014	0.009	0.005
41	0.566	0.322	0.185	0.107	0.062	0.037	0.022	0.013	0.008	0.005
42	0.558	0.314	0.178	0.101	0.058	0.034	0.020	0.012	0.007	0.004
43	0.550	0.305	0.170	0.096	0.055	0.031	0.018	0.010	0.006	0.004
44	0.542	0.297	0.164	0.091	0.051	0.029	0.016	0.009	0.005	0.003
45	0.535	0.289	0.157	0.086	0.048	0.027	0.015	0.008	0.005	0.003
46	0.528	0.281	0.151	0.082	0.044	0.024	0.014	0.008	0.004	0.002
47	0.520	0.273	0.145	0.077	0.042	0.023	0.012	0.007	0.004	0.002
48	0.513	0.266	0.139	0.073	0.039	0.021	0.011	0.006	0.003	0.002
49	0.506	0.258	0.133	0.069	0.036	0.019	0.010	0.006	0.003	0.002
50	0.499	0.251	0.128	0.066	0.034	0.018	0.009	0.005	0.003	0.001
51	0.492	0.245	0.123	0.062	0.032	0.016	0.008	0.004	0.002	0.001
52	0.485	0.238	0.118	0.059	0.030	0.015	0.008	0.004	0.002	0.001
53	0.479	0.231	0.113	0.056	0.028	0.014	0.007	0.004	0.002	0.001
54	0.472	0.225	0.108	0.053	0.026	0.013	0.006	0.003	0.002	0.001
55	0.465	0.219	0.104	0.050	0.024	0.012	0.006	0.003	0.001	0.001
56	0.459	0.213	0.100	0.047	0.023	0.011	0.005	0.003	0.001	0.001
57	0.453	0.207	0.096	0.045	0.021	0.010	0.005	0.002	0.001	0.001
58	0.446	0.202	0.092	0.042	0.020	0.009	0.004	0.002	0.001	0.001
59	0.440	0.196	0.088	0.040	0.018	0.009	0.004	0.002	0.001	0.000
60	0.434	0.191	0.085	0.038	0.017	0.008	0.004	0.002	0.001	0.000

Discount Rate 'i'

<i>Year</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.10</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.20</i>
61	0.428	0.186	0.081	0.036	0.016	0.007	0.003	0.002	0.001	0.000
62	0.422	0.180	0.078	0.034	0.015	0.007	0.003	0.001	0.001	0.000
63	0.416	0.176	0.075	0.032	0.014	0.006	0.003	0.001	0.001	0.000
64	0.411	0.171	0.072	0.031	0.013	0.006	0.003	0.001	0.001	0.000
65	0.405	0.166	0.069	0.029	0.012	0.005	0.002	0.001	0.000	0.000
66	0.399	0.162	0.066	0.027	0.011	0.005	0.002	0.001	0.000	0.000
67	0.394	0.157	0.064	0.026	0.011	0.004	0.002	0.001	0.000	0.000
68	0.389	0.153	0.061	0.025	0.010	0.004	0.002	0.001	0.000	0.000
69	0.383	0.149	0.058	0.023	0.009	0.004	0.002	0.001	0.000	0.000
70	0.378	0.145	0.056	0.022	0.009	0.004	0.001	0.001	0.000	0.000
71	0.373	0.141	0.054	0.021	0.008	0.003	0.001	0.001	0.000	0.000
72	0.368	0.137	0.052	0.020	0.008	0.003	0.001	0.000	0.000	0.000
73	0.362	0.133	0.050	0.019	0.007	0.003	0.001	0.000	0.000	0.000
74	0.357	0.130	0.048	0.018	0.007	0.003	0.001	0.000	0.000	0.000
75	0.352	0.126	0.046	0.017	0.006	0.002	0.001	0.000	0.000	0.000
76	0.348	0.123	0.044	0.016	0.006	0.002	0.001	0.000	0.000	0.000
77	0.343	0.119	0.042	0.015	0.005	0.002	0.001	0.000	0.000	0.000
78	0.338	0.116	0.040	0.014	0.005	0.002	0.001	0.000	0.000	0.000
79	0.333	0.113	0.039	0.014	0.005	0.002	0.001	0.000	0.000	0.000
80	0.329	0.110	0.037	0.013	0.004	0.002	0.001	0.000	0.000	0.000
81	0.324	0.107	0.036	0.012	0.004	0.001	0.001	0.000	0.000	0.000
82	0.320	0.104	0.034	0.011	0.004	0.001	0.000	0.000	0.000	0.000
83	0.315	0.101	0.033	0.011	0.004	0.001	0.000	0.000	0.000	0.000
84	0.311	0.098	0.032	0.010	0.003	0.001	0.000	0.000	0.000	0.000
85	0.307	0.096	0.030	0.010	0.003	0.001	0.000	0.000	0.000	0.000
86	0.303	0.093	0.029	0.009	0.003	0.001	0.000	0.000	0.000	0.000
87	0.298	0.090	0.028	0.009	0.003	0.001	0.000	0.000	0.000	0.000
88	0.294	0.088	0.027	0.008	0.003	0.001	0.000	0.000	0.000	0.000
89	0.290	0.086	0.026	0.008	0.002	0.001	0.000	0.000	0.000	0.000
90	0.286	0.083	0.025	0.007	0.002	0.001	0.000	0.000	0.000	0.000
91	0.282	0.081	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
92	0.278	0.079	0.023	0.007	0.002	0.001	0.000	0.000	0.000	0.000
93	0.274	0.077	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000
94	0.271	0.075	0.021	0.006	0.002	0.001	0.000	0.000	0.000	0.000
95	0.267	0.073	0.020	0.006	0.002	0.000	0.000	0.000	0.000	0.000
96	0.263	0.071	0.019	0.005	0.002	0.000	0.000	0.000	0.000	0.000
97	0.260	0.069	0.018	0.005	0.001	0.000	0.000	0.000	0.000	0.000
98	0.256	0.067	0.018	0.005	0.001	0.000	0.000	0.000	0.000	0.000
99	0.252	0.065	0.017	0.005	0.001	0.000	0.000	0.000	0.000	0.000
100	0.249	0.063	0.016	0.004	0.001	0.000	0.000	0.000	0.000	0.000
101	0.246	0.061	0.016	0.004	0.001	0.000	0.000	0.000	0.000	0.000
102	0.242	0.060	0.015	0.004	0.001	0.000	0.000	0.000	0.000	0.000
103	0.239	0.058	0.014	0.004	0.001	0.000	0.000	0.000	0.000	0.000
104	0.236	0.057	0.014	0.003	0.001	0.000	0.000	0.000	0.000	0.000
105	0.232	0.055	0.013	0.003	0.001	0.000	0.000	0.000	0.000	0.000
106	0.229	0.054	0.013	0.003	0.001	0.000	0.000	0.000	0.000	0.000
107	0.226	0.052	0.012	0.003	0.001	0.000	0.000	0.000	0.000	0.000
108	0.223	0.051	0.012	0.003	0.001	0.000	0.000	0.000	0.000	0.000
109	0.220	0.049	0.011	0.003	0.001	0.000	0.000	0.000	0.000	0.000
110	0.217	0.048	0.011	0.002	0.001	0.000	0.000	0.000	0.000	0.000
111	0.214	0.047	0.010	0.002	0.001	0.000	0.000	0.000	0.000	0.000
112	0.211	0.045	0.010	0.002	0.001	0.000	0.000	0.000	0.000	0.000
113	0.208	0.044	0.010	0.002	0.000	0.000	0.000	0.000	0.000	0.000
114	0.205	0.043	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000
115	0.202	0.042	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000
116	0.199	0.041	0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000
117	0.197	0.040	0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000
118	0.194	0.038	0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000
119	0.191	0.037	0.007	0.002	0.000	0.000	0.000	0.000	0.000	0.000
120	0.189	0.036	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000

GENERAL DISCOUNT FACTORS

Tax Rate = 35 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.987	0.975	0.962	0.951	0.939	0.928	0.917	0.906	0.895	0.885
2	0.974	0.950	0.926	0.904	0.882	0.861	0.840	0.820	0.801	0.783
3	0.962	0.926	0.892	0.859	0.828	0.798	0.770	0.743	0.718	0.693
4	0.950	0.902	0.858	0.816	0.777	0.740	0.706	0.673	0.642	0.613
5	0.937	0.880	0.826	0.776	0.730	0.687	0.647	0.610	0.575	0.543
6	0.925	0.857	0.795	0.738	0.685	0.637	0.593	0.552	0.515	0.480
7	0.914	0.836	0.765	0.701	0.644	0.591	0.544	0.500	0.461	0.425
8	0.902	0.814	0.736	0.667	0.604	0.548	0.498	0.453	0.413	0.376
9	0.890	0.794	0.709	0.634	0.567	0.509	0.457	0.410	0.369	0.333
10	0.879	0.774	0.682	0.602	0.533	0.472	0.419	0.372	0.331	0.295
11	0.868	0.754	0.656	0.573	0.500	0.438	0.384	0.337	0.296	0.261
12	0.856	0.735	0.632	0.544	0.470	0.406	0.352	0.305	0.265	0.231
13	0.845	0.716	0.608	0.517	0.441	0.377	0.322	0.276	0.237	0.204
14	0.835	0.698	0.585	0.492	0.414	0.349	0.295	0.250	0.212	0.181
15	0.824	0.680	0.563	0.467	0.389	0.324	0.271	0.227	0.190	0.160
16	0.813	0.663	0.542	0.444	0.365	0.301	0.248	0.205	0.170	0.141
17	0.803	0.646	0.522	0.422	0.343	0.279	0.227	0.186	0.152	0.125
18	0.793	0.630	0.502	0.402	0.322	0.259	0.209	0.168	0.136	0.111
19	0.782	0.614	0.483	0.382	0.302	0.240	0.191	0.153	0.122	0.098
20	0.772	0.598	0.465	0.363	0.284	0.223	0.175	0.138	0.109	0.087
21	0.762	0.583	0.448	0.345	0.266	0.207	0.161	0.125	0.098	0.077
22	0.753	0.569	0.431	0.328	0.250	0.192	0.147	0.113	0.088	0.068
23	0.743	0.554	0.415	0.312	0.235	0.178	0.135	0.103	0.078	0.060
24	0.733	0.540	0.399	0.296	0.221	0.165	0.124	0.093	0.070	0.053
25	0.724	0.526	0.384	0.282	0.207	0.153	0.113	0.084	0.063	0.047
26	0.715	0.513	0.370	0.268	0.194	0.142	0.104	0.076	0.056	0.042
27	0.706	0.500	0.356	0.254	0.183	0.132	0.095	0.069	0.050	0.037
28	0.697	0.487	0.343	0.242	0.171	0.122	0.087	0.063	0.045	0.033
29	0.688	0.475	0.330	0.230	0.161	0.113	0.080	0.057	0.040	0.029
30	0.679	0.463	0.317	0.219	0.151	0.105	0.073	0.051	0.036	0.026
31	0.670	0.451	0.305	0.208	0.142	0.097	0.067	0.047	0.032	0.023
32	0.661	0.440	0.294	0.197	0.133	0.090	0.062	0.042	0.029	0.020
33	0.653	0.429	0.283	0.188	0.125	0.084	0.056	0.038	0.026	0.018
34	0.645	0.418	0.272	0.178	0.118	0.078	0.052	0.035	0.023	0.016
35	0.636	0.407	0.262	0.170	0.110	0.072	0.047	0.031	0.021	0.014
36	0.628	0.397	0.252	0.161	0.104	0.067	0.043	0.028	0.019	0.012
37	0.620	0.387	0.243	0.153	0.097	0.062	0.040	0.026	0.017	0.011
38	0.612	0.377	0.234	0.146	0.091	0.058	0.037	0.023	0.015	0.010
39	0.604	0.367	0.225	0.138	0.086	0.053	0.033	0.021	0.013	0.009
40	0.597	0.358	0.216	0.132	0.081	0.050	0.031	0.019	0.012	0.008
41	0.589	0.349	0.208	0.125	0.076	0.046	0.028	0.017	0.011	0.007
42	0.581	0.340	0.201	0.119	0.071	0.043	0.026	0.016	0.010	0.006
43	0.574	0.332	0.193	0.113	0.067	0.040	0.024	0.014	0.009	0.005
44	0.566	0.323	0.186	0.107	0.063	0.037	0.022	0.013	0.008	0.005
45	0.559	0.315	0.179	0.102	0.059	0.034	0.020	0.012	0.007	0.004
46	0.552	0.307	0.172	0.097	0.055	0.032	0.018	0.011	0.006	0.004
47	0.545	0.299	0.166	0.092	0.052	0.029	0.017	0.010	0.006	0.003
48	0.538	0.292	0.159	0.088	0.049	0.027	0.015	0.009	0.005	0.003
49	0.531	0.284	0.153	0.083	0.046	0.025	0.014	0.008	0.004	0.003
50	0.524	0.277	0.148	0.079	0.043	0.023	0.013	0.007	0.004	0.002
51	0.518	0.270	0.142	0.075	0.040	0.022	0.012	0.006	0.004	0.002
52	0.511	0.263	0.137	0.072	0.038	0.020	0.011	0.006	0.003	0.002
53	0.504	0.257	0.132	0.068	0.036	0.019	0.010	0.005	0.003	0.002
54	0.498	0.250	0.127	0.065	0.033	0.017	0.009	0.005	0.003	0.001
55	0.491	0.244	0.122	0.062	0.031	0.016	0.008	0.004	0.002	0.001
56	0.485	0.238	0.117	0.058	0.029	0.015	0.008	0.004	0.002	0.001
57	0.479	0.232	0.113	0.056	0.028	0.014	0.007	0.004	0.002	0.001
58	0.473	0.226	0.109	0.053	0.026	0.013	0.006	0.003	0.002	0.001
59	0.467	0.220	0.105	0.050	0.024	0.012	0.006	0.003	0.001	0.001
60	0.461	0.214	0.101	0.048	0.023	0.011	0.005	0.003	0.001	0.001

Discount Rate 'i'

<i>Year</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.10</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.20</i>
61	0.455	0.209	0.097	0.045	0.021	0.010	0.005	0.002	0.001	0.001
62	0.449	0.204	0.093	0.043	0.020	0.009	0.005	0.002	0.001	0.001
63	0.443	0.198	0.090	0.041	0.019	0.009	0.004	0.002	0.001	0.000
64	0.438	0.193	0.086	0.039	0.018	0.008	0.004	0.002	0.001	0.000
65	0.432	0.189	0.083	0.037	0.017	0.008	0.003	0.002	0.001	0.000
66	0.426	0.184	0.080	0.035	0.016	0.007	0.003	0.001	0.001	0.000
67	0.421	0.179	0.077	0.033	0.015	0.007	0.003	0.001	0.001	0.000
68	0.415	0.175	0.074	0.032	0.014	0.006	0.003	0.001	0.001	0.000
69	0.410	0.170	0.071	0.030	0.013	0.006	0.002	0.001	0.000	0.000
70	0.405	0.166	0.069	0.029	0.012	0.005	0.002	0.001	0.000	0.000
71	0.400	0.162	0.066	0.027	0.011	0.005	0.002	0.001	0.000	0.000
72	0.395	0.158	0.064	0.026	0.011	0.004	0.002	0.001	0.000	0.000
73	0.390	0.154	0.061	0.025	0.010	0.004	0.002	0.001	0.000	0.000
74	0.385	0.150	0.059	0.023	0.009	0.004	0.002	0.001	0.000	0.000
75	0.380	0.146	0.057	0.022	0.009	0.004	0.001	0.001	0.000	0.000
76	0.375	0.142	0.055	0.021	0.008	0.003	0.001	0.001	0.000	0.000
77	0.370	0.139	0.053	0.020	0.008	0.003	0.001	0.000	0.000	0.000
78	0.365	0.135	0.051	0.019	0.007	0.003	0.001	0.000	0.000	0.000
79	0.360	0.132	0.049	0.018	0.007	0.003	0.001	0.000	0.000	0.000
80	0.356	0.128	0.047	0.017	0.006	0.002	0.001	0.000	0.000	0.000
81	0.351	0.125	0.045	0.016	0.006	0.002	0.001	0.000	0.000	0.000
82	0.347	0.122	0.043	0.016	0.006	0.002	0.001	0.000	0.000	0.000
83	0.342	0.119	0.042	0.015	0.005	0.002	0.001	0.000	0.000	0.000
84	0.338	0.116	0.040	0.014	0.005	0.002	0.001	0.000	0.000	0.000
85	0.334	0.113	0.039	0.013	0.005	0.002	0.001	0.000	0.000	0.000
86	0.329	0.110	0.037	0.013	0.004	0.002	0.001	0.000	0.000	0.000
87	0.325	0.107	0.036	0.012	0.004	0.001	0.001	0.000	0.000	0.000
88	0.321	0.104	0.035	0.012	0.004	0.001	0.000	0.000	0.000	0.000
89	0.317	0.102	0.033	0.011	0.004	0.001	0.000	0.000	0.000	0.000
90	0.313	0.099	0.032	0.010	0.003	0.001	0.000	0.000	0.000	0.000
91	0.309	0.097	0.031	0.010	0.003	0.001	0.000	0.000	0.000	0.000
92	0.305	0.094	0.030	0.009	0.003	0.001	0.000	0.000	0.000	0.000
93	0.301	0.092	0.028	0.009	0.003	0.001	0.000	0.000	0.000	0.000
94	0.297	0.090	0.027	0.009	0.003	0.001	0.000	0.000	0.000	0.000
95	0.293	0.087	0.026	0.008	0.003	0.001	0.000	0.000	0.000	0.000
96	0.289	0.085	0.025	0.008	0.002	0.001	0.000	0.000	0.000	0.000
97	0.286	0.083	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
98	0.282	0.081	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
99	0.278	0.079	0.023	0.007	0.002	0.001	0.000	0.000	0.000	0.000
100	0.275	0.077	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000
101	0.271	0.075	0.021	0.006	0.002	0.001	0.000	0.000	0.000	0.000
102	0.268	0.073	0.020	0.006	0.002	0.000	0.000	0.000	0.000	0.000
103	0.264	0.071	0.019	0.005	0.002	0.000	0.000	0.000	0.000	0.000
104	0.261	0.069	0.019	0.005	0.001	0.000	0.000	0.000	0.000	0.000
105	0.258	0.068	0.018	0.005	0.001	0.000	0.000	0.000	0.000	0.000
106	0.254	0.066	0.017	0.005	0.001	0.000	0.000	0.000	0.000	0.000
107	0.251	0.064	0.017	0.004	0.001	0.000	0.000	0.000	0.000	0.000
108	0.248	0.063	0.016	0.004	0.001	0.000	0.000	0.000	0.000	0.000
109	0.245	0.061	0.015	0.004	0.001	0.000	0.000	0.000	0.000	0.000
110	0.242	0.059	0.015	0.004	0.001	0.000	0.000	0.000	0.000	0.000
111	0.238	0.058	0.014	0.004	0.001	0.000	0.000	0.000	0.000	0.000
112	0.235	0.056	0.014	0.003	0.001	0.000	0.000	0.000	0.000	0.000
113	0.232	0.055	0.013	0.003	0.001	0.000	0.000	0.000	0.000	0.000
114	0.229	0.054	0.013	0.003	0.001	0.000	0.000	0.000	0.000	0.000
115	0.226	0.052	0.012	0.003	0.001	0.000	0.000	0.000	0.000	0.000
116	0.224	0.051	0.012	0.003	0.001	0.000	0.000	0.000	0.000	0.000
117	0.221	0.050	0.011	0.003	0.001	0.000	0.000	0.000	0.000	0.000
118	0.218	0.048	0.011	0.003	0.001	0.000	0.000	0.000	0.000	0.000
119	0.215	0.047	0.011	0.002	0.001	0.000	0.000	0.000	0.000	0.000
120	0.212	0.046	0.010	0.002	0.001	0.000	0.000	0.000	0.000	0.000

GENERAL DISCOUNT FACTORS

Tax Rate = 40 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.988	0.977	0.965	0.954	0.943	0.933	0.923	0.912	0.903	0.893
2	0.976	0.954	0.932	0.910	0.890	0.870	0.851	0.832	0.815	0.797
3	0.965	0.931	0.899	0.869	0.840	0.812	0.785	0.760	0.735	0.712
4	0.953	0.909	0.868	0.829	0.792	0.757	0.724	0.693	0.664	0.636
5	0.942	0.888	0.838	0.791	0.747	0.706	0.668	0.632	0.599	0.567
6	0.931	0.867	0.809	0.755	0.705	0.659	0.616	0.577	0.540	0.507
7	0.920	0.847	0.781	0.720	0.665	0.615	0.569	0.526	0.488	0.452
8	0.909	0.827	0.754	0.687	0.627	0.573	0.525	0.480	0.440	0.404
9	0.898	0.808	0.727	0.656	0.592	0.535	0.484	0.438	0.397	0.361
10	0.888	0.789	0.702	0.626	0.558	0.499	0.446	0.400	0.359	0.322
11	0.877	0.770	0.678	0.597	0.527	0.465	0.412	0.365	0.324	0.287
12	0.867	0.752	0.654	0.570	0.497	0.434	0.380	0.333	0.292	0.257
13	0.856	0.735	0.631	0.544	0.469	0.405	0.350	0.304	0.264	0.229
14	0.846	0.717	0.609	0.519	0.442	0.378	0.323	0.277	0.238	0.205
15	0.836	0.701	0.588	0.495	0.417	0.352	0.298	0.253	0.215	0.183
16	0.826	0.684	0.568	0.472	0.394	0.329	0.275	0.231	0.194	0.163
17	0.816	0.668	0.548	0.451	0.371	0.307	0.254	0.210	0.175	0.146
18	0.807	0.653	0.529	0.430	0.350	0.286	0.234	0.192	0.158	0.130
19	0.797	0.637	0.511	0.410	0.331	0.267	0.216	0.175	0.142	0.116
20	0.788	0.622	0.493	0.392	0.312	0.249	0.199	0.160	0.129	0.104
21	0.778	0.608	0.476	0.374	0.294	0.232	0.184	0.146	0.116	0.093
22	0.769	0.593	0.459	0.356	0.278	0.217	0.170	0.133	0.105	0.083
23	0.760	0.580	0.443	0.340	0.262	0.202	0.156	0.121	0.095	0.074
24	0.751	0.566	0.428	0.325	0.247	0.189	0.144	0.111	0.085	0.066
25	0.742	0.553	0.413	0.310	0.233	0.176	0.133	0.101	0.077	0.059
26	0.733	0.540	0.399	0.296	0.220	0.164	0.123	0.092	0.069	0.053
27	0.725	0.527	0.385	0.282	0.207	0.153	0.113	0.084	0.063	0.047
28	0.716	0.515	0.371	0.269	0.196	0.143	0.105	0.077	0.057	0.042
29	0.708	0.503	0.359	0.257	0.185	0.133	0.096	0.070	0.051	0.037
30	0.699	0.491	0.346	0.245	0.174	0.124	0.089	0.064	0.046	0.033
31	0.691	0.479	0.334	0.234	0.164	0.116	0.082	0.058	0.042	0.030
32	0.683	0.468	0.322	0.223	0.155	0.108	0.076	0.053	0.038	0.027
33	0.675	0.457	0.311	0.213	0.146	0.101	0.070	0.049	0.034	0.024
34	0.667	0.446	0.300	0.203	0.138	0.094	0.064	0.044	0.031	0.021
35	0.659	0.436	0.290	0.194	0.130	0.088	0.059	0.040	0.028	0.019
36	0.651	0.426	0.280	0.185	0.123	0.082	0.055	0.037	0.025	0.017
37	0.643	0.416	0.270	0.176	0.116	0.076	0.051	0.034	0.022	0.015
38	0.636	0.406	0.261	0.168	0.109	0.071	0.047	0.031	0.020	0.013
39	0.628	0.397	0.252	0.161	0.103	0.066	0.043	0.028	0.018	0.012
40	0.621	0.387	0.243	0.153	0.097	0.062	0.040	0.026	0.017	0.011
41	0.613	0.378	0.235	0.146	0.092	0.058	0.037	0.023	0.015	0.010
42	0.606	0.369	0.226	0.140	0.087	0.054	0.034	0.021	0.013	0.009
43	0.599	0.361	0.219	0.133	0.082	0.050	0.031	0.019	0.012	0.008
44	0.592	0.352	0.211	0.127	0.077	0.047	0.029	0.018	0.011	0.007
45	0.585	0.344	0.204	0.121	0.073	0.044	0.027	0.016	0.010	0.006
46	0.578	0.336	0.197	0.116	0.069	0.041	0.024	0.015	0.009	0.005
47	0.571	0.328	0.190	0.110	0.065	0.038	0.023	0.013	0.008	0.005
48	0.564	0.320	0.183	0.105	0.061	0.036	0.021	0.012	0.007	0.004
49	0.557	0.313	0.177	0.101	0.058	0.033	0.019	0.011	0.007	0.004
50	0.551	0.305	0.171	0.096	0.054	0.031	0.018	0.010	0.006	0.003
51	0.544	0.298	0.165	0.092	0.051	0.029	0.016	0.009	0.005	0.003
52	0.538	0.291	0.159	0.087	0.048	0.027	0.015	0.009	0.005	0.003
53	0.531	0.285	0.153	0.083	0.046	0.025	0.014	0.008	0.004	0.002
54	0.525	0.278	0.148	0.080	0.043	0.023	0.013	0.007	0.004	0.002
55	0.519	0.271	0.143	0.076	0.041	0.022	0.012	0.006	0.004	0.002
56	0.513	0.265	0.138	0.072	0.038	0.020	0.011	0.006	0.003	0.002
57	0.507	0.259	0.133	0.069	0.036	0.019	0.010	0.005	0.003	0.002
58	0.501	0.253	0.129	0.066	0.034	0.018	0.009	0.005	0.003	0.001
59	0.495	0.247	0.124	0.063	0.032	0.017	0.009	0.004	0.002	0.001
60	0.489	0.241	0.120	0.060	0.030	0.015	0.008	0.004	0.002	0.001

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
61	0.483	0.235	0.116	0.057	0.029	0.014	0.007	0.004	0.002	0.001
62	0.477	0.230	0.112	0.055	0.027	0.013	0.007	0.003	0.002	0.001
63	0.472	0.224	0.108	0.052	0.025	0.013	0.006	0.003	0.002	0.001
64	0.466	0.219	0.104	0.050	0.024	0.012	0.006	0.003	0.001	0.001
65	0.461	0.214	0.100	0.047	0.023	0.011	0.005	0.003	0.001	0.001
66	0.455	0.209	0.097	0.045	0.021	0.010	0.005	0.002	0.001	0.001
67	0.450	0.204	0.094	0.043	0.020	0.009	0.004	0.002	0.001	0.001
68	0.444	0.199	0.090	0.041	0.019	0.009	0.004	0.002	0.001	0.000
69	0.439	0.195	0.087	0.039	0.018	0.008	0.004	0.002	0.001	0.000
70	0.434	0.190	0.084	0.038	0.017	0.008	0.004	0.002	0.001	0.000
71	0.429	0.186	0.081	0.036	0.016	0.007	0.003	0.001	0.001	0.000
72	0.424	0.181	0.078	0.034	0.015	0.007	0.003	0.001	0.001	0.000
73	0.419	0.177	0.076	0.033	0.014	0.006	0.003	0.001	0.001	0.000
74	0.414	0.173	0.073	0.031	0.013	0.006	0.003	0.001	0.001	0.000
75	0.409	0.169	0.070	0.030	0.013	0.005	0.002	0.001	0.000	0.000
76	0.404	0.165	0.068	0.028	0.012	0.005	0.002	0.001	0.000	0.000
77	0.399	0.161	0.066	0.027	0.011	0.005	0.002	0.001	0.000	0.000
78	0.394	0.157	0.063	0.026	0.011	0.004	0.002	0.001	0.000	0.000
79	0.390	0.154	0.061	0.025	0.010	0.004	0.002	0.001	0.000	0.000
80	0.385	0.150	0.059	0.024	0.009	0.004	0.002	0.001	0.000	0.000
81	0.381	0.146	0.057	0.022	0.009	0.004	0.001	0.001	0.000	0.000
82	0.376	0.143	0.055	0.021	0.008	0.003	0.001	0.001	0.000	0.000
83	0.372	0.140	0.053	0.020	0.008	0.003	0.001	0.000	0.000	0.000
84	0.367	0.136	0.051	0.019	0.007	0.003	0.001	0.000	0.000	0.000
85	0.363	0.133	0.049	0.019	0.007	0.003	0.001	0.000	0.000	0.000
86	0.358	0.130	0.048	0.018	0.007	0.003	0.001	0.000	0.000	0.000
87	0.354	0.127	0.046	0.017	0.006	0.002	0.001	0.000	0.000	0.000
88	0.350	0.124	0.044	0.016	0.006	0.002	0.001	0.000	0.000	0.000
89	0.346	0.121	0.043	0.015	0.006	0.002	0.001	0.000	0.000	0.000
90	0.342	0.118	0.041	0.015	0.005	0.002	0.001	0.000	0.000	0.000
91	0.338	0.116	0.040	0.014	0.005	0.002	0.001	0.000	0.000	0.000
92	0.334	0.113	0.039	0.013	0.005	0.002	0.001	0.000	0.000	0.000
93	0.330	0.110	0.037	0.013	0.004	0.002	0.001	0.000	0.000	0.000
94	0.326	0.108	0.036	0.012	0.004	0.001	0.001	0.000	0.000	0.000
95	0.322	0.105	0.035	0.012	0.004	0.001	0.000	0.000	0.000	0.000
96	0.318	0.103	0.034	0.011	0.004	0.001	0.000	0.000	0.000	0.000
97	0.314	0.100	0.032	0.011	0.004	0.001	0.000	0.000	0.000	0.000
98	0.311	0.098	0.031	0.010	0.003	0.001	0.000	0.000	0.000	0.000
99	0.307	0.096	0.030	0.010	0.003	0.001	0.000	0.000	0.000	0.000
100	0.303	0.093	0.029	0.009	0.003	0.001	0.000	0.000	0.000	0.000
101	0.300	0.091	0.028	0.009	0.003	0.001	0.000	0.000	0.000	0.000
102	0.296	0.089	0.027	0.008	0.003	0.001	0.000	0.000	0.000	0.000
103	0.293	0.087	0.026	0.008	0.002	0.001	0.000	0.000	0.000	0.000
104	0.289	0.085	0.025	0.008	0.002	0.001	0.000	0.000	0.000	0.000
105	0.286	0.083	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
106	0.282	0.081	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
107	0.279	0.079	0.023	0.007	0.002	0.001	0.000	0.000	0.000	0.000
108	0.276	0.077	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000
109	0.272	0.075	0.021	0.006	0.002	0.001	0.000	0.000	0.000	0.000
110	0.269	0.074	0.020	0.006	0.002	0.000	0.000	0.000	0.000	0.000
111	0.266	0.072	0.020	0.005	0.002	0.000	0.000	0.000	0.000	0.000
112	0.263	0.070	0.019	0.005	0.001	0.000	0.000	0.000	0.000	0.000
113	0.260	0.069	0.018	0.005	0.001	0.000	0.000	0.000	0.000	0.000
114	0.257	0.067	0.018	0.005	0.001	0.000	0.000	0.000	0.000	0.000
115	0.254	0.065	0.017	0.005	0.001	0.000	0.000	0.000	0.000	0.000
116	0.251	0.064	0.017	0.004	0.001	0.000	0.000	0.000	0.000	0.000
117	0.248	0.062	0.016	0.004	0.001	0.000	0.000	0.000	0.000	0.000
118	0.245	0.061	0.015	0.004	0.001	0.000	0.000	0.000	0.000	0.000
119	0.242	0.059	0.015	0.004	0.001	0.000	0.000	0.000	0.000	0.000
120	0.239	0.058	0.014	0.004	0.001	0.000	0.000	0.000	0.000	0.000

GENERAL DISCOUNT FACTORS

Tax Rate = 45 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.989	0.978	0.968	0.958	0.948	0.938	0.929	0.919	0.910	0.901
2	0.978	0.957	0.937	0.917	0.898	0.880	0.862	0.845	0.828	0.812
3	0.968	0.937	0.907	0.879	0.852	0.826	0.800	0.776	0.753	0.731
4	0.957	0.917	0.878	0.842	0.807	0.774	0.743	0.714	0.686	0.659
5	0.947	0.897	0.850	0.806	0.765	0.726	0.690	0.656	0.624	0.593
6	0.936	0.878	0.823	0.772	0.725	0.681	0.641	0.603	0.568	0.535
7	0.926	0.859	0.797	0.740	0.687	0.639	0.595	0.554	0.516	0.482
8	0.916	0.840	0.771	0.709	0.652	0.600	0.552	0.509	0.470	0.434
9	0.906	0.822	0.747	0.679	0.618	0.563	0.513	0.468	0.428	0.391
10	0.896	0.804	0.723	0.650	0.585	0.528	0.476	0.430	0.389	0.352
11	0.887	0.787	0.700	0.623	0.555	0.495	0.442	0.395	0.354	0.317
12	0.877	0.770	0.677	0.596	0.526	0.464	0.411	0.363	0.322	0.286
13	0.867	0.754	0.656	0.571	0.499	0.436	0.381	0.334	0.293	0.258
14	0.858	0.737	0.635	0.547	0.473	0.409	0.354	0.307	0.267	0.232
15	0.849	0.722	0.614	0.524	0.448	0.383	0.329	0.282	0.243	0.209
16	0.839	0.706	0.595	0.502	0.425	0.360	0.305	0.259	0.221	0.188
17	0.830	0.691	0.576	0.481	0.402	0.337	0.283	0.238	0.201	0.170
18	0.821	0.676	0.557	0.461	0.381	0.316	0.263	0.219	0.183	0.153
19	0.812	0.661	0.540	0.441	0.362	0.297	0.244	0.201	0.166	0.138
20	0.803	0.647	0.522	0.423	0.343	0.279	0.227	0.185	0.151	0.124
21	0.795	0.633	0.506	0.405	0.325	0.261	0.211	0.170	0.138	0.112
22	0.786	0.620	0.490	0.388	0.308	0.245	0.196	0.156	0.125	0.101
23	0.778	0.606	0.474	0.371	0.292	0.230	0.182	0.144	0.114	0.091
24	0.769	0.593	0.459	0.356	0.277	0.216	0.169	0.132	0.104	0.082
25	0.761	0.580	0.444	0.341	0.262	0.202	0.157	0.121	0.094	0.074
26	0.752	0.568	0.430	0.326	0.249	0.190	0.145	0.112	0.086	0.066
27	0.744	0.556	0.416	0.313	0.236	0.178	0.135	0.103	0.078	0.060
28	0.736	0.544	0.403	0.299	0.223	0.167	0.125	0.094	0.071	0.054
29	0.728	0.532	0.390	0.287	0.212	0.157	0.116	0.087	0.065	0.048
30	0.720	0.521	0.378	0.275	0.201	0.147	0.108	0.080	0.059	0.044
31	0.712	0.509	0.366	0.263	0.190	0.138	0.100	0.073	0.054	0.039
32	0.705	0.498	0.354	0.252	0.180	0.129	0.093	0.067	0.049	0.035
33	0.697	0.488	0.343	0.241	0.171	0.121	0.086	0.062	0.044	0.032
34	0.689	0.477	0.332	0.231	0.162	0.114	0.080	0.057	0.040	0.029
35	0.682	0.467	0.321	0.222	0.154	0.107	0.075	0.052	0.037	0.026
36	0.674	0.457	0.311	0.212	0.146	0.100	0.069	0.048	0.033	0.023
37	0.667	0.447	0.301	0.203	0.138	0.094	0.064	0.044	0.030	0.021
38	0.660	0.437	0.291	0.195	0.131	0.088	0.060	0.041	0.028	0.019
39	0.653	0.428	0.282	0.187	0.124	0.083	0.055	0.037	0.025	0.017
40	0.646	0.419	0.273	0.179	0.117	0.078	0.051	0.034	0.023	0.015
41	0.639	0.410	0.264	0.171	0.111	0.073	0.048	0.031	0.021	0.014
42	0.632	0.401	0.256	0.164	0.106	0.068	0.044	0.029	0.019	0.012
43	0.625	0.392	0.248	0.157	0.100	0.064	0.041	0.027	0.017	0.011
44	0.618	0.384	0.240	0.150	0.095	0.060	0.038	0.024	0.016	0.010
45	0.611	0.376	0.232	0.144	0.090	0.056	0.036	0.022	0.014	0.009
46	0.605	0.368	0.225	0.138	0.085	0.053	0.033	0.021	0.013	0.008
47	0.598	0.360	0.217	0.132	0.081	0.050	0.031	0.019	0.012	0.007
48	0.591	0.352	0.210	0.127	0.077	0.047	0.028	0.017	0.011	0.007
49	0.585	0.344	0.204	0.121	0.073	0.044	0.026	0.016	0.010	0.006
50	0.579	0.337	0.197	0.116	0.069	0.041	0.025	0.015	0.009	0.005
51	0.572	0.330	0.191	0.111	0.065	0.038	0.023	0.014	0.008	0.005
52	0.566	0.323	0.185	0.107	0.062	0.036	0.021	0.012	0.007	0.004
53	0.560	0.316	0.179	0.102	0.059	0.034	0.020	0.011	0.007	0.004
54	0.554	0.309	0.173	0.098	0.056	0.032	0.018	0.011	0.006	0.004
55	0.548	0.302	0.168	0.094	0.053	0.030	0.017	0.010	0.006	0.003
56	0.542	0.296	0.162	0.090	0.050	0.028	0.016	0.009	0.005	0.003
57	0.536	0.289	0.157	0.086	0.047	0.026	0.015	0.008	0.005	0.003
58	0.530	0.283	0.152	0.082	0.045	0.025	0.014	0.008	0.004	0.002
59	0.524	0.277	0.147	0.079	0.042	0.023	0.013	0.007	0.004	0.002
60	0.519	0.271	0.143	0.076	0.040	0.022	0.012	0.006	0.003	0.002

Discount Rate 'i'

<i>Year</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.10</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.20</i>
61	0.513	0.265	0.138	0.072	0.038	0.020	0.011	0.006	0.003	0.002
62	0.507	0.259	0.134	0.069	0.036	0.019	0.010	0.005	0.003	0.002
63	0.502	0.254	0.129	0.066	0.034	0.018	0.009	0.005	0.003	0.001
64	0.497	0.248	0.125	0.064	0.032	0.017	0.009	0.005	0.002	0.001
65	0.491	0.243	0.121	0.061	0.031	0.016	0.008	0.004	0.002	0.001
66	0.486	0.238	0.117	0.058	0.029	0.015	0.007	0.004	0.002	0.001
67	0.480	0.233	0.114	0.056	0.028	0.014	0.007	0.004	0.002	0.001
68	0.475	0.228	0.110	0.054	0.026	0.013	0.006	0.003	0.002	0.001
69	0.470	0.223	0.106	0.051	0.025	0.012	0.006	0.003	0.001	0.001
70	0.465	0.218	0.103	0.049	0.024	0.011	0.006	0.003	0.001	0.001
71	0.460	0.213	0.100	0.047	0.022	0.011	0.005	0.003	0.001	0.001
72	0.455	0.209	0.097	0.045	0.021	0.010	0.005	0.002	0.001	0.001
73	0.450	0.204	0.093	0.043	0.020	0.009	0.004	0.002	0.001	0.000
74	0.445	0.200	0.090	0.041	0.019	0.009	0.004	0.002	0.001	0.000
75	0.440	0.196	0.088	0.040	0.018	0.008	0.004	0.002	0.001	0.000
76	0.435	0.191	0.085	0.038	0.017	0.008	0.004	0.002	0.001	0.000
77	0.431	0.187	0.082	0.036	0.016	0.007	0.003	0.002	0.001	0.000
78	0.426	0.183	0.079	0.035	0.015	0.007	0.003	0.001	0.001	0.000
79	0.421	0.179	0.077	0.033	0.015	0.006	0.003	0.001	0.001	0.000
80	0.417	0.175	0.074	0.032	0.014	0.006	0.003	0.001	0.001	0.000
81	0.412	0.172	0.072	0.031	0.013	0.006	0.002	0.001	0.000	0.000
82	0.408	0.168	0.070	0.029	0.012	0.005	0.002	0.001	0.000	0.000
83	0.403	0.164	0.068	0.028	0.012	0.005	0.002	0.001	0.000	0.000
84	0.399	0.161	0.065	0.027	0.011	0.005	0.002	0.001	0.000	0.000
85	0.395	0.157	0.063	0.026	0.011	0.004	0.002	0.001	0.000	0.000
86	0.390	0.154	0.061	0.025	0.010	0.004	0.002	0.001	0.000	0.000
87	0.386	0.151	0.059	0.024	0.009	0.004	0.002	0.001	0.000	0.000
88	0.382	0.147	0.057	0.023	0.009	0.004	0.001	0.001	0.000	0.000
89	0.378	0.144	0.056	0.022	0.009	0.003	0.001	0.001	0.000	0.000
90	0.374	0.141	0.054	0.021	0.008	0.003	0.001	0.001	0.000	0.000
91	0.370	0.138	0.052	0.020	0.008	0.003	0.001	0.000	0.000	0.000
92	0.366	0.135	0.050	0.019	0.007	0.003	0.001	0.000	0.000	0.000
93	0.362	0.132	0.049	0.018	0.007	0.003	0.001	0.000	0.000	0.000
94	0.358	0.129	0.047	0.017	0.007	0.002	0.001	0.000	0.000	0.000
95	0.354	0.127	0.046	0.017	0.006	0.002	0.001	0.000	0.000	0.000
96	0.350	0.124	0.044	0.016	0.006	0.002	0.001	0.000	0.000	0.000
97	0.346	0.121	0.043	0.015	0.006	0.002	0.001	0.000	0.000	0.000
98	0.342	0.119	0.042	0.015	0.005	0.002	0.001	0.000	0.000	0.000
99	0.339	0.116	0.040	0.014	0.005	0.002	0.001	0.000	0.000	0.000
100	0.335	0.113	0.039	0.013	0.005	0.002	0.001	0.000	0.000	0.000
101	0.331	0.111	0.038	0.013	0.004	0.002	0.001	0.000	0.000	0.000
102	0.328	0.109	0.036	0.012	0.004	0.001	0.001	0.000	0.000	0.000
103	0.324	0.106	0.035	0.012	0.004	0.001	0.000	0.000	0.000	0.000
104	0.321	0.104	0.034	0.011	0.004	0.001	0.000	0.000	0.000	0.000
105	0.317	0.102	0.033	0.011	0.004	0.001	0.000	0.000	0.000	0.000
106	0.314	0.100	0.032	0.010	0.003	0.001	0.000	0.000	0.000	0.000
107	0.310	0.097	0.031	0.010	0.003	0.001	0.000	0.000	0.000	0.000
108	0.307	0.095	0.030	0.010	0.003	0.001	0.000	0.000	0.000	0.000
109	0.303	0.093	0.029	0.009	0.003	0.001	0.000	0.000	0.000	0.000
110	0.300	0.091	0.028	0.009	0.003	0.001	0.000	0.000	0.000	0.000
111	0.297	0.089	0.027	0.008	0.003	0.001	0.000	0.000	0.000	0.000
112	0.294	0.087	0.026	0.008	0.002	0.001	0.000	0.000	0.000	0.000
113	0.290	0.086	0.026	0.008	0.002	0.001	0.000	0.000	0.000	0.000
114	0.287	0.084	0.025	0.007	0.002	0.001	0.000	0.000	0.000	0.000
115	0.284	0.082	0.024	0.007	0.002	0.001	0.000	0.000	0.000	0.000
116	0.281	0.080	0.023	0.007	0.002	0.001	0.000	0.000	0.000	0.000
117	0.278	0.078	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000
118	0.275	0.077	0.022	0.006	0.002	0.001	0.000	0.000	0.000	0.000
119	0.272	0.075	0.021	0.006	0.002	0.000	0.000	0.000	0.000	0.000
120	0.269	0.073	0.020	0.006	0.002	0.000	0.000	0.000	0.000	0.000

GENERAL DISCOUNT FACTORS

Tax Rate = 50 %

Discount Rate 'i'

Year	0.02	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1	0.990	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909
2	0.980	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826
3	0.971	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751
4	0.961	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683
5	0.951	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621
6	0.942	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564
7	0.933	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513
8	0.923	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467
9	0.914	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424
10	0.905	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386
11	0.896	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350
12	0.887	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319
13	0.879	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290
14	0.870	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263
15	0.861	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239
16	0.853	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218
17	0.844	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198
18	0.836	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180
19	0.828	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164
20	0.820	0.673	0.554	0.456	0.377	0.312	0.258	0.215	0.178	0.149
21	0.811	0.660	0.538	0.439	0.359	0.294	0.242	0.199	0.164	0.135
22	0.803	0.647	0.522	0.422	0.342	0.278	0.226	0.184	0.150	0.123
23	0.795	0.634	0.507	0.406	0.326	0.262	0.211	0.170	0.138	0.112
24	0.788	0.622	0.492	0.390	0.310	0.247	0.197	0.158	0.126	0.102
25	0.780	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092
26	0.772	0.598	0.464	0.361	0.281	0.220	0.172	0.135	0.106	0.084
27	0.764	0.586	0.450	0.347	0.268	0.207	0.161	0.125	0.098	0.076
28	0.757	0.574	0.437	0.333	0.255	0.196	0.150	0.116	0.090	0.069
29	0.749	0.563	0.424	0.321	0.243	0.185	0.141	0.107	0.082	0.063
30	0.742	0.552	0.412	0.308	0.231	0.174	0.131	0.099	0.075	0.057
31	0.735	0.541	0.400	0.296	0.220	0.164	0.123	0.092	0.069	0.052
32	0.727	0.531	0.388	0.285	0.210	0.155	0.115	0.085	0.063	0.047
33	0.720	0.520	0.377	0.274	0.200	0.146	0.107	0.079	0.058	0.043
34	0.713	0.510	0.366	0.264	0.190	0.138	0.100	0.073	0.053	0.039
35	0.706	0.500	0.355	0.253	0.181	0.130	0.094	0.068	0.049	0.036
36	0.699	0.490	0.345	0.244	0.173	0.123	0.088	0.063	0.045	0.032
37	0.692	0.481	0.335	0.234	0.164	0.116	0.082	0.058	0.041	0.029
38	0.685	0.471	0.325	0.225	0.157	0.109	0.076	0.054	0.038	0.027
39	0.678	0.462	0.316	0.217	0.149	0.103	0.071	0.050	0.035	0.024
40	0.672	0.453	0.307	0.208	0.142	0.097	0.067	0.046	0.032	0.022
41	0.665	0.444	0.298	0.200	0.135	0.092	0.062	0.043	0.029	0.020
42	0.658	0.435	0.289	0.193	0.129	0.087	0.058	0.039	0.027	0.018
43	0.652	0.427	0.281	0.185	0.123	0.082	0.055	0.037	0.025	0.017
44	0.645	0.418	0.272	0.178	0.117	0.077	0.051	0.034	0.023	0.015
45	0.639	0.410	0.264	0.171	0.111	0.073	0.048	0.031	0.021	0.014
46	0.633	0.402	0.257	0.165	0.106	0.069	0.044	0.029	0.019	0.012
47	0.626	0.394	0.249	0.158	0.101	0.065	0.042	0.027	0.017	0.011
48	0.620	0.387	0.242	0.152	0.096	0.061	0.039	0.025	0.016	0.010
49	0.614	0.379	0.235	0.146	0.092	0.058	0.036	0.023	0.015	0.009
50	0.608	0.372	0.228	0.141	0.087	0.054	0.034	0.021	0.013	0.009
51	0.602	0.364	0.221	0.135	0.083	0.051	0.032	0.020	0.012	0.008
52	0.596	0.357	0.215	0.130	0.079	0.048	0.030	0.018	0.011	0.007
53	0.590	0.350	0.209	0.125	0.075	0.046	0.028	0.017	0.010	0.006
54	0.584	0.343	0.203	0.120	0.072	0.043	0.026	0.016	0.010	0.006
55	0.579	0.337	0.197	0.116	0.068	0.041	0.024	0.015	0.009	0.005
56	0.573	0.330	0.191	0.111	0.065	0.038	0.023	0.013	0.008	0.005
57	0.567	0.323	0.185	0.107	0.062	0.036	0.021	0.012	0.007	0.004
58	0.562	0.317	0.180	0.103	0.059	0.034	0.020	0.012	0.007	0.004
59	0.556	0.311	0.175	0.099	0.056	0.032	0.018	0.011	0.006	0.004
60	0.550	0.305	0.170	0.095	0.054	0.030	0.017	0.010	0.006	0.003

Discount Rate 'i'

<i>Year</i>	<i>0.02</i>	<i>0.04</i>	<i>0.06</i>	<i>0.08</i>	<i>0.10</i>	<i>0.12</i>	<i>0.14</i>	<i>0.16</i>	<i>0.18</i>	<i>0.20</i>
61	0.545	0.299	0.165	0.091	0.051	0.029	0.016	0.009	0.005	0.003
62	0.540	0.293	0.160	0.088	0.049	0.027	0.015	0.008	0.005	0.003
63	0.534	0.287	0.155	0.085	0.046	0.025	0.014	0.008	0.004	0.002
64	0.529	0.282	0.151	0.081	0.044	0.024	0.013	0.007	0.004	0.002
65	0.524	0.276	0.146	0.078	0.042	0.023	0.012	0.007	0.004	0.002
66	0.519	0.271	0.142	0.075	0.040	0.021	0.011	0.006	0.003	0.002
67	0.513	0.265	0.138	0.072	0.038	0.020	0.011	0.006	0.003	0.002
68	0.508	0.260	0.134	0.069	0.036	0.019	0.010	0.005	0.003	0.002
69	0.503	0.255	0.130	0.067	0.035	0.018	0.009	0.005	0.003	0.001
70	0.498	0.250	0.126	0.064	0.033	0.017	0.009	0.005	0.002	0.001
71	0.493	0.245	0.123	0.062	0.031	0.016	0.008	0.004	0.002	0.001
72	0.488	0.240	0.119	0.059	0.030	0.015	0.008	0.004	0.002	0.001
73	0.484	0.236	0.116	0.057	0.028	0.014	0.007	0.004	0.002	0.001
74	0.479	0.231	0.112	0.055	0.027	0.013	0.007	0.003	0.002	0.001
75	0.474	0.226	0.109	0.053	0.026	0.013	0.006	0.003	0.002	0.001
76	0.469	0.222	0.106	0.051	0.025	0.012	0.006	0.003	0.001	0.001
77	0.465	0.218	0.103	0.049	0.023	0.011	0.005	0.003	0.001	0.001
78	0.460	0.213	0.100	0.047	0.022	0.011	0.005	0.002	0.001	0.001
79	0.456	0.209	0.097	0.045	0.021	0.010	0.005	0.002	0.001	0.001
80	0.451	0.205	0.094	0.043	0.020	0.009	0.004	0.002	0.001	0.000
81	0.447	0.201	0.091	0.042	0.019	0.009	0.004	0.002	0.001	0.000
82	0.442	0.197	0.089	0.040	0.018	0.008	0.004	0.002	0.001	0.000
83	0.438	0.193	0.086	0.039	0.017	0.008	0.004	0.002	0.001	0.000
84	0.434	0.189	0.083	0.037	0.017	0.007	0.003	0.002	0.001	0.000
85	0.429	0.186	0.081	0.036	0.016	0.007	0.003	0.001	0.001	0.000
86	0.425	0.182	0.079	0.034	0.015	0.007	0.003	0.001	0.001	0.000
87	0.421	0.179	0.076	0.033	0.014	0.006	0.003	0.001	0.001	0.000
88	0.417	0.175	0.074	0.032	0.014	0.006	0.003	0.001	0.001	0.000
89	0.412	0.172	0.072	0.030	0.013	0.006	0.002	0.001	0.000	0.000
90	0.408	0.168	0.070	0.029	0.012	0.005	0.002	0.001	0.000	0.000
91	0.404	0.165	0.068	0.028	0.012	0.005	0.002	0.001	0.000	0.000
92	0.400	0.162	0.066	0.027	0.011	0.005	0.002	0.001	0.000	0.000
93	0.396	0.159	0.064	0.026	0.011	0.004	0.002	0.001	0.000	0.000
94	0.392	0.155	0.062	0.025	0.010	0.004	0.002	0.001	0.000	0.000
95	0.389	0.152	0.060	0.024	0.010	0.004	0.002	0.001	0.000	0.000
96	0.385	0.149	0.059	0.023	0.009	0.004	0.002	0.001	0.000	0.000
97	0.381	0.146	0.057	0.022	0.009	0.004	0.001	0.001	0.000	0.000
98	0.377	0.144	0.055	0.021	0.008	0.003	0.001	0.001	0.000	0.000
99	0.373	0.141	0.054	0.021	0.008	0.003	0.001	0.000	0.000	0.000
100	0.370	0.138	0.052	0.020	0.008	0.003	0.001	0.000	0.000	0.000
101	0.366	0.135	0.051	0.019	0.007	0.003	0.001	0.000	0.000	0.000
102	0.362	0.133	0.049	0.018	0.007	0.003	0.001	0.000	0.000	0.000
103	0.359	0.130	0.048	0.018	0.007	0.002	0.001	0.000	0.000	0.000
104	0.355	0.128	0.046	0.017	0.006	0.002	0.001	0.000	0.000	0.000
105	0.352	0.125	0.045	0.016	0.006	0.002	0.001	0.000	0.000	0.000
106	0.348	0.123	0.044	0.016	0.006	0.002	0.001	0.000	0.000	0.000
107	0.345	0.120	0.042	0.015	0.005	0.002	0.001	0.000	0.000	0.000
108	0.341	0.118	0.041	0.014	0.005	0.002	0.001	0.000	0.000	0.000
109	0.338	0.115	0.040	0.014	0.005	0.002	0.001	0.000	0.000	0.000
110	0.335	0.113	0.039	0.013	0.005	0.002	0.001	0.000	0.000	0.000
111	0.331	0.111	0.038	0.013	0.004	0.002	0.001	0.000	0.000	0.000
112	0.328	0.109	0.036	0.012	0.004	0.001	0.001	0.000	0.000	0.000
113	0.325	0.107	0.035	0.012	0.004	0.001	0.000	0.000	0.000	0.000
114	0.322	0.105	0.034	0.011	0.004	0.001	0.000	0.000	0.000	0.000
115	0.318	0.103	0.033	0.011	0.004	0.001	0.000	0.000	0.000	0.000
116	0.315	0.101	0.032	0.011	0.003	0.001	0.000	0.000	0.000	0.000
117	0.312	0.099	0.031	0.010	0.003	0.001	0.000	0.000	0.000	0.000
118	0.309	0.097	0.031	0.010	0.003	0.001	0.000	0.000	0.000	0.000
119	0.306	0.095	0.030	0.009	0.003	0.001	0.000	0.000	0.000	0.000
120	0.303	0.093	0.029	0.009	0.003	0.001	0.000	0.000	0.000	0.000

APPENDIX E

Survey on Durability of Concrete Structures

Company Details:

1) How many engineers are currently employed in your organisation's structural department?

2) What is the approximate average annual turnover of your consulting practice?

3) Does your company support continuing education for your employee engineers? If so how?

4) Number of engineers by years of experience in structural department:

___ 1-5 ___ 6-10 ___ 11-15 ___ 16-20 ___ 20+

5) Sources of consulting work, (please give percentages):

___ Public ___ Private

6) Sizes of average project:

ie. many small contracts, few large ones?

7) Main types of work (please indicate):

___ transportation infrastructure

___ industrial infrastructure

___ industrial buildings

___ marine works

___ general building work

___ residential building

___ commercial/office development

___ township development

___ major civil infrastructure

(ie. dams, pipelines...)

___ other (please specify)

Role of Client and Consultant in Achieving Durability:

1) When requested to design a structure/project, are durability/longevity requirements usually stated by the client? If so how?

2) What is the primary concern of most clients (please specify according to public and private sectors): time, quality, or cost?

Public _____

Private _____

3) How would you define durability in the context of concrete structural engineering? What would be your requirements for a durable concrete structure?

4) What would you view as various options for achieving durable concrete structures? Do you consider these options during design?

5) How is 'durability' of the structure perceived by the client? Are clients aware of the various options mentioned in (4) above?

6) Do you in the ordinary course of events appraise the client of durability aspects of a design, and inform him of the various options for achieving durability?

7) In the event of non-compliance with a durability specification (for example, minimum cover depth) how would you as an engineer handle the contractual failure and the cost of remedial work? Would you insist on remedial measures?

Cost issues:

1) When examining the cost of various options of achieving durability, is this done on a life cycle basis? (Life Cycle costing is taken to mean, but not limited to: examining not only the initial cost of the structure but also the expected life time cost associated with the maintenance and repair of the structure for a given design.)

2) If it could be shown on the basis of life cycle costing, that the additional initial expense of producing a more durable structure is economically justifiable, would it be likely that your clients would adopt this?

3) Have you ever carried out any studies into the most cost effective methods for achieving long term durability in structures? If so what was the outcome?

Durability and the Concrete Code of Practice:

1) What is the minimum design life normally used for various structures?

- | | |
|--|--|
| <input type="checkbox"/> transportation infrastructure | <input type="checkbox"/> residential building |
| <input type="checkbox"/> industrial infrastructure | <input type="checkbox"/> commercial/office development |
| <input type="checkbox"/> industrial buildings | <input type="checkbox"/> township development |
| <input type="checkbox"/> marine works | <input type="checkbox"/> major civil infrastructure |
| <input type="checkbox"/> general building work | (ie. dams, pipelines...) |

2) In your experience does the application of the requirements of the current concrete code result in adequately durable concrete structures, given the various environments within which structures operate (please elaborate as necessary)?

3) How would you like to see the code of practice changed in order to reflect the need for durable concrete construction (assuming you identify with such a need)?

Case Studies:

Have you recently undertaken a project where durability requirements were a major concern? If yes could you provide some information relating to the following details:

- a) concrete grade _____
- cement type (ie. use of extenders) _____
- special provisions
(ie. coatings to steel or concrete surface) _____
- curing _____
- cover _____
- other design or construction details _____

b) What was the expected design life of the structure?

c) How would you classify the environment in which the structure is situated?
Extreme, Very Severe, Severe..?

d) Were there any materials constraints and if so what were they?

e) What were the major factors that governed the durability requirements that you selected?

f) Have any follow up surveys or monitoring been done on the structure?
If so what were the results?

In a hypothetical situation, if you were required to design a bridge column in the marine splash zone, what would you specify from a durability design point of view? (assuming 50 yr design life, 300 mm x 300 mm lightly loaded)

Thank you once again for your assistance