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An economic evaluation on FRP for bridge construction in South African coastal areas

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Master of Science in Civil Engineering

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Dedication

To the Almighty God

To my Father, Mother, and Sisters

To my extended Family, Friends and Colleagues.

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Abstract

Fibre Reinforced Polymers (FRP) have been used for approximately 30 years as concrete strengthening materials in structural applications. This is primarily due to Steel Reinforced Concrete (SRC) being susceptible to the corrosion of reinforcing steel, especially in coastal environments. However, the use of FRP composites for bridge construction is faced with challenges. These challenges arise from uncertainties regarding the high material and initial construction costs. Additionally, there is limited research available on the costs involved when incorporating the fibres in bridge construction. It then becomes critical to understand the life cycle costs of FRP in bridge construction. Furthermore, suitable economic and deterioration models can be used to predict these life cycle costs by employing a LCCA.

The research aim was to investigate the economic viability of using FRP as reinforcing elements in bridge construction. This was done by conducting a life cycle cost analysis (LCCA) on two highway beam bridge superstructure designs: a SRC superstructure and a GFRP-RC superstructure to determine the preferred design, which was used to conclude on the economic viability of FRP in bridge construction. The deterministic approach to the LCCA was selected and the outcome was expressed in terms of Present Worth of Costs (PWOC).

The initial construction costs were found to be the bulk, while the disposal costs were the least of the total LCC for both superstructure alternatives. Furthermore, initial construction costs of the SRC superstructure were found to be less than that of the GFRP-RC superstructure, by a margin of R 873 094. This was primarily due to the cost of E-glass reinforcement, approximately 2.1 to 2.9 times more expensive than the cost of steel reinforcement. Moreover, the cost of GFRP was seen to have decreased over the years. LCC savings were seen from the GFRP-RC superstructure over the SRC superstructure, by a margin of R4 627 830 in terms of maintenance costs. This was mainly due to the application of a corrosion inhibitor (concrete surface treatment) and the use of a cathodic protection system on the SRC bridge superstructure. Furthermore, the GFRP-RC superstructure was found to be the least cost-effective investment from approximately 34 years of a 75 year LCCA period. At the end of the analysis period, the SRC bridge superstructure was found to have cost savings of approximately R 753 921 in PWOC over the GFRP-RC superstructure.

Furthermore, a sensitivity analysis of the various input costs and discount rates of the LCCA was also conducted. Initial construction costs were found to have the highest positive correlation on the outcome of the LCCA. The other costs and as well as the discount rate were all found to have an insignificant effect on the outcome of the LCCA.

It was concluded that it was not economically viable to include FRP as reinforcing elements in bridge construction at the time. However, since the cost of FRP was seen to decrease over time, the inclusion of FRP rebars in bridge construction might be economically viable in the future.

Table of Contents

PLAGIARISM DECLARATION	I
DEDICATION	II
ACKNOWLEDGEMENTS	III
ABSTRACT.....	IV
LIST OF FIGURES	VII
LIST OF TABLES	VIII
LIST OF EQUATIONS.....	IX
LIST OF ABBREVIATIONS	X
CHAPTER 1: INTRODUCTION.....	12
1.1 BACKGROUND	12
1.2 PROBLEM STATEMENT AND SIGNIFICANCE	14
1.3 RESEARCH OBJECTIVES AND RESEARCH QUESTIONS.....	15
1.4 SCOPE AND LIMITATIONS.....	15
1.5 ORGANIZATION OF THE STUDY.....	16
CHAPTER 2: LITERATURE REVIEW	17
2.1 INTRODUCTION	17
2.2 ECONOMIC MODELS	17
2.2.1 <i>Equivalent Uniform Annual Cost (EUAC) method</i>	18
2.2.2 <i>Present Worth of Costs (PWOC) method</i>	19
2.2.3 <i>Equivalent Uniform Annual Net Return (EUANR) method</i>	20
2.2.4 <i>Net Present Value (NPV) method</i>	21
2.2.5 <i>Internal Rate of Return (IRR) method</i>	21
2.2.6 <i>Benefit-Cost Ratio (BCR) method</i>	22
2.3 LIFE-CYCLE COST ANALYSIS	24
2.3.1 <i>Direct Costs</i>	24
2.3.2 <i>Indirect Costs</i>	24
2.4 SENSITIVITY ANALYSIS.....	25
2.5 BRIDGE LIFE CYCLE COST ANALYSIS (BLCCA) STUDIES	26
2.6 DETERIORATION MODELS	40
2.6.1 <i>Introduction</i>	40
2.6.2 <i>SRC Bridge Deterioration</i>	41
2.6.3 <i>Deterioration of GFRP</i>	47
2.7 MAINTENANCE STRATEGIES	51
2.8 SUMMARY.....	56
CHAPTER 3: METHODOLOGY	58

3.1 INTRODUCTION	58
3.2 PROCEDURE	58
3.3 BRIDGE SUPERSTRUCTURE DESIGN.....	59
3.3.1 SRC T-Beam Bridge	59
3.3.2 GFRP-RC T-Beam Bridge.....	60
3.3.3 Materials	61
3.4 MAINTENANCE ACTIVITIES.....	62
3.4.1 Introduction.....	62
3.4.2 SRC superstructure	63
3.4.3 GFRP-RC superstructure	64
3.5 COST ESTIMATION	65
3.5.1 Introduction.....	65
3.5.2 Initial construction costs	65
3.5.3 Maintenance costs.....	66
3.5.4 Disposal costs.....	67
3.6 LCCA METHODS	68
3.6.1 Definition.....	68
3.6.2 Methods	68
3.7 DATA ANALYSIS AND VALIDATION	69
3.8 SUMMARY.....	70
CHAPTER 4: RESULTS AND DISCUSSIONS	71
4.1 INTRODUCTION	71
4.2 LCCA RESULTS	71
4.3 SENSITIVITY ANALYSIS.....	84
4.4 SUMMARY.....	87
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS	88
REFERENCES.....	90
APPENDICES.....	96
APPENDIX A1 – BRIDGE DESIGN	A1-1
APPENDIX A2 – DRAWINGS	A2-1
APPENDIX A3 – BILLS OF QUANTITIES	A3-1

List of Figures

Figure 1. Steel and FRP: Stress-strain diagram (CEB-Fip Task group 9.3 FRP, 2006).....	13
Figure 2. Elevation of Bridge (Ehlen & Marshall, 1996).....	26
Figure 3. Monolithic and non – monolithic deck-beam designs (Ehlen & Marshall, 1996).....	27
Figure 4. Smart Composite Bridge (Nystrom et al., 2003).....	29
Figure 5. St. James Bridge (Nystrom et al., 2003)	29
Figure 6. Learning curve (Nystrom et al., 2003).....	30
Figure 7. FRP deck panels, FRP rebars, and epoxy coated rebar during placement (Berg et al., 2006)	32
Figure 8. Total cumulative LCC displayed for the lifespan of the bridge (Bosman, 2015).....	35
Figure 9. LCC Composition (Haak, 2018)	36
Figure 10. Short-spanned vehicular bridge located in Florida (Cadenazzi et al., 2019)	37
Figure 11. The life cycle of bridge design alternatives (Cadenazzi et al., 2019).....	38
Figure 12. Bridge deterioration model (Hawk, 2002).....	40
Figure 13. The corrosion process (Mackechnie & Alexander, 2001)	42
Figure 14. Volume change of corroding steel which causes cracking (PCA, 2002).....	42
Figure 15. The probability density function of corrosion initiation time (Alipour, Shafei, & Shinozuka, 2010).....	45
Figure 16. Rijkswaterstaat’s model (Van Noortwijk & Frangopol, 2004).....	46
Figure 17. Frangopol’s model (Frangopol et al., 2000)	47
Figure 18. Effects of essential and preventative maintenance interventions bridge reliability (Frangopol et al., 2000).....	52
Figure 19. Principle of cathodic protection of steel in concrete (Highways England, 2020)....	54
Figure 20. SACP system (Byrne et al., 2016)	55
Figure 21. Bridge LCCA procedure	59
Figure 22 Bridge superstructure section view.....	60
Figure 23. Bridge superstructure plan view	60
Figure 24. The probabilistic approach to LCCA.....	69
Figure 25. GFRP/steel reinforcement cost ratio over time	73
Figure 26 LCC summary: SRC superstructure.....	81
Figure 27 LCC summary: GFRP-RC superstructure	81
Figure 28 LCC distribution: RC superstructure.....	82
Figure 29 LCC distribution: GFRP-RC superstructure	82
Figure 30. PWOC vs Time	83
Figure 31 Sensitivity of alternative superstructure LCCA to discount rate	86

.

List of Tables

Table 1. LCC of material alternatives with and without NTI costs (Ehlen & Marshall, 1996) .	28
Table 2. Life cycle costs of the bridge alternatives (Nystrom et al., 2003)	31
Table 3. Total life-cycle costs (all units in euro) (Mara et al., 2014).....	33
Table 4. Reinforcement costs (Bosman, 2015).....	34
Table 5. Bridge alternatives (Bosman, 2015)	34
Table 6. Categorised total costs of bridge alternatives (Haak, 2018).....	36
Table 7. Cost of Reinforcement alternatives (Cadenazzi et al., 2019)	39
Table 8. Bridge material properties	62
Table 9. SRC superstructure preventative maintenance activities	63
Table 10. SRC superstructure essential maintenance activities	64
Table 11. GFRP-RC superstructure preventative maintenance activities.....	65
Table 12. GFRP-RC superstructure essential maintenance activities.....	65
Table 13. SRC superstructure: Initial construction costs summary	72
Table 14. GFRP-RC superstructure: Initial construction costs summary.....	73
Table 15. SRC superstructure: Preventative maintenance costs after 10 and 20 years.....	74
Table 16. GFRP-RC superstructure: Preventative maintenance costs after 10 and 20 years ...	75
Table 17. SRC superstructure: Preventative maintenance costs after 25 years.....	76
Table 18. GFRP-RC superstructure: Preventative maintenance costs after 25 years	77
Table 19. SRC superstructure: Essential maintenance costs after 50	78
Table 20. GFRP-RC superstructure: Essential maintenance costs after 50 years.....	79
Table 21. SRC and GFRP-RC superstructure: Disposal costs.....	80
Table 22. Sensitivity of SRC superstructure LCCA to LCC.....	85
Table 23. Sensitivity of GFRP-RC superstructure LCCA to LCC	85

List of Equations

Equation (2-1).....19

Equation (2-2).....19

Equation (2-3).....19

Equation (2-4).....20

Equation (2-5).....21

Equation (2-6).....22

Equation (2-7).....22

Equation (2-8).....22

List of Abbreviations

Annual Benefits	Bj
American Concrete Institute	ACI
American Society for Testing and Materials	ASTM
American Association of State Highway and Transportation Officials	AASHTO
Aramid fibre-reinforced polymer	AFRP
Average Daily Traffic	ADT
Basalt fibre-reinforced polymer	BFRP
Benefit-Cost Ratio	BCR
Cathodic protection	CP
Carbon fibre-reinforced polymer	CFRP
Equivalent Uniform Annual Benefits	EUAB
Equivalent Uniform Annual Costs	EUAC
Equivalent Uniform Annual Net Return	EUANR
Fibre-reinforced polymers	FRP
Glass fibre-reinforced polymers	GFRP
Year	j
Initial construction costs	IC
Internal Rate of Return	IRR
Life – Cost Analysis	LCA
Life – Cycle Costing	LCC
Life – Cycle Cost Analysis	LCCA
Load and Resistance Factor Design	LRFD
Yearly Maintenance costs	Mj
Minimum Attractive Rate of Return	MARR
Net Present Benefits	NPB
Net Present Costs	NPC

Net Present Value	NPV
Operation, maintenance, and repair	OMR
Impressed Current Cathodic Protection	ICCP
Initial Investment	P
Potential of Hydrogen	pH
Present Worth of Costs	PWOC
Present Value of Costs	PVC
New Technology Introduction	NTI
National Institute of Standards and Technology	NIST
Yearly Operation costs	R _j
Reinforced Concrete	RC
Sacrificial anode protection	SACP
Salvage Value	S
South African National Standards	SANS
Single Payment Present Worth Factor	SPPWF
Stay-in-place	SIP
Seeman Composite Resin Infusion Molding Process	SCRIMP
Steel Reinforced Concrete	SRC
University of Missouri-Rolla	UMR
Uniform Series capital	USCRF
Uniform Series Sinking Fund Deposit	USSFDF
Ultraviolet	UV



Chapter 1: Introduction

1.1 Background

The 20th century has brought about a wide variety of new bridge construction materials. For example, Fibre reinforced polymers (FRP) have become commercially available as concrete strengthening materials in structural applications. According to Keller (2002), the application of FRP in the bridge construction industry has grown due to the favourable properties of the non-metallic fibres. Besides being used for aesthetics, these fibres also can be suitable alternatives to conventional bridge construction materials (Keller, 2002).

Steel reinforced concrete (SRC) is the most commonly used construction technology in the bridge construction industry, despite steel rebars being susceptible to corrosion. According to Zhang (2013), the corrosion of reinforcing steel is the most common source of distress in reinforced concrete (RC) bridges, especially in coastal environments. This is particularly prominent in splash/spray zones where the presence of corrosion inducing elements are found in seawater (Wilmot, 2007). Corrosion propagation takes place at a rate that depends on the availability of both oxygen and moisture. The process has detrimental consequences on the strength and ductility of SRC bridges (Apostolopoulos, 2012). As a result, high maintenance costs and a decreased bridge service life are expected, due to the accelerated rate of deterioration (Apostolopoulos, 2012). Research has demonstrated that replacing steel with FRP as reinforcement in SRC bridges could be a possible solution (Zhang, 2013).

FRP are made of various materials that enable these composites to function as structural elements in concrete. These factory-processed composites are mainly found in the form of Glass (GFRP), Carbon (CFRP), Aramid (AFRP), and Basalt (BFRP). The functions of the fibres are to provide structural support, while high-performance thermosetting matrices enable them to transmit forces, provide shape and protective performance (Keller, 2002). The stress-strain behaviour of these fibres is comparable to reinforcing and prestressing steel as shown in Figure 1. The fibres possess greater tensile strength than that of steel reinforcement and prestressing steel. However, the fibres exhibit brittle failure when the ultimate tensile strength has been reached.

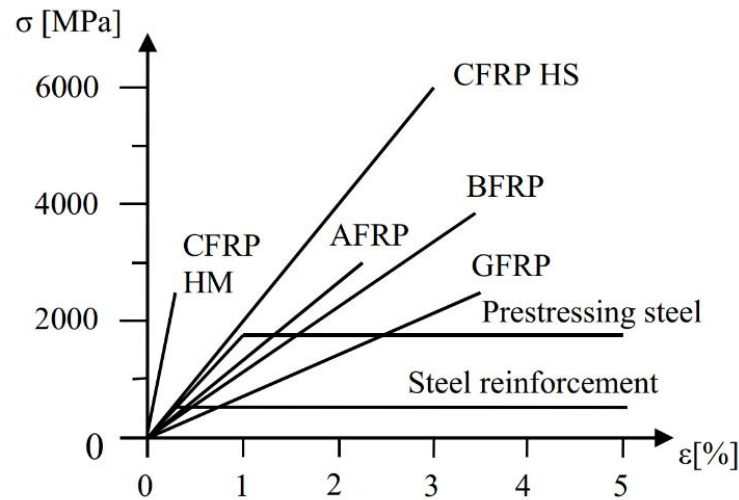


Figure 1. Steel and FRP: Stress-strain diagram (CEB-Fip Task group 9.3 FRP, 2006)

FRP products can be placed on construction sites easily, quickly, and with minimal traffic disruption (Keller, 2002). With design guidelines available the application of FRP products in construction is increasing. This is mainly due to the low weight of the fibres. Additionally, in bridge construction projects, it may be beneficial to consider the labour cost savings that can reduce life cycle costs (Mara et al., 2014). Other favourable properties of the fibres include high stiffness, a high degree of free formability, low thermal conductivity, chemical inertness, impact resistance, resistance to corrosion and fatigue (Hastak et al., 2003).

FRP can be used for existing construction and new construction purposes. FRP sheets are used for strengthening and retrofitting existing structures, which have been regarded as highly reliable (Potyrała, 2011). FRP tendons used for prestressing or posttensioning have found application in long-spanning bridges and stayed bridges (Potyrała, 2011). Furthermore, the tendons have found application in bridges exposed to aggressive environments (Burke & Dolan, 2001). The light tendons are easy to install and can be stored on-site. According to Soudki (1998), the FRP tendons are ideal for pre-stressing concrete bridge girders and deck slabs, due to their high tensile strength. The tendons can resist dead loads and thus eliminate existing deflections and close existing cracks.

However, lack of suitable anchorage systems have hampered the use of FRP in pre-stressed post-tensioned concrete (Soudki, 1998). Due to the approximately 20 to 1 axial to lateral strength ratio, the conventional anchorage systems for steel tendons cannot be used for FRP on tendons. The localised stress at the concrete ends and high FRP strains lead to the failure of the concrete components. Soudki (1998), observed that although anchorage systems were available at the time their efficiency could be enhanced. Al-Mayah et al (2001), used a modified four-wedge stainless steel anchor system for CFRP tendons and found that the tendons could be stressed at an acceptable design load without failure (Al-Mayah et al., 2001). Furthermore,



tendons can be monitored after installation with fibre optic sensors (CEB-Fip Task group 9.3 FRP, 2006) which enables engineers to monitor the behaviour and predict failure of the tendons.

In the past decades, FRP materials have been widely used in the aerospace, defence, automotive, marine, and leisure industries. However their adoption in the bridge construction industry has been rather modest (Hastak et al., 2003). This has been due to limited research and experience with the use of the materials. Furthermore, the industry bulks at high up-front costs associated with the design and use of the materials (Ehlen & Marshall, 1996). FRP bridges are expected to have higher initial costs than traditional RC bridges, due to the high costs involved in the manufacturing of the FRP (Nystrom et al., 2003). Uncertainties regarding fire resistances, lack of thermal compatibility with concrete, susceptibility to mechanical damage, low to no ductility, poor shear strength and longer load transfer length are contributing factors that obstruct the acceptance of these materials.

This study investigated the economic viability of using FRP as reinforcing elements in bridge construction in a harsh coastal environment. A life cycle cost analysis (LCCA) was performed on a SRC bridge superstructure and a Glass Fibre Reinforced Polymers – Reinforced Concrete (GFRP-RC) bridge superstructure which were designed for a coastal area to determine the cost-effective option. The outcome of the LCCA was used to draw conclusions regarding the viability of using FRP rebars in bridge construction in Cape Town, South Africa. Furthermore, the results of the study would serve as a basis for a better understanding of FRP use in bridge construction in the area.

1.2 Problem Statement and Significance

The use of FRP composites for bridge construction is faced with challenges. These challenges arise from uncertainties regarding the high material and initial construction costs (Ehlen & Marshall, 1996). Additionally, there is limited research available on the costs involved when incorporating the fibres in bridge construction. It then becomes critical to understand the life cycle costs of FRP bridge construction. Ehlen & Marshall (1996), suggested that suitable economic and deterioration models can be used to predict these life cycle costs by employing a LCCA.

Transportation agencies in South Africa stand to benefit from a LCCA of FRP. Moreover, the life cycle costs of these relatively new bridge construction materials could be better understood. The life cycle costs may then be compared to conventional bridge construction materials, such as reinforcing steel. Furthermore, this would enable planners as well as decision-makers to make informed decisions regarding the feasibility of incorporating FRP in bridge construction in the coastal areas of South Africa.



1.3 Research Objectives and Research Questions

The research aims to investigate the economic viability of using FRP as reinforcing elements in bridge construction in a coastal environment. This was done by conducting a life cycle cost analysis (LCCA) on two highway beam bridge superstructure designs: a SRC superstructure and a GFRP-RC superstructure to determine the preferred design. The results would serve as an indication of the viability of FRP in bridge construction.

This study was completed by achieving the following primary objectives:

- Performing a LCCA on a SRC highway beam bridge and a GFRP-RC highway beam bridge superstructure to determine the cost-effective investment.
- Identifying the factors critical to the cost-effectiveness of both bridge superstructure designs.

The research questions were:

- What are the major defects of GFRP-RC and what are the associated deterioration mechanisms?
- When is it feasible to use GFRP-RC in South African coastal bridge construction?

1.4 Scope and Limitations

The study was based on bridge superstructure alternatives designed for a non-saturated coastal area in Cape Town, South Africa. Furthermore, the life cycle costs considered for the economic evaluation were typical of a bridge constructed in the area. The bridges were designed according to the ACI 318 and AASTHO LRFD Bridge design specifications, due to the lack of FRP design standards for South Africa.



1.5 Organization of the study

The research study is presented as follows:

Chapter 1

The chapter firstly introduces the background of the research study, followed by the problem statement and significance briefly explained. The research objectives and research questions are then outlined. Finally, the scope and limitations of the study are presented.

Chapter 2

In this chapter, the economic models used to evaluate investments are reviewed. This was followed by the review of LCCA and Sensitivity Analysis methods. Then, previous LCCA studies that had incorporated the use of FRP in bridge construction were presented. Thereafter, the deterioration mechanisms and models for bridge structures are reviewed. Finally, the chapter is summarised.

Chapter 3

The chapter presents the methodology of the study. The procedure adopted; bridge superstructure designs; and maintenance activities are explained. Thereafter, the different methods of an LCCA are described. The method adopted for Data analysis and validation: a Sensitivity Analysis is then explained followed by a summary of the chapter.

Chapter 4

In this chapter, the results of the LCCA and Sensitivity Analysis are presented. Followed by critical discussions of the results. Lastly, a summary of the results is presented.

Chapter 5

The chapter concludes the study and provides recommendations.



Chapter 2: Literature Review

2.1 Introduction

Conducting a LCCA on a SRC and GFRP-RC bridges requires the researcher to have a clear understanding of the LCC and deterioration mechanisms of the bridge structures. However, since GFRP-RC is a relatively new material the LCC and deterioration mechanisms are more qualitative than quantitative i.e. they are not entirely understood.

This chapter reviews the literature of similar studies on economic evaluation techniques for engineering projects, namely the equivalent uniform annual cost (EUAC), present worth of costs (PWOC), equivalent uniform annual net return (EUANR), net present value (NPV), internal rate of return (IRR) and benefit-cost ratio (BCR). The LCCA and sensitivity analysis were then reviewed, followed by previous research summaries on economic assessments of FRP bridge construction materials. A LCCA is a summary of the initial construction, maintenance and rehabilitation, and disposal costs of a structure, while a sensitivity analysis was conducted to account for the uncertainty of the LCCA.

2.2 Economic Models

The existing research on the use of FRP materials in bridge construction projects is still developing and the application of FRP in structural engineering is still relatively low. Furthermore, the FRP industry faces a challenge of high initial costs. A clear understanding of the life cycle costs is necessary to overcome this cost barrier. Practical economic models may be used to evaluate these materials to aid officials and decision-makers in the adaptation of these materials. Models that apply to a project and its alternatives can be used to determine the project cost and benefits (Ehlen & Marshall, 1996).

Typically, the assessment of engineering projects is carried out using a wide range of criteria that can be monetary or non-monetary or both. Project effectiveness is linked to non-monetary criteria, while monetary criteria are based on money values. The basic theory underlying all engineering economic analysis in this respect is that the value of money is directly related to the time when the value is taken into account. (Sinha, 2003). This means that the value funds at the initial construction of a bridge are not similar in value to future costs. The combined effects of inflation and opportunity cost which cause money to lose value over time.

According to Sabya (2013), the methods of economic evaluation will all favour the best alternative for an investment project, when the correct calculations and procedures are followed. Therefore, there is no best method and the choice of method is determined by the following:

- The form of data available
- Availability of benefit and income amounts



- Analyst and Decision-maker preferences

The models are as listed below:

1. Equivalent Uniform Annual Cost (EUAC)
2. Present Worth of Costs (PWOC)
3. Equivalent Uniform Annual Net Return (EUANR)
4. Net Present Value (NPV)
5. Internal Rate of Return (IRR)
6. Benefit-Cost Ratio (BCR)

The models have the common objective of comparing the future streams of costs and benefits in such a way that for a specific future period the analysis will disclose the probable net return on the proposed investment, or the most economical design required to produce the returns (Sabya, 2013). Each method applies the principles and concepts of compound interest in a way to take into account the differences in the worth of money over time.

2.2.1 Equivalent Uniform Annual Cost (EUAC) method

The Equivalent Uniform Annual Cost (EUAC) is the ‘payment’ required to finance a project over the service life (Hoff, 2006). This ‘payment’ is measured using the same criteria used when funding mortgages. Furthermore, the LCC represents the ‘purchase price’ and the estimated uniform annual cost represents the ‘mortgage payment’ needed for a given interest rate to completely fund the LCC by the end of the specified service life (Hoff, 2006).

A major advantage of this method is that it can compare project alternatives with different service lives over the same number of years. (Emad, 1992). However, alternatives should be mutually exclusive and repeatedly renewed up to the duration of the longest life alternative (Desai, 2018). The method combines investment costs and annual expenses into a single annual sum that is equivalent to all disbursements during the analysis period. Moreover, the alternative with the least equivalent uniform annual cost is said to be the most economical (Sabya, 2013). Hoff (2006), used the method to conduct an economic analysis of roofing systems throughout the United States. Moreover, the method was said to identify the economic benefits of each roofing system.

The method combines all initial construction costs, maintenance and operation costs, and terminal salvage costs if any, of an infrastructure system into a single annual cost over the analysis period of n years. Furthermore, the general case of a system that is associated with an



initial investment P , maintenance M_j and operation costs R_j for each year j , and salvage value S at the end of its service life (Sinha, 2003). The EUAC is expressed as follows:

$$EUAC = P * USCRF(i, n) + \sum_{j=1}^n [(M_j + R_j) * SPPWF(i, j) * USCRF(i, n)] - S * USSFDF(i, n) \quad \text{Equation (2-1)}$$

Where:

$$\text{Uniform Series capital (USCRF)} = \frac{i * (1+i)^N}{(1+i)^N - 1}.$$

$$\text{Single Payment Present Worth Factor (SPPWF)} = \frac{1}{(1+i)^N}.$$

$$\text{Uniform Series Sinking Fund Deposit (USSFDF)} = \frac{i}{(1+i)^N - 1}.$$

2.2.2 Present Worth of Costs (PWOC) method

The Present Worth of Costs (PWOC) is an economic method for analysing investment alternatives capable of performing the same functions (Desai, 2018). However, the method is restricted to evaluating mutually exclusive alternatives (Desai, 2018). The method converts all initial investments, maintenance and operation costs, and terminal salvage costs if any, of an infrastructure system into an equivalent single cost incurred at the start of the analysis period (Sinha, 2003). Furthermore, the equivalent present value of costs, or Present Value of Costs, PVC, is given by the following expression, the definition of the terms are as in Section 2.2.3:

$$PWOC = P + \sum_{j=1}^n [M_j * SPPWF(i, j)] + \sum_{j=1}^n [R_j * SPPWF(i, j)] - S * SPPWF(i, n) \quad \text{Equation (2-2)}$$

Soliman et al., (2019) defined the PWOC equation for RC Bridge Decks with the following expression:

$$C_T = C_{init} + \sum_{i=1}^n (C_{main} + C_{TLi} + C_{ci} + C_{Ei}) \div (1 + r)^{yi} \quad \text{Equation (2-3)}$$

Where:

C_T = total life-cycle cost of a bridge.

C_{init} = cost of initial construction.

n = number of times that maintenance will be performed during the service life.

C_{main} = maintenance cost of i th maintenance.

C_{TLi} = traffic delay cost during i th maintenance.

C_{ci} = crash cost due to the intervention activity.

C_{Ei} = environmental influence cost during i th maintenance.

r = discount rate of money; and

y_i = number of years used in discounting future costs of i th maintenance.

The PWOC expression in equation (2-3) is the simplified version of equation (2-2), which excludes the terminal costs. Soliman et al (2019), used equation (2-3) to calculate the PWOC for bridge decks that had not reached the end of their service lives. Hence the equation (2-3) did not include terminal costs.

The discount rate reflects the value of money over time. In the study, it was assumed to be 5%, as recommended for long-term projects (Sahirman, 2009).

The use of EUAC and PWOC for economic assessment is correlated with the presumption that benefits from alternatives are identical or that it is difficult to evaluate their monetary values (Sinha, 2003). However, where there are observable and important variations in the valuation of benefits from one option to another, the use of costs alone for economic analysis is insufficient.

2.2.3 Equivalent Uniform Annual Net Return (EUANR) method

The Equivalent Uniform Annual Net Return (EUANR) is the EUAC with the inclusion of a benefit factor (Desai, 2018). The benefit factor enables the method to rank alternatives according to their desirability. Moreover, the method combines all initial costs, subsequent maintenance and operation costs and terminal salvage costs if any, and annual, periodic, and terminal benefits (B_j) of an infrastructure system into a single annual value of return (benefits less costs) over the analysis period (Sinha, 2003). Hence the method could inform the analyst of the amount by which the equivalent uniform annual income exceeds (or is less than) the equivalent uniform annual cost.

The equivalent uniform annual return, EUAR, is given by the following expression, the definition of the terms are as in Section 2.2.3:

$$EUAR = -P * USCRF(i, n) + \sum_{j=1}^n [(B_j - M_j - R_j) * SPPWF(i, j) * USCRF(i, n)] + S * USSFDF(i, n)$$

Equation (2-4)



2.2.4 Net Present Value (NPV) method

The Net Present Value (NPV) is the difference between the present value of benefits and the present value of costs of an investment (Sinha, 2003). The NPV method combines all initial construction costs, subsequent maintenance and operation costs and terminal salvage costs if any, and annual, periodic, and terminal benefits of an infrastructure system into an equivalent single value of return (benefits less costs) at the beginning of the analysis period (Sinha, 2003).

The equivalent net present value, NPV, is given by the following expression, the definition of the terms are as in Section 2.2.3:

NPV = Present worth of Benefits – Present Worth of Costs

$$NPV = \sum_{j=1}^n [B_j * SPPWF(i, j)] - P - \sum_{j=1}^n [M_j * SPPWF(i, j)] - \sum_{j=1}^n [R_j * SPPWF(i, j)] - S * SPPWF(i, n)$$

Equation (2-5)

Investments associated with the highest NPV are considered the best investments. The method most commonly used to determine the present value of future money. Furthermore, the method can be used to compare alternatives of equal, unequal, and infinite lives. When a project alternative is considered infinite, the analysis is called capitalized cost. This is the present sum of money that would need to be set aside now, at some interest rate, to yield the funds required to provide the service for the foreseeable future (Emad, 1992).

The EUANR and NPV methods consider investment benefits which makes them superior to the cost only methods. Moreover, the NPV provides a logical net benefit for an investment and is the recommended method of economic evaluation by AASTHO (Litman, 2006; Sinha, 2003)

2.2.5 Internal Rate of Return (IRR) method

An economic rate of return is defined as the interest rate at which the net present worth or equivalent uniform annual return is equal to zero (Sinha, 2003). The method of Internal Rate of Return (IRR) determines the interest rate that is associated with a zero NPV and is therefore related with equilibration of the present value of benefits and the present value of costs (Sinha, 2003).

A Minimum Attractive Rate of Return (MARR) criterion is established to specify the minimum level of economic performance all investments are required to satisfy (Desai, 2018). Once the MARR is known the IRR is compared to the (MARR). If the IRR exceeds the MARR, then the investment is considered worthwhile.

The IRR value is found as follows, the definition of the terms is as in Section 2.2.3:

Present worth of Benefits = Present Worth of Costs

$$\sum_{j=1}^n [B_j * SPPWF(i, j)] + S * SPPWF(i, n) = P + \sum_{j=1}^n [M_j * SPPWF(i, j)] + \sum_{j=1}^n [R_j * SPPWF(i, j)] \quad \text{Equation (2-6)}$$

Alternatively, the IRR value can be found as follows:

Equivalent Uniform Annual Benefits = Equivalent Uniform Annual Costs

$$\sum_{j=1}^n [B_j * SPPWF(i, j) * USCRF(i, n)] + S * USSFDF(i, n) = P * USCRF(i, n) + \sum_{j=1}^n [(M_j + R_j) * SPPWF(i, j) * USCRF(i, n)] \quad \text{Equation (2-7)}$$

Like the NPV and EUANR, the IRR method also considers both benefits and costs. The complexity of the method mainly arises from the computation of the IRR since a unique solution is not always guaranteed (Sinha, 2003). Moreover, the value of the interest rate that satisfies the above equations can be however found using trial and error, or a computer spreadsheet. If several alternative investments are being evaluated, the best investment is one that has the highest IRR.

2.2.6 Benefit-Cost Ratio (BCR) method

The Benefit-Cost Ratio (BCR) method is used for project evaluation in a municipal setting where the benefits and costs accrue to different segments of the community (Sinha, 2003). The BCR is a ratio of the equivalent uniform annual value (or net present value of all benefits to that of all costs incurred over the analysis period). Furthermore, an alternative investment with a BCR exceeding 1 is considered to be economically feasible, and the alternative with the highest BCR value is considered the best alternative (Sinha, 2003). The BCR of an investment is calculated as follows:

$$BCR = \frac{EUAB}{EUAC} = \frac{NPB}{NPC} \quad \text{Equation (2-8)}$$

Where:

EUAB: Equivalent Uniform Annual Benefits



EUAC: Equivalent Uniform Annual Costs

NPB: Net Present Benefits

NPC: Net Present Costs

It is often difficult to determine whether a cash flow is a cost. Regardless of where the cash flow is placed, an acceptable project will always have a benefit-cost ratio greater than or equal to 1.0, although the actual numerical result will depend on the placement of the cash flow. For this reason, the benefit-cost ratio alone should not be used to rank competing projects (Desai, 2018). According to Sinha 2003, the method does not provide the extent of the benefit of an investment and is therefore no longer recommended as a desirable approach.



2.3 Life-Cycle Cost Analysis

Life cycle cost analysis (LCCA) is a methodology that may be used for evaluating various transportation investment decisions. The analysis is applied when an investment under consideration requires aid on the most cost-effective way of completing the project while still satisfying the requirements of the investment (U.S. Department of Transportation, 2002). Competing design alternatives for investment, which have the same level of service are compared. This is done by converting the total life-cycle costs for each alternative into present value. When selecting a particular investment alternative, initial project costs of the structure dominate the infrastructure owner's decision (U.S. Department of Transportation, 2002). These costs alone do not provide the full picture. The infrastructure owner will also be responsible for future expenditures of maintenance and rehabilitation (M&R) activities as well as disposal costs, these costs are known as direct costs. Furthermore, users will accrue costs due to these activities. The LCCA, therefore, includes both indirect and direct costs.

2.3.1 Direct Costs

The costs are considered to be critical in the LCCA of structures. These are costs incurred to the infrastructure owner for initial construction, M&R activities and disposal of a structure. Cost estimates may be acquired from historical records, current bids, or otherwise from engineering judgment. Direct costs are affected by the value of the alternative at the end of the analysis, known as terminal value (U.S. Department of Transportation, 2002). There are types of terminal value, namely "salvage value" and "remaining service life" (RSL) value. The former is the value of the recycled materials at the end of a project's life. According to the Federal Highway Administration (1998), the salvage value may be left out, due to its little effect on the LCCA outcome. This is the case since the salvage value is discounted over a long period. The latter terminal value occurs when the design life of an investment alternative exceeds the period over which the LCCA is conducted. The investment alternative is said to have an RSL value. The RSL values differ significantly for different alternatives and should be included in an LCCA.

2.3.2 Indirect Costs

These costs are accrued by the users of the investment alternative and are derived from vehicle operating costs, travel time costs, and crash costs. Moreover, they are a product of timing, duration, scope, and the number of construction and rehabilitation work zones, which restrict the normal capacity of the facility and reduce traffic flow. The incorporation of user costs in an LCCA increases the reliability of the results. However, these costs are often similar between alternatives and may be removed from the analysis, due to the complex task of determining these costs (U.S. Department of Transportation, 2002).



2.4 Sensitivity Analysis

The estimates of costs in a deterministic LCCA does not incorporate uncertainty and variability. This is due to the difficulty in obtaining accurate information for cost estimation which may vary depending on individuals and conditions (Litman, 2006). To take into account the parameters of uncertainty for a deterministic LCCA, a sensitivity analysis is carried out (Cadenazzi et al., 2020). Furthermore, an economic analysis is made more accurate once a sensitivity analysis has been performed (How & Rahman, 2012). The sensitivity analysis is used to determine which inputs when varied have the greatest effect on the outcome of an LCCA (Cavalline et al., 2015).

Cadenazzi et al (2020), conducted sensitivity analyses on FRP and SRC bridge structures in a corrosive environment. The parameters varied were the cost of reinforcement, chloride concentration levels over the service life of the bridge and the discount rate. Parameters of cost of reinforcement and chloride concentration levels were found to have a slight impact on the PWOC. However, the discount rate had minimal impact on the low-maintenance cost-bridge alternatives, while having a considerable impact on the high-maintenance cost-bridge alternatives. When the bridge alternatives were plotted for each PWOC while varying the discount rates. For alternatives that had not reached a breakeven point, these alternatives were said to only be affected by the initial cost of construction (Cadenazzi et al., 2020).

Sahirman (2009), performed a sensitivity analysis on the LCC of FRP and SRC bridge decks. The cost of manufacturing FRP was found to have a major impact on the LCC of the FRP decks. Moreover, the average daily traffic (ADT) was found to have minimal effect on the LCC of SRC decks while having a significant impact on the LCC of the FRP decks. The discount rate was found to affect the LCC of FRP decks much more than for SRC decks.

Similarly, Bosman (2015) conducted a sensitivity analysis on various spanning FRP and SRC bridge decks. It was found that the discount factor followed by the change in work zone length had the greatest influence on the LCC results. Furthermore, the other variables were found to have a minimal impact on the LCC.

2.5 Bridge Life Cycle Cost Analysis (BLCCA) studies

Ehlen & Marshall (1996) presented a framework for evaluating new-technology materials for highway bridge decking. The PWOC model was used to compare the economic efficiency of new materials to that of conventional materials to motivate decision-makers to consider the use of FRP materials in bridge construction.

A bridge that was still under construction in North Carolina, USA was used for the case study. The bridge had two 26 m lanes directly over an existing four-lane – interstate, which had a reinforced concrete deck as shown in Figure 2. Expansion joints were directly over the outer bents.

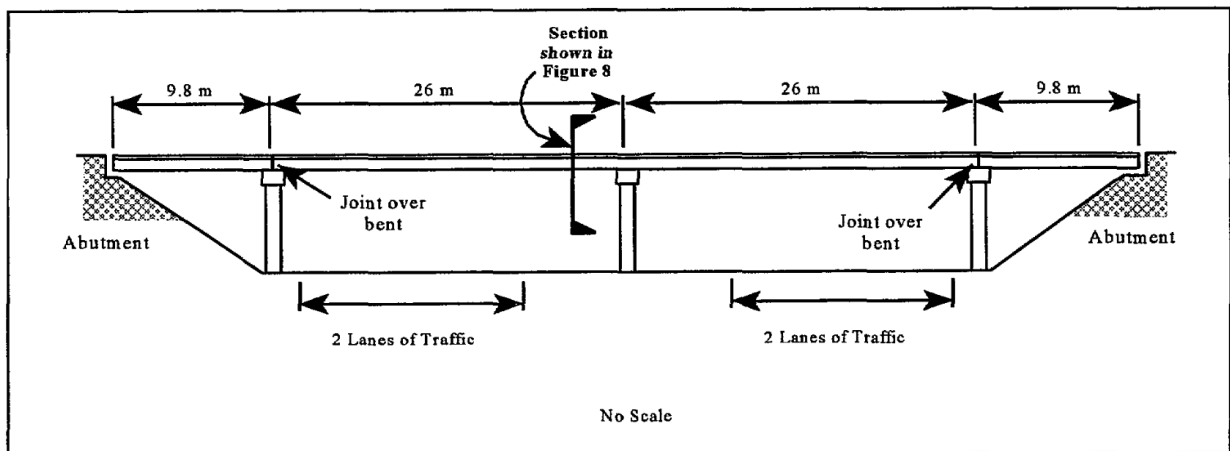


Figure 2. Elevation of Bridge (Ehlen & Marshall, 1996)

The alternatives considered were:

- SCRIMP FRP (Seeman Composite Resin Infusion Molding Process): Made of an E-glass fabric with a foam core.
- Wood-Core Sandwich: Composed of bamboo sections that assembled into a rigid “sandwich” core covered with layers of fibreglass
- Pultruded-Plank Decks: Made of fibreglass fabric and fibreglass strand

The reinforced concrete deck and SCRIMP FRP deck were based on the superior monolithic deck-beam design. The Wood-Core and Pultruded-Plank decks are based on non-monolithic deck-beam designs as illustrated in Figure 3 below. Alternative materials were only used in the bridge decks. The bridge alternatives were considered to have Jersey concrete barriers that were attached to the decks via protruding reinforcing steel. An asphalt polymer concrete was used as a road surface on the bridge decks. Furthermore, the bridge decks rested on the existing seven prestressed concrete beams at 2.4 m c-c.

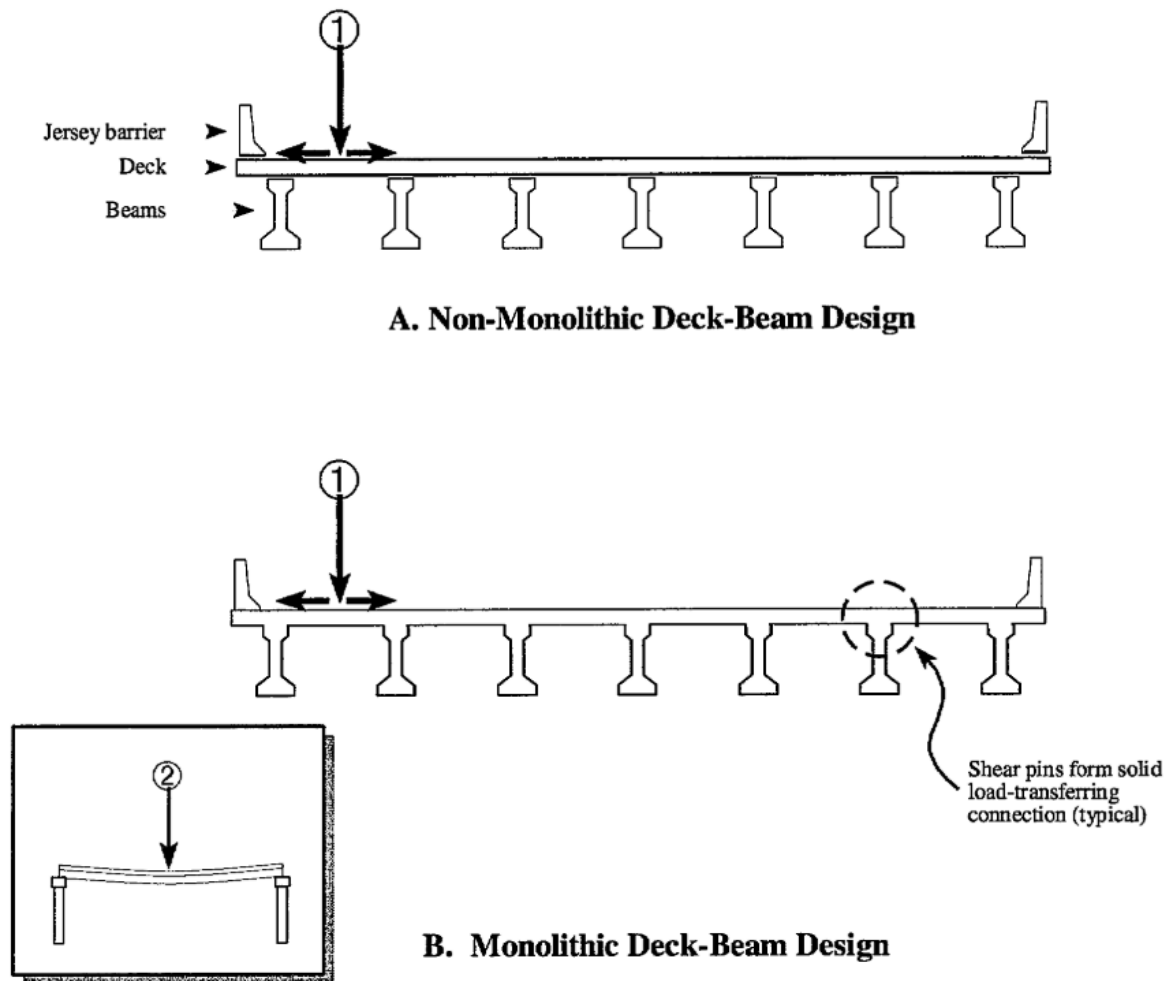


Figure 3. Monolithic and non – monolithic deck-beam designs (Ehlen & Marshall, 1996)

The life-cycle cost of each deck considered installation, inspection, maintenance and repair, and disposal of the deck while also satisfying the minimum load requirements of AASHTO HS20. The life of the bridge was 40 years with a real discount rate of 3.0% for computing the present value of all future costs among other assumptions.

While infrastructure owner costs and user costs were identified for each alternative, no third-party costs were found due to the rural location of the bridge. The researchers found, as shown in Table 1 that the reinforced concrete deck was the most cost-effective alternative when new technology introduction (NTI) costs were considered. The Pultruded-Plank FRP deck was the most expensive alternative. The Wood-Core deck would have been the most cost-effective if the NTI costs were not considered. This was encouraging as these costs would be spread out over long periods of using FRP composites.



Table 1. LCC of material alternatives with and without NTI costs (Ehlen & Marshall, 1996)

Material	LCC with NTI Costs	LCC without NTI Costs
Reinforced Concrete	\$ 345 374	\$ 345 375
SCRIMP FRP	\$ 634 548	\$ 548 174
Wood-Core FRP	\$ 401 163	\$ 314 789
Pultruded-Plank FRP	\$ 673 195	\$ 586 821

To deal with uncertainty, breakeven and sensitivity analysis were carried out. The breakeven analysis results showed that there was no point at which the pultruded-plank FRP deck was cost-effective. The sensitivity analysis proved the total LCC is most vulnerable to material cost and the length of the roadwork.

Nystrom et al (2003), evaluated the viability of FRP materials use for standard short-span bridges in Missouri USA. The bridges spanned less than 10m and were primarily found in rural highways and city streets. These bridges could be transported in nearly complete form to a bridge site and had fibre optic sensors incorporated with them for long term observations. The study investigated at the time, current and future costs of two FRP short-span bridges to a conventional steel-reinforced bridge to evaluate the cost competitiveness. New bridge construction was used for the study.

Bridge no. 1 was the pedestrian Smart Composite Bridge located at the University of Missouri Rolla (UMR) Campus as shown in Figure 4. Furthermore, the bridge was built in July 2000. With an approximate length of 9.1 m and width of 2.8 m, it had been designed for an AASHTO HS20 highway load rating with a safety factor of three. Made of 76 mm modular alternating assembly of pultruded FRP square tubes and Carbon tubes in the top and bottom continuous layers. Bridge no. 2 was the residential St. James Bridge located in St. Francis Street as shown in Figure 5. Moreover, the bridge was built in November 2000. The approximate length of 8 m and width of 8.33 m was also designed according to AASHTO HS20. Made of four 600mm GFRP honeycomb sandwich panels with a 9.5 mm polymer concrete wear surface. Material costs for Bridge no.2 were less than for Bridge no.1, based on experience and a design that was more focused on cost efficiency.

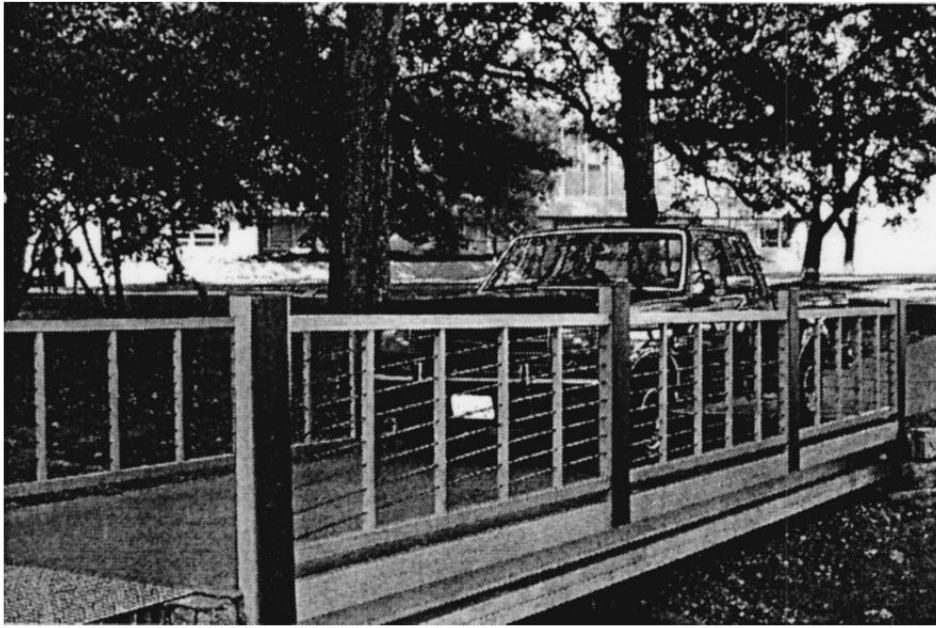


Figure 4. Smart Composite Bridge (Nystrom et al., 2003)



Figure 5. St. James Bridge (Nystrom et al., 2003)

Initial construction costs, life-cycle costs, future cost estimates, and indirect costs were observed for the bridge analysis. The analysis focused on the construction costs, due to the costs representing the largest costs in a bridges life (Nystrom et al., 2003). The construction

expenditures included material, manufacturing, fabrication, assembly, shipment, installation, and testing costs.

Lifecycle costs were also analysed, these included maintenance, inspection, repair, disposal, and replacement costs. Included in the analysis were future cost estimates for the construction and life-cycle costs. Lastly, indirect costs took account of aesthetics, disruption to the local community during construction, increased ability to withstand earthquakes, and the ability to incorporate health-monitoring sensors (Nystrom et al., 2003). The RC bridge had a service life of 40 years as per North Carolina Department of Transportation (NCDOT) standards while the FRP bridges had 60 years of service life.

Based on the Smart Composite and St. James bridge, cost estimates were made for a future bridge with the assumption that the initial costs would decrease due to improvements in the FRP industry. The learning curve approach was used to estimate these improvements. As shown in Figure 6, the approach predicts that with maturity in the design and manufacturing of FRP products the initial construction costs will decrease. For instance, in the case of GFRP applications, the fibres were found to cost less over the past 18 years (Nystrom et al., 2003).

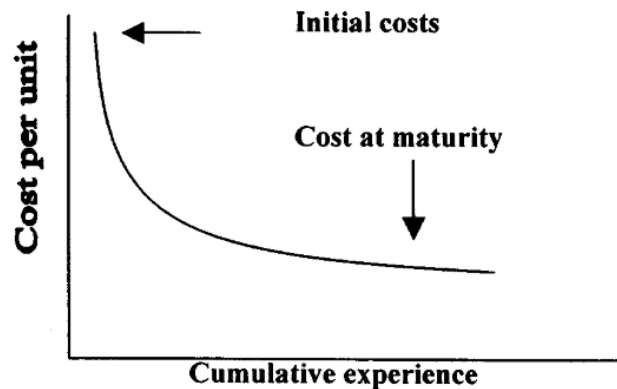


Figure 6. Learning curve (Nystrom et al., 2003)

The bridge surface area was assumed to be 100 m² with the abutments being excluded from the superstructure costs. However, the reinforced concrete bridge was not analysed with the learning curve approach, due to little to no impact expected in the technology. The learning curve approach predicted a 35% decrease in the initial construction costs (Nystrom et al., 2003). As shown in Table 2, the researcher subsequently found the conventional bridges to be cost-effective although the cost of the FRP bridges is expected to decrease according to the learning curve approach. The production processes were found to be wasteful and expensive, and with improvements, the construction costs will still be significantly higher.



Table 2. Life cycle costs of the bridge alternatives (Nystrom et al., 2003)

Description	RC bridges	Future bridge	FRP premium
Construction costs	\$ 430/m ²	\$ 740/m ²	\$ 310/m ²
Impact of disposal	\$ 45/m ²	\$ 9/m ²	\$ 36/m ²
Total cost including disposal	\$ 475/m ²	\$ 749/m ²	\$ 274/m ²
Impact of replacements	\$ 119/m ²	\$ 67/m ²	\$ 52/m ²
Total cost including disposal and longer life	\$ 594/m ²	\$ 816/m ²	\$ 222/m ²

Berg et al (2006), observed the construction process and costs of concrete highway bridge decks in Waupun, the USA which was built in May 2003. The first bridge deck, an FRP reinforced bridge deck was composed of two continuous spans of 32.7 m and a width of 12.75 m and a thickness of 215.9 mm. Reinforcement of the deck was glass–fibre reinforced vinyl ester FRP parts and the overhangs and parapet walls were reinforced with epoxy-coated steel as seen in Figure 7. The second bridge was an adjacent twin to the first bridge. The bridge was reinforced with conventional epoxy coated steel rebars and with a reduced deck thickness of 200 mm carrying traffic in the southbound direction. M2 m²

The combination of FRP materials in the project was unique and designed to reduce labour costs. This was done to cut down on the high initial costs associated with FRP materials in comparison to steel reinforcement. The combination of FRP reinforcing materials observed was made of three different components; stay-in-place (SIP) FRP pultruded deck panels, pultruded FRP rebars, and bi-directional FRP pultruded grids. Testing on these materials before construction produced satisfactory results. The panels were the most expensive from the materials used. Six quality assurance tests were performed on the materials, namely the longitudinal tension, longitudinal short beam shear, fibre volume fraction, water absorption, dimensional tolerance, and aggregate distribution.

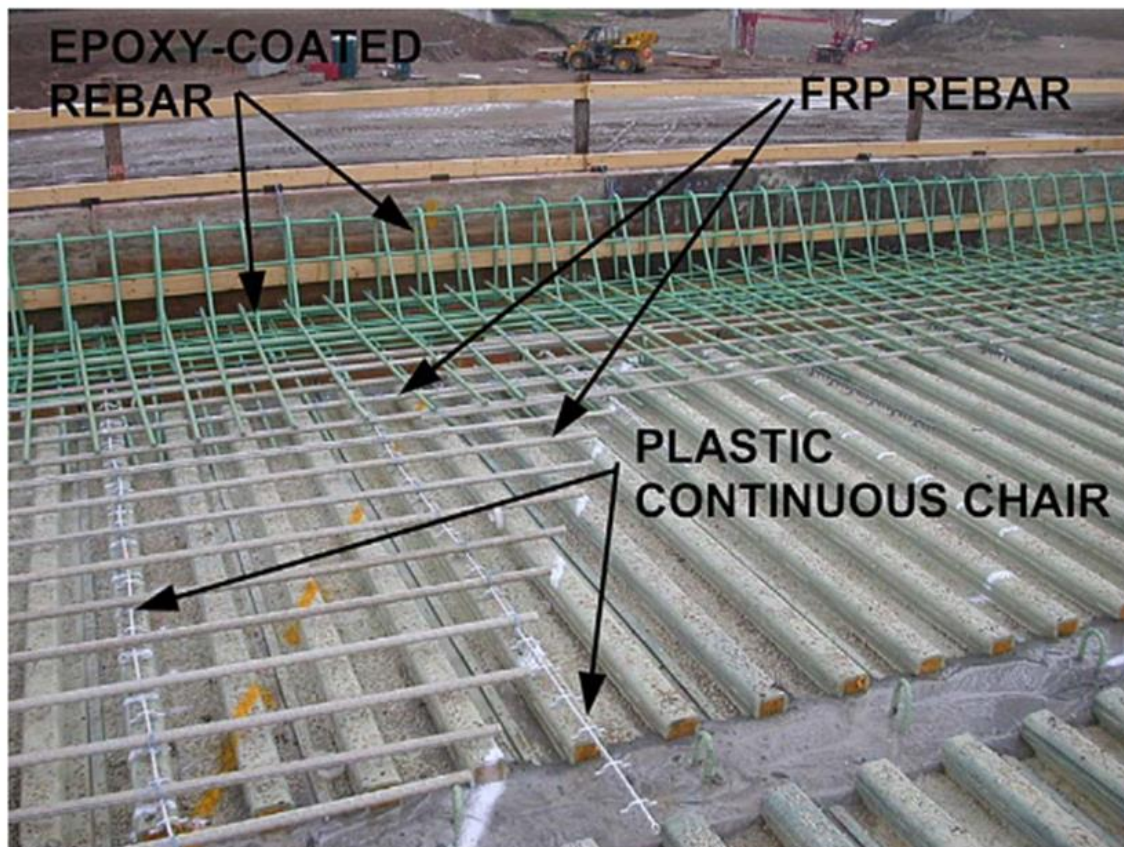


Figure 7. FRP deck panels, FRP rebars, and epoxy coated rebar during placement (Berg et al., 2006)

Material and labour costs were recorded during the construction of the two bridges. These costs were subsequently compared. The material costs for the FRP reinforced bridge were found to be over 60% higher than that of the conventional bridge. The conventional bridge required over 57% more labour costs, which saw cost savings in the FRP reinforced bridge. The researcher found that given savings in labour costs and potential long term benefits, the FRP reinforced bridge was said to be cost-effective. Furthermore, FRP material costs could have potentially decreased if optimization of designs and competitive bidding was encouraged (Berg et al., 2006).

Mara et al (2014), conducted a LCCA on an existing ageing steel-concrete bridge structure which had been built in 1948 in the north of Sweden over a small watercourse called Rokån. The bridge was simply supported with a 12 metres span and width of 6 metres carrying two lanes of traffic. The entire replacement of superstructure (alternative 1) and the replacement of the deck with a GFRP deck (alternative 2) were the two scenarios considered.

The LCCA for both alternatives considered initial construction costs, maintenance costs, social costs, environmental costs and end-of-life costs. However, only the maintenance of the bridge deck was considered and the life span was based on 80 years for both alternatives. The

discount rate of 4% was used to translate costs into present value. The researcher found that for all the costs evaluated, the GRFP bridge deck was found to be cheaper (at 31%) than the conventional bridge deck replacement as shown in Table 3.

Table 3. Total life-cycle costs (all units in euro) (Mara et al., 2014)

Cost category	Alternative 1	Alternative 2
1- By life-cycle costs		
Initial costs	165 153	123 312
Maintenance and repair costs	26 920	9 697
End-of-life costs	893	193
Total costs	192 966	133 202
2-By cost entity		
Infrastructure owner costs	178 799	126 561
Social and environmental costs	14 167	6 641
Total costs	192 966	133 202

A sensitivity analysis was is performed by varying the average daily traffic (ADT) on the LCCA results. This showed that with increasing average daily traffic (ADT) ranging from 796 to 20 000 vehicles/day, the FRP deck bridges were similarly found to be more cost-effective.

Given the high initial cost of construction, it had been found that the GFRP deck contributed to potential cost-effectiveness over the life of the bridge. Fewer carbon emissions were also found for the GFRP deck option, as well as an overall promising environmental impact (Mara et al., 2014).

Bosman (2015), analysed the life cycle costs of FRP bridge decks with a parametric LCC calculation tool. Only pre-stressed concrete bridges were considered for the study. A tool that allowed the input of the design and maintenance plan to determine total LCC costs. The bridge on which the LCCA was based was known as ‘The Trekvleitbrug’ which was situated in the Dutch city of Leiden for which plans for an upgrade were expected.

The base alternative was a simply supported single-span concrete bridge, offering six traffic lanes and two cycle lanes for a service life of 100 years. Comprising of a single sub-structure the two bridge decks had a total width of 34.5 meters and a total span of 30 meters. The other alternative was an FRP bridge deck which had a similar substructure and surrounding to the base alternative. The cost of various reinforcement alternatives was as shown in Figure 4. Furthermore, the various spans and service lives that were studied to determine their effect on the LCC results as listed in Figure 5.



Table 4. Reinforcement costs (Bosman, 2015)

Material	Material Costs (€/kg)	Density (kg/m ³)
E-Glass	2.5	2600
Carbon	27.5	1800
Polyester	2.25	1178
PVC	11.11	46

Table 5. Bridge alternatives (Bosman, 2015)

Design alternatives		
Bridge deck material	Span	Service lives
Concrete	10	100 and 75
Concrete	15	100 and 75
Concrete	20	100 and 75
Concrete	25	100 and 75
Concrete	30	100 and 75
FRP	10	100 and 150
FRP	15	100 and 150
FRP	20	100 and 150
FRP	25	100 and 150
FRP	30	100 and 150

The results showed that the concrete deck had the lowest LCC, GFRP deck second lowest and CFRP deck had by far the highest LCC this became clear at longer spans as seen in Figure 8. However, at spans of 10 to 24 meters was GFRP decks able to compete with RC decks. The researcher also found that GFRP decks became much more cost-effective at smaller spans provided they had long service lives (Bosman, 2015). The LCC were largely dominated by initial construction costs.

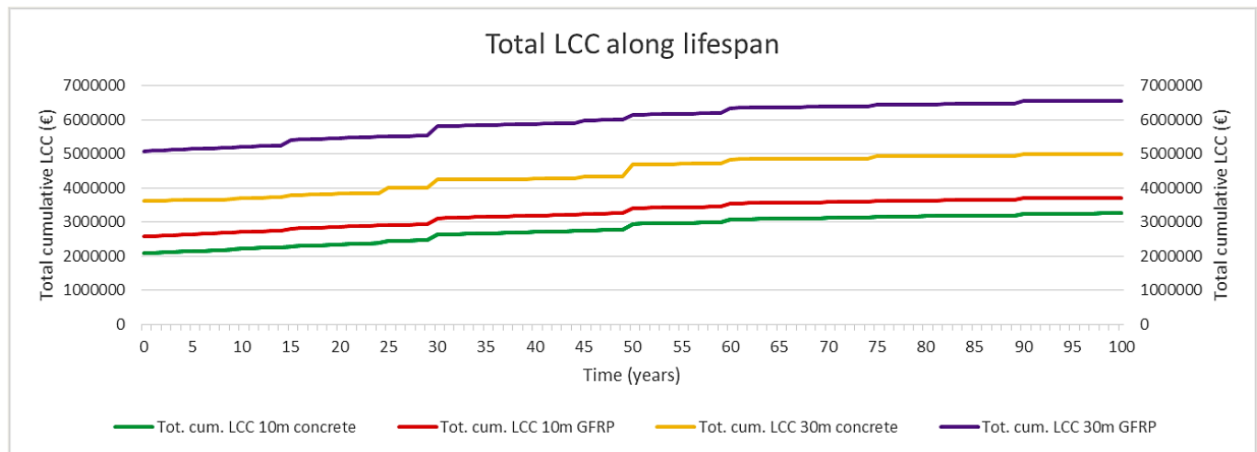


Figure 8. Total cumulative LCC displayed for the lifespan of the bridge (Bosman, 2015)

Haak (2018), carried out a LCCA to compare the economic efficiency of a Pultruded GFRP deck as the alternative with a reinforced concrete bridge deck as the base case in terms of bridge deck replacement. The BridgeLCC 2.0 software by NIST based on ASTM standard E917 was used to carry out a full life-cycle on bridge decks.

The bridge costing was done following the approach adopted by Ehlen and Marshall (1996) although the size was 35% smaller. For that reason, costs were adjusted not only to the size of the bridge but also to the current dollar values using Consumer Price Index (CPI) and the improved manufacturing and design process for FRP (Haak, 2018).

The analysis was performed on the Canonchet Bridge (Bridge No. 0567501) which carried the Woodville Alton Road in Hopkinton, Rhode Island - USA. Built-in 1969, according to an inspection report in 2015, it had a superstructure and substructure rated as 'fair'. However, the bridge required rehabilitation due to structural deterioration and inadequate strength. The bridge is 43.8 meters long with a total deck area of 892 square meters. The service life of the bridge was assumed to be 75 years, while the real discount rate was 3.2%.

The LCC evaluations included the social and environmental aspects of the bridge alternatives that are conventionally considered for a Life cycle analysis (LCA). This was done to emphasize the importance of the environment in the construction industry (Haak, 2018).

The costs were categorised into cost by bearers and costs by timing, due to only considering the bridge decks as shown in Figure 9. The costs by bearers were subcategorised into initial, operation, repair and maintenance costs and disposal costs. The costs by timing were then sub – categorised into direct costs, indirect costs and social costs. Each of these categories is segmented into levels of costs by its bearer that are infrastructure owner costs and user costs. Due to the scope limitation of the study third-party costs are not included in this analysis.

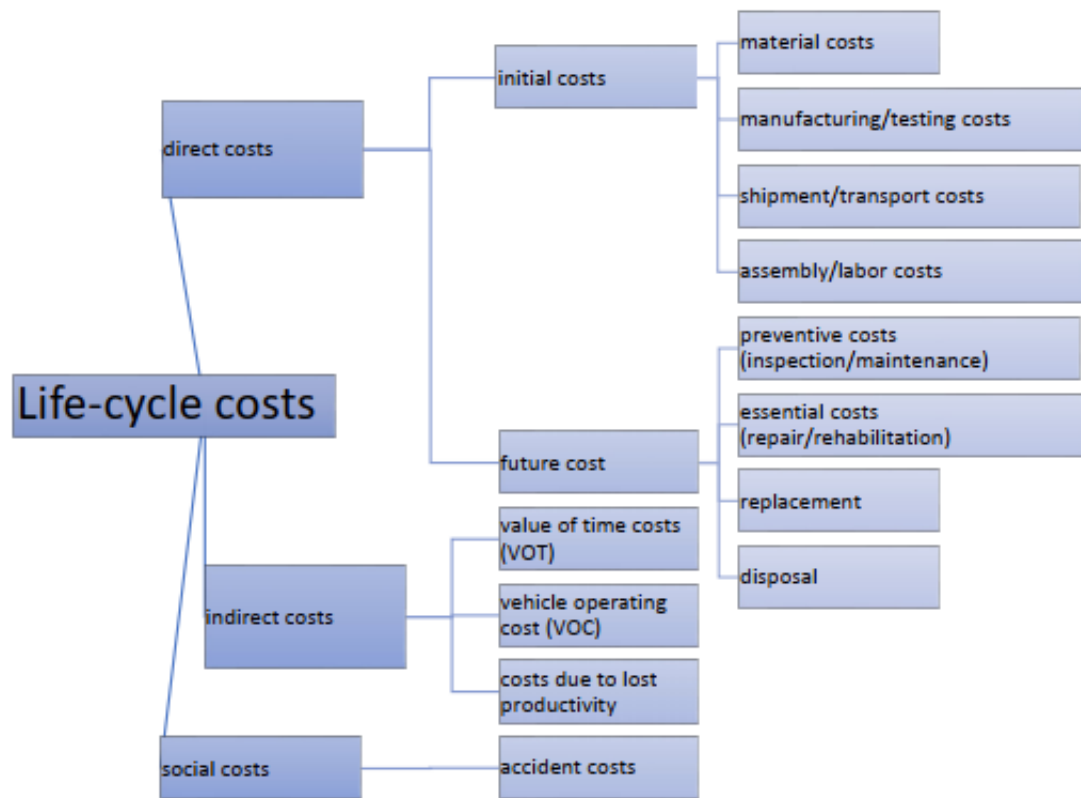


Figure 9. LCC Composition (Haak, 2018)

The software was able to simulate a full LCCA, while also accounting for risks and varying costs. Table 6, summarised the total Life-cycle costs for the two cases that were found to be fairly similar, with the FRP deck found to be the most cost-effective. A sensitivity analysis and risk analysis indicated that the inclusion of uncertainties and risks would make yield the same results.

Table 6. Categorised total costs of bridge alternatives (Haak, 2018)

	Name	Base Case	Alternative #1
	Total Life-Cycle Cost	\$ 704 893	\$ 704 661
By Cost Bearer:	Infrastructure owner Costs	\$ 634 448	\$ 420 231
	User Costs	\$ 70 445	\$ 284 429
	Third-Party Costs	\$ 0	\$ 0
By Cost Timing:	Initial Construction Costs	\$ 633 118	\$ 470 843
	OM&R Costs	\$ 58 874	\$ 166 080
	Disposal Costs	\$ 12 901	\$ 67 738
By Cost Component:	Elemental Costs	\$ 586 114	\$ 704 661
	Non-elemental Costs	\$ 0	\$ 0
	New-Technology Introduction	\$ 118 779	\$ 0

Cadenazzi et al (2019), carried out a LCCA and LCA at the design stage of a short-spanned vehicular FRP-RC and PC composite bridge in Florida, shown in Figure 10. The bridge would replace an existing structure that had reached its functional deficiency and service life. The new bridge had a total length of 56.7 m and a width of 17.6 m. Furthermore, the structure included CFRP-PC bearing piles, CFRP-RC and GFRP-RC sheet piles. The bridge deck, traffic railing, approach slab, gravity wall, bent and bulkhead caps were all comprised of GFRP-RC. The FRP-RC/PC bridge was designed for 100 years and was compared to a traditional RC and PC alternative designed for 75 years. Moreover, the RC and PC bridge was reconstructed at the end of 75 years for comparison purposes.

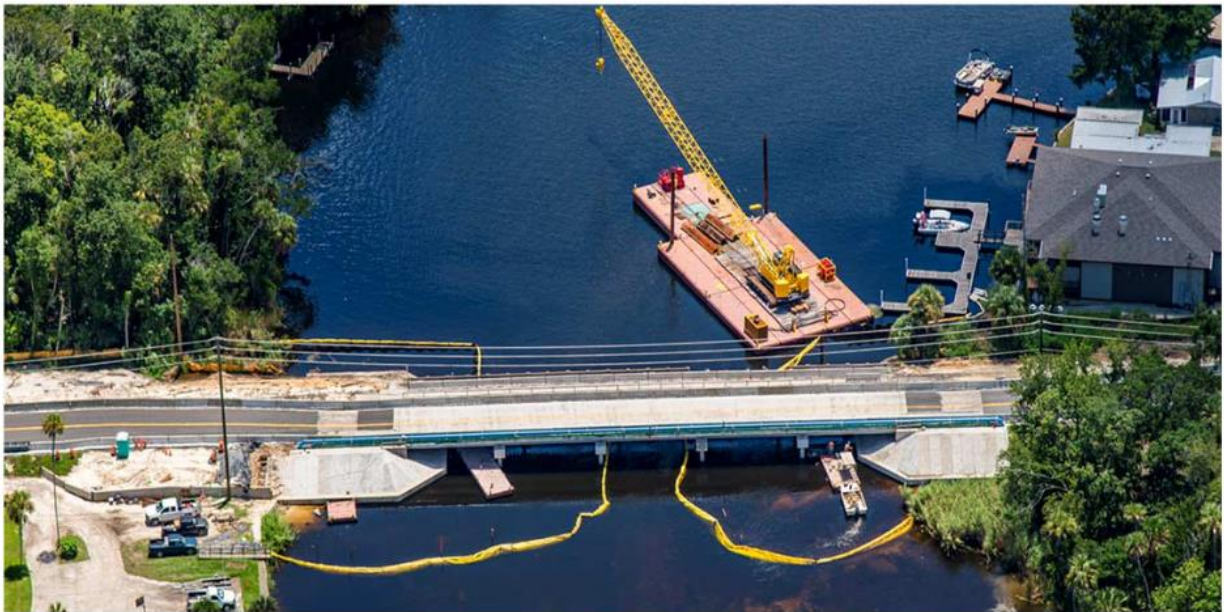


Figure 10. Short-spanned vehicular bridge located in Florida (Cadenazzi et al., 2019)

The life cycle stages considered for the GFRP-RC and PC bridge consisted of the following:

- Product stage (transportation of raw materials, and manufacturing)
- Construction stage (transportation to the construction site, construction and installation)
- Use stage (user costs and environmental impacts, maintenance, repair, and replacement); and
- End of life stage (demolition, transportation, waste processing, disposal, and recycling).

In addition to the life cycle stages considered for the GFRP-RC and PC bridge, the following stages were considered for the RC and PC bridge:

- Product stage for reconstruction (transportation of raw materials, manufacturing and transportation to the construction site)

- Reconstruction process stage (construction and installation), and
- Use stage over the first 25 years of second life (user costs and environmental impacts, maintenance, repair, and replacement).

A maintenance and repair model was developed by the Life -365 (version 2.2.3) software which was based on chloride-induced corrosion. Additionally, when the critical chloride threshold reached 1.17 kg/m^3 , the corrosion of steel was assumed to have initiated. The maintenance activities included patch repairs and cathodic protection as shown in figure 11.

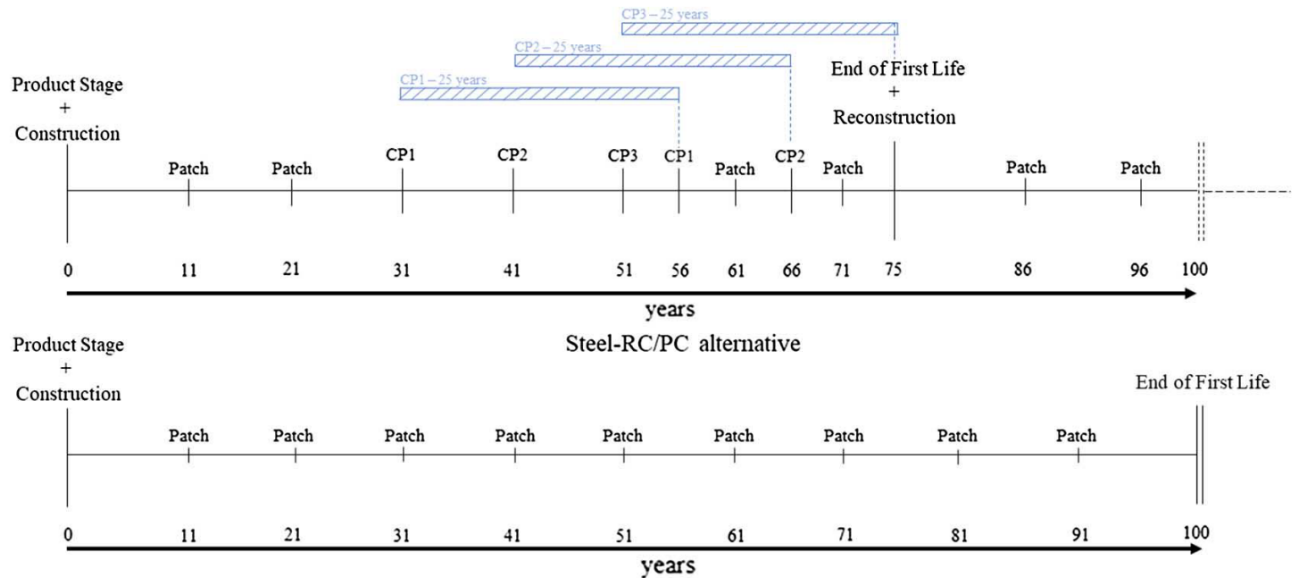


Figure 11. The life cycle of bridge design alternatives (Cadenazzi et al., 2019)

The costs of the various reinforcement alternatives used for the construction of the bridges was as shown in Table 7. The cost of the FRP alternatives was much more than that of steel reinforcement, with the GRFP being 1.6 to 2.3 more costly than steel. Additionally, CFRP strands were 3.8 more costly than steel strands.



Table 7. Cost of Reinforcement alternatives (Cadenazzi et al., 2019)

Reinforcing Bars						
Bar Size	CS		GFRP		CFRP	
	Unit Weight, kg/m	Cost, \$/m	Unit Weight, kg/m	Cost, \$/m	Unit Weight, kg/m	Cost, \$/m
M10	0.561	0.75	0.159	1.71	...	...
M13	0.996	1.31	0.281	2.36	...	...
M16	1.556	2.07	0.427	3.80	...	...
M19	2.240	2.95	0.607	4.99	...	...
M25	3.982	5.25	1.046	8.56	...	...
1 x 7, 15.2 mm strand	1.210	3.30	...	...	0.221	12.50

The LCCA was conducted at a discount rate of 1% using the PWOC model. The results showed that the RC and PC bridge became the more economical alternative after 41 years. At the end of the analysis, the RC and PC was 25% more favourable with a net savings of \$1,570,670.

The results of the LCA indicated that the environmental impact of the RC and PC bridge had much more adverse effects in terms of global warming, photochemical oxidant creation, acidification, and eutrophication. However, the FRP-RC and PC bridge contributed to ozone depletion about four times the impact of the RC and PC bridge.

2.6 Deterioration models

2.6.1 Introduction

The deterioration of bridge components needs to be understood when determining the necessary maintenance and repair activities throughout the predicted service life of a bridge structure. This can be understood with the help of deterioration models. Deterioration models predict the condition of bridge components at a given time, as a response to wearing and ageing as seen in figure 12 (Hawk, 2002). The models are governed by deterioration mechanisms and may be expressed in the form of a mathematical expression. These models help planners and decision-makers in timing maintenance and repair activities to ensure a bridge will last its service life. The deterioration models are either deterministic or probabilistic. These will be discussed in the proceeding sections.

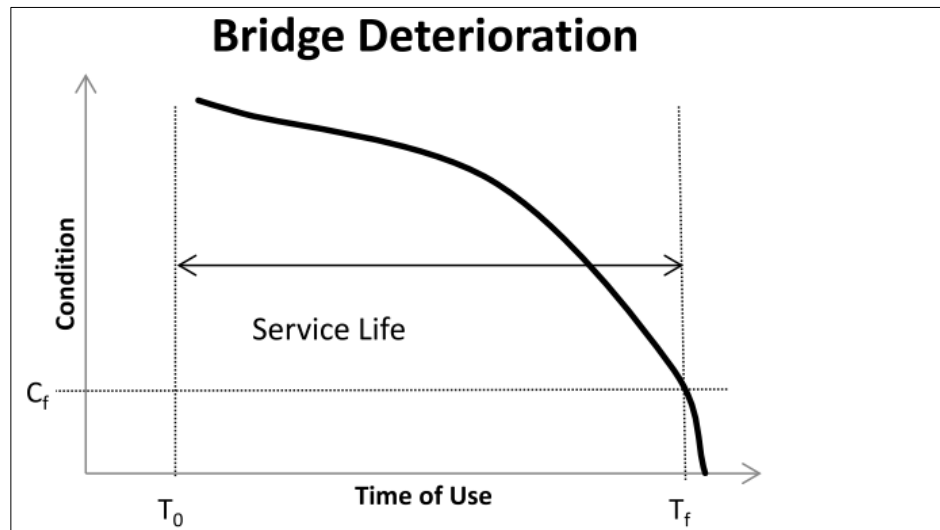


Figure 12. Bridge deterioration model (Hawk, 2002)

Deterministic models are based on the simplest principle of defining a deterioration process of the various bridge elements. The approach predicts the most likely value of condition measure as a function of age and other variables with simple statistical calculations such as the mean standard deviation, and regression (Kotze et al., 2015). However, the uncertainty of the deterioration process is neglected in the models (Agrawal et al., 2010).

Probabilistic models are theoretically more capable of capturing the complexity and randomness of the deterioration process of bridge elements. According to Kotze et al. (2015), probabilistic models define the condition states of bridge elements by assuming that the bridge elements are random variables, which are modelled by an underlying probability distribution. Common examples of these models are the Markov and Weibull Survival models. These models are favoured over deterministic models.

2.6.2 SRC Bridge Deterioration

2.6.2.1 Deterioration mechanisms

The deterioration of SRC bridges in coastal areas is governed by various deterioration mechanisms. The mechanisms mainly describe processes that result in the formation of cracks on the concrete (Rodrigues et al., 2020). The primary mechanisms responsible for crack formation are carbonation and chloride ion ingress (Revie & Uhlig, 2008). These mechanisms are catalysts for the corrosion of the embedded steel in the RC bridge components. The corrosion process and mechanisms are explained in the following sections.

2.6.2.1.1 Corrosion process

Corrosion is the process by which a refined metal is naturally converted to its more stable form. Steel is prevented from corrosion in concrete by the formation of a passive layer on the surface, which forms due to the alkalinity of the concrete (Strohmeier, 1994). Corrosion of steel is began when the passive layer is disrupted, this happens when the alkalinity of the concrete is lowered (Jassa & Beushausen, 2017). The electrochemical process involves four basic parts as shown in Figure 13 (Li & Yang, 2021):

- A metal, which serves as an electrical conductor for anodic and cathodic electronic transfer,
- An anode, where electrochemical oxidation takes place and electrons are released,
- A cathode, where electrochemical reduction occurs, and electrons transferred from the anode are consumed,
- An electrolyte, the steel is exposed to.

The oxidation reaction also known as the anodic reaction, results in the loss of electrons on the steel surface is expressed by the following reaction (Revie & Uhlig, 2008):



The reduction reaction is also known as the cathodic reaction, electrons that are released from the anode migrate to the cathode and react with water and oxygen to produce hydroxyl ions. The reaction is expressed as follows:

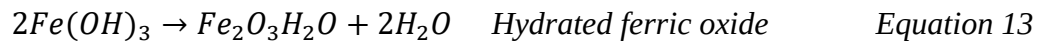


Equation 1 and 2 reactions are responsible for corrosion initiation. Further oxidation reactions occur to produce rust. The oxidation reactions are as follows:

- Hydroxyl ions migrate to the anode and react with the ferrous ions to form ferrous oxide.



- Ferrous hydroxide is further oxidised to form hydrated ferric oxide in the presence of oxygen and water.



Rust occupies a volume equal to three to six times that of the original steel (Revie & Uhlig, 2008). Mackechnie & Alexander (2001), suggested that rust may swell up to ten times the volume of steel. The change in volume stresses the concrete surrounding the steel, resulting in crack formation, delamination and spalling of the concrete as seen in Figure 14. Furthermore, the corrosion process is accelerated by the provision of ease of access for water and chlorides to reach the steel surface.

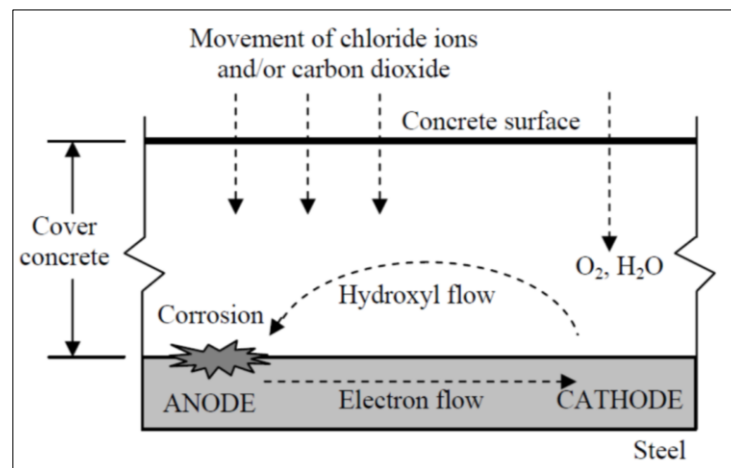


Figure 13. The corrosion process (Mackechnie & Alexander, 2001)

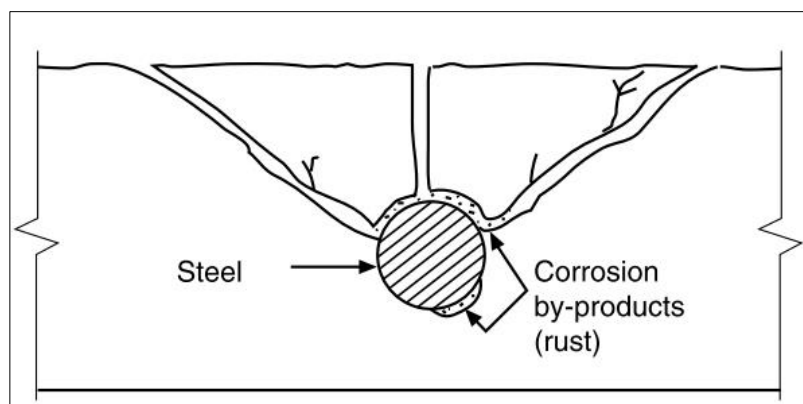


Figure 14. Volume change of corroding steel which causes cracking (PCA, 2002)



2.6.2.1.2 Mechanisms

The mechanisms responsible for the corrosion of steel are described as follows:

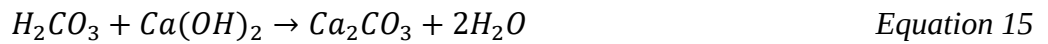
- **Carbonation-induced corrosion**

In RC the embedded steel is passivated due to the high alkalinity of the surrounding concrete. Concrete in its natural state has a pH of 12 and is lowered to approximately 8.3, by the carbonation process (Mackechnie & Alexander, 2001). Furthermore, when the pH of the concrete is lowered to below 10.5, the passive film on the steel is broken down and paves the way for corrosion initiation in the presence of oxygen and moisture (Mackechnie & Alexander, 2001). The process of Carbonation is explained as follows:

- Carbon dioxide CO_2 diffuses into concrete and reacts with water H_2O present in the concrete pores to produce carbonic acid H_2CO_3 :



- The carbonic acid H_2CO_3 then reacts with calcium hydroxide $Ca(OH)_2$ to form calcium carbonate Ca_2CO_3 :



The reactions explained in Equation 1 and Equation 2, are responsible for lowering the pH of concrete. This process is however slow, due to the difficulty in penetrating the concrete cover. Furthermore, factors such as temperature and the amount of cement hydrates govern the rate of carbonation (Atis, 2003). The process merely process conditions suitable for corrosion in the concrete (State of Queensland-Department of Transport and Main Roads, 2016).

- **Chloride-ion induced corrosion**

The deterioration of SRC structures is primarily caused by chloride-induced reinforcement corrosion in marine environments, even in highly alkaline structures. The deterioration is initiated when free chloride ions beyond the chloride threshold value have accumulated on the steel-concrete interface. The chloride ions locally break down the passive layer on the steel surface, thereby initiating corrosion. As a result, excessive pitting corrosion on steel may be found.

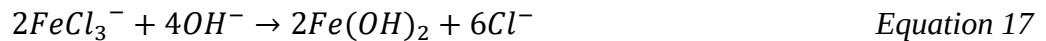
Chloride-ion induced corrosion takes place as follows:

- Chloride ions decrease the resistivity of the concrete cover and break down the passive layer on the steel surface:





- Iron III chloride $FeCl_3^-$ reacts with hydroxyl ions to form rust $2Fe(OH)_2$:



Maintenance activities due to corrosion of reinforcing steel were estimated to be the most costly of maintenance activities for structures located in coastal areas (Cadenazzi et al., 2019).

There are other forms of deterioration mechanisms induced by environmental effects which result in crack formation. These mechanisms are briefly explained as follows (Strohmeier, 1994):

- **Unsound cement**

When the cement used for concrete does not meet the specifications, un-hydrated calcium oxide or magnesium oxide may react with moisture to cause internal expansion. The internal expansion of the concrete may cause crack formation.

- **Freezing-and-Thawing**

The activities of freezing and thawing of moisture in the capillary cavities of hardened cement paste cause internal expansion of concrete. As a result, the concrete may crack.

- **Alkali-Silica Reaction**

Concrete made of reactive silica in the aggregates may react with alkalis in the cement paste. Thus, a hydrophilic gel is formed which swells when moisture is in contact with concrete. The process may cause crack formation. The process is slow and results may be seen after 5 to 10 years (State of Queensland-Department of Transport and Main Roads, 2016).

- **Plastic shrinkage**

In the instance the surface of freshly placed concrete is exposed to rapid drying in the early stages of hardening, crack formation is likely to occur.

- **Sulphate Attack**

Sulphates dissolved in-ground moisture migrate in the concrete and react with the hydrated compounds in the hardened cement. The reaction can lead to extensive cracking.

- **Thermal Contraction**

The effect temperature changes on restrained concrete members may lead to crack formation.

- **Drying Shrinkage**

The shrinkage results from the drying out of moisture from the hardened cement, which leads to contraction and ultimately crack formation

2.6.2.2 Deterioration models

Alipour et al. (2010) presented a paper that studied reinforced concrete highway bridges in chloride contaminated environments through a probabilistic approach. The mechanisms for deterioration of the elements of the bridge were mass and strength loss of rebars, cracking and spalling of concrete cover, and loss of bond between the concrete and steel (Alipour et al., 2010). These mechanisms had degraded the durability of the highway bridges. When the chloride content reached a threshold of 3.50 kg/m^3 near reinforcing bars, corrosion was assumed to have initiated. This is seen in the model in Figure 15, which predicts the probability of corrosion occurrence over time for bridge elements of various concrete covers. Once corrosion of the reinforcement began, the structural degradation and serviceability failure were assumed to have begun shortly after.

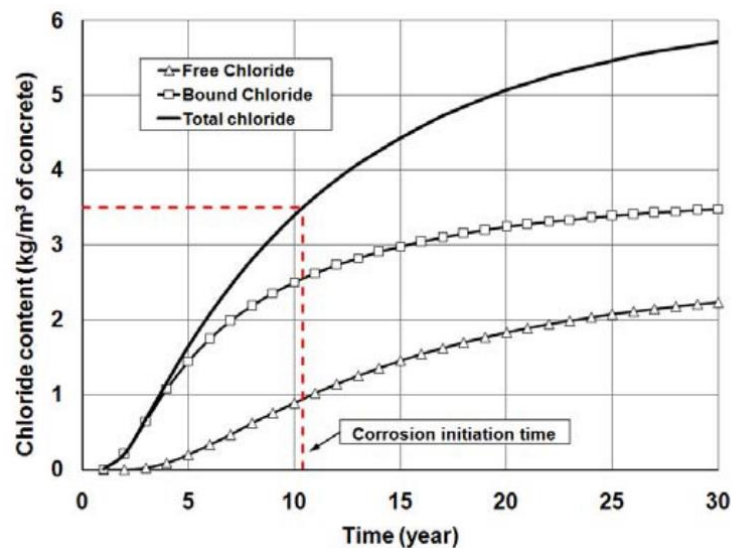


Figure 15. The probability density function of corrosion initiation time (Alipour, Shafei, & Shinozuka, 2010)

Agrawal et al. (2010), studied the deterioration rates of bridge elements in New York, Unites States of America. These rates were influenced by factors such as reinforcement corrosion, concrete degradation, creep, shrinkage, cracking, fatigue, etc. The deterioration rates were used to predict the service life of the bridge elements with two stochastic models. The first model used was a second level Markov chains approach to account for the nonlinear optimization drawbacks of a first-level Markov chains approach. A Weibull-Distribution based approach was also used. The researcher found that the latter approach had modelled the deterioration curves better.

Frangopol & Neves (2003) developed a probabilistic model to predict the performance of deteriorating structures under various maintenance strategies. The indicators: condition, safety and cost were used to predict the performance of the structures over time. Maintenance strategies of Minor concrete repairs; Silane application; Rebuilding; Cathodic protection; and Replacement of expansion joints were considered.

Van Noortwijk & Frangopol (2004) described and compared two maintenance models for civil infrastructures. These models were optimised for structural reliability at a minimal life cycle cost. Referred to as the Rijkswaterstaat's model and Frangopol's model as shown in Figure 16 and Figure 17, respectively. The former was used in the optimization of maintenance measures for the Netherlands Ministry of Transport, Public Works and Water Management (Rijkswaterstaat), while the latter contributed towards the bridge management methodology of the UK Highways Agency. The models were found to be quite different. Frangopol's model was reliability-based, modelled by a probabilistic deterioration process. However, Rijkswaterstaat's model was condition-based and modelled the deterioration process as deterministic. The advantage Frangopol's model had over Rijkswaterstaat's model was that more components, failure modes, and uncertainties were incorporated into the model. Furthermore, Frangopol's model was found to be more flexible when analysing combinations of service life extension measures thereby optimising the maintenance process. Furthermore, given that preventive maintenance interventions were repeated after 10, 20 and 25 years, an essential maintenance intervention should be carried out between 50 and 120 years, on a bridge structure (Frangopol et al., 2000). Furthermore, the Frangopol's model was used for the study.

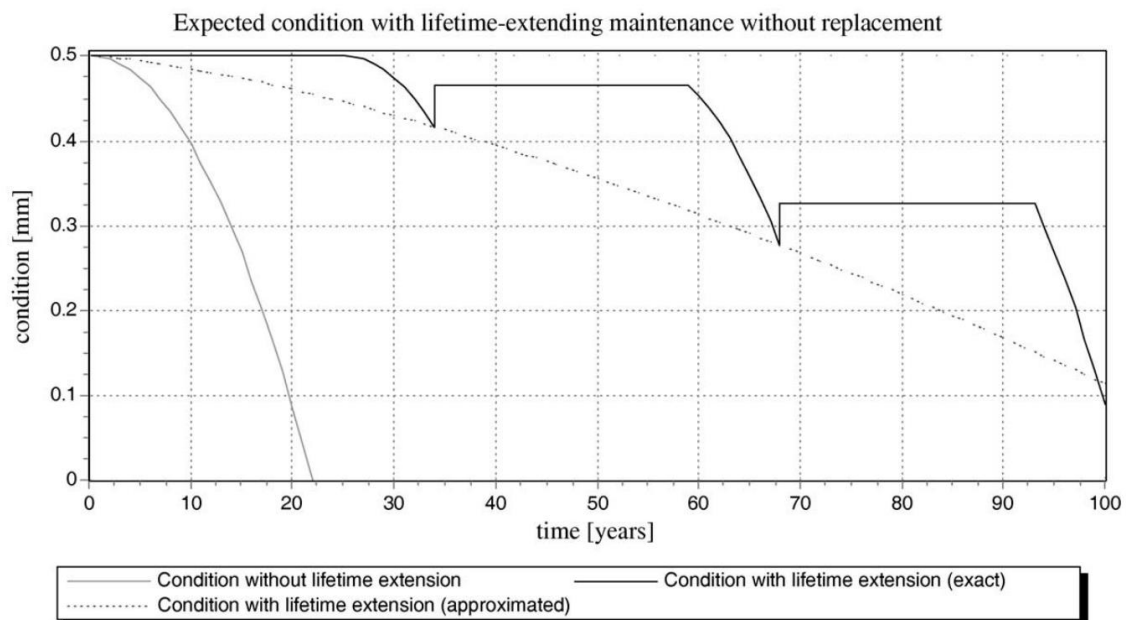


Figure 16. Rijkswaterstaat's model (Van Noortwijk & Frangopol, 2004)

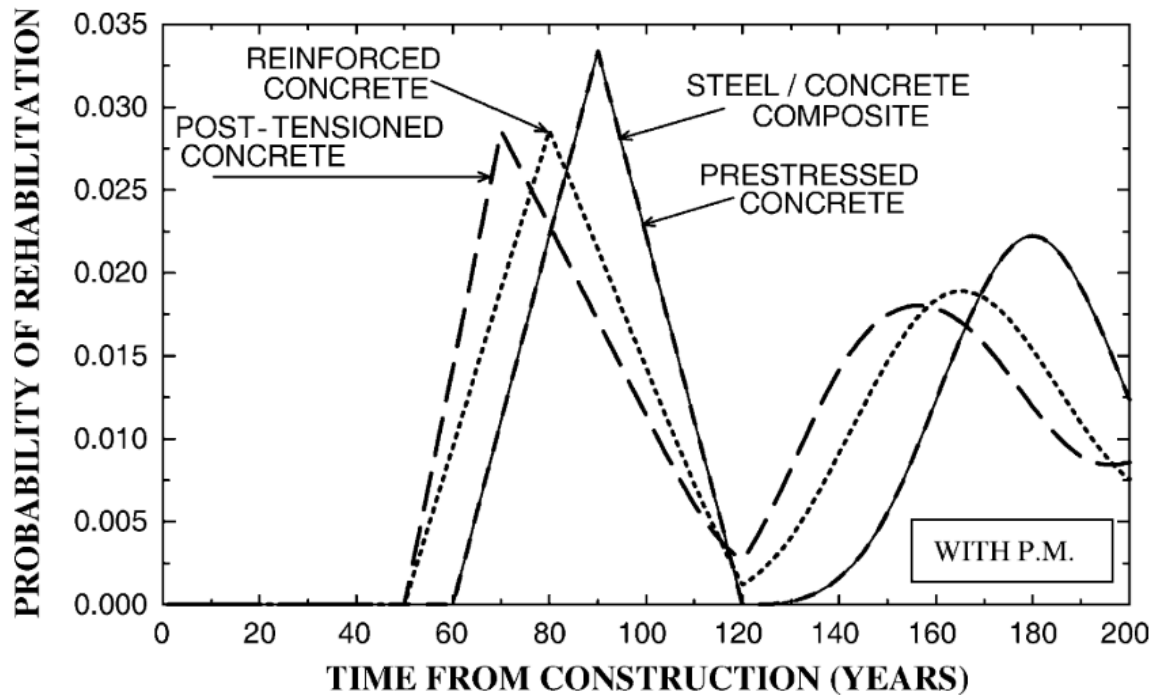


Figure 17. Frangopol's model (Frangopol et al., 2000)

2.6.3 Deterioration of GFRP

2.6.3.1 Deterioration mechanisms

There is a lack of deterioration models that predict the service life of FRP bars. The approaches adopted in studying of deterioration of FRP's in alkaline environments are generally qualitative, and no serious attempt was made to predict service life (Sahirman, 2009). However, the deterioration of GFRP bars has been investigated more than other FRP bars. It is understood that mainly, the hydrolysis of the ester bonds that compose the polymer matrix in the fibres is the leading deterioration mechanism (Sahirman, 2009). The deterioration of FRP bars is mainly due to the environmental factors of moisture (water, humid air, liquid), temperature (freeze-thaw cycling, elevated temperature, fire) weather conditions (physical, chemical, UV rays), physically weathering conditions (static load, fatigue, creep), and chemical weathering conditions (exposure to alkaline, acid, aqueous). These factors have been used by researchers to define the durability of the fibres.

The deterioration of GFRP bars is further explained as follows:

General

- The deterioration of GFRP composites mainly affects the durability and serviceability of the fibres. The deterioration process is revealed by the formation of cracks when



failure of the fibres is initiated. According to Bhide & Zurale (1999), the processes include:

- i. Micro cracking of the polymer matrix
- ii. Debonding at the fibre/matrix interface
- iii. Reduction of fibre strength and modulus

According to Bhide & Zurale (1999), the durability and serviceability issues of GFRP bars resulting from the effects of environmental factors are described as follows:

- Ageing of polymer matrix

The durability of the polymers is most susceptible to changes in the polymer matrix, in response to the environment in which the polymers are exposed. The polymer matrix mainly transfers stresses between fibres, provides a barrier against the environment and protects the polymer surface from mechanical abrasion. The polymer matrix characteristics change over time in response to the environmental exposure conditions, namely temperature and moisture. This is known as the ageing of the polymers matrix, which results in the polymers becoming stiffer and brittle. It is therefore recommended to use GFRP bars consisting of vinyl ester resin with a surface coating to delay the effects of the ageing polymer matrix (Benmokrane et al., 1996).

- Influence of moisture

When polymers are exposed to humid air or moist environments, the polymers absorb moisture through diffusion and surface absorption. This process has a detrimental effect on the properties of the polymers.

When moisture is absorbed by the resin, the properties and glass transition temperature of the polymer matrix may change. Furthermore, the changes may degrade the stiffness of the polymer matrix. The resin swells, reducing the compressive strength at the fibre/matrix interface which results in a stress release. Additionally, moisture entrapped in the interface voids may also cause blisters.

The silica present in glass fibres may disperse alkaline metal oxides when exposed to water for long periods which may damage the fibres. E&S glass only contains small amounts of alkaline metal oxides and are unlikely to be affected. Furthermore, moisture at the glass fibre interface may lower the surface energy, which in turn promotes crack growth.

The silica are likely to react in alkaline environments to form expansive silica gels. The highly alkaline concrete could therefore affect the durability of GFRP bars. Vijay (1999), found that GRFP bars had increased moisture absorption when exposed to increased temperatures and alkaline conditions. Furthermore, the increase in moisture absorption resulted in the tensile strength reductions of the bars over time.



- Low-temperature effects

Temperature changes may have detrimental effects on GFRP bars since the coefficient of thermal expansion (CTE) of the polymer matrix is greater than that of the fibres. When the bars are exposed to low temperatures, the matrix may shrink.

- Freeze-Thaw cycles

GFRP composites contain about 0.4% voids, which when filled with water and undergoing freeze-thaw effects may affect the strength of the composites. As a result, the induced stresses may cause micro-cracking in the resin-fibre interface. However, for a temperature range between 30°C and -20°C, research has concluded that the effect of freeze-thaw cycles on the tensile strength of GFRP bars was insignificant (Bhide & Zurale, 1999; Cusson & Xi, 2002).

- Ultra Violet (UV) rays

When polymer composites are exposed to long periods of sunlight, the properties of the composites could be affected. The polymer matrix may harden and become discoloured. This phenomenon may be avoided by the incorporation of u-v resistant additives in the polymer matrix.

- Creep

GFRP bars over a long period under conditions of increasing strain at a constant level of strain may exhibit failure in the form of stress rupture.

- Fatigue

Cyclic loading affects the properties of GFRP bars by the distortion of the fibre alignment.

- Fire

GFRP composites are susceptible to degradation when exposed to fire. This is why it is paramount for the composites to comply with the available design standards.

2.6.3.2 Deterioration of GFRP-RC

The deterioration of GFRP-RC was studied and it was understood that the bond between GFRP and concrete was likely to deteriorate first, due to alkalis from concrete (Mufti et al., 2005). This happens when the delaminated zones at the GFRP/concrete interface facilitate the accumulation of water and consequent formation of localized areas with different moisture contents, alkalinity, thus accelerating the degradation of GFRP (Mufti et al., 2005). The processes described in Section 2.6.3.1 may also lead to the deterioration of the GFRP and concrete bond

due to the weakening of the GFRP matrix. However, the deterioration process may take a while to initiate. Mufti et al (2005), found that after 5 to 8 years of exposure to alkalinity, freeze-thaw and wet-dry cycles, de-icing salts, saltwater and thermal loading, no effect on the integrity of the GFRP/concrete interface was observed.

Ceroni et al. (2006), investigated the durability of GFRP rebars. By observing the vulnerability of FRP to environmental agents (water, alkali, salt solution) or circumstances (temperature) due to resin penetration or degradation, which protects the fibres and allows them to collaborate through bonding. The behaviour of the concrete-GFRP interface was found to reduce strength and stiffness in the concrete members investigated. This was due to GFRP bars having a lower modulus of elasticity than that of steel which meant that the formation of cracks in a GFRP-RC member would be more prominent even under service loads (Rajput & Sharma, 2017). The bond strength of the GFRP bars is estimated to be approximately 1.2 to 1.5 times smaller than that of steel (Malvar, 1995). It is therefore important to consider the GFRP rebar surface to improve the bond strength.

The mechanical properties of relaxation and creep were also studied. It had been found that the bars undergo around 10% strength reduction per decade of a logarithmic lifetime. The creep failure strength retained ranged around 29 - 55% after 50 years. Furthermore, it was concluded that the effects of creep and relaxation were less prominent those than those experienced by RC.

Gergely et al (2007), carried out an experimental study on a GFRP-RC deck and analysed the durability of four GFRP bars types. The experimental study included laboratory tests, in-situ static and dynamic testing of the deck. While the durability testing included the absorption, tensile strength, and bond strength testing in an alkaline environment. The experimental test results showed the GFRP rebar strain levels were less than maximum permitted values and the dynamic load did not increase the live load impact factor by more than 9%. Subsequently, the girder deformations and measured distribution were below the limits specified by AASHTO. The absorption tests after 18 months found that GFRP bars had a strain of approximately $700 \mu\epsilon$, less than that of the threshold strain of concrete acting in compression. Tensile strength and stiffness properties were found to decrease with extended exposure to the alkaline environment and elevated temperatures. Furthermore, the tensile strength reductions were as high as 25% for some of the GFRP bars in comparison to the control bars. The use of fine silica sand as a coating on the surface of the GFRP bars was seen to delay the deterioration processes and enhance the bond strength. The cost ratio GFRP/steel at the time was approximately ranged from 3:1 to 4:1.

Davalos et al. (2011), observed the durability of GFRP-RC beams immersed in tap water. The beams were exposed to elevated temperatures under sustained loads to accelerate the ageing of the GFRP rebars. The study found that the deterioration of the interface between the fibre and matrix was the leading form of degradation. Furthermore, the tensile strength retention of the GFRP bars was found to be 38% after 50 years for temperatures between 5°C and 30°C.

Robert & Benmokrane (2013) studied the durability and properties of sand coated GFRP bars in reinforced concrete exposed to a saline condition at various temperatures. The GFRP bars were observed to have a decrease in tensile strength (25%) after 35 and 200 years for temperatures as high as 70°C. The bar-concrete interface and resin were said to be unaffected by moisture absorption after 395 days.

Fergani et al (2018), studied GFRP bars exposed to severe environments while under sustained loads. The environments in which the bars were observed to were categorised as ‘moist concrete’, ‘alkaline’ and ‘tap water’. The rate of moisture absorption of the bars was found to be primarily dependent on temperature as observed for temperature ranges between 20°C and 60°C. The higher the temperature the higher the rate of moisture absorption and as a result tensile strength reduction. Furthermore, the GFRP bars were exposed to the ‘alkaline’ environment and were found to have the largest tensile strength reduction.

2.7 Maintenance Strategies

The maintenance of highway bridges is a major component of the life-cycle costs. In addition, the maintenance activities should be carefully selected. A reliability-based approach when selecting bridge maintenance activities was used to minimise life cycle costs (Thoft-Christensen et al., 2006). This is primarily due to some costly maintenance activities which have minor effects on the bridge condition. Therefore, the maintenance activities adopted for this study were retrieved from the findings of Thoft-Christensen et al (2006), due to the time and scope limitation of the study.

The maintenance activities were categorised as preventative and essential maintenance. Preventative maintenance was defined to reduce the rate of deterioration of the bridge, while essential maintenance improved the bridge reliability as shown in Figure 18. Furthermore, preventative maintenance is carried out when it was considered that the activity would be more expensive to perform in the future (Frangopol et al., 2000). While essential maintenance was carried out when without it the bridge would be unsafe, which was when the bridge no longer provided the target level of performance. The maintenance activities of the bridge superstructure are described in the following sections.

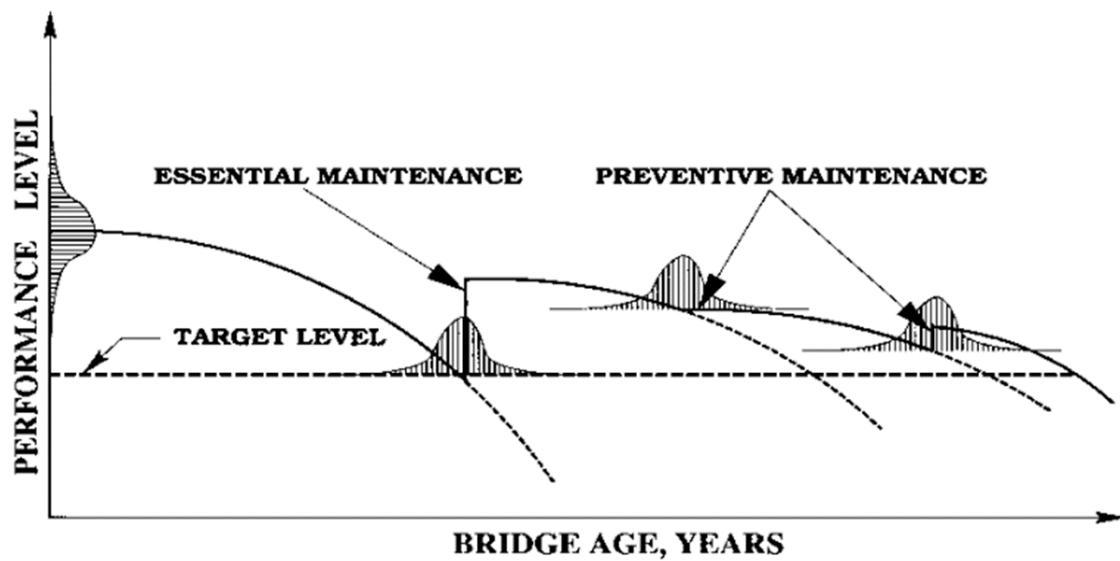


Figure 18. Effects of essential and preventative maintenance interventions bridge reliability (Frangopol et al., 2000)

1. Deck expansion joint maintenance

Expansion joints accommodate movements of the bridge superstructure. These movements are primarily due to live loads, thermal changes and the physical changes of the bridge materials (Wells et al., 2016). Therefore if expansion joints are not properly maintained, the bridge performance is affected. The maintenance activities are briefly described as follows:

- Inspection

The condition of the expansion joints is investigated. The work is carried out by a professional to identify the necessary maintenance intervention.

- Cleaning of expansion joints

The cleaning of the bridge involves:

- i. The removal of debris
- ii. Removal of overgrown vegetation that impedes cleaning
- iii. Low-pressure washing

- Repair and Replacement

Expansion joints may be repaired depending on their condition. When it is no longer feasible to repair the joints, they are replaced. The activities of repair and replacement of the bridge joints are usually according to product specifications.

2. Deck surfacing

The deck surface is exposed to environmental elements and variable loading conditions of passing vehicles which contributes to the deterioration of the bridge deck. A deck surface



overlay is constructed to provide prevent the early deterioration of the bridge deck surface. An asphalt overlay was selected as the deck surfacing method. Furthermore, the overlay would provide continuity of riding surface since a highway bridge was part of an existing road. The following methods of asphalt overlay maintenance were considered (Phalla et al., 2017):

- Rut Correction

Depressions caused by the wheel paths on the asphalt overlay are repaired by this method. The process includes the cleaning, spreading aggregate which is followed by compacted of the depressed area. Lastly, the depressed area is resealed with a binder.

- Crack sealing

The method is used to seal cracks on the asphalt surface. The process includes cleaning and filling the crack with either cutback bitumen or bituminous slurry depending on the crack width.

- Patch Repair

Wearing of the asphalt overlay may lead to the formation of potholes. The potholes are seen as bowl-shaped holes in the asphalt overlay. The process of repairing the potholes is began by removing all loose materials from the hole, backfilling the hole with aggregate which is then compacted. Finally, a binder is used to reseat the repaired surface.

- Replacement

When the asphalt overlay repair is considered to be no longer cost-effective, the overlay surface is milled and the concrete bridge deck is resurfaced.

3. Concrete surface treatment

As a result of SRC deterioration mechanisms, bridge superstructures deteriorate by cracking, delamination and spalling of concrete. Treating the concrete surface may delay the deterioration process. Among many concrete surface treatments are hydrophobic impregnation and corrosion inhibitors.

A hydrophobic impregnation is a coating that when applied to the concrete surface that increases the durability of a concrete structure (Sika, 2015). When applied on the concrete surface the film penetrates the surface pores and capillaries, reducing the surface tension which produces a water-repellent concrete surface. The surface would then be able to repel water and soluble salts, such as chlorides and sulphates.

Corrosion inhibitors have been used on RC as a corrosion-protection measure. The inhibitors are chemical admixtures that are added to the concrete mix during batching and delay the initiation of corrosion (Smith & Virmani, 2000). Furthermore, the inhibitors may be applied

to the concrete surface, which migrate through the concrete to reach the steel to form a protective barrier (Sika, 2009). Thus, the corrosion rate is decreased.

4. Cathodic protection

Cathodic protection (CP) is a process that limits the corrosion of RC structures. In principle, CP inhibits the occurrence of anodic sites on the structure being protected by allowing the anodic reactions to occur on installed anodes (CPC, 2016). As shown in Figure 19, an external anode (more reactive) introduces a small current to the reinforcement through the concrete, this creates an electrochemical cell and makes the reinforcement act as the cathode. Hydroxide ions are formed by a cathodic reaction at the reinforcement surface from oxygen and water. The pH of the concrete is increased and its charge facilitates the migration of chloride ions to the concrete surface anode (Polder, 1998). The ions then oxidise to produce oxygen and electrons.

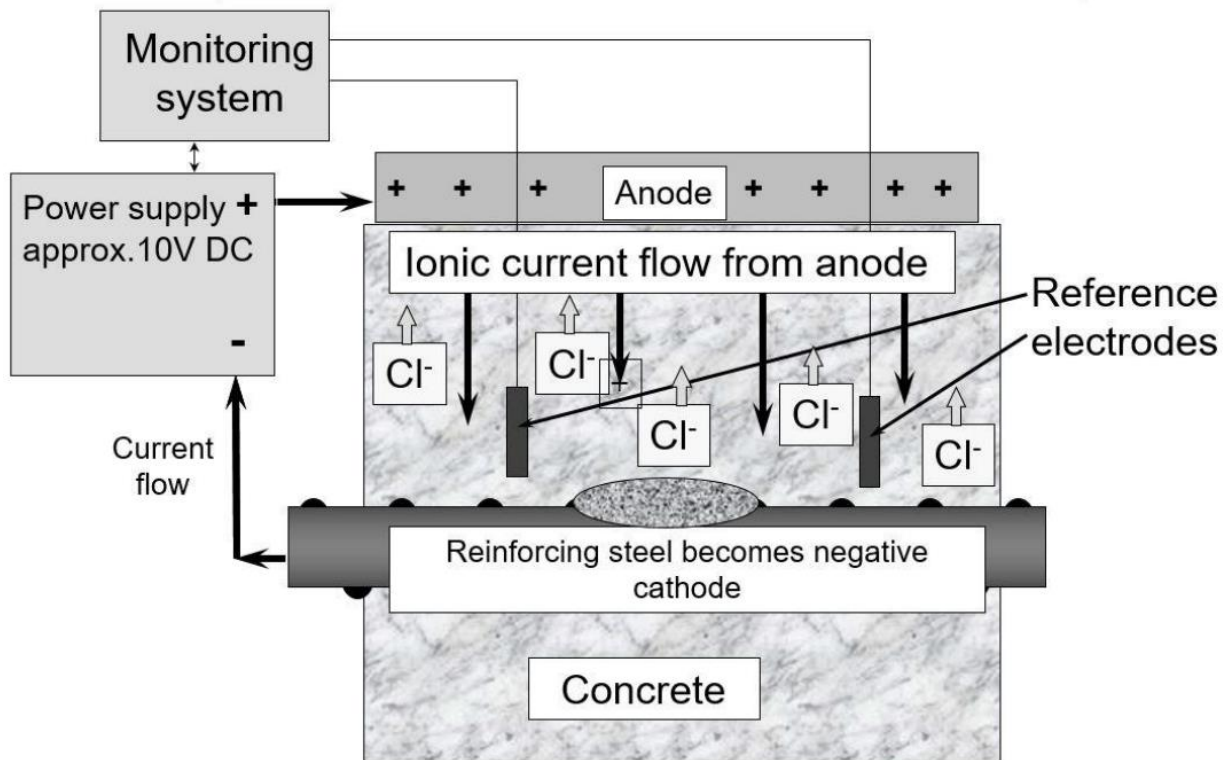


Figure 19. Principle of cathodic protection of steel in concrete (Highways England, 2020)

The process regulates corrosion and reduces the amount of repair work needed. The two methods of CP are the impressed current cathodic protection (ICCP), which is shown in Figure 19 and sacrificial (or galvanic) anode protection (SACP). The main difference between the methods is that ICCP needs an external power source to operate while, SACP makes use of the natural electrochemical potential difference between different metallic components (CPC, 2016). The SACP method was considered for study as the method is simple to install, operate and maintain, and is economical.

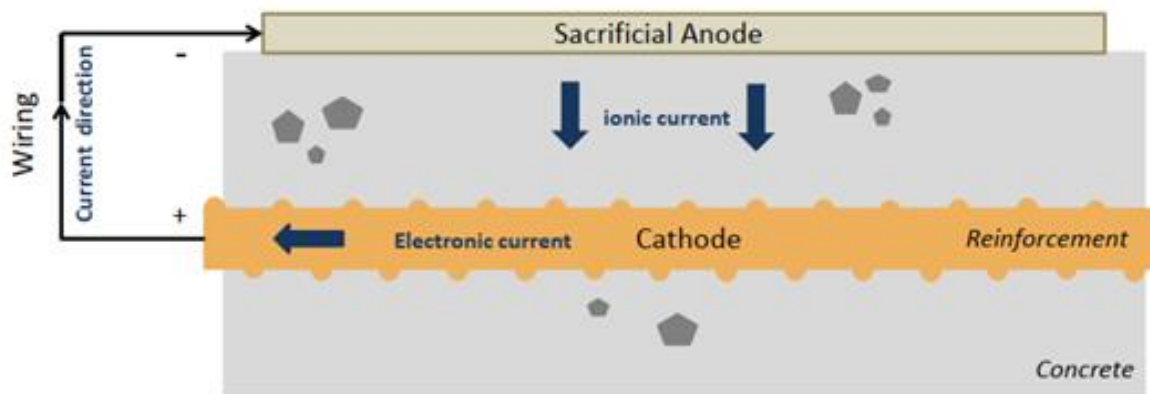


Figure 20. SACP system (Byrne et al., 2016)

The SACP method utilises reactive metals anodes that are electrically linked to the reinforcement being protected as shown in Figure 16. A positive current flows in the electrolyte from the anode to the reinforcement. The concrete surface then becomes a more negatively charged cathode and the new anode corrodes sacrificially (Byrne et al., 2016). The method has commonly found applications for minor repairs, due to the lifespan of the system typically lasting 10 to 20 years (Byrne et al., 2016).

5. Concrete Repairs

Concrete repair methods are mainly used to restore bridge concrete components to an acceptable level of service (Weyers et al., 1993). The following methods were considered as concrete repair maintenance activities for the bridge superstructures (JICA, 2017):

- Patch Repair

This method is used to restore deteriorated concrete which is delaminating and spalling. The repair includes the removal of unsound concrete and the preparation of the remaining sound concrete surface. Thereafter, the reinforcement is repaired followed by the placement of repair mortar.

- Crack injection

Crack injection is used to fill the cracks on the concrete surface. The process involves the selection of suitable injection material, equipment and method of application.

- Replacement

The replacement of a concrete component is conducted when the component is severely defective, damaged and deteriorated. This is done when the further deterioration of the component could comprise the serviceability of the structure. The process includes demolition, setting up of formwork and the reconstruction of the concrete component.

2.8 Summary

The acceptance of FRP composites as bridge construction materials is subject to a clear understanding of life cycle costs. The costs may be evaluated with economic models, namely the EUAC, PWOC, EUANR, NPV, IRR and BCR which were reviewed from the available literature. These models evaluate both monetary and non-monetary criteria of an investment. According to Sabya (2013), the methods all favour the best alternative for an investment project, when the correct calculations and procedures are followed. Therefore, there is no best method.

The majority of the research reviewed appears to exclusively use the PWOC method in the LCCA. In addition to the time allocated to complete the study and the use of the method by previous researchers, the PWOC method was selected for the study. Moreover, the majority of the researchers only considered the decks of the bridges when a LCCA was conducted (Ehlen & Marshall (1996); Haak (2018); Mata et al. (2014); and Bosman (2015)). FRP bridge decks were in some instances found to be cost-effective in comparison to conventional bridges. Nystrom (2003) suggested that improvements in the production of FRP materials would bring about improvements in the initial construction costs. Furthermore, labour costs and smaller bridge spans were identified as critical factors in FRP bridge cost-effectiveness.

The EUAC and PWOC models are suitable for the evaluation of investment alternatives that have an almost identical monetary value. The alternatives should also be mutually exclusive and have the same life spans. The EUANR, IRR and NPV consider investment benefits in addition to the investment costs. The latter is the recommended method for economic evaluations while the BCR is no longer endorsed, due to the shortcomings of the method.

Economic models can determine a cost-effective investment when used for a LCCA. The LCCA which may be deterministic or probabilistic is a tool for evaluating investment decisions. Furthermore, the analysis considers both direct and indirect costs, of initial construction, maintenance and rehabilitation and disposal activities in the service life of a structure. A deterministic LCCA may be followed by sensitivity analysis to account for the uncertainty and variability of LCC.

The deterioration of RC bridges in coastal areas is governed by mechanisms responsible for crack formation which are primarily carbonation and chloride ion ingress. These mechanisms are catalysts for the corrosion of reinforcing steel in the RC bridge components. The deterioration of RC bridge components was understood to govern maintenance and repair activities that ensure a bridge structure lasts its service life. Furthermore, deterioration models can help researchers predict these activities. These models can either be deterministic or probabilistic, with the latter able to capture the uncertainty of the deterioration process.

A reliability-based and probabilistic deterioration model developed by Frangopol et al. (2000), was used for the study. The model was flexible when analysing combinations of service life extension measures thereby optimising the maintenance of the bridge (Van Noortwijk &



Frangopol, 2004). Preventive maintenance interventions were to be repeated after 10, 20 and 25 years, and an essential maintenance intervention carried was out at 50 years, on the bridge structure.

The deterioration of GFRP bars has been investigated however, deterioration models were yet to be developed. Furthermore, the hydrolysis of the ester bonds that compose the polymer matrix in the fibres was understood to be the leading cause of degradation. The deterioration of GFRP-RC was also investigated. Moreover, the bond between the GFRP bar and concrete was found to deteriorate first, due to alkalis from concrete. This resulted in strength and stiffness reduction of the concrete member. Hence, the GFRP bar surface was considered when improving the bond strength between the GFRP bar and concrete. Gergely et al (2007), found that the use of silica sand as a coating on the surface of the GFRP bars enhanced the bond strength.

There were no models that predicted the deterioration of GFRP-RC bridges. Therefore, the deterioration model for the SRC superstructure was also used for the GFRP-RC superstructure. Observations from durability investigations of GFRP bars and GFRP-RC were used to determine the likely maintenance and repair activities for the GFRP-RC superstructure.

The maintenance activities used for the study were described. These activities were selected based on a reliability-based approach to minimise the LCC of the bridge superstructures. The activities included deck expansion joint maintenance, deck surfacing, concrete surface treatment, cathodic protection and concrete repairs.

The next chapter of this dissertation discusses the research design and methodology for achieving the aim and objectives.

Chapter 3: Methodology

3.1 Introduction

In this chapter, a description of the procedure adopted for the research study is provided. This is followed by the description of the bridge superstructures; maintenance activities carried out over the service lives of the bridge's alternatives; and the estimation of life cycle costs. The LCCA methods are then explained. Furthermore, a brief description of how data analysis and validation are conducted is explained. Lastly, a summary of the chapter is provided.

3.2 Procedure

The procedure for the study includes the design of two bridge superstructures followed by a deterministic LCCA adopted from Azizinamini et al. (2013). The procedure of the research study which is also summarized in Figure 21, is as follows:

- Design Bridge Superstructures

Two bridge superstructures are designed. The first superstructure is a SRC bridge and the second is a GFRP-RC bridge.

- Characterise bridges and their elements

The bridges studied in the analysis are described in terms of the characteristics relevant to their LCC. All the design, management and other available information related to the LCC are also gathered.

- Define planning horizon, analysis scenario(s), and base case

A selected period is based on both the analysed physical elements and the type of decisions to be made. The analysis scenario is composed of a description of the maintenance activity. The base case is then described in terms of maintenance and vulnerability costs.

- Select appropriate deterioration models and parameters

The bridge components and alternative management methods characterize the deterioration models. The particular rates of deterioration expected for the bridge elements under consideration are described by these models.

- Estimate costs

Any of the tasks that make up the management plan included both infrastructure owner and user costs. Estimates of these costs are based on the deterioration modelling,

as well as the details of the behaviour and the study scenario. Each measure is defined as taking place over a future period and its costs are calculated at a specified discount rate.

- Calculate PWOC

The approximate costs of all actions are discounted to compute their equivalent present values. The sum of all costs associated with each management strategy, including the residual value and terminal costs, are calculated as the PWOC of that strategy.

- Review results

The review is based on expectations and previous experience.

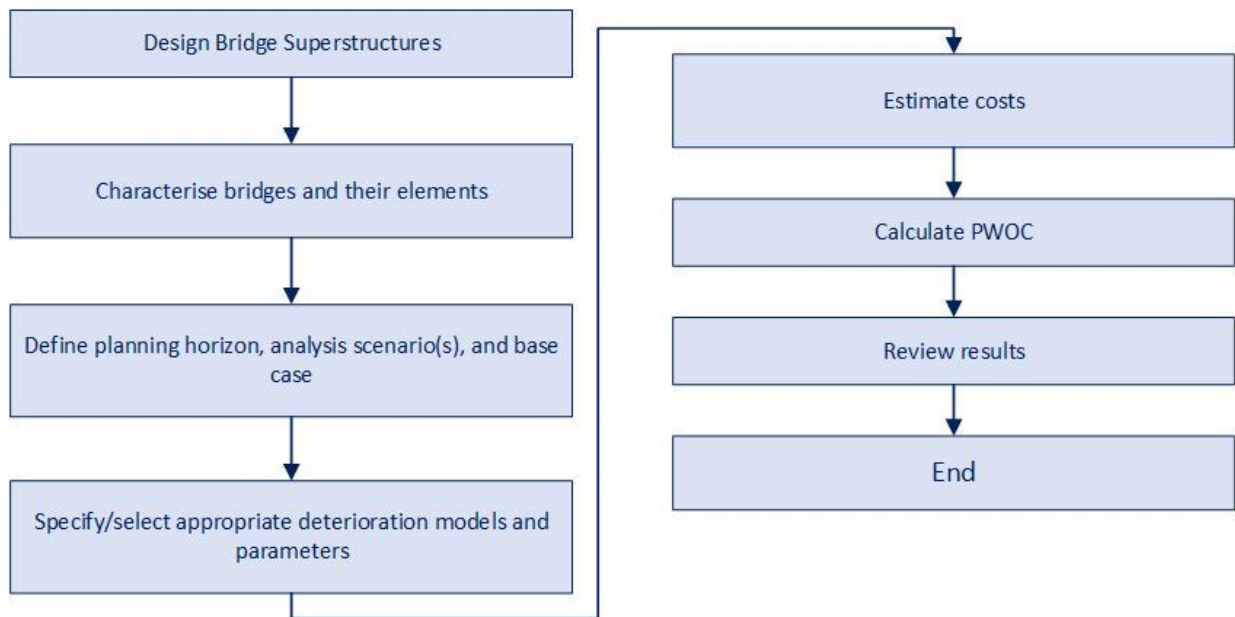


Figure 21. Bridge LCCA procedure

3.3 Bridge superstructure design

3.3.1 SRC T-Beam Bridge

A medium spanning SRC T-beam bridge superstructure was designed for an HL-93 live load and a TL-4 test level concrete parapets using the approximate analysis method, according to the AASHTO LRFD Bridge Specifications (AASHTO, 2014) as shown in Appendix A1. As shown in Figure 22, the deck had a thickness of 203 mm, while the beams supporting the deck were spaced at 2.44 m c-c and had a stem width of 356 mm. The wearing surface was composed of a 76.2 mm thick bituminous overlay (Cape seal). The width of the roadway was 13.4 m and had three spans of 10.7 m, 20.1 m, and 10.7 m with a skewness of 30° as shown in Figure 23.

Once the design was completed the SRC superstructure deck, beams and parapets were then detailed according to the SANS standards as shown in Appendix A2. The T-beam bridge

superstructures were all designed based on design examples according to Barker & Puckett (2007).

3.3.2 GFRP-RC T-Beam Bridge

A GFRP-RC bridge superstructure was designed following the AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete (AASHTO, 2018) and AASHTO LRFD Bridge Specifications (AASHTO, 2014) as shown in Appendix A1. The superstructure was designed with the same geometrical considerations as the SRC superstructure described in Section 3.3.1. The difference between the two bridge alternatives was that the RC T-beam bridge was reinforced with steel reinforcing bars while the GFRP T-beam bridge was reinforced with E-glass reinforcing bars (GFRP).

These bridge designs were designed to be constructed in an unsaturated coastal environment in Cape Town, South Africa. Furthermore, the GFRP-RC superstructure deck, beams and parapets were then detailed as shown in Appendix A2.

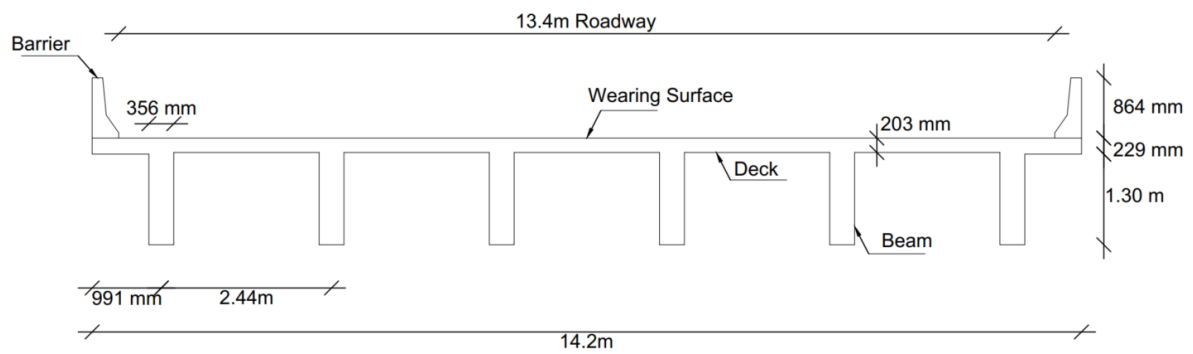


Figure 22 Bridge superstructure section view

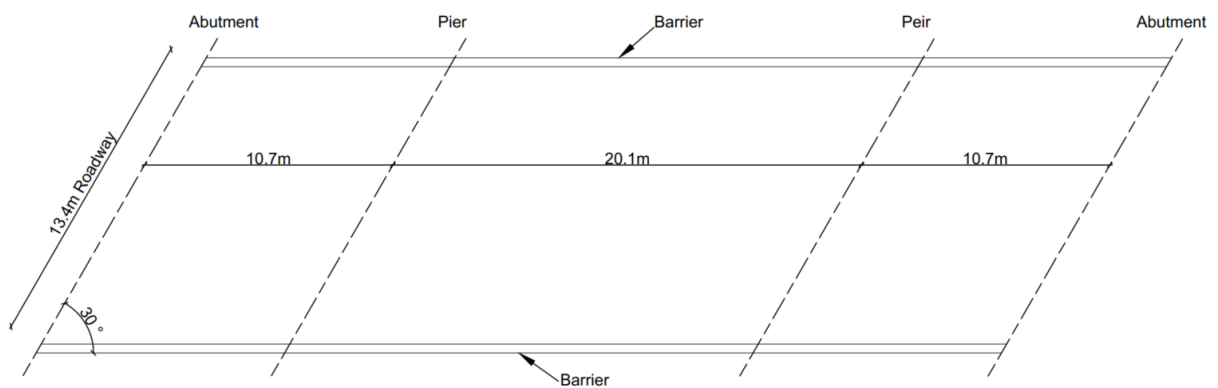


Figure 23. Bridge superstructure plan view



3.3.3 Materials

The bridge construction materials properties for the two bridges were summarised in Table 8. The material properties were selected according to the AASHTO LRFD Bridge Specifications and ACI 318, which were translated into approximate SANS/Eurocode standard properties.

3.3.3.1 Concrete

- AASHTO LRFD Bridge Specifications and ACI 318

The exposure conditions for a reinforced concrete structure near or on the coast (C0) was according to Table 4.2.1 of ACI 318. The minimum concrete characteristic strength was 17 MPa according to Table 4.3.1. The concrete characteristic strength was chosen to be 31 MPa for the superstructure deck and T-beams, while the 28 MPa was chosen for the parapets (ACI, 2007). The binder type and water/binder (w/b) ratio were not specified. These properties were used for the design of the deck, T-beams and parapets for both bridge superstructures as shown in Table 8.

- SANS /Eurocode

The exposure conditions were assumed to be equivalent to XS1 according to SANS 10100-2 (Kessy et al., 2015). MPa. According to the durability requirements of SANS 10100-2, the characteristic strength was equivalent to concrete C28/30 for the deck, T-beams and parapets. A minimum concrete cover of 60 mm was selected (SABS, 2014). The binder selected for the deck and T-beams was CEM IIB-V with w/b: 0.45 while the parapets had a CEM IIB-V with w/b: 0.50 according to Eurocode 2: Table A.5 (CEN, 2004).

3.3.3.2 Reinforcement

- AASHTO LRFD Bridge Specifications and ACI 318

The strength of the steel reinforcement used was 414 MPa according to clause 9.4 of ACI 318.

- SANS /Eurocode Standards

The steel grade equivalent was high tensile steel of 450 MPa as per the specification of SANS 920:2011.

The GFRP reinforcing bars were made from Vinyl Ester resin and E-glass UD reinforcing bars sourced from Industrial Composites cc in Pretoria, South Africa. These fibres had a minimum guaranteed tensile strength of 620.5 MPa and could be cut at a maximum length of 6 meters. To improve the GFRP bar and concrete bond strength the GFRP bar were sand coated.

3.3.3.3 Deck surfacing

The bridge decks were surfaced with a Cape seal wearing course. A bond coat of 30% stable-grade emulsion at an application rate of 0,40 l/m² was firstly applied onto the prepared deck surface. Then 19 mm stone aggregates were evenly spread onto the unbroken emulsion. Furthermore, a diluted fog spray was applied followed by the first layer of slurry. After some time to sufficiently ensure that the spaces between stone chippings are filled a second layer of the slurry was applied.

Table 8. Bridge material properties

RC				GFRP-RC			
Deck				Deck			
Material	Type (ACI)	Type(SABS)	Mass (kg/m3)	Material	Type (ACI)	Type (SABS)	Mass (kg/m3)
Concrete	f'c: 31 Mpa	C32/40	2320	Concrete	f'c: 31 Mpa	C32/40	2320
Binder	-	CEM IIB-V w/b: 0,45	-	Binder	-	CEM IIB-V w/b: 0,45	-
Finish	-	F2	-	Finish	-	F2	-
Rebar	High tensile steel (414 MPa)	High tensile steel (450 MPa)	-	Rebar	E-glass (538 - 1103) Mpa and	E-glass (538 - 1103) Mpa and 620,5 Mpa	-
Surfacing	-	Cape Seal	2250	Bitumen	-	Cape seal	2250
Parapets				Parapets			
Material	Type (ACI)	Type(SABS)	Mass (kg/m3)	Material	Type (ACI)	Type(SABS)	Mass (kg/m3)
Concrete	f'c: 28 Mpa	C28/36	2320	Concrete	f'c: 28 Mpa	C28/36	2320
Cement	-	CEM IIB-V w/b: 0,50	-	Binder	-	CEM IIB-V w/b: 0,50	-
Finish	-	F2	-	Finish	-	F2	-
Rebar	High tensile steel (414 MPa)	High tensile steel (450 MPa)	-	Rebar	E-glass (538 - 1103) Mpa and	E-glass (538 - 1103) Mpa and 620,5 Mpa	-
T-beams				T-beams			
Material	Type (ACI)	Type(SABS)	Mass (kg/m3)	Material	Type (ACI)	Type(SABS)	Mass (kg/m3)
Concrete	f'c: 31 Mpa	C32/40	2320	Concrete	f'c: 31 Mpa	C32/40	2320
Binder	-	CEM IIB-V w/b: 0,45	-	Binder	-	CEM IIB-V w/b: 0,45	-
Finish	-	F2	-	Finish	-	F2	-
Rebar	High tensile steel (414 MPa)	High tensile steel (450 MPa)	-	Rebar	E-glass (538 - 1103) Mpa and 620,5 Mpa	E-glass (538 - 1103) Mpa and 620,5 Mpa	-

3.4 Maintenance Activities

3.4.1 Introduction

The deterioration model selected for the study was described in Section 2.6. The model stated that given three preventative maintenance activities were carried out at 10, 20 and 25 years, essential maintenance could be carried out at 50 years of bridge service life. Moreover, the maintenance activities described in Section 2.7, were performed on both bridge superstructures. Maintenance activities were also executed based on the Committee of Transport Officials (COTO) Standard Specifications.

3.4.2 SRC superstructure

The preventative maintenance activities over the service life of the RC superstructure were as listed in Table 9. Maintenance of the bridge deck expansion joints and surface overlay (Cape seal) were carried out at 10 and 20 years, while the replacement of the facilities was carried out after 25 years. The application of surface treatments on the concrete in terms of a hydrophobic impregnation and a corrosion inhibitor were done at 10, 20 and 25 years. Furthermore, general repairs were also carried out at 10, 20 and 25 years. A cathodic protection system was installed at 25 years.

Table 9. SRC superstructure preventative maintenance activities

Preventative maintenance			
Activities	10 years	20 years	25 years
Deck expansion joints			
Maintenance	✓	✓	
Replacement			✓
Deck surfacing			
Maintenance	✓	✓	
Replacement			✓
Concrete surface treatment			
Hydrophobic impregnation	✓	✓	✓
Corrosion inhibitor	✓	✓	✓
Cathodic protection			
Installation			✓
General repairs	✓	✓	✓

Essential maintenance activities carried out after 50 years of service life of the RC superstructure were enumerated in Table 10. These activities included the maintenance of the deck expansion joints and surface overlay, the application of a hydrophobic impregnation and a corrosion inhibitor, installation and maintenance of the cathodic protection system, concrete repairs on the deck and T-beams as well as the replacement of the parapets.

Table 10. SRC superstructure essential maintenance activities

Essential maintenance	
Activities	50 years
Deck expansion joints	
Maintenance	✓
Deck surfacing	
Maintenance	✓
Concrete surface treatment	
Hydrophobic impregnation	✓
Corrosion inhibitor	✓
Cathodic protection	
Installation	✓
Maintenance of anodes	✓
Concrete repairs	
Deck	✓
T-beams	✓
Replacement	
Parapets	✓

3.4.3 GFRP-RC superstructure

The preventative maintenance activities at 10, 20 and 25 years of service life were listed in Table 11, while the essential maintenance activities at 50 years for the GFRP-RC superstructure were listed in Table 12. The preventative maintenance activities carried out were similar to that of the SRC superstructure while excluding the application of a corrosion inhibitor as concrete surface treatment and the use of a cathodic protection system.

Table 11. GFRP-RC superstructure preventative maintenance activities

Preventative maintenance			
Activities	10 years	20 years	25 years
Deck expansion joints			
Maintenance	✓	✓	
Replacement			✓
Deck surfacing			
Maintenance	✓	✓	
Replacement			✓
Concrete surface treatment			
Hydrophobic impregnation	✓	✓	✓
General repairs	✓	✓	✓

Table 12. GFRP-RC superstructure essential maintenance activities

Essential maintenance	
Activities	50 years
Deck expansion joints	
Maintenance	✓
Deck surfacing	
Maintenance	✓
Concrete surface treatment	
Hydrophobic impregnation	✓
Concrete repairs	
Deck	✓
T-beams	✓
Replacement	
Parapets	✓

3.5 Cost Estimation

3.5.1 Introduction

Cost estimation of initial construction, maintenance and disposal of the SRC superstructure and GFRP-RC superstructure were made according to the Standard Specifications for Road and Bridge Works for South African Road Authorities. These cost estimates were incurred by the infrastructure owner and the users of the bridge superstructures. Based on unit rates from the TMH19 standards the estimated costs were summarised in bills of quantities as seen in Appendix A3 (COTO, 2020). Other cost estimates were made by industry experts.

3.5.2 Initial construction costs



The initial construction costs were retrieved from the Standard Specifications for Road and Bridge Works for South African Road Authorities. The costs considered according to the Chapters of the specification were as follows:

- Chapter 1

The costs of General Requirements and Provisions, Contractor's Site establishment and General obligations, Facilities for the Engineer and Accommodation of Traffic (COTO, 2020a). These costs accounted for the Traffic Delay, Crash Risk at Work Zone, and Environmental Influence costs described in Section 2.3.

- Chapter 9

The costs for the construction of asphalt base and surfacing layers (COTO, 2020f).

- Chapter 13

The costs for the erection of all falsework and formwork for construction, placement of reinforcing steel in concrete, placement, finishing, curing, protection and testing concrete in bridges, installation of all joints which allow movement between the structural members, the construction works relevant for bridge parapets, and drainage pipes erection (COTO, 2020b).

- Chapter 20

The costs for the execution of the works; control testing conducted on materials; and workmanship for monitoring compliance with the requirements (COTO, 2020d).

3.5.3 Maintenance costs

Preventative Maintenance activities at 10 and 20 years of the bridge alternatives were identical, resulting in similar maintenance costs. The preventative maintenance costs for the bridge superstructures were taken from the Chapters to the Standard Specifications for Road and Bridge Works for South African Road Authorities. The costs were as follows:

- Chapter 1 and Chapter 20

The costs were as described in Section 3.5.2

- Chapter 8

The deck surfacing maintenance costs of Rut Correction, Crack Sealing, and Patch Repairs (COTO, 2020e).



- Chapter 14

Repair and Rehabilitation costs for concrete structures, consisting of access for Bridge Rehabilitation, Anchoring of Reinforcement, Grouting and Crack Injection, Protective Coatings for Concrete, and Repair and Replacement of Ancillary Structural elements (COTO, 2020c).

Preventative maintenance costs at 25 years of the bridge alternatives included the following:

- Chapter 1 and Chapter 20

The costs were as described in Section 3.5.2

- Chapter 9

Asphalt layer replacement costs.

- Chapter 13

The filling and sealing of the deck expansion joints costs.

- Chapter 14

The costs were as described for preventative maintenance costs at 10 and 20 years, with the addition of bridge jacking costs.

Lastly, the estimated costs for the installation of a cathodic protection system were included.

Essential maintenance costs at 50 years of the bridge alternatives included the following:

- Chapter 1 and Chapter 20

The costs were as described in Section 3.5.2.

- Chapter 8

The costs were as described for preventative maintenance costs at 10 and 20 years.

- Chapter 14

The costs were as described for preventative maintenance costs at 25 years.

Finally, costs estimates for the installation of a cathodic protection system and maintenance of anodes were included.

3.5.4 Disposal costs

The bridge demolition and disposal costs considered were similarly extracted from the Standard Specifications for Road and Bridge Works for South African Road Authorities. The costs considered according to the Chapters of the specification were as follows:

- Chapter 1 and Chapter 20

The costs were as described in Section 3.5.2

- Chapter 9

The costs of milling the asphalt surfacing on the bridge deck

- Chapter 14

The costs for the Demolition and Removal of Structural Concrete and Steelwork and Bridge Access

3.6 LCCA Methods

3.6.1 Definition

A LCCA can aid researchers in predicting the economic performance of a structure. There are two methods for conducting an LCCA, which can either be the deterministic or the probabilistic approach. These methods are further described in Section 3.6.2.

3.6.2 Methods

- **Deterministic Approach**

The deterministic approach to an LCCA makes use of a single set of input values to produce a single estimated value of total life-cycle cost for a specific bridge management strategy (Hawk, 2002). All LCCA input variables are considered as fixed values based on statistics and nonlinear regression of actually occurring data (Azizinamini et al., 2013). This means that the method does not account for uncertainty in the input values. Furthermore, the method is simple and requires the least amount of computation time. The deterministic approach was selected for the study and conducted in Excel. Primarily, due to limited expertise and manufacturers/distributors of FRP materials in South Africa.

- **Probabilistic Approach**

A stochastic approach may be adopted to characterize the relative likelihood of different potential outcomes of a LCCA. Uncertain input variables of an investment option are identified and are used to develop a sampling distribution of possible values. These values are then used to produce a probability distribution of Net Present Value's (NPV's) as depicted in Figure 24. The resulting NPV distribution can then be compared with the projected NPVs for alternatives, and

the most economical option for implementing the project can be determined for any given risk level (Azizinamini et al., 2013).

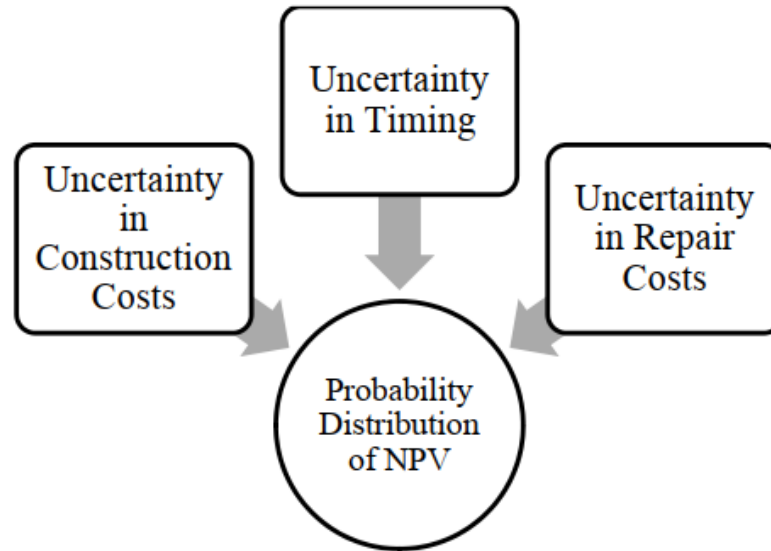


Figure 24. The probabilistic approach to LCCA

- **Monte Carlo simulation**

When the probabilistic approach contains several uncertain parameters the LCCA computation becomes very complex. For this reason, a Monte Carlo simulation could be used to deal with such computations. The simulation is a widely used computer-based method that randomly selects a value for each parameter from the probability distribution and makes use of the specific sampled values to compute the desired outcome parameter, e.g., the total present value of a bridge and its management strategy. With repetition, the analysis produces a set of output computations that are then used to calculate the probability distribution for the outcome parameter (Hawk, 2002).

3.7 Data Analysis and Validation

The deterministic approach to an LCCA was carried out as described in Section 3.8.2. However, the method does not address the issue of variability and uncertainty of the LCCA input parameters. A sensitivity analysis explained in Section 2.4, was hence combined with the deterministic approach to account for the uncertainty in the input parameters. In the analysis, the input parameters of LCC and discount rate were varied to determine their effect on the result of the LCCA. The analysis was carried out with Excel.



3.8 Summary

Two medium spanning T-beam bridge (SRC and GFRP-RC) superstructures were designed for purpose of the study. The AASHTO and LRFD Bridge Design Specifications were followed in the design as well as material selection for the two bridge superstructures. Once the design was completed, the maintenance activities (preventative and essential) for bridge alternatives were specified according to the deterioration model described in Section 2.6. Thereafter, cost estimation was carried out according to the TMH19 and COTO Standard Specifications. The deterministic approach for the LCCA was selected due to the limited expertise and manufacturers/distributors of FRP materials in South Africa. The LCCA outcome for both superstructure alternatives was expressed in terms of PWOC as defined in Section 2.2.2. Furthermore, a Sensitivity Analysis of the various input parameters of the LCCA of the bridge designs was conducted.

Chapter 4: Results and Discussions

4.1 Introduction

This chapter presented the observations from the applied methodology described in Chapter 3. The outcome of LCCA of the two bridge design alternatives is presented and discussed. The sensitivity analysis carried out on the result of the LCCA was also presented and discussed.

4.2 LCCA results

The LCCA for the SRC and GFRP-RC bridge superstructure alternatives were based on initial construction, maintenance, and disposal costs for a service life of 75 years. Following the cost estimation described in Section 3.5. LCC were summarised from the Bills of Quantities (BOQ's) shown in Appendix A3. 15 % of Value added tax was included in the costs for each phase of the bridge life cycle.

Initial construction costs which summed to R 8 330 020 for the SRC superstructure were as summarised in Table 13. Moreover, these were the largest of the SRC superstructure LCC. Costs for the accommodation of traffic at R 661 640 were the majority of the general costs. General costs totalled R 1 544 432; these were the largest across the stages of LCC since initial construction was assumed to take the longest time to complete. Deck surfacing costs were summed to R 217 140. The construction costs for the bridge deck, T-beams, joints, and parapets were the largest of the initial costs which totalled R 5 399 263. Furthermore, the bulk of the costs were for concrete works at R 3 606 003, followed by reinforcement costs at R 725 587. Quality assurance costs totalled R 28 750 and were similar for all stages of the bridge life cycle.

The total initial construction costs of the GFRP-RC superstructure were R 9 203 114 as shown in Table 14. This meant that the GFRP-RC superstructure was more expensive to construct in comparison to the SRC superstructure. The differences were seen in the costs for concrete works, ancillary structural elements (parapets) and reinforcement. The application of a corrosion inhibitor on the SRC superstructure was the cause of the difference in the concrete works and ancillary elements. GFRP bars were more expensive than steel bars, which was why the reinforcement costs differed. The cost ratio of GFRP/ steel ranged from 2.1 to 2.9. The relationship of the cost ratio of GFRP/steel over the years is shown in Figure 25. Furthermore, the graph was derived from the findings of Gergely et al (2007), Cadenazzi et al (2019) and the rates provided by Industrial Composites cc. The findings indicated a decrease in the cost of GFRP over time.



Table 13. SRC superstructure: Initial construction costs summary

Description	Cost	Total
General		
General Requirements and Provisions	R 330 602	
Contractor's Site Establishment and General Obligations	R 518 500	
Facilities for the Engineer	R 33 600	
Accommodation of Traffic	R 661 640	R 1 544 342
Asphalt Layers		
Asphalt Layers	R 271 140	R 271 140
Structures		
Falsework, Formwork and Concrete Finish	R 327 727	
Steel Reinforcement	R 725 587	
Concrete	R 3 606 003	
Joints	R 39 361	
Ancillary Structural Elements	R 700 585	R 5 399 263
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Subtotal		
		R 7 243 495
Value Added Tax:		
15% Of Subtotal		R 1 086 524
Total		
		R 8 330 020

Table 14. GFRP-RC superstructure: Initial construction costs summary

Description	Cost	Total
General		
General Requirements and Provisions	R 330 602	
Contractor's Site Establishment and General Obligations	R 518 500	
Facilities for the Engineer	R 33 600	
Accommodation of Traffic	R 661 640	R 1 544 342
Asphalt Layers		
Asphalt Layers	R 271 140	R 271 140
Structures		
Falsework, Formwork and Concrete Finish	R 327 727	
GFRP Reinforcement	R 2 126 005	
Concrete	R 3 071 223	
Joints	R 39 361	
Ancillary Structural Elements	R 594 160	R 6 158 476
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Subtotal		
		R 8 002 708
Value Added Tax:		
15% Of Subtotal		R 1 200 406
Total		
		R 9 203 114

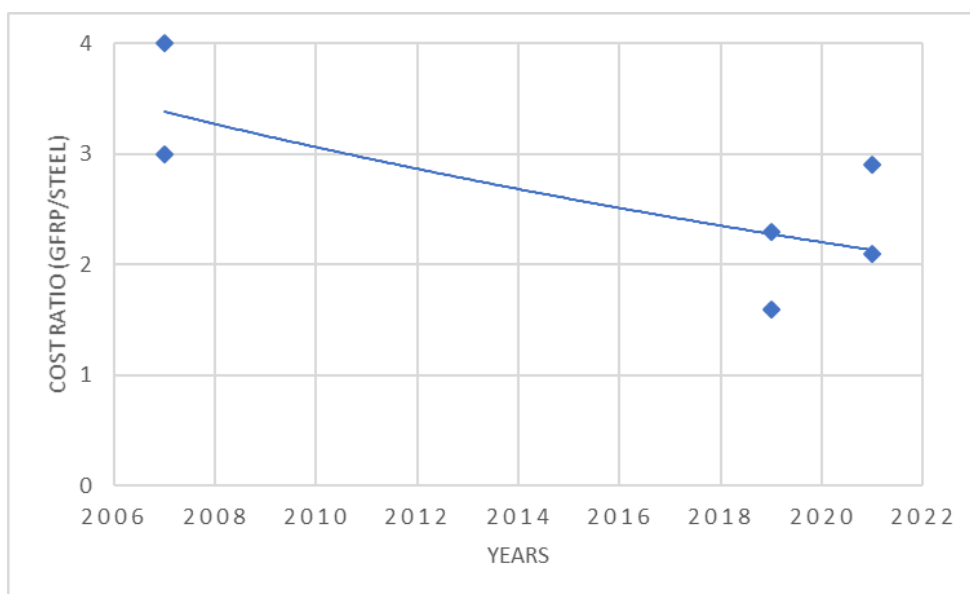


Figure 25. GFRP/steel reinforcement cost ratio over time



Preventative maintenance costs at 10 and 20 years each totalled R 3 005 063 for the SRC superstructure as shown in Table 15. The costs for the repair of the deck surface overlay summed R 129 658, which were the least of the maintenance costs. The majority of the maintenance costs were for the repair of the concrete components of the bridge superstructure at R 1 577 148.

The costs for preventative maintenance at 10 and 20 years for GFRP-RC superstructure were R 2 267 626, which were cheaper in comparison to the SRC superstructure as seen in Table 16. The differences in the costs were brought about by the application of a corrosion inhibitor on the SRC superstructure concrete surface.

Table 15. SRC superstructure: Preventative maintenance costs after 10 and 20 years

Description	Cost	Total
General		
General Requirements and Provisions	R 187 002	
Contractor's Site Establishment and General Obligations	R 288 500	
Facilities for the Engineer	R 21 600	
Accommodation of Traffic	R 380 440	R 877 542
Pretreatment and Repair Existing Layers		
Rut And/Or Depression Correction	R 17 650	
Standard Crack Sealing	R 32 963	
Patching And Edge Break Repair	R 79 045	R 129 658
Repair and Rehabilitation of Structures		
Access For Bridge Rehabilitation	R 14 220	
Anchoring of Reinforcement, Grouting and Crack Injection	R 17 500	
Protective Coatings and Treatments for Concrete	R 1 482 000	
Repair and Replacement of Ancillary Structural Elements	R 63 428	R 1 577 148
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Subtotal		R 2 613 098
Value Added Tax:		
15% Of Subtotal		R 391 965
Total		R 3 005 063



Table 16. GFRP-RC superstructure: Preventative maintenance costs after 10 and 20 years

Description		Cost	Total
General			
General Requirements and Provisions	R	187 002	
Contractor's Site Establishment and General Obligations	R	288 500	
Facilities for the Engineer	R	21 600	
Accommodation of Traffic	R	380 440	R 877 542
Pretreatment and Repair Existing Layers			
Rut And/Or Depression Correction	R	17 650	
Standard Crack Sealing	R	32 963	
Patching And Edge Break Repair	R	79 045	R 129 658
Repair and Rehabilitation of Structures			
Access For Bridge Rehabilitation	R	14 220	
Anchoring of Reinforcement, Grouting and Crack Injection	R	17 500	
Protective Coatings and Treatments for Concrete	R	840 750	
Repair and Replacement of Ancillary Structural Elements	R	63 428	R 935 898
Quality Assurance			
Testing Materials and Judgement of Workmanship	R	28 750	R 28 750
Subtotal			
			R 1 971 848
Value Added Tax:			
15% Of Subtotal			R 295 777
Total			
			R 2 267 626

Preventative maintenance costs at 25 years summed R 4 600 356 for the SRC superstructure as shown in Table 17. General costs were R 877 542 and similar to that of preventative maintenance at 10 and 25 years. This was the case since the preventative maintenance activities were assumed to have a similar duration. The costs for the repair and rehabilitation were the majority at R 1 991 737. Furthermore, the cost incurred from the installation of a cathodic protection system was R 1 991 737.

The costs for preventative maintenance costs at 25 years for the GFRP-RC had a total of R 3 141 869 as seen in Table 18. This also indicated cheaper preventative maintenance in comparison to the SRC superstructure. Differences came from the use of corrosion inhibitors and



the installation of a CP system on the SRC superstructure, which were not used on the GFRP-RC superstructure.

Table 17. SRC superstructure: Preventative maintenance costs after 25 years

Description	Cost	Total
General		
General Requirements and Provisions	R 187 002	
Contractor's Site Establishment and General Obligations	R 288 500	
Facilities for the Engineer	R 21 600	
Accommodation of Traffic	R 380 440	R 877 542
Asphalt Layers		
Asphalt Layers	R 435 920	R 435 920
Structures		
Joints	R 39 361	R 39 361
Repair and Rehabilitation of Structures		
Access for Bridge Rehabilitation	R 14 220	
Surface and Structural Repair of Concrete Members	R 326 325	
Anchoring of Reinforcement, Grouting and Crack Injection	R 17 500	
Protective Coatings and Treatments for Concrete	R 1 482 000	
Repair and Replacement of Ancillary Structural Elements	R 94 672	
Jacking of Bridge Structures	R 57 020	R 1 991 737
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Cathodic Protection	R 627 000	R 627 000
Subtotal		
		R 4 000 310
Value Added Tax:		
15% Of Subtotal		R 600 046
Total		
		R 4 600 356

Table 18. GFRP-RC superstructure: Preventative maintenance costs after 25 years

Description	Cost	Total
General		
General Requirements and Provisions	R 187 002	
Contractor's Site Establishment and General Obligations	R 288 500	
Facilities for the Engineer	R 21 600	
Accommodation of Traffic	R 380 440	R 877 542
Asphalt Layers		
Asphalt Layers	R 435 920	R 435 920
Structures		
Joints	R 39 361	R 39 361
Repair and Rehabilitation of Structures		
Access for Bridge Rehabilitation	R 14 220	
Surface and Structural Repair of Concrete Members	R 326 325	
Anchoring of Reinforcement, Grouting and Crack Injection	R 17 500	
Protective Coatings and Treatments for Concrete	R 840 750	
Repair and Replacement of Ancillary Structural Elements	R 94 672	
Jacking of Bridge Structures	R 57 020	R 1 350 487
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Subtotal		
		R 2 732 060
Value Added Tax:		
15% Of Subtotal		R 409 809
Total		
		R 3 141 869

Essential maintenance costs at 50 years for the SRC superstructure summed R 5 525 049 as shown in Table 19. The general costs (R 1 044 242) were more than the general costs for preventative maintenance, due to a longer duration of essential maintenance activities. The cost of replacing the parapets was R 473 515. The majority of the essential maintenance costs were for the repair and rehabilitation of the structure at R 2 198 883. Moreover, the costs for the installation and maintenance of the cathodic protection system were R 832 200.

The essential maintenance costs of the GFRP-RC were less than that of the SRC superstructure at R 3 830 581 as seen in Table 20. The difference between the two bridge



alternatives was similar to that observed for preventative maintenance at 25 years, with the addition of maintenance of the anodes for the CP system.

Table 19. SRC superstructure: Essential maintenance costs after 50

Description	Cost	Total
General		
General Requirements and Provisions	R 222 902	
Contractor's Site Establishment and General Obligations	R 346 000	
Facilities for the Engineer	R 24 600	
Accommodation of Traffic	R 450 740	R 1 044 242
Pretreatment and Repair Existing		
Rut and/or Depression Correction	R 34 670	
Standard Crack Sealing	R 49 820	
Patching and Edge Break Repair	R 142 310	R 226 800
Structures		
Ancillary Structural Elements	R 473 515	R 473 515
Repair And Rehabilitation Of Structures		
Access for Bridge Rehabilitation	R 14 220	
Demolition and Removal of Structural Concrete and Steelwork	R 20 735	
Surface and Structural Repair of Concrete Members	R 543 980	
Anchoring of Reinforcement, Grouting and Crack Injection	R 17 500	
Protective Coatings and Treatments for Concrete	R 1 482 000	
Repair and Replacement of Ancillary Structural Elements	R 63 428	
Jacking of Bridge Structures	R 57 020	R 2 198 883
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Cathodic Protection	R 832 200	R 832 200
Subtotal		
		R 4 804 390
Value Added Tax:		
15% Of Subtotal		R 720 659
Total		
		R 5 525 049



Table 20. GFRP-RC superstructure: Essential maintenance costs after 50 years

Description	Cost	Total
General		
General Requirements and Provisions	R 222 902	
Contractor's Site Establishment and General Obligations	R 346 000	
Facilities for the Engineer	R 24 600	
Accommodation of Traffic	R 450 740	R 1 044 242
Pretreatment and Repair Existing		
Rut and/or Depression Correction	R 34 670	
Standard Crack Sealing	R 49 820	
Patching and Edge Break Repair	R 142 310	R 226 800
Structures		
Ancillary Structural Elements	R 473 515	R 473 515
Repair And Rehabilitation Of Structures		
Access for Bridge Rehabilitation	R 14 220	
Demolition and Removal of Structural Concrete and Steelwork	R 20 735	
Surface and Structural Repair of Concrete Members	R 543 980	
Anchoring of Reinforcement, Grouting and Crack Injection	R 17 500	
Protective Coatings and Treatments for Concrete	R 840 750	
Repair and Replacement of Ancillary Structural Elements	R 63 428	
Jacking of Bridge Structures	R 57 020	R 1 557 633
Quality Assurance		
Testing Materials and Judgement of Workmanship	R 28 750	R 28 750
Subtotal		
		R 3 330 940
Value Added Tax:		
15% Of Subtotal		R 499 641
Total		
		R 3 830 581



Disposal costs were assumed to be similar for both the SRC and GFRP-RC superstructure at R 1 188 426 as shown in Table 21. These costs were assumed to be similar for both superstructures. Furthermore, the largest portion of costs were for accommodating traffic (R 310 140) during the demolition of the superstructure. The costs of demolition and removal of the structural concrete were R 129 042.

Table 21. SRC and GFRP-RC superstructure: Disposal costs

Description	Cost	Total
General		
General Requirements and Provisions	R151 102	
Contractor's Site Establishment and General Obligations	R231 000	
Facilities for the Engineer	R18 600	
Accommodation of Traffic	R310 140	R710 842
Asphalt Layers		
Asphalt Layers	R164 780	R164 780
Repair And Rehabilitation Of Structures		
Access for Bridge Rehabilitation	R14 220	
Demolition and Removal of Structural Concrete and Steelwork	R114 822	R129 042
Quality Assurance		
Testing Materials and Judgement of Workmanship	R28 750	R28 750
Subtotal		R1 033 414
Value Added Tax:		
15% Of Subtotal		R155 012
Total		R1 188 426

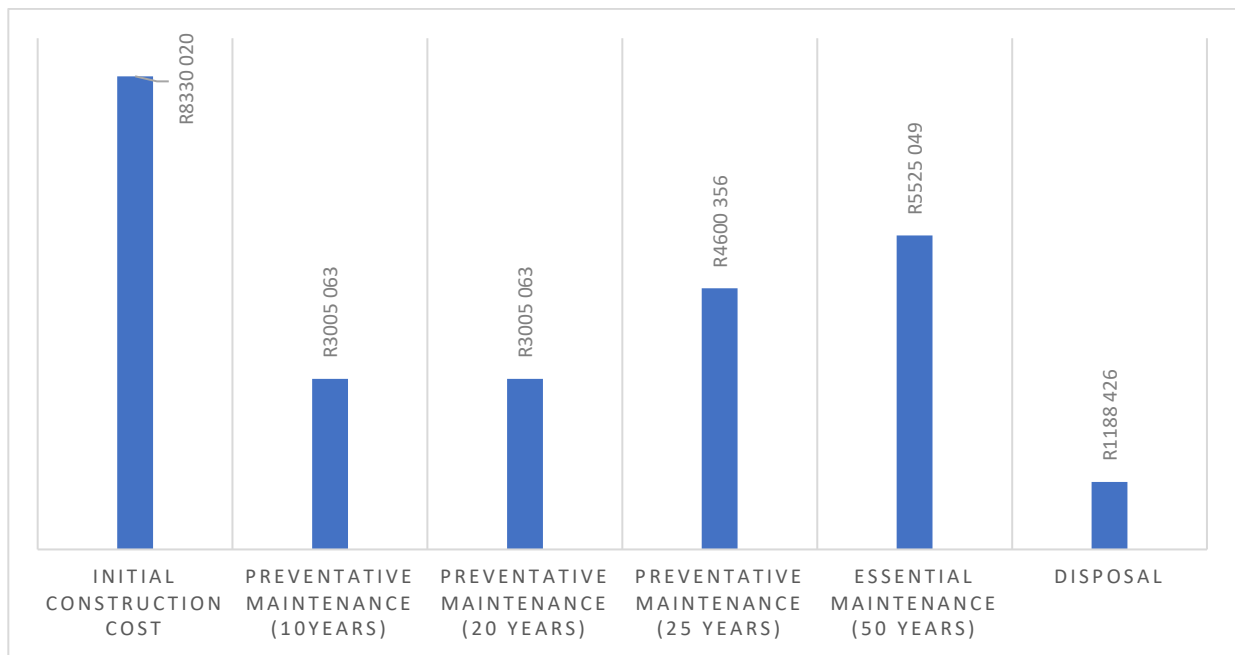


Figure 26 LCC summary: SRC superstructure

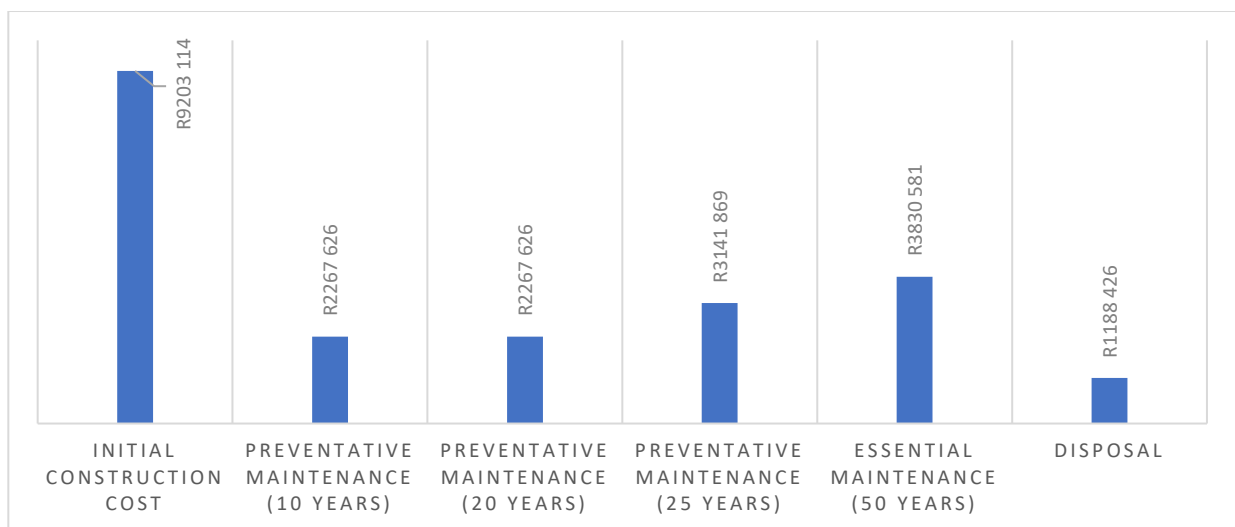


Figure 27 LCC summary: GFRP-RC superstructure

The differences in the LCC of the two bridge superstructures were shown in Figure 26 and Figure 27. The initial construction LCC of the SRC bridge superstructure were found to be 10.5 % less than that of the GFRP-RC bridge superstructure, i.e., by a margin of R 873 094. The maintenance (preventative maintenance at 10, 20 and 25 years; essential, maintenance at 50 years) LCC of SRC were found to be 28.7% more than that of GFRP-RC bridge maintenance LCC, with a cost savings of R4 627 830. This was mainly due to the application of a corrosion inhibitor (concrete surface treatment) and the use of a cathodic protection system on the SRC

bridge superstructure. Moreover, the reinforcement cost also contributed to LCC differences. The disposal costs of both bridge superstructures were found to be similar.

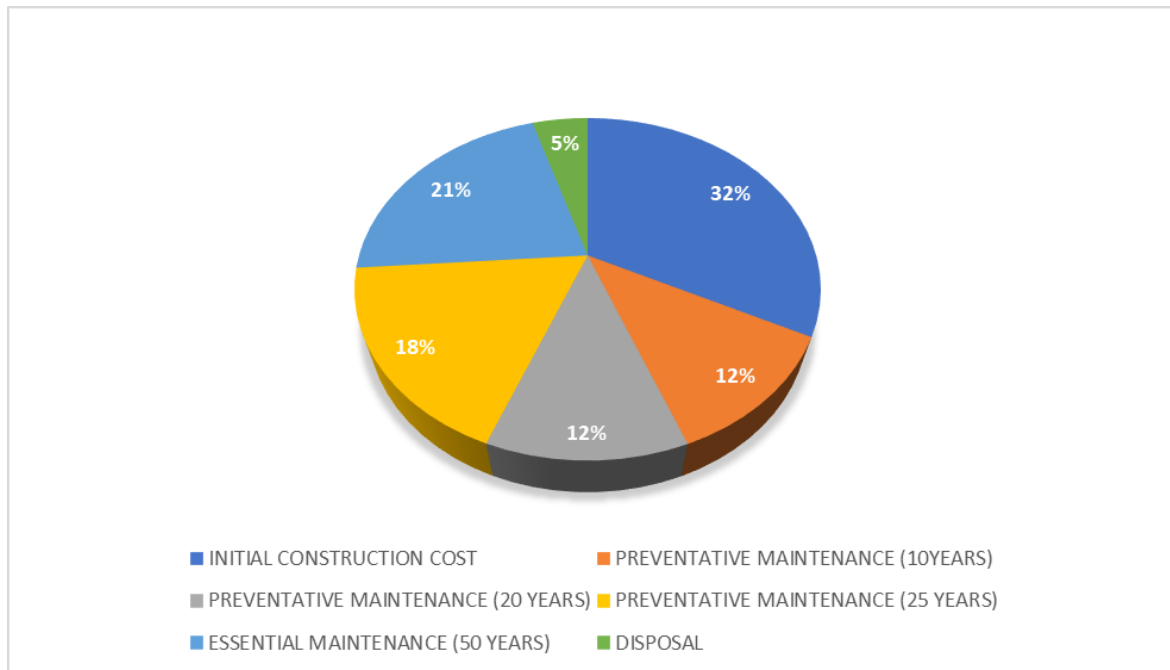


Figure 28 LCC distribution: RC superstructure

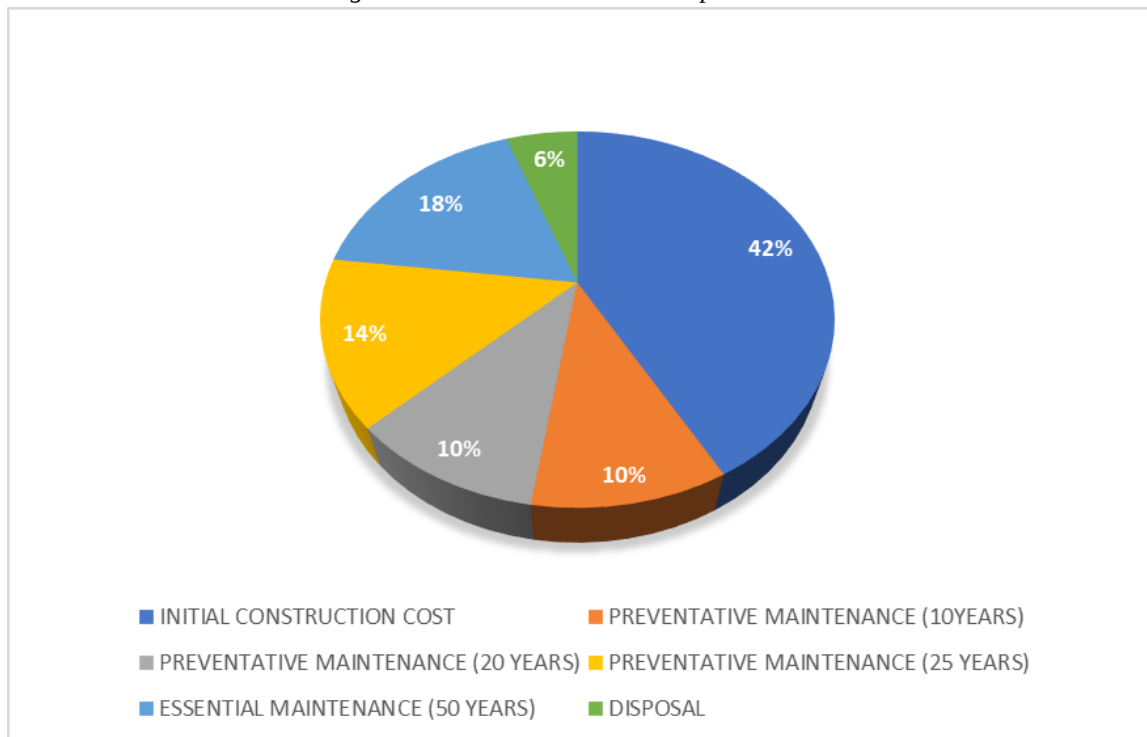


Figure 29 LCC distribution: GFRP-RC superstructure

The LCC distribution for the SRC bridge superstructure were as shown in Figure 28. Initial construction costs accounted for 32% of the total LCC. Followed by similar preventative

maintenance costs at 10 and 20 years, preventative maintenance costs at 25 years and essential maintenance costs at 50 years which had a proportion of 12%, 18%, and 21% of the total LCC, respectively. The disposal costs of the SRC bridge superstructure were found to make up 5% of the total LCC.

The LCC distribution for the GFRP-RC bridge superstructure were shown in Figure 29. The initial construction costs were found to be the largest of the total LCC at 42%. Preventative maintenance activities at 10 and 20 years were both found to constitute 10%, while preventative maintenance at 25 years was 14%. An essential maintenance intervention at 50 years was the second largest of the total LCC, accounting for 18% of the total LCC. The least of the total LCC had a proportion of 6%, associated with the disposal of the GFRP bridge superstructure.

The differences in distributions of the LCC for the two bridge superstructures shown in Figure 28 and Figure 29 showed that the initial construction cost distribution of the total LCC for the GFRP bridge superstructure was larger than that of the SRC bridge superstructure, by a margin of 10%. A marginal difference ranging from 2%-3% was seen for preventative maintenance, as well as a 4% difference for essential maintenance. Moreover, the disposal LCC for the two bridge alternatives had the least differences of 1%. This meant that initial construction costs were the largest, while the disposal costs were the least contributor to variation between the total LCC for the two bridge superstructures.

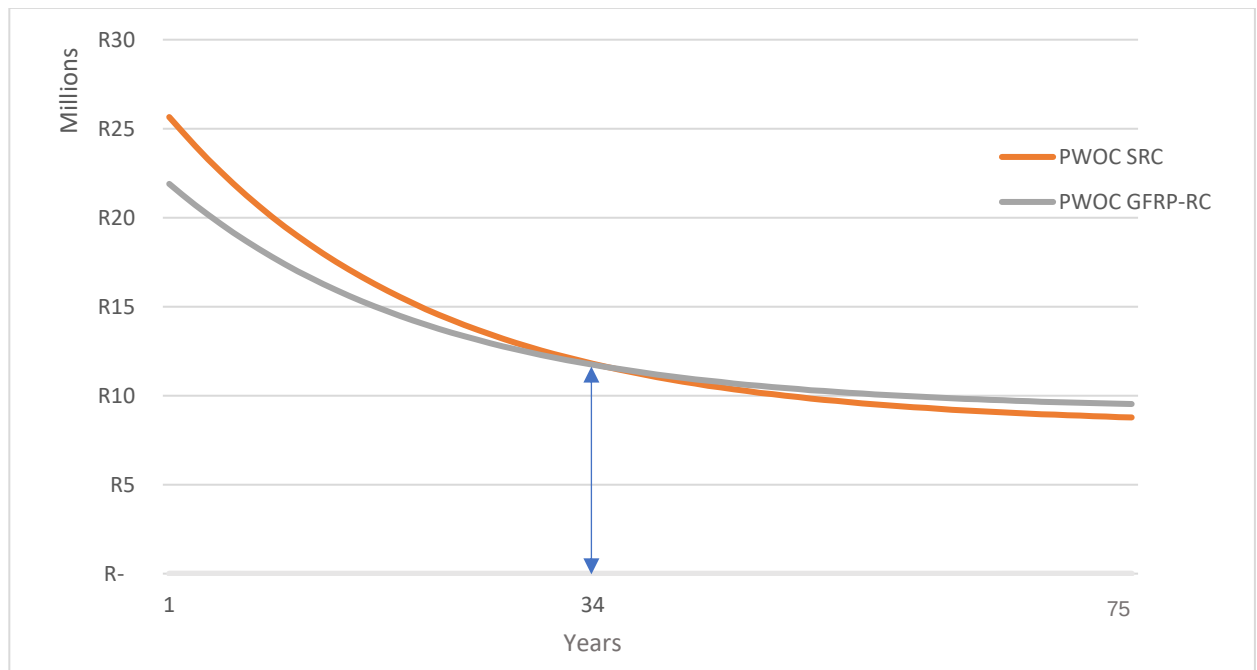


Figure 30. PWOC vs Time

The equation (2-3) for the LCCA was applied at a discount rate of 5% to the LCC in Figures 26 and 27. This was done to convert the LCC of the two superstructures to PWOC as shown in Figure 30. With a PWOC of R 25 653 977 at the start of the LCCA, the SRC

superstructure was the more expensive investment, while the GFRP-RC superstructure was R 21 899 241. Around the period of 34 years of service life of both bridge superstructures, the GFRP-RC bridge superstructure became the more expensive investment alternative. This trend continued till the end of the LCCA, after 75 years of service life for both bridge-superstructure alternatives. At the end of the LCCA, the SRC bridge superstructure had a PWOC of R 8 776 137, while the GFRP-superstructure had a PWOC of R 9 530 058. In other words, the SRC bridge superstructure was cheaper than the GFRP-RC bridge superstructure by R 753 921.

It was therefore concluded that the RC superstructure was the preferred design investment as opposed to the GFRP-RC superstructure, due to the PWOC of the investments at the end of the LCCA. This was primarily due to the high initial construction costs of the GFRP-RC superstructure.

4.3 Sensitivity Analysis

A sensitivity analysis was conducted on the LCCA outcome of the two bridge design alternatives, to determine which input variables were critical to the LCCA. Furthermore, the sensitivity analysis would provide a better understanding and interpretation of the LCCA results. The input LCC and discount rates of the two alternatives were varied to determine their effect on the PWOC. The results of the Sensitivity Analysis are shown in Table 22, Table 23 and Figure 31.

The correlation of LCC change and the resulting PWOC of the SRC superstructure was shown in Table 22. This was done to determine the sensitivity of the PWOC of the SRC bridge superstructure in response to LCC changes. At a discount rate of 5%, the initial construction costs, preventative and essential maintenance costs; and disposal costs were varied. This was done by increasing and decreasing the LCC by 10%. When an increase in PWOC was caused by a decrease in an input cost value, a negative correlation was observed. Furthermore, a positive correlation was observed when an increase in the input cost value led to an increased PWOC. It could be considered that a positive correlation value is directly proportional to the output, whereas a negative correlation value is inversely proportional to the output. The initial construction costs were found to have the highest positive correlation at 9.49%, this also meant that the initial costs were directly proportional to the PWOC of the SRC bridge superstructure.

LCC which yielded correlations of less than 1% were considered to be ineffective and had no significant effect on the LCCA results (Morcous, 2013). In this case, preventative and essential maintenance costs; and disposal costs had no significance to the PWOC of the SRC bridge superstructure.



Table 22. Sensitivity of SRC superstructure LCCA to LCC

Description	LCC	LCC after 10% decrease	PWOC	Percent change	LCC after 10% increase	PWOC	Percent change
Initial Construction	R8 330 020	R 7 497 018	R 7 943 135	-9,49%	R 9 163 021	R9 609 139	9,49%
Preventative Maintenance (10 and 20 years)	R3 005 063	R 2 704 557	R 8 768 399	-0,09%	R 3 305 569	R8 783 876	0,09%
Preventative Maintenance (25 years)	R4 600 356	R 4 140 321	R 8 764 291	-0,13%	R 5 060 392	R8 787 984	0,13%
Essential Maintenance (50 years)	R5 525 049	R 4 972 544	R 8 761 910	-0,16%	R 6 077 554	R8 790 365	0,16%
Disposal	R1 188 426	R 1 069 584	R 8 773 077	-0,03%	R 1 307 269	R8 779 198	0,03%

The correlation between LCC change and the resulting PWOC of the GFRP-RC superstructure was shown in Table 23. Similar to the SRC bridge superstructure, at a discount rate of 5% the LCC were increased and decreased by 10% to determine their effect on the PWOC of the GFRP-RC superstructure. The initial construction costs were found to have the highest positive correlation at 9.66 %, implying that the initial costs were directly proportional to the PWOC of the GFRP-RC bridge superstructure. The other LCC were also found to have no significant impact on the PWOC of the GFRP-RC superstructure.

Table 23. Sensitivity of GFRP-RC superstructure LCCA to LCC

Description	LCC	LCC after 10% decrease	PWOC	Percent change	LCC after 10% increase	PWOC	Percent change
Initial Construction Cost	R9 203 114	R 8 282 802	R8 609 747	-9,66%	R10 123 425	R10 450 370	9,66%
Preventative Maintenance (10 and 20 years)	R2 267 626	R 2 040 863	R9 524 219	-0,06%	R 2 494 388	R 9 535 898	0,06%
Preventative Maintenance (25 years)	R3 141 869	R 2 827 682	R9 521 967	-0,08%	R 3 456 056	R 9 538 149	0,08%
Essential Maintenance (50 years)	R3 830 581	R 3 447 523	R9 520 194	-0,10%	R 4 213 639	R 9 539 923	0,10%
Disposal	R1 188 426	R 1 069 584	R9 526 998	-0,03%	R 1 307 269	R 9 533 119	0,03%



The discount rate used for the LCCA for both bridge alternatives was varied as seen in Figure 31. The increase of the discount rate was seen to have a slight negative correlation on the PWOC of both bridge alternatives. As a result, for discount rates ranging from 5% to 8%, the outcome of the LCCA of both bridge superstructures was not significantly affected.

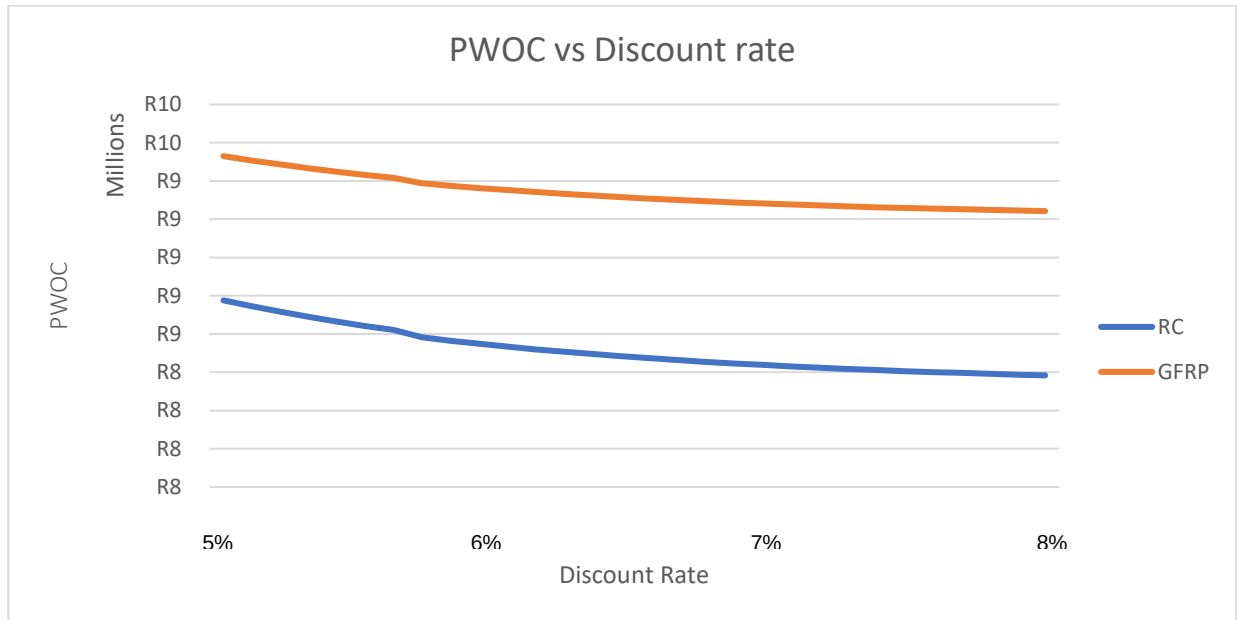


Figure 31 Sensitivity of alternative superstructure LCCA to discount rate



4.4 Summary

In this chapter, LCC, the LCCA and sensitivity analysis results were presented and discussed. The two bridge designs namely, the SRC and GFRP-RC bridge superstructure were compared in terms of PWOC to determine the cost-effective investment.

The LCC considered were the initial construction costs, maintenance/repair/replacement costs and disposal costs for both bridge design alternatives. The maintenance costs were further characterised into preventative maintenance activities after 10, 20 and 25 years and an essential maintenance activity after 50 years of bridge service life. The initial construction costs were found to be the bulk, while the disposal costs were the least of the total LCC for both alternatives. The initial construction costs of the SRC bridge superstructure were found to be less than that of the GFRP-RC bridge superstructure, by a margin of R 873 094. This was due to the cost of E-glass reinforcement, approximately 2.1 to 2.9 times more expensive than the cost of steel reinforcement. However, LCC savings were seen from the GFRP-RC bridge superstructure over the SRC bridge superstructure, by a margin of R4 627 830 in the case of maintenance costs. This was mainly due to the application of a corrosion inhibitor (concrete surface treatment) and the use of a cathodic protection system on the SRC bridge superstructure.

The LCCA was conducted at a 5% discount rate and a service life of 75 years. Furthermore, the GFRP-RC superstructure was found to be the least cost-effective investment from approximately 34 years of service life. At the end of the analysis period, the SRC bridge superstructure was found to have cost savings of approximately R 753 921 in PWOC over the GFRP-RC bridge superstructure.

A sensitivity analysis was conducted to interpret the results of the LCCA. The analysis was done by varying the input LCC to determine their effect on the LCCA. All input LCC were increased and decreased by 10% and the discount rate was varied between 5% and 8%. Initial construction costs were found to have the highest positive correlation with LCC. A positive correlation of 9.49% and 9.66% for the SRC and GFRP-RC superstructure to the outcome of the LCCA. The other costs and as well as the discount rate were all found to have an insignificant effect on the outcome of the LCCA.



Chapter 5: Conclusion and Recommendations

SRC is arguably the most commonly used construction material in the bridge construction industry. However, the corrosion of the reinforcing steel is an issue, especially in coastal environments. Furthermore, corrosion contributes to the high maintenance costs associated with SRC bridge structures. The development of fibre-reinforced polymers (FRP) offers alternative reinforcing materials in RC construction, primarily since the polymers do not corrode.

However, the high initial construction costs of FRP limits their use. Furthermore, there is a lack of research available on the costs of these materials when used for bridge construction. Nonetheless, a good understanding of the LCC of FRP would help bridge the knowledge gap and aid the incorporation of the materials in bridge construction. Moreover, this would enable planners and decision-makers in making informed decisions regarding the feasibility of incorporating FRP in bridge construction in the coastal areas of South Africa.

The research aim of the study was to investigate the economic viability of using FRP as reinforcing elements in bridge construction. This was done by conducting a life cycle cost analysis (LCCA) on two highway beam bridge superstructure designs: a SRC superstructure and a GFRP-RC superstructure to determine the preferred design. The results would serve as an indication of the viability of FRP in bridge construction.

The observations and conclusions drawn from the LCCA were as follows:

- The SRC superstructure was found to be the more cost-effective compared to the GFRP-RC superstructure, by a margin of R 753 921.
- The initial construction LCC of the SRC bridge superstructure were found to be 10.5 % less than that of the GFRP-RC bridge superstructure, i.e., by a margin of R 873 094. Mainly due to the more expensive GFRP reinforcement.
- The maintenance (preventative maintenance at 10, 20 and 25 years and essential maintenance at 50 years) LCC of SRC superstructure were found to be 28.7% more than that of GFRP-RC bridge maintenance LCC, with a cost savings of R4 627 830. This was primarily due to the application of a corrosion inhibitor and the installation of a CP system on the SRC superstructure.
- Meaning that even though the maintenance costs of the GFRP-RC superstructure were less, the high initial construction costs prevented the GFRP-RC superstructure from being cost-effective in comparison to the SRC superstructure.
- The sensitivity analysis of the superstructure alternatives showed the initial construction costs, controlled the results of the LCCA. The preventative and essential maintenance, and disposal costs as well as the discount rate (5%-8%) had no significant impact on the outcome of the LCCA.



- The GFRP/steel cost ratio was seen to decrease over time. Due to the acceptance of FRP materials in various applications following the learning curve theory developed by Nystrom et al (2003). This meant that the application of GFRP bars in bridge construction could be viable in the future.

The recommendations of the study are as follows:

- The study was limited to a non-saturated coastal area, such as Cape Town. A future study could investigate the feasibility of FRP-type bridges in a saturated environment in South Africa.
- Only steel and E-glass reinforcement were compared, other FRP bars such as AFRP, CFRP and BFRP could be used for a future study.
- Medium-spanning SRC bridge superstructure designs were used for the LCCA. Future studies could investigate a wide range of bridge types and spans, and/or existing bridges that require rehabilitation/replacement.
- It is recommended that future studies could consider a probabilistic LCCA of the study.



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Appendices



Appendix A1 – Bridge Design



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(Barker & Puckett, 2007) Table A.1 of Appendix A	2. Overhang (Calculated from design aid) $h_0 = 9.0 \text{ in}, w_0 = 0.113 \text{ ksf}, L = 3.25 \text{ ft}$ $R_{200} = w_0(\text{net area cantilever}) = 0.462 \frac{\text{kips}}{\text{ft}} (2.06 \frac{\text{kN}}{\text{m}})$ $M_{200} = w_0(\text{net area cantilever}) L^2 = -0.597 \text{ kips} \frac{\text{ft}}{\text{ft}} (-0.809 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ $M_{204} = w_0(\text{net area cantilever}) L^2 = -0.294 \text{ kips} \frac{\text{ft}}{\text{ft}} (-0.399 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ $M_{300} = w_0(\text{net area cantilever}) L^2 = 0.161 \text{ kips} \frac{\text{ft}}{\text{ft}} (0.218 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ 3. Barrier (Calculated from design aid) $P_b = 0.320 \frac{\text{kips}}{\text{ft}}, L = 3.25 - 0.42 = 2.83 \text{ ft}$ $R_{200} = P_b(\text{influence line coordinate}) = 0.464 \frac{\text{kips}}{\text{ft}} (2.06 \frac{\text{kN}}{\text{m}})$ $M_{200} = P_b(\text{influence line coordinate}) L = -0.906 \text{ kips} \frac{\text{ft}}{\text{ft}} (-1.22 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ $M_{204} = P_b(\text{influence line coordinate}) L = -0.446 \text{ kips} \frac{\text{ft}}{\text{ft}} (-0.605 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ $M_{300} = P_b(\text{influence line coordinate}) L = 0.245 \text{ kips} \frac{\text{ft}}{\text{ft}} (0.332 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ 4. Future Wearing Surface (Calculated from design aid) $w_{DW} = 0.035 \text{ ksf}, L = 3.25 - 1.25 = 2.0 \text{ ft}, S = 8 \text{ ft}$ $R_{200} = w_{DW}(\text{net area cantilever})L + (\text{net area w/o cantilever})S = 0.191 \frac{\text{kips}}{\text{ft}} (0.85 \frac{\text{kN}}{\text{m}})$ $M_{200} = w_{DW}(\text{net area w/o cantilever})L^2 = -0.070 \frac{\text{kips}}{\text{ft}} (-0.095 \frac{\text{kN}}{\text{m}})$ $M_{204} = w_{DW}(\text{net area cantilever})L^2 + (\text{net area w/o cantilever})S^2 = 0.138 \text{ kips} \frac{\text{ft}}{\text{ft}} (0.187 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$ $M_{300} = w_{DW}(\text{net area cantilever})L^2 + (\text{net area w/o cantilever})S^2 = -0.221 \text{ kips} \frac{\text{ft}}{\text{ft}} (-0.300 \text{ kN} \cdot \frac{\text{m}}{\text{m}})$	



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(AASHTO, 2014) A4.6.2.1 A3.6.1.3.3 A3.6.1.2.2-1 A3.6.1.3.1 Table A4.6.2.1.3-1 A3.6.1.2.5 A4.6.2.1.6 A3.6.1.1.1 A3.6.1.1.2 A3.6.1.3.4 A13.7.2 (Barker & Puckett, 2007) Table A.1 of Appendix A	D. Vehicular Live Load-General - Design according to the approximate strip method - Strips are transverse and designed for the 32.0 – <i>kip</i> axle of the design truck - Wheel loads on the axle are assumed to be equally spaced at 6.0 <i>ft</i> apart. - The equivalent length of transverse strip - Overhang, 45.0 + 10.0<i>X</i> - Positive moment, 26.0 + 6.6<i>S</i> - Negative moment, 48.0 + 3.0<i>S</i> - Number of design lanes (N_L) $N_L = INT \left(\frac{44.0}{12.0} \right) = 3$ - Multiple presence factor (m) - One lane: 1.2 - Two lanes: 1.0 - Three lanes: 0.85 1. Overhang Negative Live-Load Moment Equivalent width= 45.0 + 10.0<i>X</i> = 55.0 <i>in</i> = 4.58 <i>ft</i> $m = 1.2$ $M_{200} = \frac{-1.2 (16.0)(1.0)}{(4.58)} = -4.19 \text{ kips } \frac{ft}{ft} \left(-5.68 \text{ kN} \cdot \frac{m}{m} \right)$ 2. Maximum Positive Live-Load Moment Equivalent width= 26.0 + 6.6<i>S</i> = 78.8 <i>in</i> = 6.57 <i>ft</i> $m = 1.2$ One loaded lane ($m = 1.2$) (<i>governs</i>): $R_{200} = 1.2(0.5100 - 0.0510) \left(\frac{16.0}{6.57} \right) = 1.34 \frac{kips}{ft} \left(5.96 \frac{kN}{m} \right)$ $M_{200} = 1.2(0.2040 - 0.0204)(8.0) \left(\frac{16.0}{6.57} \right) = 4.29 \text{ kips } \frac{ft}{ft} \left(4.29 \text{ kN} \cdot \frac{m}{m} \right)$ 3. Maximum Interior Negative Live-Load Moment Equivalent width= 48.0 + 3.0<i>S</i> = 72.0 <i>in</i> = 6.0 <i>ft</i> $m = 1.2$ $M_{300} = 1.2(-0.1010 - 0.0782)(8.0) \left(\frac{16.0}{6.57} \right) = -4.59 \text{ kips } \frac{ft}{ft} \left(-6.22 \text{ kN} \cdot \frac{m}{m} \right)$	



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Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 05
(Barker & Puckett, 2007) Table A.1 of Appendix A (AASHTO, 2014) A1.3.2.1-1 A1.3.2.1-2 A1.3.3 A1.3.4 A1.3.5 Tables 3.4.1-1 Table A3.4.1-2 A3.6.2.1 A4.6.2.1.6	4. Maximum Live-Load Reaction on Exterior Girder Equivalent width= $45.0 + 10.0X = 55.0 \text{ in} = 4.58 \text{ ft}$ $m = 1.2$ $R_{200} = 1.2(1.1588 + 0.2739) \left(\frac{16.0}{4.58} \right) = 6.01 \frac{\text{kips}}{\text{ft}} \left(26.7 \frac{\text{kN}}{\text{m}} \right)$ E. Strength Limit State - Each component shall satisfy $\sum \eta_i \gamma_i Q_i \leq \phi R_n$ $\eta_i = \eta_D \eta_R \eta_I \geq 0.95$ $\eta_i = \frac{1.0}{\eta_D \eta_R \eta_I} \leq 1.0$ $\eta_D = 1; \eta_R = 1; \eta_I = 1 \therefore \eta_i = 1$ $\sum \eta_i \gamma_i Q_i = 1.00 \gamma_p DC + 1.00 \gamma_p DW + 1.00(1.75)(LL + IM)$ $R_{200} = 1.00[1.25(0.314 + 0.462 + 0.464) + 1.50(0.191) + 1.75(1.33)(6.01)] = 15.83 \frac{\text{kips}}{\text{ft}} \left(70.4 \frac{\text{kN}}{\text{m}} \right)$ $M_{200} = 1.00[1.25(-0.597 - 0.906) + 1.50(-0.070) + 1.75(1.33)(-4.19)] = -11.74 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(-15.9 \frac{\text{kNm}}{\text{m}} \right)$ $M_{204} = 1.00[1.25(0.494) + 0.9(-0.294 - 0.446) + 1.50(0.138) + 1.75(1.33)(4.29)] = 10.14 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(13.7 \frac{\text{kNm}}{\text{m}} \right)$ $M_{300} = 1.00[1.25(-0.685) + 0.9(0.161 + 0.245) + 1.50(-0.221) + 1.75(1.33)(-4.59)] = -11.51 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(-15.6 \frac{\text{kNm}}{\text{m}} \right)$ - Critical negative moment at interior face of exterior support 1. Deck slab $M_s = 0.166 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(0.225 \frac{\text{kNm}}{\text{m}} \right)$ 2. Overhang $M_o = -0.541 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(-0.733 \frac{\text{kNm}}{\text{m}} \right)$	



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Student no.: NDTSAM002		Title: SRC Deck Design	Sheet: 09
(Barker & Puckett, 2007) (AASHTO, 2014) A9.7.3.2 A9.7.2.3	3. Distribution Reinforcement $Percentage = \frac{220}{\sqrt{S_e}} \leq 67\%$ $S_e = 8.0 - \frac{14}{12} = 6.83 \text{ ft (2 082 mm)}$ $Percentage = \frac{220}{\sqrt{6.83}} = 84\% \quad \text{use } 67\%$ $dist A_s = 0.67(pos A_s) = 0.67(0.41) = 0.27 \frac{in^2}{ft}$ $\therefore$ longitudinal bottom bars, Use No. 4 at 8 in, $A_s = 0.29 \frac{in^2}{ft}$		
A5.10.8.2	4. Shrinkage and Temperature Reinforcement $temp A_s \geq 0.11 \frac{A_g}{f_y}$ $temp A_s \geq 0.11 \frac{8 \times 12}{60} = 0.18 \frac{in^2}{ft}$ For the top face longitudinal bars, $\frac{1}{2}(temp A_s) = 0.09 \frac{in^2}{ft}$ Use No. 4 at 18 in, $A_s = 0.13 \frac{in^2}{ft}$		
A5.7.3.4	G. Control of Cracking-General $s \leq \frac{700\gamma_e}{\beta_s f_s} - 2d_c$ Where: $\beta_s = 1 + \frac{d_c}{0.7(h-d_c)}$ $\gamma_e = 1.00$ or 0.75 (exposure class) d_c = depth of concrete cover from extreme tension fiber to center of closest flexural reinforcement f_s = tensile stress in reinforcement at the service limit state h = overall thickness		
A3.4.1	$M = M_{DC} + M_{DW} + 1.33M_{LL}$		



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Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 10
(Barker & Puckett, 2007) (AASHTO, 2014) A5.7.1 A5.4.3.2 A5.4.2.4 C5.4.2.4	- Based on transformed elastic, cracked section properties - The modular ratio η transforms the steel reinforcement into equivalent concrete $E_c = 33,000 K_1 w_c^{1.5} \sqrt{f'_c}$ Where $K_1 = \text{correction factor for source of aggregate}$ $w_c = \text{unit weight of concrete (pcf)}$ For normal-weight concrete and $K_1 = 1.0$ $E_c = 1820 \sqrt{f'_c} = 1820 \sqrt{4.5} = 3860 \text{ ksi (26 614 MPa)}$ $\eta = \frac{E_c}{E_s} = \frac{29000}{3860} = 7.5, \text{ Use } n = 7$ 1. Check of Positive Moment Reinforcement $M_{204} = M_{DC} + M_{DW} + 1.33M_{LL}$ $= (0.494 - 0.294 - 0.446) + 0.138 + 1.33(4.29)$ $= 5.60 \text{ kip} \cdot \frac{ft}{ft} \left(7.59 \frac{kNm}{m} \right)$ Neutral axis $0.5bx^2 = nA'_s(d' - x) + nA_s(d - x)$ $0.5(12)x^2 = 7(0.53)(2.81 - x) + 7(0.41)(6.19 - x)$ $x = 1.63 \text{ in (41.4 mm)} < 2.81 \text{ in (71.4 mm)}$ $I_{cr} = \frac{bx^3}{3} + A'_s(d' - x)^2 + nA_s(d - x)^2$ $= \frac{12(1.63)^3}{3} + 7(0.53)(2.81 - 1.63)^2 + 7(0.41)(6.19 - 1.63)^2$ $= 82.17 \frac{in^4}{ft}$ $f_s = n \left(\frac{M_y}{I_{cr}} \right) = 7 \left(\frac{5.60(12)(6.19 - 1.63)}{82.17} \right) = 26.1 \text{ ksi (180 MPa)}$	



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Student no.: NDTSAM002		Title: SRC Deck Design	Sheet: 11
(Barker & Puckett, 2007)	$d_c = 1.31 \text{ in} \quad \text{and} \quad \beta_s = 1 + \frac{1.31}{0.7(8.0-1.31)} = 1.28$ For class 2 exposure conditions, $\gamma_e = 0.75$ $s_{max} = \frac{700(0.75)}{1.28(26.1)} = 15.71 \text{ in (400 mm)} >$ $9.0 \text{ in (228.6)}, \quad \textbf{OKAY} \quad \text{Use No.5 @ 9 in}$ 2. Check of Negative Moment Reinforcement $M_{204} = M_{DC} + M_{DW} + 1.33M_{LL}$ $= (0.166 - 0.541 - 0.823) - 0.005 + 1.33(-3.128)$ $= -5.36 \text{ kip} \cdot \frac{ft}{ft} \left(7.27 \frac{kNm}{m} \right)$ Neutral axis $0.5bx^2 + (n - 1)A'_s(x - d') = nA_s(d - x)$ $0.5(12)x^2 - (6)(0.41)(x - 1.31) = 7(0.53)(4.69 - x)$ $x = 1.41 \text{ in (35.8 mm)} > 1.31 \text{ in (33.3 mm)}$ $I_{cr} = \frac{bx^3}{3} + (n - 1)A'_s(x - d')^2 + nA_s(d - x)^2$ $= \frac{12(1.41)^3}{3} + (6)(0.41)(1.41 - 1.31)^2 + 7(0.53)(4.69 - 1.41)^2$ $= 51.15 \frac{in^4}{ft}$ $f_s = n \left(\frac{M_y}{I_{cr}} \right) = 7 \left(\frac{5.36(12)(4.69-1.41)}{51.15} \right) = 28.9 \text{ ksi (199 MPa)}$ $d_c = 2.81 \text{ in} \quad \text{and} \quad \beta_s = 1 + \frac{2.81}{0.7(8.0-2.81)} = 1.77$ For class 1 exposure conditions(critical), $\gamma_e = 1.00$, $s_{max} = \frac{700(1.00)}{1.77(28.9)} = 13.68 \text{ in(347 mm)} > s =$ $7.0 \text{ in (178 mm)}, \quad \textbf{OKAY} \quad \text{Use No.5 @ 7.0 in}$		





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Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 12
(Barker & Puckett, 2007) (AASHTO, 2014) A9.7.1.5 A3.6.1.3.4 A13.6.1 A13.6.2 A1.3.4 A13.7.2 A13.7.3.1.2 A13.7.3.2 Table AA13.2-1 A1.3.2.1 Tables A3.4.1-1 and A13.6.2 A13.7.3.1 A13.7.3.1.1 AA13.3.1	Deck Overhang Design - Strength I and Extreme Event II Limit States investigated. 1. Strength I Limit State $M_b = -\frac{P_b(39.0-7.0-5.0)}{12} = -0.720 \text{ kip} \cdot \frac{ft}{ft} \left(-0.976 \frac{kNm}{m} \right)$ $M_o = -\frac{w_o(39.0-7.0)^2}{2 \times 12^2} = -0.402 \text{ kip} \cdot \frac{ft}{ft} \left(-0.545 \frac{kNm}{m} \right)$ $M_{DW} = -\frac{w_{DW}(39.0-7.0-15.0)^2}{2 \times 12^2} = -0.035 \text{ kip} \cdot \frac{ft}{ft} \left(-0.047 \frac{kNm}{m} \right)$ $M_{LL} = -\frac{W(19.0-14.0)^2}{12} = -1.746 \text{ kip} \cdot \frac{ft}{ft} \left(-2.37 \frac{kNm}{m} \right)$ $M_o = \eta[1.25M_{DC} + 1.50M_{DC} + 1.75(1.33M_{DC})]$ $= 1.05[1.25(-0.720 - 0.402) + 1.50(-0.035) + 1.75 \times 1.33(-1.746)] = -5.79 \text{ kip} \cdot \frac{ft}{ft} \left(-7.85 \frac{kNm}{m} \right)$ 2. Extreme Event II Limit State - The loads applied to the barrier are for test level TL-4 - The minimum edge thickness of the deck overhang is 8.0 in - The minimum height of barrier for TL-4 is 32.0 in - The transverse and longitudinal forces are distributed over a length of barrier of 3.5 ft - The resistance factors ϕ are taken as 1.0 - The vehicle collision load factor is 1.0 H. Concrete Barrier Strength $R_w = \left(\frac{2}{2L_c - L_t} \right) \left(8M_b + 8M_w + \frac{M_c L_c^2}{H} \right)$ $L_c = \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2} \right)^2 + \frac{8H(M_b + M_w)}{M_c}}, M_b = 0, H = \frac{34}{12} = 2.83 \text{ ft}$ Where: H = height of wall (ft), L_c = critical length of yield line failure pattern (ft), L_t = longitudinal distribution length of impact force (ft), M_b = additional flexural resistance of beam, if any, at top of wall (kip.ft), M_c = flexural resistance of wall about an axis parallel to the longitudinal axis of the bridge (kip.ft/ft) M_w = flexural resistance of wall about vertical axis (kip.ft) R_w = nominal railing resistance to transverse load (kips)	



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021	
Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 13	
(Barker & Puckett, 2007)	1. Flexural Resistance of Wall about Vertical Axis, M_w $f'_c = 4 \text{ ksi (27.6 MPa)}, f_y = 60 \text{ ksi (414 MPa)}$ Segment I $A_s = 2 - No. 3's = 2(0.11) = 0.22 \text{ in}^2$ $d_{avg} = \frac{3.0 + 2.75 + 1.375}{2} = 3.56 \text{ in}$ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.22(60)}{0.85(4)(21)} = 0.185 \text{ in}$ $\phi M_n = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.22)(60) \left(3.56 - \frac{0.185}{2} \right) / 12$ $= 3.81 \text{ kip.ft (5.17 kNm)}$ Segment II $A_s = 1 - No. 3 = 0.11 \text{ in}^2$ $d_{pos} = 3.25 + 3.50 = 6.75 \text{ in}$ $d_{neg} = 2.75 + 3.25 = 6.0 \text{ in}$ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.11(60)}{0.85(4)(10)} = 0.194 \text{ in}$ $\phi M_{n pos} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.11)(60) \left(6.75 - \frac{0.194}{2} \right) / 12 = 3.66 \text{ kip.ft (4.96 kNm)}$ $\phi M_{n neg} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.11)(60) \left(6.00 - \frac{0.194}{2} \right) / 12 = 3.25 \text{ kip.ft (4.41 kNm)}$ $\phi M_{n II} = \frac{\phi M_{n pos} + \phi M_{n neg}}{2} = 3.45 \text{ kip.ft (4.68 kNm)}$		



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo		MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002		Title: SRC Deck Design	Sheet: 14
(Barker & Puckett, 2007)	Segment III $A_s = 1 - No.3 = 0.11 \text{ in}^2$ $d = 9.50 + 2.75 = 12.25 \text{ in}$ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.11(60)}{0.85(4)(3.0)} = 0.647 \text{ in}$ $\phi M_{n \text{ pos}} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.11)(60) \left(12.25 - \frac{0.647}{2} \right) / 12 = 6.56 \text{ kip.ft (8.89 kNm)}$ $M_w = \phi M_{nI} + \phi M_{nII} + \phi M_{nIII}$ $= 3.81 + 3.45 + 6.56 = 13.82 \text{ kip.ft (18.7 kNm)}$ 2. Flexural Resistance of Wall about an Axis Parallel to the Longitudinal Axis of the Bridge, M_c For the vertical bars in the barrier, try No.4 @ 6 in ($A_s = 0.39 \text{ in}^2$) $d = 7.0 + 2.0 = 4.75 \text{ in}$ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.39(60)}{0.85(4)(12)} = 0.574 \text{ in}$ $M_{cI} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.39)(60) \left(4.75 - \frac{0.574}{2} \right) / 12 = 8.70 \text{ kip.ft} \left(11.8 \frac{\text{kNm}}{\text{m}} \right)$ $d = 2.0 + 0.50 + 6.0 + 0.25 = 8.75 \text{ in}$ $M_{cII+III} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.39)(60) \left(8.75 - \frac{0.574}{2} \right) / 12 = 16.50 \text{ kip.ft} \left(22.4 \frac{\text{kNm}}{\text{m}} \right)$ $M_c = \frac{M_{cI}(21.0) + M_{cII+III}(10.0 + 3.0)}{34.0} = \frac{8.70(21.0) + 16.50(13.0)}{34.0} =$ $11.68 \text{ kip.ft} \left(15.8 \frac{\text{kNm}}{\text{m}} \right)$		



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 16
(Barker & Puckett, 2007) (AASHTO, 2014) A5.8.4.1 A5.11.2.4. A5.11.2.4.2 C5.11.2.4.1	$A_{vf} \geq \frac{0.05b_v}{f_y}$ $A_{vf} \geq \frac{0.05(15.0)}{60} (12) = 0.15 \frac{in.^2}{ft}$ Since No. 4 bars at 6 in. ($A_s = 0.39 \frac{in.^2}{ft}$) OKAY $l_{hb} = \frac{38d_b}{\sqrt{f'_c}} = 8.96 \text{ in } (228 \text{ mm})$ $l_{dh} = 0.7(8.96) = 6.27 \text{ in } (159 \text{ mm})$, Available $l_{dh} = 9.0 - 2.0 = 7.0 \text{ in } (178 \text{ mm})$ OKAY The standard 90° hook with an extension of $12db + 4db = 16 (0.50) = 8.0 \text{ in } (203.2 \text{ mm})$ 6. Top Reinforcement in Deck Overhang Collision Moment $M_{CT} = -\frac{R_w H}{L_c + 2H} = \frac{59.1(2.83)}{7.17 + 2(2.83)} = -13.04 \text{ kip} \cdot \frac{ft}{ft} \left(-17.7 \frac{kNm}{m} \right)$ $M_u = \eta [1.25M_{DC} + 1.50M_{DW} + M_{CT}]$ $= 1.0 [1.25(-0.720 - 0.402) + 1.50(-0.035) - 13.04]$ $= -14.50 \text{ kip} \cdot \frac{ft}{ft} \left(-19.7 \frac{kNm}{m} \right)$ Alternating a No. 3 bar with the No. 5 top bar at 7.5 in $A_s = 0.18 + 0.49 = 0.67 \frac{in.^2}{ft}$ $d = 9.0 - 3.0 - \frac{0.625}{2} = 5.69 \text{ in}$ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.67(60)}{0.85(4.5)(12)} = 0.88 \text{ in}$ $\phi M_{n pos} = \phi A_s f_y \left(d - \frac{a}{2} \right)$ $= 1.0(0.67)(60) \left(5.69 - \frac{0.88}{2} \right) / 12 = 17.59 \text{ kip} \cdot ft \left(23.8 \frac{kNm}{m} \right)$ $T = V_{CT} = \frac{R_w}{L_c + 2H}$ $T = \frac{59.1}{7.17 + 2(2.83)} = 4.61 \text{ kips/ft}$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet	
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021	
Student no.: NDTSAM002	Title: SRC Deck Design	Sheet: 17	
(Barker & Puckett, 2007) (AASHTO, 2014) A5.11.2.4.1 A5.11.1.2 A5.11.2.1.1	$\frac{P_u}{\phi P_n} + \frac{M_u}{\phi M_n} \leq 1.0$ where $P_u = T$ and $\phi P_n = \phi A_{st} f_y$ $A_{st} = \text{No. 3 at 7.5 in., No. 5 at 7.5 in., No. 5 at 9 in.}$ $= 0.18 + 0.49 + 0.41 = 1.08 \text{ in.}^2/\text{ft}$ $\phi P_n = 1.0(1.08)(60) = 64.8 \text{ kips/ft} \left(288 \frac{\text{kN}}{\text{m}} \right)$ $M_u \leq 17.59 \left(1.0 - \frac{4.61}{64.8} \right) = 16.34 \text{ kip} \cdot \frac{\text{ft}}{\text{ft}} \left(22.15 \frac{\text{kNm}}{\text{m}} \right)$ $\therefore$ Use (No. 3 and No. 5) at 7.5 in. $l_{dh} = l_{dh} \cdot \text{modification factors}$ For No.5 bar $\phi = 1$ $l_{hb} = \frac{38d_b}{\sqrt{f'_c}} = \frac{38(0.625)}{\sqrt{4.5}} = 11.2 \text{ in (284 mm)}$ $l_{dh} = (0.7)(1.2) \left(\frac{14.50}{17.59} \right) = 6.46 \text{ in (164 mm), Available } l_{dh} =$ $0.625 + 6.0 + 0.3125 = 6.94 \text{ in. (176 mm)} >$ $6.46 \text{ in. } \quad \textbf{OKAY}$ 7. Length of the Additional Deck Overhang Bars Additional No. 3 bars At a distance x from the centreline of the exterior T-beam, the collision moment is approximately $M_{CT}(x) = -12.2 \left(1 - \frac{x}{5.33} \right); x = 0.74 \text{ ft} = 8.9 \text{ in}$ $\text{Add, } 15 \text{ db} = 15(0.375) = 5.6 \text{ in, } l = 8.9 + 5.6 = 14.5 \text{ in}$		



		University of Cape Town Department of Civil Engineering		Calculation Sheet	
Name: Samuel E.D Ndeutapo		MSc Dissertation		Date: 01/11/2021	
Student no.: NDTSAM002		Title: SRC Deck Design		Sheet: 18	
(Barker & Puckett, 2007)	$l_{dh} = 1.25 \frac{A_b f_y}{\sqrt{f'_c}} = 1.25 \frac{0.11(60)}{\sqrt{4.5}} = 3.9 \text{ in (99.1 mm)}$ $0.4d_b f_y = 0.4(0.375)(60) = 9.0 \text{ in (229 mm)}$ controls				



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo		MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002		Title: SRC T-beam Design	Sheet: 19
(Barker & Puckett, 2007) (AASHTO, 2014) Section 5, Appendix A5.3 A5.14.1.5.1a A9.7.1.1 A5.14.1.5.1c C5.14.1.5.1c A5.10.3.1.1 Table A2.5.2.6.3-1 A5.14.1.5.2a 			



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet																
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021																
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 21																
(Barker & Puckett, 2007) (AASHTO, 2014) Table A3.4.1-1 A3.6.1.1.1 A3.6.1.1.2 A3.6.2.1 A4.6.2.2.1 A4.6.2.2.2 Table A4.6.2.2.1-1 A4.6.2.2.2b Table A4.6.2.2.2b-1	F. Select Applicable Load Combinations • Strength I Limit State • Service I Limit State • Fatigue Limit State G. Calculate Live-Load Force Effects 1. Select Number of Lanes As previously calculated under ‘SRC Deck Design’, $N_L = 3$ 2. Multiple Presence <table><tr><td>No. of Loaded Lanes</td><td>m</td></tr><tr><td>1</td><td>1.20</td></tr><tr><td>2</td><td>1</td></tr><tr><td>3</td><td>0.85</td></tr></table> 3. Dynamic Load Allowance <table><tr><td>Component</td><td>IM (%)</td></tr><tr><td>Deck joints</td><td>75</td></tr><tr><td>Fatigue</td><td>15</td></tr><tr><td>All other</td><td>33</td></tr></table> 4. Distribution Factors for Moment $d_e = 3.25 - 1.25 = 2.0\text{ ft} < 3.0\text{ ft}$ OKAY No. of beams $N_b = 6$ $t_s = 7.5\text{ in}$ $S = 8\text{ ft}$ $L_1 = L_3 = 35\text{ ft}, L_2 = 66\text{ ft}$ A. Interior Beams with Concrete Decks For preliminary design $\frac{K_g}{12Lt_s^3} = 1.0$ and $\frac{l}{j} = 1.0$ One design lane loaded: $mg_M^{SI} = 0.06 + \left(\frac{S}{14}\right)^{0.4} \left(\frac{S}{L}\right)^{0.3} \left(\frac{K_g}{12Lt_s^3}\right)^{0.1}$ mg = girder distribution factor with multiple presence factor included	No. of Loaded Lanes	m	1	1.20	2	1	3	0.85	Component	IM (%)	Deck joints	75	Fatigue	15	All other	33	
No. of Loaded Lanes	m																	
1	1.20																	
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NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



		University of Cape Town Department of Civil Engineering		Calculation Sheet													
Name: Samuel E.D Ndeutapo		MSc Dissertation		Date: 01/11/2021													
Student no.: NDTSAM002		Title: SRC T-beam Design		Sheet: 23													
(Barker & Puckett, 2007)	<table border="1"> <tr> <th>Reduction Factor</th> <th>L_1</th> <th>L_{avg}</th> <th>L_2</th> </tr> <tr> <td>c_1</td> <td>0.120</td> <td>0.100</td> <td>0.087</td> </tr> <tr> <td>r_{skew}</td> <td>0.947</td> <td>0.956</td> <td>0.962</td> </tr> </table>					Reduction Factor	L_1	L_{avg}	L_2	c_1	0.120	0.100	0.087	r_{skew}	0.947	0.956	0.962
	Reduction Factor	L_1	L_{avg}	L_2													
	c_1	0.120	0.100	0.087													
	r_{skew}	0.947	0.956	0.962													
	D. Distributed Live-Load Moments (SAP2000) $M_{LL+IM} = mgr \left[(M_{Tr} \text{ or } M_{Ta}) \left(1 + \frac{IM}{100} \right) + M_{Ln} \right]$																
	Live-load placement for maximum positive moment in exterior span																
	$M_{Ta} = 332.17 \text{ kip.ft}$ $M_{Ln} = 85.25 \text{ kip.ft}$																
	Interior girders: $M_{LL+IM} = 0.746(0.947)[332.17(1.33) + 85.25] = 372.3 \text{ kip.ft}$																
	Exterior girders: $M_{LL+IM} = 0.750(0.947)[332.17(1.33) + 85.25] = 374.3 \text{ kip.ft}$																
	Live-load placement for maximum negative moment at interior support																
$M_{Tr} = -323.30 \text{ kip.ft}$ $M_{Ln} = -208.57 \text{ kip.ft}$ $1.33M_{Tr} + M_{Ln} = 1.33(-323.3) - 208.57 = -638.6 \text{ kip.ft}$																	
Interior girders: $M_{LL+IM} = 0.699(0.956)(-638.6) = 426.7 \text{ kip.ft}$																	
Exterior girders: $M_{LL+IM} = 0.750(0.956)(-638.6) = 426.7 \text{ kip.ft}$																	



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021	
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 25	
(Barker & Puckett, 2007)	- Live-load placement for maximum shear at exterior support $V_{Tr} = 21.70 \text{ kips}$ $V_{Ln} = 11.93 \text{ kips}$ $1.33V_{Tr} + V_{Ln} = 1.33(21.70) + 11.93 = 40.8 \text{ kips}$ Interior girders: $V_{LL+IM} = 0.814(1.115)(40.8) = 37.0 \text{ kips}$ Exterior girders: $M_{LL+IM} = 0.750(1.115)(40.8) = 34.1 \text{ kips}$ - Live-load placement for maximum shear to left of interior support. $V_{Tr} = 23.45 \text{ kips}$ $V_{Ln} = 17.16 \text{ kips}$ $1.33V_{Tr} + V_{Ln} = 1.33(23.45) + 17.16 = 48.3 \text{ kips}$ Interior girders: $V_{LL+IM} = 0.814(1.115)(48.3) = 43.8 \text{ kips}$ Exterior girders: $M_{LL+IM} = 0.750(1.115)(48.3) = 40.4 \text{ kips}$ - Live-load placement for maximum shear to right of interior support. $V_{Tr} = 45.69 \text{ kips}$ $V_{Ln} = 20.37 \text{ kips}$ $1.33V_{Tr} + V_{Ln} = 1.33(45.69) + 20.37 = 81.14 \text{ kips}$ Interior girders: $V_{LL+IM} = 0.814(1.115)(81.14) = 73.6 \text{ kips}$ Exterior girders: $M_{LL+IM} = 0.750(1.115)(81.14) = 67.9 \text{ kips}$		



	University of Cape Town Department of Civil Engineering	Calculation Sheet																																																																																
Name: Samuel E.D Ndeutapo Student no.: NDTSAM002	MSc Dissertation Title: SRC T-beam Design	Date: 01/11/2021 Sheet: 26																																																																																
(Barker & Puckett, 2007)	H. Calculate Force Effects from Other Loads (SAP2000) Uniformly distributed dead load, w 1. Interior Girders $DC: \text{Slab}, (0.150)(8.0/12)8 = 0.800 \text{ kips/ft}$ $Girder \text{ stem}, (0.150)(14)(60 - 8)/12^2 = 0.758 \text{ kips/ft}$ $w_{DC} = 1.558 \text{ kips/ft}$ $DW: \text{FWS}, w_{DW} = (0.140)(3.0/12)8 = 0.280 \text{ kips/ft}$ Interior girder unfactored moments and shears <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr> <th colspan="2"></th> <th colspan="3">Moments (kip.ft)</th> <th colspan="3">Shears (kips)</th> </tr> <tr> <th>Load Type</th> <th>w (k/ft)</th> <th>M_{104}</th> <th>M_{200}</th> <th>M_{205}</th> <th>V_{100}</th> <th>V_{110}</th> <th>V_{200}</th> </tr> <tr> <td>DC</td> <td>1.558</td> <td>34.49</td> <td>-478.31</td> <td>370.02</td> <td>-13.7</td> <td>40.93</td> <td>-51.41</td> </tr> <tr> <td>DW</td> <td>0.280</td> <td>6.20</td> <td>-85.96</td> <td>66.50</td> <td>-2.44</td> <td>7.36</td> <td>-9.24</td> </tr> <tr> <td>LL-IM</td> <td>N/A</td> <td>372.3</td> <td>-426.7</td> <td>477.3</td> <td>37.0</td> <td>43.8</td> <td>73.6</td> </tr> </table> 2. Exterior Girders $DC: \text{Slab}, 0.314 \text{ kips/ft}$ $\text{Overhang}, 0.462 \text{ kips/ft}$ $\text{Barrier}, 0.464 \text{ kips/ft}$ $Girder \text{ stem}, 0.150 \times 7 \frac{[(60-9) + (60-8)]}{12^2} = 0.751 \text{ kips/ft}$ $w_{DC} = 1.991 \text{ kips/ft}$ $DW: \text{FWS}, w_{DW} = 0.191 \text{ kips/ft}$ Exterior girder unfactored moments and shears <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr> <th colspan="2"></th> <th colspan="3">Moments (kip.ft)</th> <th colspan="3">Shears (kips)</th> </tr> <tr> <th>Load Type</th> <th>w (k/ft)</th> <th>M_{104}</th> <th>M_{200}</th> <th>M_{205}</th> <th>V_{100}</th> <th>V_{110}</th> <th>V_{200}</th> </tr> <tr> <td>DC</td> <td>1.991</td> <td>44.08</td> <td>-611.24</td> <td>472.86</td> <td>-17.38</td> <td>52.31</td> <td>-65.70</td> </tr> <tr> <td>DW</td> <td>0.191</td> <td>3.22</td> <td>-58.64</td> <td>45.36</td> <td>-1.67</td> <td>5.02</td> <td>-6.30</td> </tr> <tr> <td>LL-IM</td> <td>N/A</td> <td>374.32</td> <td>-457.9</td> <td>537.4</td> <td>34.1</td> <td>40.4</td> <td>67.9</td> </tr> </table>				Moments (kip.ft)			Shears (kips)			Load Type	w (k/ft)	M_{104}	M_{200}	M_{205}	V_{100}	V_{110}	V_{200}	DC	1.558	34.49	-478.31	370.02	-13.7	40.93	-51.41	DW	0.280	6.20	-85.96	66.50	-2.44	7.36	-9.24	LL-IM	N/A	372.3	-426.7	477.3	37.0	43.8	73.6			Moments (kip.ft)			Shears (kips)			Load Type	w (k/ft)	M_{104}	M_{200}	M_{205}	V_{100}	V_{110}	V_{200}	DC	1.991	44.08	-611.24	472.86	-17.38	52.31	-65.70	DW	0.191	3.22	-58.64	45.36	-1.67	5.02	-6.30	LL-IM	N/A	374.32	-457.9	537.4	34.1	40.4	67.9
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Load Type	w (k/ft)	M_{104}	M_{200}	M_{205}	V_{100}	V_{110}	V_{200}																																																																											
DC	1.991	44.08	-611.24	472.86	-17.38	52.31	-65.70																																																																											
DW	0.191	3.22	-58.64	45.36	-1.67	5.02	-6.30																																																																											
LL-IM	N/A	374.32	-457.9	537.4	34.1	40.4	67.9																																																																											



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 28
(Barker & Puckett, 2007) (AASHTO, 2014) Table A5.10.2.3-1 A5.7.3.4	Try 3 No. 9 bars, provided $A_s = 3.00 \text{ in}^2$ For No. 3 stirrup and No. 9 bar Inside radius $= 2d_s > \frac{1}{2}d_b$ $2(0.38) = 0.76 \text{ in.} > \frac{1}{2}(1.128) = 0.564 \text{ in.}$ $b_{min} = 2(1.50 + 2d_s) + 2d_b + 2(1.5d_b)$ $= 2(1.50 + 2(0.38) + 5(1.128) =$ $13.16 \text{ in (334 mm) OKAY}$ $y_s = 3.0 + 0.38 + 1.5(1.128) = 5.072 \text{ in. (129 mm)}$ $d_{pos} = (60 - 0.38) - 5.072 = 54.5 \text{ in (1384 mm)}$ Elastic-cracked transformed section analysis $n = \frac{E_s}{E_c} = 7, b = b_e = 82 \text{ in}$ $x = -\frac{nA_s}{b} + \sqrt{\left(\frac{nA_s}{b}\right)^2 + \frac{2nA_sd}{b}}$ $= \frac{-7(3.00)}{82} + \sqrt{\left(\frac{7(3.00)}{82}\right)^2 + \frac{2(7)(3.00)(54.5)}{82}}$ $= 5.03 \text{ in (128 mm)} < h_f = 7.5 \text{ in (191 mm)}$ The neutral axis lies in flange; therefore, assumption OKAY $s = 7 - 3(0.38) - 3.0 = 2.86 \text{ in (72.6 mm)}$ $s \leq \frac{700\gamma_e}{\beta_s f_s} - 2d_c, d_c = 3.0 - 0.38 - \frac{1.128}{2} =$ $3.944 \text{ in (100 mm)}$ $\gamma_e = 0.75$ $\beta_s = 1 + \frac{d_c}{0.7(h-d_c)} = 1 + \frac{3.9}{0.7(59.5-3.9)} = 1.10$ $I_{cr} = \frac{bx^3}{3} + nA_s(d-x)^2$ $= \frac{82(5.03)^3}{3} + 7(3.00)(54.5 - 5.03)^2 =$ $54871 \text{ in}^4 (0.023 \text{ m}^4)$	



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 32
(Barker & Puckett, 2007) (AASHTO, 2014) A5.7.3.6.2 C5.4.2.4 5.4.2.6	C. Estimated Live-Load Deflection at Location 205 (SAP2000) $M_{210} = -302.50 \text{ kip.ft } (-410 \text{ kNm})$ $M_{205} = 473.50 \text{ kip.ft } (642 \text{ kNm})$ $M_a = M_{DC} + M_{DW} + mgM_{LL}(1 + IM)$ $= 370.02 + 66.50 + 0.425(473.00)(1.33) = 703.9 \text{ kip.ft } (954 \text{ kNm})$ Effective moment of inertia $f'_c = 4.5 \text{ ksi}$ $E_c = 1820\sqrt{f'_c} = 3860 \text{ ksi}$ $f_r = 0.24\sqrt{f'_c} = 0.509 \text{ ksi}$ $M_{cr} = f_r \frac{I_g}{y_t} = 0.509 \frac{468\,800}{39.93 \times 12} = 497.99 \text{ kip.ft } (675 \text{ kNm})$ $I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \leq I_g$ $\left(\frac{M_{cr}}{M_a}\right)^3 = \left(\frac{497.99}{703.9}\right)^3 = 0.354$ $I_e = (0.354)(468\,800) + (1 - 0.354)(54\,871) = 201\,402 \text{ in}^4 (0.084 \text{ m}^4)$ $EI = E_c I_e = (3860)(201\,402) = 777.4 \times 10^6 \text{ kip.in}^2$ Deflection estimate by superposition $y_1 = \frac{L^2}{6EI} [M_{ij}(2\xi - 3\xi^2 + \xi^3) - M_{ji}(\xi - \xi^3)], \xi = \frac{x}{L}$ $M_{ij} = 0, M_{ji} = M_{210} = -302.50 \text{ kip.ft}$ $L = 66 \text{ ft} = 792 \text{ in}, \xi = 0.4$ $y_1 = \frac{-(792)^2}{6(777.4 \times 10^6)} [-(-302.50 \times 12)(0.4 - 0.4^3)]$ $= 0.165 \text{ in } (4.19 \text{ mm}), \text{ upwards}$	



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021	
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 34	
(Barker & Puckett, 2007)	$I_g: \lambda = 4.0$ $I_e: \lambda = 3.0 - 1.2 \left(\frac{A'_s}{A_s} \right) \geq 1.6$ Location 104, $x = 0.4L = 168 \text{ in } (4267 \text{ mm})$ $w = 1.0 \frac{\text{kips}}{\text{ft}} \text{ (unit load)}, M_{ij} = 0, M_{ji} = -307 \text{ kip.ft}$ $\Delta_i = \frac{1.0(168/12)}{24 \times 774.4 \times 10^6} [(420)^3 - 2(420)(168)^2 + (168)^3] - \frac{(420)^2}{6 \times 774.4 \times 10^6} [-(-307 \times 12)(0.4 - 0.4^3)] =$ $0.005 \text{ in } (0.127 \text{ mm}) \textbf{ upward}$ Using A_s 3 No.9 bars 3.0 in.^2, A'_s two No.6 bars 0.88 in.^2 $\lambda = 3.0 - 1.2 \frac{0.88}{3.00} = 2.65$ Exterior girder, $w_e = 2.182 \text{ kips/ft}$ $\Delta_{camber} = 2.182(1 + 2.65)(-0.005) = -0.040 \text{ in } (-1.02 \text{ mm})$ $\left(w_i = 1.0 \frac{\text{kips}}{\text{ft}} \right) = 0.034 \text{ in, average} = -0.037 \text{ in } (-0.94 \text{ mm})$ Location 205, Assume EI = Location 104 $w = 1.0 \frac{\text{kips}}{\text{ft}} \text{ (unit load)}, M_{ij} = 0, M_{ji} = -307 \text{ kip.ft}, x = 0.5L, L = 792 \text{ in}$ $\Delta_i = \frac{5}{384} \left(\frac{1.0(792)^4/12}{774.4 \times 10^6} \right) - \frac{(792)^2}{6 \times 774.4 \times 10^6} [(-307 \times 12)(0.75)] =$ $0.178 \text{ in } (4.52 \text{ mm}) \textbf{ downward}$ $\lambda = 2.65, w_e = 2.182 \frac{\text{kips}}{\text{ft}} \left(31.8 \frac{\text{kN}}{\text{m}} \right)$ $\Delta_{camber} = 2.182(1 + 2.65)(0.178) = 1.42 \text{ in } (36.1 \text{ mm})$ $\left(w_i = 1.838 \frac{\text{kips}}{\text{ft}} \right) = 1.19 \text{ in, average} = 1.31 \text{ in } (33.3 \text{ mm})$		



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 36
(Barker & Puckett, 2007) (AASHTO, 2014) A5.8.2.4 A5.8.2.5 A5.8.2.7 A5.8.2.9 A5.8.3 A5.8.3.3 A5.8.3.4 A5.8.3.4.1 C5.8.3.3 A5.8.3.4 A5.8.3.4.1 A5.8.3.4.2 A5.8.3.5	2. Shear (SAP2000) A. General Requirements $V_u \geq 0.5\phi(V_c + V_p), \phi = \phi_v = 0.9$ $A_v \geq 0.0316\sqrt{f'_c} \frac{b_v s}{f_y}$ If $v_u < 0.125f'_c$, then $s_{max} = 0.8d_v \leq 24 \text{ in (610 mm)}$ If $v_u \geq 0.125f'_c$, then $s_{max} = 0.4d_v \leq 12 \text{ in (305 mm)}$ $v_u = \frac{ V_u - \phi V_p }{\phi b_v d_v}$ B. Sectional Design Model Lesser of: $V_n = V_c + V_s + V_p$ $V_n = 0.25f'_c b_v d_v + V_p$ $V_c = 0.0316\beta\sqrt{f'_c} b_v d_v$ $\beta = 2.0$ $V_s = \frac{A_v f_y d_v (\cot \theta + \cot \alpha) \sin \alpha}{s}$ $\alpha = 90$ $v_u = \frac{V_u}{\phi b_v d_v}$ $\epsilon_x = \frac{\frac{ M_u }{d_v} + 0.5 V_u \cot \theta}{2E_s A_s} \leq 0.001$ $A_s f_y \geq \frac{ M_u }{d_v \phi_f} + \left(\frac{ V_u }{\phi_v} - 0.5V_s \right) \cot \theta$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 37
(Barker & Puckett, 2007) (AASHTO, 2014) A5.8.2.7 A5.8.3.4.2	Step 1 Location $200 + d_v$ $A_s = 9.42 \text{ in}^2, b_v = 14 \text{ in}, b_w = 14 \text{ in}$ $a = \frac{(9.42)(60)}{0.85(4.5)(14)} = 10.6 \text{ in}$ $d = d_e = d_s = (60 - 0.5) - \left(3 + \frac{1.0}{2}\right) = 56 \text{ in}$ $d_v = \max \begin{cases} d - \frac{a}{2} = 56 - \frac{10.6}{2} = 50.7 \text{ in, governs} \\ 0.9d_e = 0.9(56) = 50.4 \text{ in} \\ 0.72(60) = 43.2 \text{ in} \end{cases}$ Distance from support as a percentage of the span $\frac{d_v}{L_2} = \frac{50.7}{66 \times 12} = 0.064$ $V_{200.64} = -175.6 \text{ kips } (-781 \text{ kN})$ $M_{200.64} = -1\,473.6 \text{ kip.ft } (-1997 \text{ kNm})$ Step 2 $v_u = \frac{ V_u }{\phi b_v d_v} = \frac{ 175.6 }{0.9(14)(50.7)} = 0.275 \text{ ksi } (1.90 \text{ MPa})$ $\frac{v_u}{f'_c} = \frac{0.275}{4.5} = 0.0611$ Step 3-4 Assume $\theta = 35, \cot \theta = 1.455$ $\epsilon_x = \frac{\frac{ M_u }{d_v} + 0.5 V_u \cot \theta}{2E_s A_s} = \frac{\frac{1\,473.6 \times 12}{50.7} + 0.5(175.6)(1.455)}{2(29\,000)(9.43)}$ $= 0.0009 \leq 0.001 \text{ OKAY}$ Use $\theta = 35, \beta = 2.31$	



	University of Cape Town Department of Civil Engineering		Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021	
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 38	
(Barker & Puckett, 2007)	Step 5 $V_s = \frac{ V_u }{\phi_v} - 0.0316\beta\sqrt{f'_c}b_vd_v$ $= \frac{175.6}{0.9} - 0.031(2.31)\sqrt{4.50}(14)(50.7) = 87.28 \text{ kips (388 kN)}$ Step 6 Using No.5 U stirrups, $A_v = 2(0.31) = 0.62 \text{ in}^2$ $s \leq \frac{A_s f_y d_v \cot \theta}{V_s} = \frac{0.62(60)(50.7)(1.455)}{87.78} = 31.44 \text{ in}$ $\leq \frac{A_s f_y}{0.0316\beta\sqrt{f'_c}b_v} = \frac{0.62(60)}{0.0316\sqrt{4.5}(14)} = 39.67 \text{ in}$ $v_u = 0.275 \text{ ksi} < 0.125f'_c = 0.125(4.5) = 0.563 \text{ ksi}$ $s \leq 0.8d_v = 0.8(50.7) = 40.59 \text{ in}$ Use $s = 10 \text{ in (254 mm)}$ Step 7 $A_s f_y \geq \frac{ M_u }{d_v \phi_f} + \left(\frac{ V_u }{\phi_v} - 0.5V_s \right) \cot \theta$ $V_s = \frac{A_v f_y d_v (\cot \theta)}{s} = \frac{0.62(60)(50.7)(1.455)}{10} = 274.4 \text{ kips (1221 kN)}$ $9.43(60) \geq \frac{1473.6 \times 12}{50.7 \times 0.9} + \left[\frac{167.7}{0.9} - 0.5(274.4) \right] (1.455)$ $565.8 \geq 471.78$ The above procedure is repeated for each of the tenth points.		



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: GFRP-RC Deck	Sheet: 40
(FDOT, 2020) (AASHTO, 2018) 2.4.2.1 2.4.2.1-1	C. Reinforcement properties $E_f = 6500 \text{ ksi (44 816 MPa)}$ $C_E = 0.7$ $C_b = 0.83$ $C_C = 0.3$ 1. Design of Reinforcement $f_{fu.slab.pr} = 90 \text{ ksi}$ $f_{fd.slab.pr} = (90)(0.7) = 63 \text{ ksi (434 MPa)}$ Assuming No.3 bar, $d_b = 0.375 \text{ in}$, $A_b = 0.11 \text{ in}^2$ $d_{pos} = 8.0 - 0.5 - 1.5 - \frac{0.375}{2} = 5.81 \text{ in (148 mm)}$ $d_{neg} = 8.0 - 1.5 - \frac{0.375}{2} = 6.31 \text{ in (160 mm)}$ $s_{max} = 11.25 \text{ in (286 mm)}$ $s_{min} = 1.9 \text{ in (48.3 mm)}$ $posM_u = 10.14 \text{ kip} \cdot \frac{ft}{ft} \text{ (13.7 kN} \cdot \frac{m}{m} \text{)}$ $negM_u = -8.84 \text{ kip} \cdot \frac{ft}{ft} \text{ (12.0 kN} \cdot \frac{m}{m} \text{)}$ Primary Reinforcement $BarSize_{slab.pr} = 0.375 \text{ in (48.3 mm)}$ $BarSpace_{slab.pr} = 10 \text{ in (254 mm)}$ Secondary Reinforcement $BarSize_{slab.sec} = 0.375 \text{ in (48.3 mm)}$ $BarSpace_{slab.sec} = 7 \text{ in (178 mm)}$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: GFRP-RC Deck	Sheet: 41
(FDOT, 2020) (AASHTO, 2014) 5.6.2.2	Calculate Positive Moment Capacity $\alpha_1 = \max(0.75, 0.85 - 0.02(4.5 - 10)) = 0.90$ $\beta_1 = 0.85 - 0.05(4.5 - 4) = 0.83$ Area of primary reinforcement per linear foot Area of GFRP reinforcement per foot of positive moment $A_{f2.slabs} = (0.11) \left(\frac{12}{10} \right) = 0.132 \text{ in}^2$ FRP reinforcement ratio $\rho_{f2.slabs} = \frac{A_{f2.slabs}}{b.d_{f2.slabs}} = \frac{0.132}{12(5.81)} = 0.0019$ Maximum tensile stress in the GFRP $f_{f2.slabs} = \sqrt{\frac{(E_f \epsilon_{cu})^2}{4} + \frac{0.85 \beta_1 f'_c E_f \epsilon_{cu}}{\rho_{f2.slabs}}} - 0.5 E_f \epsilon_{cu}$ $= \sqrt{\frac{(6500 \times 0.003)^2}{4} + \frac{0.85(0.83)(4.5)(6500)(0.003)}{0.0019}} - 0.5(6500)(0.003) = 171 \text{ ksi (1179 MPa)}$ $f_{f2.slabs} = \min(f_{f2.slabs}, f_{fd.slabs.pr}) = 63 \text{ ksi}$ Tensile strain $\epsilon_{ft.slabs.pr} = \frac{f_{f2.slabs}}{E_f} = 0.0263$ Guaranteed design tensile strain $\epsilon_{fd.slabs.pr} = \frac{f_{fd.slabs.pr}}{E_f} = 0.0097$ $f_f > f_{fd}$, FRP rupture is the failure mode Resistance factor for flexural strength $\phi_{2.slabs} = 0.75$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: GFRP-RC Deck	Sheet: 42
(FDOT, 2020) (AASHTO, 2018) 2.6.3.2.2 2.6.7	Stress-block $a_{f2.slub} = \frac{A_{f2.slub} \cdot f_{f2.slub}}{0.5f'_c b_s} = \frac{0.132(63)}{0.85(4.5)(12)} = 1.81 \times 10^{-4} in$ Depth c_b at balanced strain conditions $c_{f2.slub} = \frac{a_{f2.slub}}{\beta_1} = \frac{1.81 \times 10^{-4}}{0.83} = 2.18 \times 10^{-4} in$ Nominal moment capacity $M_{n.2.slub} = A_{f2.slub} \cdot f_{fd.slub.pr} \left(d_{pos} - \frac{a_{f2.slub}}{2} \right)$ $= 0.132(63) \left(5.81 - \frac{2.18 \times 10^{-4}}{2} \right) = 48 kip.ft (65.1 kNm)$ Design flexural resistance $M_{r.2.slub} = \phi_{2.slub} \cdot M_{n.2.slub} = 0.75(48) = 36 kip.ft (48.8 kNm)$ Since $M_{r.2.slub} > posM_u$ OKAY Calculate Negative Moment Capacity Area of GFRP reinforcement per foot of negative moment $A_{f1.slub} = (0.11) \left(\frac{12}{7} \right) = 0.19 in^2$ FRP reinforcement ratio $\rho_{f1.slub} = \frac{A_{f1.slub}}{b \cdot d_{f1.slub}} = \frac{0.19}{12(6.31)} = 2.51 \times 10^{-3}$ Maximum tensile stress in the GFRP $f_{f1.slub} = \sqrt{\frac{(E_f \epsilon_{cu})^2}{4} + \frac{0.85 \beta_1 f'_c E_f \epsilon_{cu}}{\rho_{f1.slub}}} - 0.5 E_f \epsilon_{cu}$ $= \sqrt{\frac{(6500 \times 0.003)^2}{4} + \frac{0.85(0.83)(4.5)(6500)(0.003)}{2.51 \times 10^{-3}}} - 0.5(6500)(0.003) = 147.6 ksi (1018 MPa)$ $f_{f1.slub} = \min(f_{f1.slub}, f_{fd.slub.pr}) = 63 ksi$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 43
(FDOT, 2020)	Tensile strain $\varepsilon_{ft.slabs.pr} = \frac{f_{f1.slabs}}{E_f} = 0.023$ Guaranteed design tensile strain $\varepsilon_{fd.slabs.pr} = \frac{f_{fd.slabs.pr}}{E_f} = 0.0097$ $f_f > f_{fd}$, FRP rupture is the failure mode Resistance factor for flexural strength $\phi_{1.slabs} = 0.75$ Stress-block $a_{f1.slabs} = \frac{A_{f1.slabs} \cdot f_{f1.slabs}}{0.5f'_c b_s} = \frac{0.19(63)}{0.85(4.5)(12)} = 2.61 \times 10^{-4} in$ Depth c_b at balanced strain conditions $c_{f1.slabs} = \frac{a_{f1.slabs}}{\beta_1} = \frac{2.61 \times 10^{-4}}{0.83} = 2.61 \times 10^{-4} in$ Nominal moment capacity $M_{n.1.slabs} = A_{f1.slabs} \cdot f_{fd.slabs.pr} \left(d_{pos} - \frac{a_{f1.slabs}}{2} \right)$ $= 0.19(63) \left(6.31 - \frac{2.61 \times 10^{-4}}{2} \right) = 75.5 \text{ kip.ft (102 kNm)}$ Design flexural resistance $M_{r.1.slabs} = \phi_{1.slabs} \cdot M_{n.1.slabs} = 0.75(75.5) = 56.6 \text{ kip.ft (79.7 kNm)}$ Since $M_{r.1.slabs} > negM_u$ OKAY	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 44
(FDOT, 2020) (AASHTO, 2018) 2.9.7.3.2 2.9.7.6 2.9.7.4.1-1 2.9.7.4.1-1 (AASHTO, 2014) 2.9.7.6	Development Length at Support $L_{d.neg.min} = \max(d_{neg}, 12BarSize_{slab.pr}, 0.0625L_{span})$ $L_{d.neg.min} = \max(6.31 \text{ in}; 7.5 \text{ in}; 6 \text{ in}) = 7.5 \text{ in (191 mm)}$ $\therefore \text{Use } L_{d.neg} = 8.0 \text{ in (203 mm)}$ Development Length at mid-span $L_{d.pos.min} = \max(t_s, 15BarSize_{slab.pr}, \frac{L_{span}}{20})$ $L_{d.pos.min} = \max(8 \text{ in}; 9.375 \text{ in}; 4.8 \text{ in}) = 9.4 \text{ in (239 mm)}$ $\therefore \text{Use } L_{d.pos} = 10 \text{ in (254 mm)}$ Reinforcement splices $a_{neg.slab} = 1.5$ $a_{pos.slab} = 1.0$ $L_{d.tension.neg.slab} = \max \left[BarSize_{slab.pr} \frac{\left(31.6a_{neg.slab} \frac{f_{f1.slab}}{\sqrt{f'_c}} - 340 \right)}{13.6 + \frac{c_c}{d_{neg}}}, 20BarSize_{slab.pr} \right]$ $= \max(28.9 \text{ in}, 7.5 \text{ in})$ $L_{d.tension.pos.slab} = \max \left[BarSize_{slab.pr} \frac{\left(31.6a_{pos.slab} \frac{f_{f2.slab}}{\sqrt{f'_c}} - 340 \right)}{13.6 + \frac{c_c}{d_{pos}}}, 20BarSize_{slab.pr} \right]$ $= \max(28.9 \text{ in}, 7.5 \text{ in})$ $L_{sp.neg.req} = \max(12 \text{ in}, 1.3L_{d.tension.neg.slab}) = 39.6 \text{ in (930 mm)}$ $L_{sp.pos.req} = \max(12 \text{ in}, 1.3L_{d.tension.pos.slab}) = 39.6 \text{ in}$ $\text{Use } 40 \text{ in (1016 mm)} = L_{sp}$	



	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 45
(FDOT, 2020) (AASHTO, 2018) 2.7 2.5.3	If a bridge deck conforms to AASHTO minimum thickness requirements, the deck does not require a shear check. Creep Rupture $C_c = 0.3$ Creep rupture limit stress $f_{f.creep} = C_c f_{f.d.slabs.pr} = 0.3(63) = 18.9 \text{ ksi (130 MPa)}$ Support $M_{200} = (-0.597 - 0.906 - 0.070) + 0.2(-4.19) = -2.41 \text{ kip} \cdot \frac{ft}{ft} \left(-3.27 \text{ kN} \cdot \frac{m}{m} \right)$ $n = \frac{E_f}{E_c} = 1.6$ $k_{1.slabs} = \sqrt{2\rho_{f1.slabs} + (\rho_{f1.slabs} \cdot n)^2} - \rho_{f1.slabs} \cdot n = 0.022$ $I_{cr1.slabs} = \frac{b \cdot d_{f1.slabs}^3}{3} \cdot k_{1.slabs}^3 + n \cdot A_{f1.slabs} (d_{f1.slabs} - k_{1.slabs} \cdot d_{f1.slabs})^2 = 11.6 \text{ in}^4$ $f_{f1.creep} = \frac{n \cdot d_{f1.slabs} (1 - k_{1.slabs})}{I_{cr1.slabs}} \cdot M_{200} = 2.05 \text{ ksi (14.1 MPa)}$ $f_{f.creep} > f_{f1.creep}$ OKAY Middle Span $M_{204} = (0.494 - 0.294 - 0.446 + 0.138) + 0.2(4.29) = 0.75 \text{ kip} \cdot \frac{ft}{ft} \left(1.02 \text{ kN} \cdot \frac{m}{m} \right)$ $k_{2.slabs} = \sqrt{2\rho_{f2.slabs} + (\rho_{f2.slabs} \cdot n)^2} - \rho_{f2.slabs} \cdot n = 0.059$ $I_{cr2.slabs} = \frac{b \cdot d_{f2.slabs}^3}{3} \cdot k_{2.slabs}^3 + n \cdot A_{f2.slabs} (d_{f2.slabs} - k_{2.slabs} \cdot d_{f2.slabs})^2 = 6.47 \text{ in}^4$	



NDTSAM002 – University of Cape Town
Department of Civil Engineering – Structural Engineering Program

	University of Cape Town Department of Civil Engineering	Calculation Sheet
Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: SRC T-beam Design	Sheet: 47
(FDOT, 2020) (AASHTO, 2018) 2.10.2.1 2.7.2.7 2.9.3	$d_c = t_s - d_{f1.slabb} = 1.69 \text{ in (42.9 mm)}$ $c_c = \min(d_c, c_c) = 1.5 \text{ in}$ $\zeta = \frac{t_s - k_{1.slabb} \cdot d_{f1.slabb}}{d_{f1.slabb} - k_{1.slabb} \cdot d_{f1.slabb}} = 1.27 \text{ in (32.3 mm)}$ $GFRPMaxd_c = \frac{C_b E_f W}{2 \cdot f_{f1.creep} \cdot \zeta} = 29 \text{ in (736.6 mm)}$ $d_c < GFRPMaxd_c$ OKAY Secondary Reinforcement - Distribution Reinforcement The required secondary reinforcement $A_{sec.req.slabb} = \min\left(50\%, \frac{100\%}{\sqrt{L_{span}}}\right) \cdot A_{f2.slabb} = 0.05 \text{ in}^2$ $N_{sec.req.slabb} = \frac{A_{sec.req.slabb}}{Area_{slabb.sec}} = \frac{0.05 \text{ in}^2}{0.132 \text{ in}^2} = 0.38$ $S_{sec.req.slabb} = \frac{b_{trans}}{N_{sec.req.slabb}} = \frac{12}{0.38} = 32 \text{ in (812 mm)}$ $S_{sec.max.slabb} = \min(0.5t_s, 24 \text{ in}, S_{sec.req.slabb}) = 4 \text{ in (102 mm)}$ $S_{sec.max.slabb} = \min(1.5Dia_{slabb.sec}, 1.5) = 0.9 \text{ in (22.9 mm)}$ $\therefore$ Use 4 in for Positive Moment Region Shrinkage and Temperature Reinforcement Minimum area of temperature reinforcing required $\rho_{f.st} = \min\left(0.0036, \max\left(\frac{3132}{E_f f_{fd.slabb.pr}}, 0.0014\right)\right) = 0.0036$ $A_{g.trans} = b_{trans} \cdot t_s = 90 \text{ in}^2$	



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(FDOT, 2020) (AASHTO, 2014)		GFRP shrinkage and temperature reinforcement $AreaTemp_{slab.pr.req} = \rho_{f.st} A_{g.trans} = 0.324 \text{ in}^2$ Provide No.3 @ 4 in, $A_s = 0.33 \frac{\text{in}^2}{ft}$			



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(FDOT, 2020) (Barker & Puckett, 2007) (AASHTO, 2014) 5.6.2.2	GFRP Overhang Design Segment 1 $f'_c = 4.0 \text{ ksi (27.6 MPa)}$ $f_{fd.I} = 63 \text{ ksi (434 MPa)}$ $\alpha_1 = 0.97$ $\beta_1 = 0.85$ Area of GFRP reinforcement per foot of positive moment $A_s = 2 - No. 4's = 2(0.20) = 0.40 \text{ in}^2$ $d_{avg} = \frac{3.0 + 2.75 + 1.375}{2} = 3.56 \text{ in (90.4 mm)}$ FRP reinforcement ratio $\rho_{fI} = \frac{0.40}{1(3.56)} = 0.11$ Maximum tensile stress in the GFRP $f_{f.I} = \sqrt{\frac{(6500 \times 0.003)^2}{4} + \frac{0.85(0.85)(4.0)(6500)(0.003)}{0.11}} - 0.5(6500)(0.003) = 13 \text{ ksi (89.6 MPa)}$ $f_{f.I} = \min(f_{fI}, f_{fd.I.}) = 13 \text{ ksi}$ Tensile strain $\varepsilon_{ft.I} = \frac{f_{f.I}}{E_f} = 0.002$ Guaranteed design tensile strain $\varepsilon_{fd} = \frac{f_{fd.I}}{E_f} = 0.0097$ $f_{f.I} < f_{fd}, \text{ Concrete crushing is the failure mode}$ Resistance factor for flexural strength $\phi_I = 0.75$	



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(FDOT, 2020) (Barker & Puckett, 2007)	Stress-block $a_{fI} = \frac{\varepsilon_{cu} \cdot d_{avg}}{\varepsilon_{cu} + \varepsilon_{fd}} = \frac{0.19(63)}{0.85(4.5)(12)} = 0.80 \text{ in}$ Nominal moment capacity $M_{n.I} = A_{fI} \cdot f_{fd.I} \left(d_{avg} - \frac{a_{fI}}{2} \right)$ $= 0.40(63) \left(3.56 - \frac{0.80}{2} \right) = 5.70 \text{ kip.ft (7.73 kNm)}$ Design flexural resistance $M_{r.I} = \phi_I \cdot M_{n.I} = 0.75(5.70) = 4.27 \text{ kip.ft (5.79 kNm)}$ Segment 2 $A_s = 1 - No.3 = 0.20 \text{ in}^2$ $d_{pos} = 6.75 \text{ in (171 mm)}$ $\rho_{fII} = \frac{0.20}{1(6.75)} = 0.030$ $f_{f.II} = \sqrt{\frac{(6500 \times 0.003)^2}{4} + \frac{0.85(0.85)(4.0)(6500)(0.003)}{0.030}} -$ $0.5(6500)(0.003) = 34.7 \text{ ksi (239 MPa)}$ $f_{f.II} = \min(f_{fII}, f_{fd}) = 34.7 \text{ ksi}$ $\varepsilon_{ft.II} = \frac{f_{f.II}}{E_f} = 0.0053$ $\varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0097$ $f_{f.II} < f_{fd}$, Concrete crushing is the failure mode $\phi_I = 0.75$ $a_{fI} = \frac{\varepsilon_{cu} \cdot d_{pos}}{\varepsilon_{cu} + \varepsilon_{fd}} = 1.53 \text{ in}$	



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(FDOT, 2020) (Barker & Puckett, 2007)	$M_{n.I} = A_{fI} \cdot f_{fd.I} \left(d_{avg} - \frac{a_{fI}}{2} \right)$ $= 0.40(63) \left(3.56 - \frac{0.80}{2} \right) = 5.70 \text{ kip.ft (7.73 kNm)}$ $M_{r.II.pos} = \phi_{II} \cdot M_{n.II} = \phi_{II} \cdot A_{fII} \cdot f_{fd.II} \left(d_{pos} - \frac{a_{fII}}{2} \right) =$ $\frac{0.75(0.20)(63) \left(6.75 - \frac{1.53}{2} \right)}{12} = 4.05 \text{ kip.ft (5.49 kNm)}$ $d_{neg} = 6.0 \text{ in (152 mm)}, a_{fII} = 1.36 \text{ in}$ $M_{r.II.neg} = \frac{0.75(0.20)(63) \left(6.00 - \frac{1.36}{2} \right)}{12} = 3.60 \text{ kip.ft (4.88 kNm)}$ $M_{r.II.avg} = 3.83 \text{ kip.ft (5.19 kNm)}$ Segment 3 $A_s = 0.20 \text{ in}^2$ $d_{pos} = 12.25 \text{ in}$ $\rho_{fIII} = 0.016$ $f_{f.III} = 50.4 \text{ ksi (347 kNm)}$ $f_{f.III} = \min(f_{f.III}, f_{fd}) = 50.4 \text{ ksi}$ $\varepsilon_{ft.III} = \frac{f_{f.III}}{E_f} = 0.0078$ $\varepsilon_{fd} = \frac{f_{fd.III}}{E_f} = 0.0097$ $f_{f.III} < f_{fd}, \text{ Concrete crushing is the failure mode}$ $\phi_{III} = 0.75$ $a_{fIII} = 1.07 \text{ in}$	



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(FDOT, 2020) (Barker & Puckett, 2007)	$M_{r.III} = \frac{0.75(0.20)(63)\left(12.25 - \frac{1.07}{2}\right)}{12} = 7.92 \text{ kip.ft (10.7 kNm)}$ $M_w = M_{r.I} + M_{r.II} + M_{r.III}$ $= 4.27 + 3.83 + 7.92 = 16.02 \text{ kip.ft (21.7 kNm)}$ 2. Try No. 4 @ 4.5 in $\left(A_s = \frac{0.52 \text{ in}^2}{\text{ft}}\right)$ $d_I = 7.0 - 1.5 - 0.25 = 5.25 \text{ in (133 mm)}$ $\rho_f = 0.099, f_f = 16.02 \text{ ksi (110 MPa)}, f_{f.} = \min(f_f, f_{fd}) = 16.02 \text{ ksi}$ $\varepsilon_{ft} = \frac{f_f}{E_f} = 0.0025, \varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0083$ $f_f < f_{fd}$, Concrete crushing is the failure mode $\phi = 0.75, a_f = 1.19 \text{ in}$ $M_{cl} = \frac{0.75(0.52)(63)\left(5.25 - \frac{1.19}{2}\right)}{12} = 8.18 \text{ kip.ft (11.1 kNm)}$ $d_{II+III} = 8.25 \text{ in (210 mm)}$ $\rho_f = 0.063, f_f = 21.7 \text{ ksi (150 MPa)}, f_{f.} = \min(f_f, f_{fd}) = 21.7 \text{ ksi}$ $\varepsilon_{ft} = \frac{f_f}{E_f} = 0.0033, \varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0083$ $f_f < f_{fd}$, Concrete crushing is the failure mode $\phi = 0.75, a_f = 1.86 \text{ in}$ $M_{cII+III} = \frac{0.75(0.52)(63)\left(8.25 - \frac{1.86}{2}\right)}{12} = 12.88 \text{ kip.ft (17.5 kNm)}$ $M_c = \frac{8.18(2.10) + 12.88(13.0)}{34.0} = 9.98 \text{ kip.ft (13.5 kNm)}$	



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(FDOT, 2020) (Barker & Puckett, 2007)	3. $L_t = 3.5 \text{ ft}$ $L_c = \frac{3.5}{2} + \sqrt{\left(\frac{3.5}{2}\right)^2 + \frac{8(2.83)(0+16.02)}{9.98}} = 8.03 \text{ ft } (244 \text{ 754 mm})$ 4. $R_w = \left(\frac{2}{2(8.03)-3.5}\right) \left(0 + 8(16.02) + \frac{9.98(8.03)^2}{2.83}\right)$ $R_w = 56.62 \text{ kips } (252 \text{ kN}) > F_t = 54.0 \text{ kips } (240 \text{ kN}) \quad \textbf{OKAY}$ 5. $T = \frac{59.1}{8.03 + 2(2.83)} = 4.14 \text{ kips/ft}$ $V_n = cA_{cv} + \mu(A_{vf}f_y + P_c)$ where: $A_{cv} = 15(12) = 180 \text{ in.}^2/\text{ft}$ $A_{vf} = 0.52 \text{ in.}^2/\text{ft}$ $c = 0.075 \text{ ksi}$ $f'_c = 4 \text{ ksi}$ $f_y = 63 \text{ ksi}$ $P_c = P_b = 0.320 \text{ kips/ft}$ $\mu = 0.6$ $V_n \leq 0.2 f'_c A_{cv} = 0.2(4)(180) = 144 \text{ kips/ft}$ $\leq 0.8 A_{cv} = 0.8(180) = 144 \text{ kips/ft}$ $V_n = cA_{cv} + \mu(A_{vf}f_y + P_c) = 0.075(180) + 0.6[0.52(63) + 0.320] = 35.13 \frac{\text{kips}}{\text{ft}} \left(156 \frac{\text{kN}}{\text{m}}\right) > V_{ct} = T \quad \textbf{OKAY}$ $A_{vf} \geq \frac{0.05b_v}{f_y}$ $A_{vf} \geq \frac{0.05(15.0)}{60} (12) = 0.15 \text{ Since No. 4 bars at 6 in. } (A_s = 0.39 \text{ in.}^2/\text{ft}) \therefore \textbf{OKAY}$	



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(FDOT, 2020) (Barker & Puckett, 2007)	$l_{hb} = \frac{38d_b}{\sqrt{f'_c}} = 8.96 \text{ in (228 mm)}$ $l_{dh} = 0.7(8.96) = 6.27 \text{ in (159 mm)}, \text{ Available } l_{dh} = 9.0 - 2.0 = 7.0 \text{ in (178 mm)} \quad \textbf{OKAY}$ The standard 90° hook with an extension of $12db + 4db = 16 (0.50) = 8.0 \text{ in (203 mm)}$ Top Reinforcement in Deck Overhang $\text{Collision Moment } M_{CT} = -\frac{R_w H}{L_c + 2H} = \frac{59.1(2.83)}{7.17 + 2(2.83)} = -13.04 \text{ kip.ft (-17.7 kNm)}$ $M_u = \eta[1.25M_{DC} + 1.50M_{Dw} + M_{CT}]$ $= 1.0[1.25(-0.720 - 0.402) + 1.50(-0.035) - 13.04] = -14.50 \text{ kip.ft (19.7 kNm)}$ Alternating a No. 3 bar with the No. 5 top bar at 7.5 in $A_s = 0.18 + 0.49 = 0.67 \text{ in.}^2/\text{ft}$ $d = 9.0 - 1.5 - \frac{0.625}{2} = 7.19 \text{ in (183 mm)}$ $\rho_f = 0.093, f_f = 17.83 \text{ ksi (123 MPa)}, f_{fd} = \min(f_f, f_{fd}) = 17.83 \text{ ksi}$ $\varepsilon_{ft} = \frac{f_f}{E_f} = 0.0027, \varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0083$ $f_f < f_{fd}$, Concrete crushing is the failure mode $\phi = 0.75, a_f = 1.62 \text{ in}$ $M_r = \frac{0.75(0.62)(63)\left(7.19 - \frac{1.62}{2}\right)}{12} = 16.83 \text{ kip.ft (22.8 kNm)}$ $T = 4.14 \frac{\text{kips}}{\text{ft}} \left(18.4 \frac{\text{kN}}{\text{m}}\right)$	



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(FDOT, 2020) (Barker & Puckett, 2007)	$\frac{P_u}{\phi P_n} + \frac{M_u}{\phi M_n} \leq 1.0$ where $P_u = T$ and $\phi P_n = \phi A_{st} f_y$ $A_{st} = \text{No. 3 at } 7.5 \text{ in.}, \text{No. 5 at } 7.5 \text{ in.}, \text{No. 5 at } 9 \text{ in.}$ $= 1.08 \text{ in.}^2/\text{ft}$ $\phi P_n = 0.75(1.08)(63) = 51.03 \frac{\text{kips}}{\text{ft}} \left(227 \frac{\text{kN}}{\text{m}} \right)$ $M_u \leq 16.83 \left(1.0 - \frac{4.14}{51.03} \right) = 15.46 \text{ kip.ft } (21 \text{ kNm})$ $\therefore$ Use (No. 3 and No. 5) at 7.5 in.		



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Name: Samuel E.D Ndeutapo	MSc Dissertation	Date: 01/11/2021
Student no.: NDTSAM002	Title: GFRP T-beam Design	Sheet: 56
(ACI 440.1R-06, 2006)	From Deck design: $b_w = 14 \text{ in}, h = 60 \text{ in}, c_c = 1.5 \text{ in}, M_u = 422.1 \text{ kip.ft}$ Design rupture stress of the FRP bars $f_{fu} = (90)(0.7) = 63 \text{ ksi (434 MPa)}$ Positive Bending Reinforcement Try 3 No.9 bars, $d_b = 1.128 \text{ in}, A_s = 3.00 \text{ in}^2$ $d_{pos} = 56.05 \text{ in (1424 mm)}$ $\alpha_1 = 0.96$ $\beta_1 = 0.83$ $\rho_f = 0.0038, f_f = 127.9 \text{ ksi (882 MPa)}, f_{fd} = \min(f_f, f_{fd}) = 63 \text{ ksi}$ $\varepsilon_{ft} = \frac{f_f}{E_f} = 0.0197, \varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0097$ $f_f > f_{fd}$, FRP rupture is the failure mode $\phi = 0.55, a_f = 3.61 \text{ in}$ $M_{r.pos} = \frac{0.55(3.00)(63)\left(56.05 - \frac{3.61}{2}\right)}{12} = 469.9 \text{ kip.ft (637 kNm)} > M_u \text{ OKAY}$ Negative Bending Reinforcement Try 9 No.9 bars, $d_b = 1.128 \text{ in}, A_s = 9.00 \text{ in}^2$ $d_{neg} = 57.9 \text{ in (1471 mm)}$ $\alpha_1 = 0.96$ $\beta_1 = 0.83$	



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(ACI 440.1R-06, 2006)	$\rho_f = 0.011, f_f = 71.52 \text{ ksi (493 MPa)}, f_{fd} = \min(f_f, f_{fd}) = 63 \text{ ksi}$ $\varepsilon_{ft} = \frac{f_f}{E_f} = 0.0197, \varepsilon_{fd} = \frac{f_{fd}}{E_f} = 0.0097$ $f_f > f_{fd}, \text{ FRP rupture is the failure mode}$ $\phi = 0.55, a_f = 10.84 \text{ in}$ $M_{r.pos} = \frac{0.55(9.00)(63)\left(57.9 - \frac{10.84}{2}\right)}{12} = 1363 \text{ kip.ft (1848 kNm)} > M_u \text{ OKAY}$ Check the crack width (Positive Bending Reinforcement-Exterior Girder) $M_{DL+LL} = 422.1 \text{ kip.ft (573 kNm)}$ $n = \frac{6500}{3860} = 1.68, \text{ Use } n = 1.6$ $k = \sqrt{2pn + (pn)^2} - pn = \sqrt{2(0.0038)(1.6) + (0.0038 \times 1.6)^2} - (0.0038)(1.6) = 0.104$ $f_f = \frac{M_{DL+LL}}{A_f d(1-k/3)} = \frac{422.1 \times 12}{3 \times 56.05(1-0.104/3)} = 31.2 \text{ ksi (215 MPa)}$ $\beta = \frac{h-kd}{d(1-k)} = \frac{60-0.104(56.05)}{56.05(1-0.104)} = 1.079$ $L_{eff} = 28.5 \text{ in (724 mm)}$ $b_e = 85.5 \text{ in (2172 mm)}$ $\frac{1}{10} \text{ average span} = 60.6 \text{ in (1539 mm)}$ Add 4 No.4 bars additional reinforcement	



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(ACI 440.1R-06, 2006)	$d_c = 60 - 56.05 = 3.95 \text{ in (100 mm)}$ $s = 14 - 2(3.95) = 6.1 \text{ in (155 mm)}$ $w = 2 \frac{f_f}{E_f} \beta k_b \sqrt{(d_c)^2 + \left(\frac{s}{2}\right)^2}$ $w = 2 \left(\frac{63}{6500}\right) (1.079)(1.4) \sqrt{3.95^2 + \left(\frac{6.1}{2}\right)^2} =$ $0.042 \text{ in (1.07 mm)} < 0.146 \text{ in (3.71 mm)}$ Check the long term deflection $I_g = \frac{bh^3}{12} = 252\,000 \text{ in}^4, M_u = 703.9 \text{ kip.ft}$ $f_r = 7.5\sqrt{4000} = 503 \text{ psi (3.47 MPa)}$ $M_{cr} = \frac{2f_r I_g}{h \times 12\,000} = 352.2 \text{ kip.ft (478 kNm)}$ $I_{cr} = \frac{bx^3}{3} k^3 + nA_s d^2 (1 - k)^2$ $= \frac{14(56.05)^3}{3} (0.104)^3 + 1.6(3.0)(56.05)^2 (1 - 0.104)^2 =$ $13\,031 \text{ in}^4$ $B_d = \alpha_b \left[\frac{E_f}{E_s} + 1 \right] = 0.5 \left[\frac{6500}{29000} + 1 \right] = 0.61$ $I_e = \left(\frac{M_{cr}}{M_a} \right)^3 B_d I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] I_{cr} \leq I_g$ $I_e = \left(\frac{352.2}{703.9} \right)^3 (0.61)(252\,000) + \left[1 - \left(\frac{352.2}{703.9} \right)^3 \right] (13\,031)$ $= 30\,650 \text{ in}^4$ $(\Delta_i)_{DL+LL} = \frac{5M_{DL+LL}l^2}{48E_c(I_e)_{DL+LL}} = \frac{5(703.9)(66)^2 \times 12^2}{48(3680)(30\,650)} =$ $0.41 \text{ in (10.4 mm)} < \Delta_{allow} = 0.53 \text{ in } \textbf{OKAY}$	

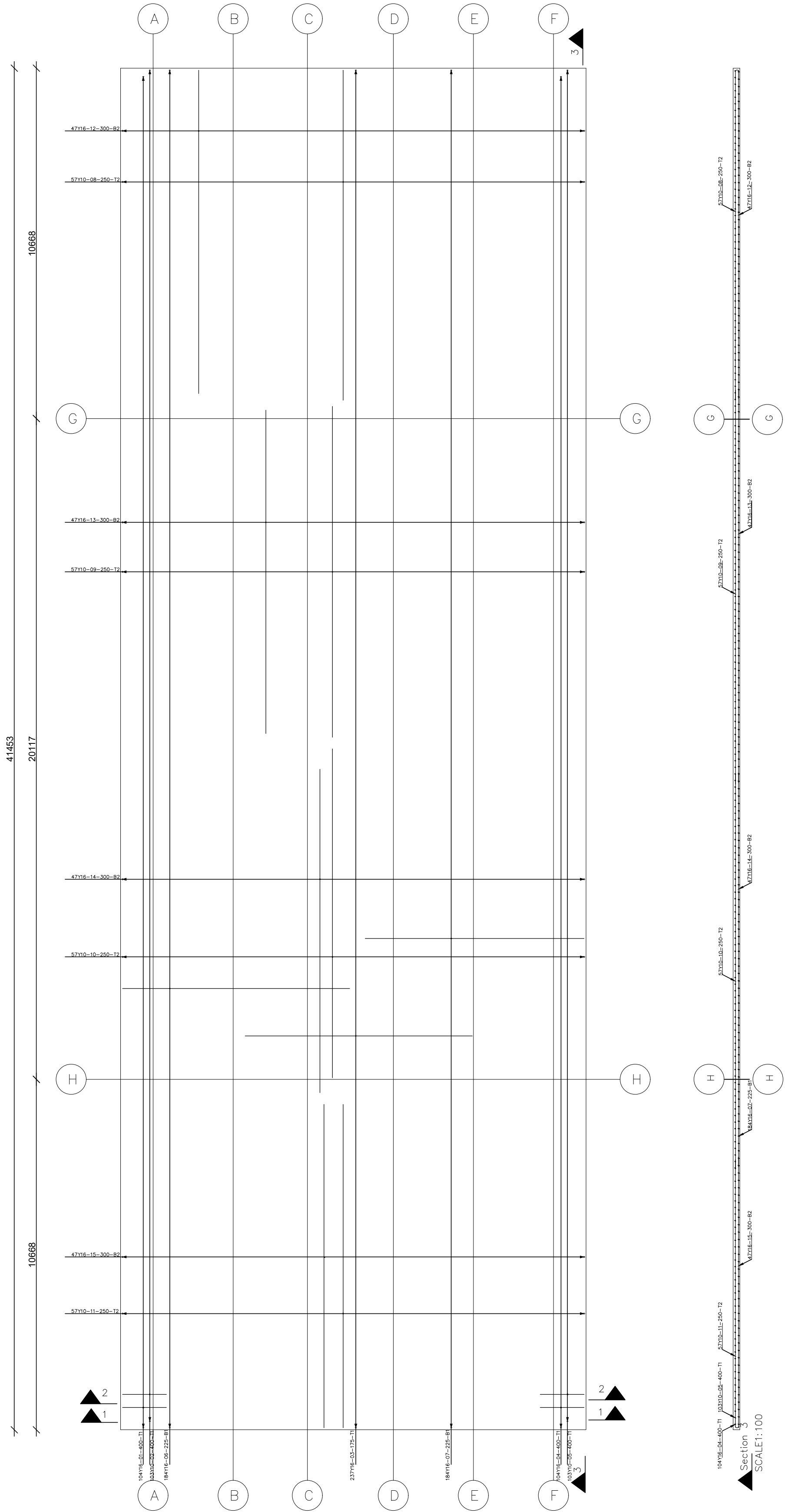


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(ACI 440.1R-06, 2006)	Creep rupture stress limits $f_{f,s} = \frac{M_s}{A_f d (1 - k/3)} = \frac{(47.3 + 130.8)(12)}{3(56.05)(1 - \frac{0.104}{3})} = 13.2 \text{ ksi (91.0 MPa)}$ $f_{f,s} \leq 0.20 f_{fu} = 18 \text{ ksi (124 MPa) OKAY}$ Design for shear $V_u = 175.6 \text{ kips (781 kN)}$ $k = 0.104, d = 56.05 \text{ in}, c = (0.104)(56.05) = 5.83 \text{ in (148 mm)}$ $V_c = 5\sqrt{f'_c} b_w c = 5 \frac{\sqrt{4500}}{1000} (14)(5.83) = 27.4 \text{ kips (122 kN)}$ Therefore shear reinforcement is required Use No.5 U-stirrups, $A_v = 2(0.31) = 0.62 \text{ in}^2$ $f_{fb} = \left(0.05 \frac{r_b}{d_b} + 0.3\right) f_{fu} = \left(0.05 \frac{3(0.63)}{0.63} + 0.3\right) (63) = 28.4 \text{ ksi (196 MPa)}$ $f_{fv} = 0.004 E_f (26 \text{ ksi}) \leq f_{fb}$ $s = \frac{\phi A_{fv} f_{fv} d}{(V_u - \phi V_c)} = \frac{0.75 \times 0.62 \times 26 \times 56.05}{(175.6 - 0.75(27.4))} = 4.37 \text{ in (111 mm)}$ Check max\min spacing limit $\max s = \frac{d}{2} = 28.03 \text{ in (712 mm) or } 24 \text{ in (610 mm)}$ $\min s = \frac{A_{fv} f_{fv}}{50 b_w} = \frac{0.62(26\ 000)}{50(14)} = 23 \text{ in (584 mm) Use No.5 at 4 in}$	



Appendix A2 – Drawings

SRC DECK SCALE1:100 41453 X 14173

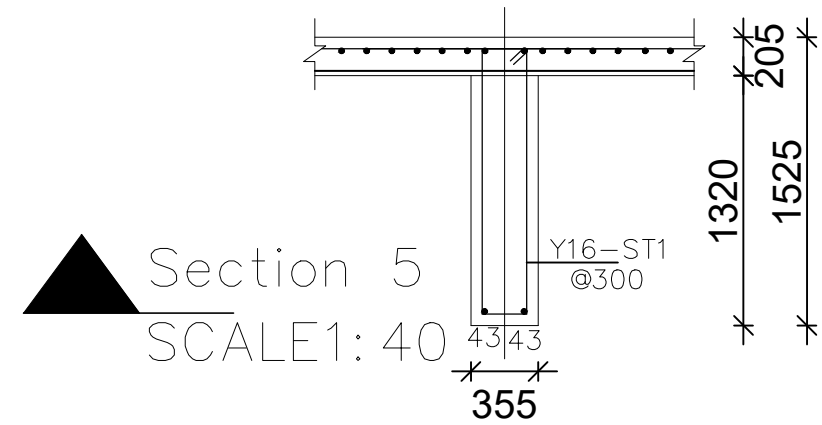
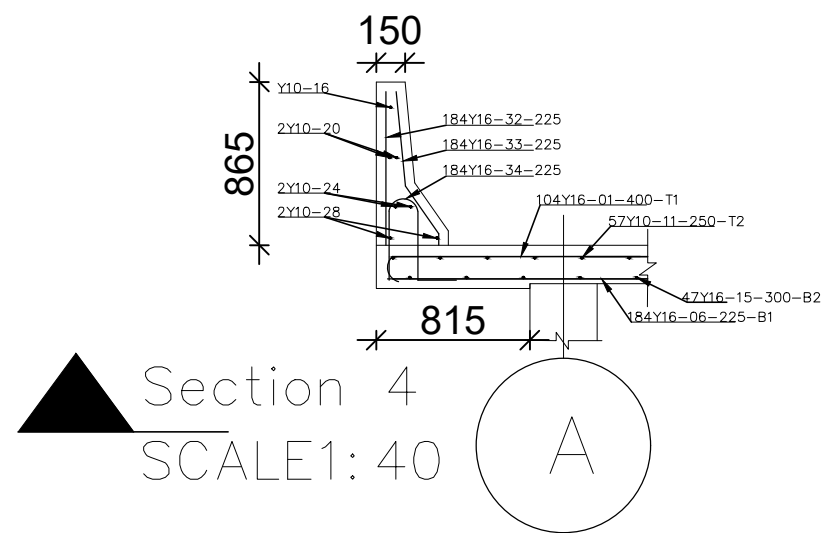


SRC DECK BAR SCHEDULE							
BAR MARK	TYPE/ SIZE	BARS/ MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
01	Y16	104	1	104	1 510	200	1 310
02	Y10	103	1	103	1 430		
03	Y16	237	1	237	12 000	120	1310
04	Y16	104	1	104	1 510		
05	Y10	103	1	103	1 430	200	1 310
06	Y16	184	1	184	6 940		
07	Y16	184	1	184	7 420	120	10 000
08	Y10	57	1	57	10 120		
09	Y10	57	1	57	12 000	120	8 140
10	Y10	57	1	57	12 000		
11	Y10	57	1	57	8 260	120	8 140
12	Y16	47	1	47	10 000		
13	Y16	47	1	47	12 000	120	12 000
14	Y16	47	1	47	12 000		
15	Y16	47	1	47	8 250	120	8 250

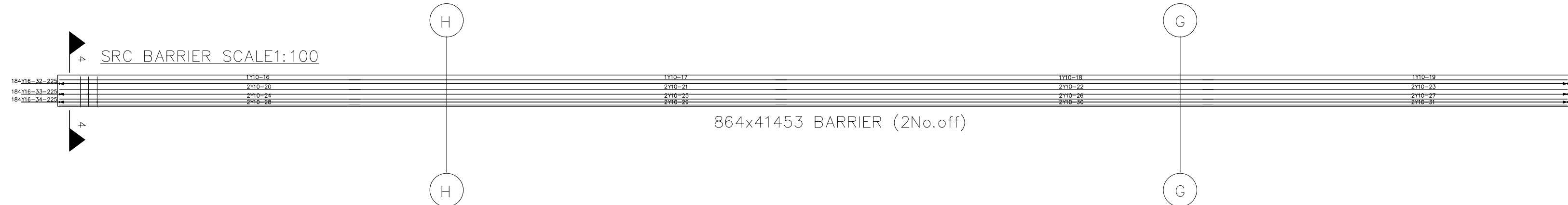
SRC BARRIER BAR SCHEDULE X2							
BAR MARK	TYPE/ SIZE	BARS/ MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
16	Y10	1	1	1	8 250	8	250
17	Y10	1	1	1	12 000		
18	Y10	1	1	1	12 000	12	000
19	Y10	1	1	1	10 000		
20	Y10	2	1	2	8250	8	250
21	Y10	2	1	2	12 000		
22	Y10	2	1	2	12 000	12	000
23	Y10	2	1	2	10 000		
24	Y10	2	1	2	8250	8	250
25	Y10	2	1	2	12 000		
26	Y10	2	1	2	12 000	12	000
27	Y10	2	1	2	10 000		
28	Y10	2	1	2	8250	8	250
29	Y10	2	1	2	12 000		
30	Y10	2	1	2	12 000	12	000
31	Y10	2	1	2	10 000		
32	Y16	184	1	184	880	80	015
33	Y16	184	1	184	820		
34	Y16	184	1	184	1180	370	240

BEAM BAR SCHEDULE X6							
BAR MARK	TYPE/ SIZE	BARS/ MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
35	Y25	12	1	12	8 440	8	140
36	Y25	12	1	12	12 000		
37	Y25	12	1	12	12 000	12	000
38	Y25	12	1	12	10 360		
39	Y16	2	1	2	8 340	8	140
40	Y16	2	1	2	12 000		
41	Y16	2	1	2	12 000	12	000
42	Y16	2	1	2	10 260		
43	Y32	2	1	2	8 530	8	140
44	Y32	2	1	2	12 000		
45	Y32	2	1	2	12 000	12	000
46	Y32	2	1	2	10 450		
ST1	Y16	131	1	131	3480	1	400

SRC T-beam SCALE1:100



SRC BARRIER SCALE1:100

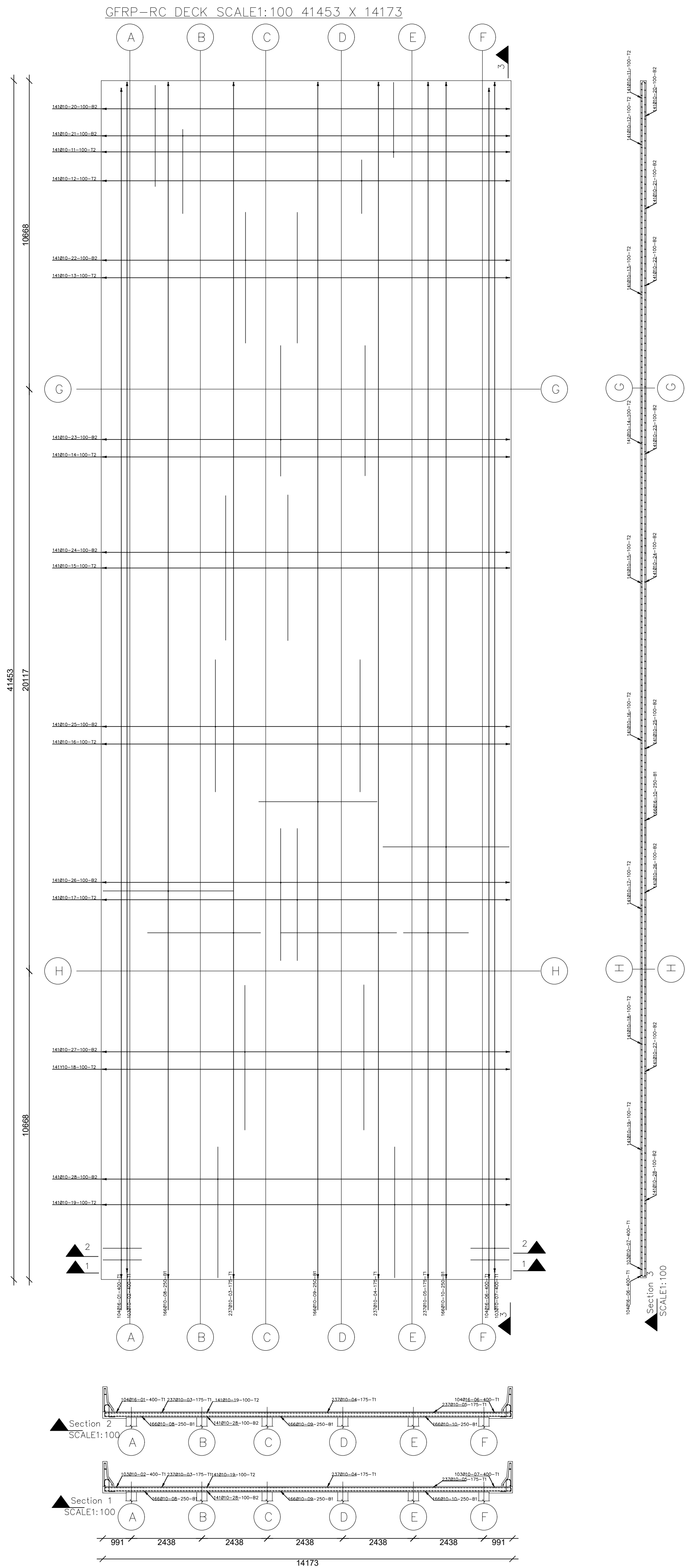


PROJECT TITLE:
SRC T-beam Bridge

DRAWING TITLE:
SUBMISSION DRAWINGS

Scale: AS SHOWN ON	DRAWN: NDTSAM002 Date: 18/11/2021
Project Number:	Revision: 01
Drawing Number:	Paper Size: A1

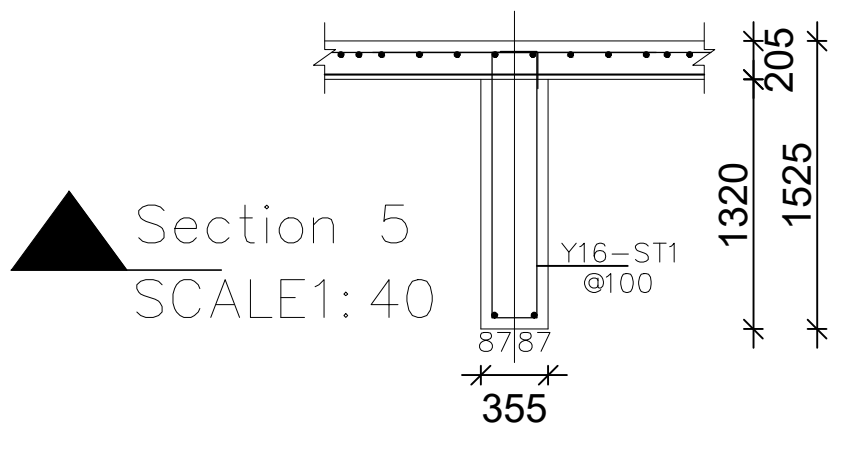
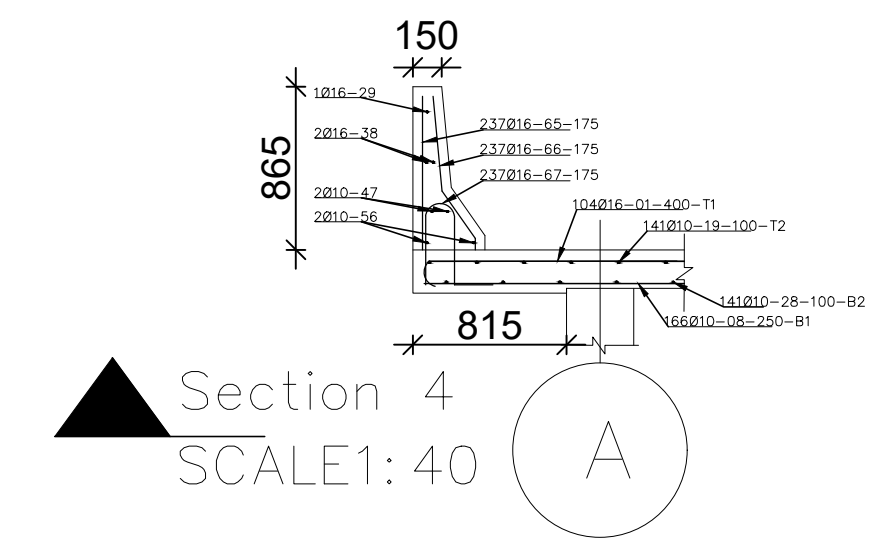
FOR APPROVAL



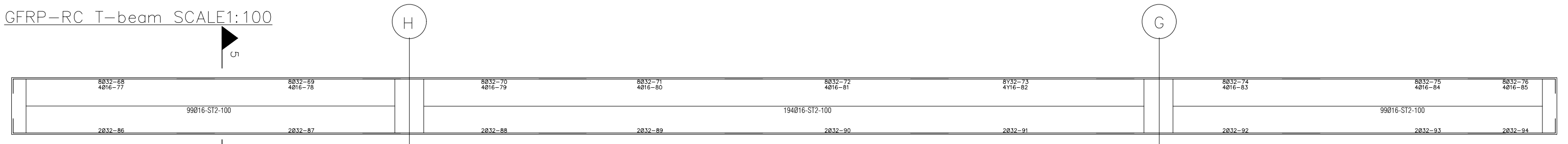
GFRP-RC DECK BAR SCHEDULE							
BAR MARK	TYPE / SIZE	BAR NO. / MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
01	#16	104	1	104	1 510	200	1 310
02	#10	103	1	103	1 430		
03	#10	237	1	237	6 000	120	1 310
04	#10	237	1	237	6 000		
05	#10	237	1	237	3 430	200	1 340
06	#16	104	1	104	1 540		
07	#10	103	1	103	1 460	120	1 340
08	#10	166	1	166	5 750		
09	#10	166	1	166	5 750	200	1 830
10	#10	166	1	166	4 610		
11	#10	141	1	141	1 950	120	1 830
12	#10	141	1	141	6 000		
13	#10	141	1	141	6 000	200	1 440
14	#10	141	1	141	6 000		
15	#10	141	1	141	6 000	120	1 440
16	#10	141	1	141	6 000		
17	#10	141	1	141	6 000	200	1 440
18	#10	141	1	141	6 000		
19	#10	141	1	141	6 000	120	1 440
20	#10	141	1	141	1 440		
21	#10	141	1	141	6 000	200	1 440
22	#10	141	1	141	6 000		
23	#10	141	1	141	6 000	120	1 440
24	#10	141	1	141	6 000		
25	#10	141	1	141	6 000	200	1 440
26	#10	141	1	141	6 000		
27	#10	141	1	141	6 000	120	1 440
28	#10	141	1	141	6 000		

GFRP BEAM BAR SCHEDULE X6							
BAR MARK	TYPE / SIZE	BAR NO. / MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
68	#32	8	1	8	5 800	300	5 410
69	#32	8	1	8	6 000		
70	#32	8	1	8	6 000	300	5 410
71	#32	8	1	8	6 000		
72	#32	8	1	8	6 000	300	5 410
73	#32	8	1	8	6 000		
74	#32	8	1	8	6 000	300	5 410
75	#32	8	1	8	6 000		
76	#32	8	1	8	2 740	300	5 410
77	#16	4	1	4	5 610		
78	#16	4	1	4	6 000	300	5 410
79	#16	4	1	4	6 000		
80	#16	4	1	4	6 000	300	5 410
81	#16	4	1	4	6 000		
82	#16	4	1	4	6 000	300	5 410
83	#16	4	1	4	6 000		
84	#16	4	1	4	6 000	300	5 410
85	#16	4	1	4	2 550		
86	#32	2	1	2	5 800	300	5 410
87	#32	2	1	2	6 000		
88	#32	2	1	2	6 000	300	5 410
89	#32	2	1	2	6 000		
90	#32	2	1	2	6 000	300	5 410
91	#32	2	1	2	6 000		
92	#32	2	1	2	6 000	300	5 410
93	#32	2	1	2	6 000		
94	#32	2	1	2	2 740	300	5 410
95	#16	392	1	392	3 680		

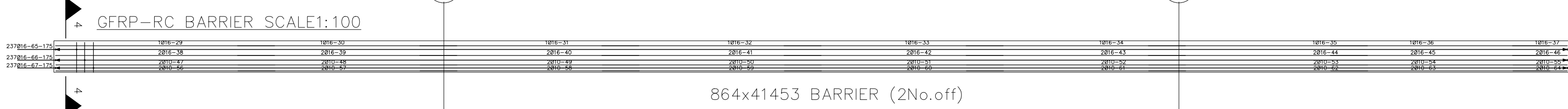
GFRP-RC BARRIER BAR SCHEDULE X2							
BAR MARK	TYPE / SIZE	BAR NO. / MEMBERS	NO. MEMBERS	TOTAL BARS	LENGTH mm	SHAPE	
29	#16	1	1	1	6 000	300	5 410
30	#16	1	1	1	6 000		
31	#16	1	1	1	6 000	300	5 410
32	#16	1	1	1	6 000		
33	#16	1	1	1	6 000	300	5 410
34	#16	1	1	1	6 000		
35	#16	1	1	1	6 000	300	5 410
36	#16	1	1	1	6 000		
37	#16	1	1	1	1 500	300	5 410
38	#16	2	1	2	6 000		
39	#16	2	1	2	6 000	300	5 410
40	#16	2	1	2	6 000		
41	#16	2	1	2	6 000	300	5 410
42	#16	2	1	2	6 000		
43	#16	2	1	2	6 000	300	5 410
44	#16	2	1	2	6 000		
45	#16	2	1	2	6 000	300	5 410
46	#16	2	1	2	1 500		
47	#10	2	1	2	6 000	300	5 410
48	#10	2	1	2	6 000		
49	#10	2	1	2	6 000	300	5 410
50	#10	2	1	2	6 000		
51	#10	2	1	2	1 500	300	5 410
52	#10	2	1	2	6 000		
53	#10	2	1	2	6 000	300	5 410
54	#10	2	1	2	6 000		
55	#10	2	1	2	6 000	300	5 410
56	#10	2	1	2	6 000		
57	#10	2	1	2	6 000	300	5 410
58	#10	2	1	2	6 000		
59	#10	2	1	2	6 000	300	5 410
60	#10	2	1	2	6 000		
61	#10	2	1	2	1 500	300	5 410
62	#10	2	1	2	6 000		
63	#10	2	1	2	6 000	300	5 410
64	#10	2	1	2	1 500		
65	#16	237	1	237	880	300	5 410
66	#16	237	1	237	820		
67	#16	237	1	237	1190	300	5 410
68	#16	237	1	237	1190		



GFRP-RC T-beam SCALE:1:100



GFRP-RC BARRIER SCALE:1:100



PROJECT TITLE:
GFRP-RC T-beam Bridge

DRAWING TITLE:
SUBMISSION DRAWINGS

Scale: AS SHOWN ON	DRAWN: NDTSAM002 Date: 18/11/2021
Project Number:	Revision: 01
Drawing Number:	Paper Size: A1

FOR APPROVAL



Appendix A3 – Bills of Quantities

BILLS OF QUANTITIES-SRC BRIDGE CONSTRUCTION

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	12	R 2 500,00	R 30 000,00
	C1.2.1.2	Dedicated environmental officer	month	12	R 15 000,00	R 180 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	12	R 450,00	R 5 400,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 330 602,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	12	R 28 750,00	R 345 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 518 500,00

C1.4**FACILITIES FOR THE ENGINEER**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	12	R 1 500,00	R 18 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 33 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2				Accommodation of vehicular traffic	month	12	R 15 000,00	R 180 000,00
C1.5.3				Liaison with traffic authorities	month	12	R 5 000,00	R 60 000,00
C1.5.7				Temporary traffic control facilities				
	C1.5.7.1			Delineators including mounting bases and ballast:				
		(b)		Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3			Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4			Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5			Provision of illuminated traffic signs:				
		(a)		Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
			(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
			(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)		Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)		Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)		Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6			Maintenance of illuminated traffic signs:				
		(a)		Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	12	R 2 500,00	R 30 000,00
		(c)		Illuminated road sign – R & TR series (diameter indicated)	month	12	R 2 500,00	R 30 000,00
		(d)		Illuminated road sign – TW series (length of sides indicated)	month	12	R 2 500,00	R 30 000,00
		(e)		Mobile variable message sign	month	12	R 2 500,00	R 30 000,00
C1.5.8				Traffic safety officer	man-month	12	R 4 650,00	R 55 800,00
C1.5.9				Traffic safety vehicle	month	12	R 500,00	R 6 000,00
C1.5.12				Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1			Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2			Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY								R 661 640,00

C9.1

ASPHALT LAYERS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.8			Surfacing of bridge decks				
	C9.1.8.1		Levelling course: Continuously graded, medium grade, (TRH8) A-E2 binder (30mm thick). Nominal Binder content 5,3%	ton (t)	38,8	2000	R 77 600,00
	C9.1.8.2		Surfacing Continuously graded, medium grade, (TRH8)A-E2 binder (45mm thick).Nominal Binder content 5,3%	ton (t)	58,2	2000	R 116 400,00
	C9.1.8.3		Bond coat of 30% stable-grade emulsion (nominal rate 0,40l/m²)	litre (ℓ)	223	280	R 62 440,00
C9.1.9			Application of rolled in chippings (19 mm maximum size, pre-coated, 4kg/m²)				
	C9.1.9.1		By means of chip spreader	ton (t)	21	700	R 14 700,00
TOTAL CARRIED FORWARD TO SUMMARY							R 271 140,00

C13.2

FALSEWORK, FORMWORK AND CONCRETE FINISH

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.2.1		Formwork to provide				
	(a)	Class F2 surface finish to:				
	(i)	Deck	square metre (m ²)	436,3	230,00	R 100 349,00
	(ii)	Parapet	square metre (m ²)	236,5	230,00	R 54 395,00
	(iii)	Beams	square metre (m ²)	752,1	230,00	R 172 983,00
TOTAL CARRIED FORWARD TO SUMMARY						R 327 727,00

C13.3

STEEL REINFORCEMENT

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.3.1		Reinforcement for:				
	C13.3.1.1	Complete structure:				
		(b) High-yield-stress-steel bars (450 Mpa)	lump sum			R 725 587,42
TOTAL CARRIED FORWARD TO SUMMARY						R 725 587,42

C13.4

CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.4.2		Labour enhanced cast in situ concrete and Curing				
	C13.4.2.1	(a) Normal concrete Class 32/40 Commercially-Sourced concrete:				
		(i) Deck	cubic metre (m ³)	105,3	11410	R 1 201 473,00
		(ii) Beams	cubic metre (m ³)	117	11410	R 1 334 970,00
C13.4.6		Curing and surface protection of labour enhanced cast in situ concrete				
	C13.4.6.1	Deck soffit (Corrosion inhibitor + Hydrophobic impregnation)	square metre (m ²)	436,3	900	R 392 670,00
		Beams (Corrosion inhibitor + Hydrophobic impregnation)	square metre (m ²)	752,1	900	R 676 890,00
TOTAL CARRIED FORWARD TO SUMMARY						R 3 606 003,00

C13.7

JOINTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.7.2		Filled joints				
	C13.7.2.	10mm wide joint between parapet panels (filled with impregnated softboard)	square metre (m²)	5,4	4572	R 24 688,80
C13.7.4		Sealing joints with: (Silicone Sealant)				
	C13.7.4.1	10mmx10mm to joints between parapet panels	metre (m)	52,4	280	R 14 672,00
TOTAL CARRIED FORWARD TO SUMMARY						R 39 360,80

C13.8

ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C13.8.1		Concrete barriers and parapets					
	C13.8.1.2	Parapets (all concrete)	metre (m)	41,5	R	11 410,00	R 473 515,00
	C13.8.1.3	Surface Treatment (Corrosion inhibitor + Hydrophobic impregnation)	square metre (m²)	236,5	R	900,00	R 212 850,00
C13.8.10		Drainage pipes and weep holes	no	2	R	7 110,00	R 14 220,00
TOTAL CARRIED FORWARD TO SUMMARY							R 700 585,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	330 602,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	518 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	33 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	661 640,00	R	1 544 342,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	271 140,00	R	271 140,00

STRUCTURES

C13.2	FALSEWORK, FORMWORK AND CONCRETE FINISH	R	327 727,00		
C13.3	STEEL REINFORCEMENT	R	725 587,42		
C13.4	CONCRETE	R	3 606 003,00		
C13.7	JOINTS	R	39 360,80	R	4 698 678,22

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R 6 542 910,22

VALUE ADDED TAX:

15% of Subtotal

R 981 436,53

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R 7 524 346,75

BILLS OF QUANTITIES-SRC BRIDGE SUPERSTRUCTURE PREVENTATIVE MAINTENACE (10&20 YEARS)

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	4	R 2 500,00	R 10 000,00
	C1.2.1.2	Dedicated environmental officer	month	4	R 15 000,00	R 60 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	4	R 450,00	R 1 800,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 187 002,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	4	R 28 750,00	R 115 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 288 500,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	4	R 1 500,00	R 6 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 21 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	4	R 15 000,00	R 60 000,00
C1.5.3			Liaison with traffic authorities	month	4	R 5 000,00	R 20 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	4	R 2 500,00	R 10 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	4	R 2 500,00	R 10 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	4	R 2 500,00	R 10 000,00
		(e)	Mobile variable message sign	month	4	R 2 500,00	R 10 000,00
C1.5.8			Traffic safety officer	man-month	4	R 4 650,00	R 18 600,00
C1.5.9			Traffic safety vehicle	month	4	R 500,00	R 2 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 380 440,00

C8.4

RUT AND/OR DEPRESSION CORRECTION

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.4.1			Rut and/or Depression correction (screeding)				
	C8.4.1.1		60 % Anionic stable grade emulsion (Diluted 50% Emulsion 50% Water)	litre (l)	91	10	R 910,00
	C8.4.1.2		Correction material				
		a	Continuously graded, medium grade, (TRH8), A-E2 binder (45mm thick), Nominal Binder content 5,3%	ton (t)	2,7	6200	R 16 740,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 650,00

C8.5

STANDARD CRACK SEALING

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.5.1			Standard crack sealing				
	C8.5.1.1		Cleaning cracks				
		a	Cleaning crack with hot compressed air	metre (m)	25	143	R 3 575,00
	C8.5.1.3		Primer(MSP 1)	litre (ℓ)	391	24,3	R 9 501,30
	C8.5.1.4		Sealing the cracks				
		a	Sealing using (Viaflex)	litre (ℓ)	91	82	R 7 462,00
	C8.5.1.5		Heating of surface before rolling	metre (m)	25	263	R 6 575,00
	C8.5.1.6		Rolling the cracks	metre (m)	25	234	R 5 850,00
TOTAL CARRIED FORWARD TO SUMMARY							R 32 963,30

C8.8

PATCHING AND EDGE BREAK REPAIR

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.8.1			Saw cutting pavement layers for patching				
	C8.8.1.1		Asphalt or bituminous surfacing to an average depth				
		a	Not exceeding 50 mm	metre (m)	25	481	R 12 025,00
C8.8.2			Excavation in existing pavements for patching (non-milling)				
	C8.8.2.1		Asphalt layers				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	cubic metre (m ³)	30	500	R 15 000,00
C8.8.3			Compacting the floor of excavations for patching	square metre (m ²)	112	315	R 35 280,00
C8.8.4			Backfilling of excavations for patching with				
	C8.8.4.3		Asphalt for a patch with a surface area (state type and density)				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	ton (t)	2,7	6200	R 16 740,00
TOTAL CARRIED FORWARD TO SUMMARY							R 79 045,00

C14.1**ACCESS FOR BRIDGE
REHABILITATION**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.5.7		Crack filling					
	C14.5.7.1	Repair	metre (m)	25	R	700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 500,00

C14.7**PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE**

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R	140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments					
		(a) Corrosion inhibitor	square metre (m²)	1425	R	450,00	R 641 250,00
		(b) Hydrophobic impregnation	square metre (m²)	1425	R	450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY							R 1 482 000,00

C14.9**REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS**

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R	320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R	700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system					
	C14.9.3.1	Service and repair of bridge joints	metre (m)	31	R	1 460,00	R 45 260,00
TOTAL CARRIED FORWARD TO SUMMARY							R 63 428,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2	C20.1.2.2			Special tests requested by the Engineer				
				Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

C2.3 SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	187 002,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	288 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	21 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	380 440,00	R	877 542,00

PRETREATMENT AND REPAIR EXISTING LAYERS

C8.4	RUT AND/OR DEPRESSION CORRECTION	R	17 650,00		
C8.5	STANDARD CRACK SEALING	R	32 963,30		
C8.8	PATCHING AND EDGE BREAK REPAIR	R	79 045,00	R	129 658,30

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	1 482 000,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	63 428,00	R	1 577 148,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	2 613 098,30

VALUE ADDED TAX:

15% of Subtotal

R	391 964,75

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	3 005 063,05

BILLS OF QUANTITIES-SRC BRIDGE SUPERSTRUCTURE PREVENTATIVE MAINTENACE (25 YEARS)

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	4	R 2 500,00	R 10 000,00
	C1.2.1.2	Dedicated environmental officer	month	4	R 15 000,00	R 60 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	4	R 450,00	R 1 800,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 187 002,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	4	R 28 750,00	R 115 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 288 500,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	4	R 1 500,00	R 6 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 21 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	4	R 15 000,00	R 60 000,00
C1.5.3			Liaison with traffic authorities	month	4	R 5 000,00	R 20 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	4	R 2 500,00	R 10 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	4	R 2 500,00	R 10 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	4	R 2 500,00	R 10 000,00
		(e)	Mobile variable message sign	month	4	R 2 500,00	R 10 000,00
C1.5.8			Traffic safety officer	man-month	4	R 4 650,00	R 18 600,00
C1.5.9			Traffic safety vehicle	month	4	R 500,00	R 2 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 380 440,00

C9.1

ASPHALT LAYERS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.8		Surfacing of bridge decks				
	C9.1.8.1	Levelling course: Continuously graded, medium grade, (TRH8) A-E2 binder (30mm thick). Nominal Binder content 5,3%	ton (t)	38,8	2000	R 77 600,00
	C9.1.8.2	Surfacing Continuously graded, medium grade, (TRH8)A-E2 binder (45mm thick).Nominal Binder content 5,3%	ton (t)	58,2	2000	R 116 400,00
	C9.1.8.3	Bond coat of 30% stable-grade emulsion (nominal rate 0,40l/m ²)	litre (ℓ)	223	280	R 62 440,00
C9.1.9		Application of rolled in chippings (14 mm maximum size, pre-coated, 4kg/m²)				
	C9.1.9.1	By means of chip spreader	ton (t)	21	700	R 14 700,00
C9.1.15		Milling of bridge decks and keys adjacent to bridge decks				
	C9.1.15.1	Provision of an appropriate sized milling machine	number (No)	lump sum		R 15 000,00
	C9.1.15.2	Milling of bridge decks and keys to bridge deck approaches	cubic metre (m ³)	50	1436,00	R 71 800,00
	C9.1.15.3	Cleaning of milled surfaces	square metre (m ²)	557	140,00	R 77 980,00
TOTAL CARRIED FORWARD TO SUMMARY						R 435 920,00

C13.7

JOINTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.7.2		Filled joints				
	C13.7.2.	10mm wide joint between parapet panels (filled with impregnated softboard)	square metre (m²)	5,4	4572	R 24 688,80
C13.7.4		Sealing joints with: (Silicone Sealant)				
	C13.7.4.1	10mmx10mm to joints between parapet panels	metre (m)	52,4	280	R 14 672,00
TOTAL CARRIED FORWARD TO SUMMARY						R 39 360,80

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.4

SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.4.3		Proprietary cementitious repair system (Class and generic description) in positions as indicated in accordance with Table A14.4.5-1.				
	C14.4.3.2	Class R3 Repair Mortar	cubic metre (m³)	28,5	R 10 400,00	R 296 400,00
C14.4.4		Curing of repair surfaces				
	C14.4.4.2	Curing	square metre (m²)	285	R 105,00	R 29 925,00
TOTAL CARRIED FORWARD TO SUMMARY						R 326 325,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.5.7		Crack filling					
	C14.5.7.1	Repair	metre (m)	25	R	700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 500,00

C14.7

PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R	140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments					
	C14.7.2.1	(a) Corrosion inhibitor	square metre (m²)	1425	R	450,00	R 641 250,00
	C14.7.2.2	(b) Hydrophobic impregnation	square metre (m²)	1425	R	450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY							R 1 482 000,00

C14.9**REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R 320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R 700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system				
	C14.9.3.1	Service and repair of bridge joints (Removal)	metre (m)	52,4	R 1 460,00	R 76 504,00
TOTAL CARRIED FORWARD TO SUMMARY						R 94 672,00

C14.10

JACKING OF BRIDGE
STRUCTURES

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.10.1		Jacking - complicated (provide jack support work)	no			R 57 020,00
TOTAL CARRIED FORWARD TO SUMMARY						R 57 020,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

CATHODIC PROTECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
1		Installing of CP system	square metre (m²)	285	R 2 200,00	R 627 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 627 000,00

C2.3 SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	187 002,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	288 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	21 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	380 440,00	R	877 542,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	435 920,00	R	435 920,00

STRUCTURES

C13.7	JOINTS	R	39 360,80	R	39 360,80

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.4	SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS	R	326 325,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	1 482 000,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	94 672,00		
C14.10	JACKING OF BRIDGE STRUCTURES	R	57 020,00	R	1 991 737,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

CATHODIC PROTECTION

R	627 000,00	R	627 000,00

SUBTOTAL A

R	4 000 309,80

VALUE ADDED TAX:

15% of Subtotal

R	600 046,47

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	4 600 356,27

BILLS OF QUANTITIES-SRC BRIDGE SUPERSTRUCTURE ESSENTIAL MAINTENACE (50 YEARS)

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	6	R 2 500,00	R 15 000,00
	C1.2.1.2	Dedicated environmental officer	month	6	R 15 000,00	R 90 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	6	R 450,00	R 2 700,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 222 902,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	6	R 28 750,00	R 172 500,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 346 000,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	6	R 1 500,00	R 9 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 24 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	6	R 15 000,00	R 90 000,00
C1.5.3			Liaison with traffic authorities	month	6	R 5 000,00	R 30 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	6	R 2 500,00	R 15 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	6	R 2 500,00	R 15 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	6	R 2 500,00	R 15 000,00
		(e)	Mobile variable message sign	month	6	R 2 500,00	R 15 000,00
C1.5.8			Traffic safety officer	man-month	6	R 4 650,00	R 27 900,00
C1.5.9			Traffic safety vehicle	month	6	R 500,00	R 3 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 450 740,00

C8.4

RUT AND/OR DEPRESSION CORRECTION

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.4.1			Rut and/or Depression correction (screeding)				
	C8.4.1.1		60 % Anionic stable grade emulsion (Diluted 50% Emulsion 50% Water)	litre (l)	181	10	R 1 810,00
	C8.4.1.2		Correction material				
		a	Continuously graded, medium grade, (TRH8), A-E2 binder (45mm thick), Nominal Binder content 5,3%	ton (t)	5,3	6200	R 32 860,00
TOTAL CARRIED FORWARD TO SUMMARY							R 34 670,00

C8.5

STANDARD CRACK SEALING

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.5.1			Standard crack sealing				
	C8.5.1.1		Cleaning cracks				
		a	Cleaning crack with hot compressed air	metre (m)	25	143	R 3 575,00
	C8.5.1.3		Primer(MSP 1)	litre (ℓ)	781	24,3	R 18 978,30
	C8.5.1.4		Sealing the cracks				
		a	Sealing using (Viaflex)	litre (ℓ)	181	82	R 14 842,00
	C8.5.1.5		Heating of surface before rolling	metre (m)	25	263	R 6 575,00
	C8.5.1.6		Rolling the cracks	metre (m)	25	234	R 5 850,00
TOTAL CARRIED FORWARD TO SUMMARY							R 49 820,30

C8.8

PATCHING AND EDGE BREAK REPAIR

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.8.1			Saw cutting pavement layers for patching				
	C8.8.1.1		Asphalt or bituminous surfacing to an average depth				
		a	Not exceeding 50 mm	metre (m)	25	481	R 12 025,00
C8.8.2			Excavation in existing pavements for patching (non-milling)				
	C8.8.2.1		Asphalt layers				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	cubic metre (m ³)	55,6	500	R 27 800,00
C8.8.3			Compacting the floor of excavations for patching	square metre (m ²)	223	315	R 70 245,00
C8.8.4			Backfilling of excavations for patching with				
	C8.8.4.3		Asphalt for a patch with a surface area (state type and density)				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	ton (t)	5,2	6200	R 32 240,00
TOTAL CARRIED FORWARD TO SUMMARY							R 142 310,00

C13.8

ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C13.8.1		Concrete barriers and parapets					
	C13.8.1.2	Parapets (all concrete)	metre (m)	41,5	R	11 410,00	R 473 515,00
TOTAL CARRIED FORWARD TO SUMMARY							R 473 515,00

C14.1**ACCESS FOR BRIDGE
REHABILITATION**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.3

DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.3.1		Demolition of concrete members				
	C14.3.1.1	Full demolition of:				
		(i) Parapets	cubic metre (m³)	31,9	R 650,00	R 20 735,00
TOTAL CARRIED FORWARD TO SUMMARY						R 20 735,00

C14.4**SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.4.3		Proprietary cementitious repair system (Class and generic description) in positions as indicated in accordance with Table A14.4.5-1.				
	C14.4.3.2	Class R3 Repair Mortar	cubic metre (m³)	47,5	R 10 400,00	R 494 000,00
C14.4.4		Curing of repair surfaces				
	C14.4.4.2	Curing	square metre (m²)	476	R 105,00	R 49 980,00
TOTAL CARRIED FORWARD TO SUMMARY						R 543 980,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.5.7		Crack filling				
	C14.5.7.1	Repair	metre (m)	25	R 700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY						R 17 500,00

C14.7**PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE**

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R	140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments					
		(a) Corrosion inhibitor	square metre (m²)	1425	R	450,00	R 641 250,00
		(b) Hydrophobic impregnation	square metre (m²)	1425	R	450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY							R 1 482 000,00

C14.9

REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R 320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R 700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system				
	C14.9.3.1	Service and repair of bridge joints	metre (m)	31	R 1 460,00	R 45 260,00
TOTAL CARRIED FORWARD TO SUMMARY						R 63 428,00

C14.10

JACKING OF BRIDGE
STRUCTURES

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.10.1		Jacking - complicated (provide jack support work)	no			R 57 020,00
TOTAL CARRIED FORWARD TO SUMMARY						R 57 020,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2	C20.1.2.2			Special tests requested by the Engineer				
				Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

CATHODIC PROTECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
1		Installing of CP system	square metre (m²)	285	R	2 200,00	R 627 000,00
2		Maintenance of Anodes	square metre (m²)	114	R	1 800,00	R 205 200,00
TOTAL CARRIED FORWARD TO SUMMARY							R 832 200,00

C2.3 SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	222 902,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	346 000,00		
C1.4	FACILITIES FOR THE ENGINEER	R	24 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	450 740,00	R	1 044 242,00

PRETREATMENT AND REPAIR EXISTING LAYERS

C8.4	RUT AND/OR DEPRESSION CORRECTION	R	34 670,00		
C8.5	STANDARD CRACK SEALING	R	49 820,30		
C8.8	PATCHING AND EDGE BREAK REPAIR	R	142 310,00	R	226 800,30

STRUCTURES

C13.8	ANCILLARY STRUCTURAL ELEMENTS	R	473 515,00	R	473 515,00

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.3	DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK	R	20 735,00		
C14.4	SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS	R	543 980,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	1 482 000,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	63 428,00		
C14.10	JACKING OF BRIDGE STRUCTURES	R	57 020,00	R	2 198 883,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

CATHODIC PROTECTION

R	832 200,00	R	832 200,00

SUBTOTAL A

R	4 804 390,30

VALUE ADDED TAX:

15% of Subtotal	R	720 658,55

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	5 525 048,85

BILLS OF QUANTITIES-SRC BRIDGE SUPERSTRUCTURE DEMOLITION

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	2	R 2 500,00	R 5 000,00
	C1.2.1.2	Dedicated environmental officer	month	2	R 15 000,00	R 30 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	2	R 450,00	R 900,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 151 102,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	2	R 28 750,00	R 57 500,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 231 000,00

C1.4**FACILITIES FOR THE ENGINEER**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	2	R 1 500,00	R 3 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 18 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	2	R 15 000,00	R 30 000,00
C1.5.3			Liaison with traffic authorities	month	2	R 5 000,00	R 10 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	2	R 2 500,00	R 5 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	2	R 2 500,00	R 5 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	2	R 2 500,00	R 5 000,00
		(e)	Mobile variable message sign	month	2	R 2 500,00	R 5 000,00
C1.5.8			Traffic safety officer	man-month	2	R 4 650,00	R 9 300,00
C1.5.9			Traffic safety vehicle	month	2	R 500,00	R 1 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 310 140,00

C9.1

ASPHALT LAYERS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.15			Milling of bridge decks and keys adjacent to bridge decks				
	C9.1.15.1		Provision of an appropriate sized milling machine	number (No)	lump sum		R 15 000,00
	C9.1.15.2		Milling of bridge decks and keys to bridge deck approaches	cubic metre (m³)	50	1436	R 71 800,00
	C9.1.15.3		Cleaning of milled surfaces	square metre (m²)	557	140	R 77 980,00
TOTAL CARRIED FORWARD TO SUMMARY							R 164 780,00

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.3

DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.3.1		Demolition of concrete members					
	C14.3.1.1	Full demolition of:					
		(i) Parapets	cubic metre (m³)	31,9	R	451,70	R 14 409,23
		(ii) Deck	cubic metre (m³)	105,3	R	451,70	R 47 564,01
		(iii) Beams	cubic metre (m³)	117	R	451,70	R 52 848,90
TOTAL CARRIED FORWARD TO SUMMARY							R 114 822,14

C20.1**TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP**

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

C2.3 SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	151 102,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	231 000,00		
C1.4	FACILITIES FOR THE ENGINEER	R	18 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	310 140,00	R	710 842,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	164 780,00	R	164 780,00

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.3	DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK	R	114 822,14	R	129 042,14

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	1 033 414,14

VALUE ADDED TAX:

15% of Subtotal	R	155 012,12

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	1 188 426,26

BILLS OF QUANTITIES-GFRP-RC BRIDGE SUPERSTRUCTURE CONSTRUCTION

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the	month	12	R 2 500,00	R 30 000,00
	C1.2.1.2	Dedicated environmental officer	month	12	R 15 000,00	R 180 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	12	R 450,00	R 5 400,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 330 602,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	12	R 28 750,00	R 345 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 518 500,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	12	R 1 500,00	R 18 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 33 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2				Accommodation of vehicular traffic	month	12	R 15 000,00	R 180 000,00
C1.5.3				Liaison with traffic authorities	month	12	R 5 000,00	R 60 000,00
C1.5.7				Temporary traffic control facilities				
	C1.5.7.1			Delineators including mounting bases and ballast:				
		(b)		Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3			Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4			Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5			Provision of illuminated traffic signs:				
		(a)		Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)		900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)		1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)		Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)		Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)		Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6			Maintenance of illuminated traffic signs:				
		(a)		Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	12	R 2 500,00	R 30 000,00
		(c)		Illuminated road sign – R & TR series (diameter indicated)	month	12	R 2 500,00	R 30 000,00
		(d)		Illuminated road sign – TW series (length of sides indicated)	month	12	R 2 500,00	R 30 000,00
		(e)		Mobile variable message sign	month	12	R 2 500,00	R 30 000,00
C1.5.8				Traffic safety officer	man-month	12	R 4 650,00	R 55 800,00
C1.5.9				Traffic safety vehicle	month	12	R 500,00	R 6 000,00
C1.5.12				Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1			Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2			Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY								R 661 640,00

C9.1

ASPHALT LAYERS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.8			Surfacing of bridge decks				
	C9.1.8.1		Levelling course: Continuously graded, medium grade, (TRH8) A-E2 binder (30mm thick). Nominal Binder content 5,3%	ton (t)	38,8	2000	R 77 600,00
	C9.1.8.2		Surfacing Continuously graded, medium grade, (TRH8)A-E2 binder (45mm thick).Nominal Binder content 5,3%	ton (t)	58,2	2000	R 116 400,00
	C9.1.8.3		Bond coat of 30% stable-grade emulsion (nominal rate 0,40l/m²)	litre (ℓ)	223	280	R 62 440,00
C9.1.9			Application of rolled in chippings (14 mm maximum size, pre-coated, 4kg/m²)				
	C9.1.9.1		By means of chip spreader	ton (t)	21	700	R 14 700,00
TOTAL CARRIED FORWARD TO SUMMARY							R 271 140,00

C13.2

FALSEWORK, FORMWORK AND CONCRETE FINISH

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.2.1		Formwork to provide				
	(a)	Class F2 surface finish to:				
	(i)	Deck	square metre (m ²)	436,3	230,00	R 100 349,00
	(ii)	Parapet	square metre (m ²)	236,5	230,00	R 54 395,00
	(iii)	Beams	square metre (m ²)	752,1	230,00	R 172 983,00
TOTAL CARRIED FORWARD TO SUMMARY						R 327 727,00

C13.3

GFRP REINFORCEMENT

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.3.1		Reinforcement for:				
	C13.3.1.1	Complete structure:				
		a) E glass (GFRP)	lump sum			R 2 126 004,89
TOTAL CARRIED FORWARD TO SUMMARY						R 2 126 004,89

C13.4

C13.4

CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.4.2		Labour enhanced cast in situ concrete and Curing				
	C13.4.2.1	(a) Normal concrete Class 32/40 Commercially-Sourced concrete:				
		(i) Deck	cubic metre (m ³)	105,3	11410	R 1 201 473,00
		(ii) Beams	cubic metre (m ³)	117	11410	R 1 334 970,00
C13.4.6		Curing and surface protection of labour enhanced cast in situ concrete				
	C13.4.6.1	Deck soffit (Hydrophobic impregnation)	square metre (m ²)	436,3	450	R 196 335,00
		Beams (Hydrophobic impregnation)	square metre (m ²)	752,1	450	R 338 445,00
TOTAL CARRIED FORWARD TO SUMMARY						R 3 071 223,00

C13.7

JOINTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.7.2		Filled joints				
	C13.7.2.	10mm wide joint between parapet panels (filled with impregnated softboard)	square metre (m²)	5,4	4572	R 24 688,80
C13.7.4		Sealing joints with: (Silicone Sealant)				
	C13.7.4.1	10mmx10mm to joints between parapet panels	metre (m)	52,4	280	R 14 672,00
TOTAL CARRIED FORWARD TO SUMMARY						R 39 360,80

C13.8

ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C13.8.1		Concrete barriers and parapets					
	C13.8.1.2	Parapets (all concrete)	metre (m)	41,5	R	11 410,00	R 473 515,00
	C13.8.1.3	Surface Treatment (Hydrophobic impregnation)	square metre (m²)	236,5	R	450,00	R 106 425,00
C13.8.10		Drainage pipes and weep holes	no	2	R	7 110,00	R 14 220,00
TOTAL CARRIED FORWARD TO SUMMARY							R 594 160,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	330 602,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	518 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	33 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	661 640,00	R	1 544 342,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	271 140,00	R	271 140,00

STRUCTURES

C13.2	FALSEWORK, FORMWORK AND CONCRETE FINISH	R	327 727,00		
C13.3	STEEL REINFORCEMENT	R	2 126 004,89		
C13.4	CONCRETE	R	3 071 223,00		
C13.7	JOINTS	R	39 360,80		
C13.8	ANCILLARY STRUCTURAL ELEMENTS	R	594 160,00	R	6 158 475,69

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	8 002 707,69

VALUE ADDED TAX:

15% of Subtotal	R	1 200 406,15

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	9 203 113,84

BILLS OF QUANTITIES-GFRP-RC BRIDGE SUPERSTRUCTURE PREVENTATIVE MAINTENANCE (10&20 YEARS)

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the	month	4	R 2 500,00	R 10 000,00
	C1.2.1.2	Dedicated environmental officer	month	4	R 15 000,00	R 60 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	4	R 450,00	R 1 800,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 187 002,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	4	R 28 750,00	R 115 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 288 500,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	4	R 1 500,00	R 6 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 21 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	4	R 15 000,00	R 60 000,00
C1.5.3			Liaison with traffic authorities	month	4	R 5 000,00	R 20 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	4	R 2 500,00	R 10 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	4	R 2 500,00	R 10 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	4	R 2 500,00	R 10 000,00
		(e)	Mobile variable message sign	month	4	R 2 500,00	R 10 000,00
C1.5.8			Traffic safety officer	man-month	4	R 4 650,00	R 18 600,00
C1.5.9			Traffic safety vehicle	month	4	R 500,00	R 2 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 380 440,00

C8.4

RUT AND/OR DEPRESSION CORRECTION

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.4.1			Rut and/or Depression correction (screeding)				
	C8.4.1.1		60 % Anionic stable grade emulsion (Diluted 50% Emulsion 50% Water)	litre (l)	91	10	R 910,00
	C8.4.1.2		Correction material				
		a	Continuously graded, medium grade, (TRH8), A-E2 binder (45mm thick), Nominal Binder content 5,3%	ton (t)	2,7	6200	R 16 740,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 650,00

C8.5

STANDARD CRACK SEALING

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.5.1			Standard crack sealing				
	C8.5.1.1		Cleaning cracks				
		a	Cleaning crack with hot compressed air	metre (m)	25	143	R 3 575,00
	C8.5.1.3		Primer(MSP 1)	litre (ℓ)	391	24,3	R 9 501,30
	C8.5.1.4		Sealing the cracks				
		a	Sealing using (Viaflex)	litre (ℓ)	91	82	R 7 462,00
	C8.5.1.5		Heating of surface before rolling	metre (m)	25	263	R 6 575,00
	C8.5.1.6		Rolling the cracks	metre (m)	25	234	R 5 850,00
TOTAL CARRIED FORWARD TO SUMMARY							R 32 963,30

C8.8

PATCHING AND EDGE BREAK REPAIR

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.8.1			Saw cutting pavement layers for patching				
	C8.8.1.1		Asphalt or bituminous surfacing to an average depth				
		a	Not exceeding 50 mm	metre (m)	25	481	R 12 025,00
C8.8.2			Excavation in existing pavements for patching (non-milling)				
	C8.8.2.1		Asphalt layers				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	cubic metre (m ³)	30	500	R 15 000,00
C8.8.3			Compacting the floor of excavations for patching	square metre (m ²)	112	315	R 35 280,00
C8.8.4			Backfilling of excavations for patching with				
	C8.8.4.3		Asphalt for a patch with a surface area (state type and density)				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	ton (t)	2,7	6200	R 16 740,00
TOTAL CARRIED FORWARD TO SUMMARY							R 79 045,00

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.5.7		Crack filling					
	C14.5.7.1	Repair	metre (m)	25	R	700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 500,00

C14.7

PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R 140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments				
		(a) Hydrophobic impregnation	square metre (m²)	1425	R 450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY						R 840 750,00

C14.9**REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS**

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R	320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R	700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system					
	C14.9.3.1	Service and repair of bridge joints	metre (m)	31	R	1 460,00	R 45 260,00
TOTAL CARRIED FORWARD TO SUMMARY							R 63 428,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	187 002,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	288 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	21 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	380 440,00	R	877 542,00

PRETREATMENT AND REPAIR EXISTING LAYERS

C8.4	RUT AND/OR DEPRESSION CORRECTION	R	17 650,00		
C8.5	STANDARD CRACK SEALING	R	32 963,30		
C8.8	PATCHING AND EDGE BREAK REPAIR	R	79 045,00	R	129 658,30

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	840 750,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	63 428,00	R	935 898,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	1 971 848,30

VALUE ADDED TAX:

15% of Subtotal

R	295 777,25

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	2 267 625,55

BILLS OF QUANTITIES-GFRP-RC BRIDGE SUPERSTRUCTURE PREVENTATIVE MAINTENANCE (25 YEARS)

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the EMP	month	4	R 2 500,00	R 10 000,00
	C1.2.1.2	Dedicated environmental officer	month	4	R 15 000,00	R 60 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	4	R 450,00	R 1 800,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 187 002,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	4	R 28 750,00	R 115 000,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 288 500,00

C1.4**FACILITIES FOR THE ENGINEER**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	4	R 1 500,00	R 6 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 21 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	4	R 15 000,00	R 60 000,00
C1.5.3			Liaison with traffic authorities	month	4	R 5 000,00	R 20 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	4	R 2 500,00	R 10 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	4	R 2 500,00	R 10 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	4	R 2 500,00	R 10 000,00
		(e)	Mobile variable message sign	month	4	R 2 500,00	R 10 000,00
C1.5.8			Traffic safety officer	man-month	4	R 4 650,00	R 18 600,00
C1.5.9			Traffic safety vehicle	month	4	R 500,00	R 2 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 380 440,00

C9.1

ASPHALT LAYERS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.8		Surfacing of bridge decks				
	C9.1.8.1	Levelling course: Continuously graded, medium grade, (TRH8) A-E2 binder (30mm thick). Nominal Binder content 5,3%	ton (t)	38,8	2000	R 77 600,00
	C9.1.8.2	Surfacing Continuously graded, medium grade, (TRH8)A-E2 binder (45mm thick).Nominal Binder content 5,3%	ton (t)	58,2	2000	R 116 400,00
	C9.1.8.3	Bond coat of 30% stable-grade emulsion (nominal rate 0,40l/m²)	litre (ℓ)	223	280	R 62 440,00
C9.1.9		Application of rolled in chippings (14 mm maximum size, pre-coated, 4kg/m²)				
	C9.1.9.1	By means of chip spreader	ton (t)	21	700	R 14 700,00
C9.1.15		Milling of bridge decks and keys adjacent to bridge decks				
	C9.1.15.1	Provision of an appropriate sized milling machine	number (No)	lump sum		R 15 000,00
	C9.1.15.2	Milling of bridge decks and keys to bridge deck approaches	cubic metre (m³)	50	1436,00	R 71 800,00
	C9.1.15.3	Cleaning of milled surfaces	square metre (m²)	557	140,00	R 77 980,00
TOTAL CARRIED FORWARD TO SUMMARY						R 435 920,00

C13.7

JOINTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C13.7.2		Filled joints				
	C13.7.2.	10mm wide joint between parapet panels (filled with impregnated softboard)	square metre (m²)	5,4	4572	R 24 688,80
C13.7.4		Sealing joints with: (Silicone Sealant)				
	C13.7.4.1	10mmx10mm to joints between parapet panels	metre (m)	52,4	280	R 14 672,00
TOTAL CARRIED FORWARD TO SUMMARY						R 39 360,80

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.4

SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.4.3		Proprietary cementitious repair system (Class and generic description) in positions as indicated in accordance with Table A14.4.5-1.				
	C14.4.3.2	Class R3 Repair Mortar	cubic metre (m ³)	28,5	R 10 400,00	R 296 400,00
C14.4.4		Curing of repair surfaces				
	C14.4.4.2	Curing	square metre (m ²)	285	R 105,00	R 29 925,00
TOTAL CARRIED FORWARD TO SUMMARY						R 326 325,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.5.7		Crack filling					
	C14.5.7.1	Repair	metre (m)	25	R	700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 500,00

C14.7

PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R 140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments				
	C14.7.2.2	(a) Hydrophobic impregnation	square metre (m²)	1425	R 450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY						R 840 750,00

C14.9**REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS**

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R	320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R	700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system					
	C14.9.3.1	Service and repair of bridge joints (Removal)	metre (m)	52,4	R	1 460,00	R 76 504,00
TOTAL CARRIED FORWARD TO SUMMARY							R 94 672,00

C14.10

JACKING OF BRIDGE
STRUCTURES

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.10.1		Jacking - complicated (provide jack support work)	no			R 57 020,00
TOTAL CARRIED FORWARD TO SUMMARY						R 57 020,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	187 002,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	288 500,00		
C1.4	FACILITIES FOR THE ENGINEER	R	21 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	380 440,00	R	877 542,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	435 920,00	R	435 920,00

STRUCTURES

C13.7	JOINTS	R	39 360,80	R	39 360,80

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.4	SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS	R	326 325,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	840 750,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	94 672,00		
C14.10	JACKING OF BRIDGE STRUCTURES	R	57 020,00	R	1 350 487,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R 2 732 059,80

VALUE ADDED TAX:

15% of Subtotal R 409 808,97

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R 3 141 868,77

BILLS OF QUANTITIES-GFRP-RC BRIDGE SUPERSTRUCTURE ESSENTIAL MAINTENANCE

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the	month	6	R 2 500,00	R 15 000,00
	C1.2.1.2	Dedicated environmental officer	month	6	R 15 000,00	R 90 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	6	R 450,00	R 2 700,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 222 902,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	6	R 28 750,00	R 172 500,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 346 000,00

C1.4**FACILITIES FOR THE ENGINEER**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	6	R 1 500,00	R 9 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 24 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	6	R 15 000,00	R 90 000,00
C1.5.3			Liaison with traffic authorities	month	6	R 5 000,00	R 30 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	6	R 2 500,00	R 15 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	6	R 2 500,00	R 15 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	6	R 2 500,00	R 15 000,00
		(e)	Mobile variable message sign	month	6	R 2 500,00	R 15 000,00
C1.5.8			Traffic safety officer	man-month	6	R 4 650,00	R 27 900,00
C1.5.9			Traffic safety vehicle	month	6	R 500,00	R 3 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 450 740,00

C8.4

RUT AND/OR DEPRESSION CORRECTION

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.4.1			Rut and/or Depression correction (screeding)				
	C8.4.1.1		60 % Anionic stable grade emulsion (Diluted 50% Emulsion 50% Water)	litre (l)	181	10	R 1 810,00
	C8.4.1.2		Correction material				
		a	Continuously graded, medium grade, (TRH8), A-E2 binder (45mm thick), Nominal Binder content 5,3%	ton (t)	5,3	6200	R 32 860,00
TOTAL CARRIED FORWARD TO SUMMARY							R 34 670,00

C8.5

STANDARD CRACK SEALING

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.5.1			Standard crack sealing				
	C8.5.1.1		Cleaning cracks				
		a	Cleaning crack with hot compressed air	metre (m)	25	143	R 3 575,00
	C8.5.1.3		Primer(MSP 1)	litre (ℓ)	781	24,3	R 18 978,30
	C8.5.1.4		Sealing the cracks				
		a	Sealing using (Viaflex)	litre (ℓ)	181	82	R 14 842,00
	C8.5.1.5		Heating of surface before rolling	metre (m)	25	263	R 6 575,00
	C8.5.1.6		Rolling the cracks	metre (m)	25	234	R 5 850,00
TOTAL CARRIED FORWARD TO SUMMARY							R 49 820,30

C8.8

PATCHING AND EDGE BREAK REPAIR

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C8.8.1			Saw cutting pavement layers for patching				
	C8.8.1.1		Asphalt or bituminous surfacing to an average depth				
		a	Not exceeding 50 mm	metre (m)	25	481	R 12 025,00
C8.8.2			Excavation in existing pavements for patching (non-milling)				
	C8.8.2.1		Asphalt layers				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	cubic metre (m ³)	55,6	500	R 27 800,00
C8.8.3			Compacting the floor of excavations for patching	square metre (m ²)	223	315	R 70 245,00
C8.8.4			Backfilling of excavations for patching with				
	C8.8.4.3		Asphalt for a patch with a surface area (state type and density)				
		a	Not exceeding 10 m ² including for edge repairs wider than 250 mm	ton (t)	5,2	6200	R 32 240,00
TOTAL CARRIED FORWARD TO SUMMARY							R 142 310,00

C13.8

ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C13.8.1		Concrete barriers and parapets					
	C13.8.1.2	Parapets (all concrete)	metre (m)	41,5	R	11 410,00	R 473 515,00
TOTAL CARRIED FORWARD TO SUMMARY							R 473 515,00

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.3

DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.3.1		Demolition of concrete members				
	C14.3.1.1	Full demolition of:				
		(i) Parapets	cubic metre (m³)	31,9	R 650,00	R 20 735,00
TOTAL CARRIED FORWARD TO SUMMARY						R 20 735,00

C14.4**SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS**

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.4.3		Proprietary cementitious repair system (Class and generic description) in positions as indicated in accordance with Table A14.4.5-1.				
	C14.4.3.2	Class R3 Repair Mortar	cubic metre (m³)	47,5	R 10 400,00	R 494 000,00
C14.4.4		Curing of repair surfaces				
	C14.4.4.2	Curing	square metre (m²)	476	R 105,00	R 49 980,00
TOTAL CARRIED FORWARD TO SUMMARY						R 543 980,00

C14.5

ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.5.7		Crack filling					
	C14.5.7.1	Repair	metre (m)	25	R	700,00	R 17 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 17 500,00

C14.7

PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.7.1		Cleaning and preparation of concrete surface	square metre (m²)	1425	R 140,00	R 199 500,00
C14.7.2		Application of protective coatings and treatments				
		(a) Hydrophobic impregnation	square metre (m²)	1425	R 450,00	R 641 250,00
TOTAL CARRIED FORWARD TO SUMMARY						R 840 750,00

C14.9

REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.9.1		Removal of debris from expansion gaps	metre (m)	52,4	R 320,00	R 16 768,00
C14.9.2		Clear bridge drainage system	number (No)	2	R 700,00	R 1 400,00
C14.9.3		Service and repair of existing joint system				
	C14.9.3.1	Service and repair of bridge joints	metre (m)	31	R 1 460,00	R 45 260,00
TOTAL CARRIED FORWARD TO SUMMARY						R 63 428,00

C14.10

JACKING OF BRIDGE
STRUCTURES

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.10.1		Jacking - complicated (provide jack support work)	no			R 57 020,00
TOTAL CARRIED FORWARD TO SUMMARY						R 57 020,00

C20.1

TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	222 902,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	346 000,00		
C1.4	FACILITIES FOR THE ENGINEER	R	24 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	450 740,00	R	1 044 242,00

PRETREATMENT AND REPAIR EXISTING LAYERS

C8.4	RUT AND/OR DEPRESSION CORRECTION	R	34 670,00		
C8.5	STANDARD CRACK SEALING	R	49 820,30		
C8.8	PATCHING AND EDGE BREAK REPAIR	R	142 310,00	R	226 800,30

STRUCTURES

C13.8	ANCILLARY STRUCTURAL ELEMENTS	R	473 515,00	R	473 515,00

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.3	DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK	R	20 735,00		
C14.4	SURFACE AND STRUCTURAL REPAIR OF CONCRETE MEMBERS	R	543 980,00		
C14.5	ANCHORING OF REINFORCEMENT, GROUTING AND CRACK INJECTION	R	17 500,00		
C14.7	PROTECTIVE COATINGS AND TREATMENTS FOR CONCRETE	R	840 750,00		
C14.9	REPAIR AND REPLACEMENT OF ANCILLARY STRUCTURAL ELEMENTS	R	63 428,00		
C14.10	JACKING OF BRIDGE STRUCTURES	R	57 020,00	R	1 557 633,00

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	3 330 940,30

VALUE ADDED TAX:

15% of Subtotal

R	499 641,05

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	3 830 581,35

BILLS OF QUANTITIES-GFRP-RC BRIDGE SUPERSTRUCTURE DEMOLITION

C1.2

GENERAL REQUIREMENTS AND PROVISIONS

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.2.1		Environmental Management				
	C1.2.1.1	Monitoring of compliance with and reporting on the	month	2	R 2 500,00	R 5 000,00
	C1.2.1.2	Dedicated environmental officer	month	2	R 15 000,00	R 30 000,00
C1.2.5		Safety				
	C1.2.5.1	Health and safety plan	lump sum	lump	sum	R 4 300,00
	C1.2.5.2	Implementation of health and safety plan	month	2	R 450,00	R 900,00
C1.2.8		Dayworks				
	C1.2.8.1	Personnel				
		(a) Unskilled labourer	hour (h)	32	R 36,00	R 1 152,00
		(b) Semi-skilled labourer	hour (h)	32	R 40,00	R 1 280,00
		(c) Skilled labourer	hour (h)	16	R 52,00	R 832,00
		(d) Gang leader	hour (h)	32	R 60,00	R 1 920,00
		(e) Foreman	hour (h)	32	R 144,00	R 4 608,00
		(f) Skilled artisan	hour (h)	8	R 150,00	R 1 200,00
	C1.2.8.2	Construction equipment				
		(e) Tractor loader backhoe	hour (h)	16	R 190,00	R 3 040,00
		(g) Compressor	hour (h)	8	R 840,00	R 6 720,00
	C1.2.8.3	Vehicles				
		(a) Light delivery vehicle (1800cc minimum)	kilometre (km)	150	R 5,00	R 750,00
		(b) Flatbed truck	kilometre (km)	50	R 6,00	R 300,00
		(c) Dump truck (6m ³)	kilometre (km)	50	R 12,00	R 600,00
	C1.2.8.4	Materials				
		(a) Procurement of materials	provisional sum	Prov	Sum	R 20 000,00
		(b) Contractor's handling costs, profit and all other charges in respect of item C1.2.8.4(a)	percentage (%)	R 20 000,00	10,00%	R 2 000,00
C1.2.9		Disposal of non-useable assets				
	C1.2.9.2	Disposal of non-useable assets not identified at time of tender	provisional sum	Prov	Sum	R 15 000,00
	C1.2.9.3	Handling cost, profit and all other charges in respect of item C1.2.9.2	percentage (%)	R 15 000,00	10,00%	R 1 500,00
PC1.2.10		Dispute Adjudication Board (DAB)				
	C1.2.10.1	Employer's contribution to DAB (50%)	prime cost (PC) sum	Prime	Cost	R 50 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 151 102,00

C1.3

CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
PC1.3.1			The Contractor's general obligations				
	C1.3.1.1		Fixed obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.2		Value-related obligations	lump sum	lump	sum	R 80 000,00
	C1.3.1.3		Time-related obligations				
		(a)	Mobilisation period	month			R -
		(b)	Execution of the works	month	2	R 28 750,00	R 57 500,00
	C1.3.1.4		Suspension Cost				
		(a)	De-establishment	number			R -
		(b)	Re-establishment	number			R -
		(c)	Suspension period	month			R -
		(d)	Engineer's cost	prime cost (PC) sum	prime	cost	R 10 000,00
C1.3.2			Contract sign boards	square metre (m ²)	10	R 350,00	R 3 500,00
TOTAL CARRIED FORWARD TO SUMMARY							R 231 000,00

C1.4

FACILITIES FOR THE ENGINEER

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C1.4.1		Site accommodation				
	C1.4.1.1	Offices and conference room	square metre (m ²)	35	R 200,00	R 7 000,00
C1.4.4		Prime cost items				
	C1.4.4.1	Cell phones costs, including pro-rata rentals, for calls made in connection with contract administration	prime cost (PC) sum	prime	cost	R 6 000,00
	C1.4.4.2	Handling costs and profit in respect of item C1.4.4.1	percentage (%)	R 6 000,00	10,00%	R 600,00
C1.4.5		Services at site offices, laboratories and site accommodation				
	C1.4.5.1	Fixed costs	lump sum	lump	sum	R 2 000,00
	C1.4.5.2	Running costs	month	2	R 1 500,00	R 3 000,00
TOTAL CARRIED FORWARD TO SUMMARY						R 18 600,00

C1.5

ACCOMMODATION OF TRAFFIC

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C1.5.2			Accommodation of vehicular traffic	month	2	R 15 000,00	R 30 000,00
C1.5.3			Liaison with traffic authorities	month	2	R 5 000,00	R 10 000,00
C1.5.7			Temporary traffic control facilities				
	C1.5.7.1		Delineators including mounting bases and ballast:				
		(b)	Double sided, reversible left or right (250 x 1000mm)	number (No.)	12	R 100,00	R 1 200,00
	C1.5.7.3		Flagmen	man-shift	50	R 80,00	R 4 000,00
	C1.5.7.4		Traffic controllers	man-shift	24	R 110,00	R 2 640,00
	C1.5.7.5		Provision of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (2 lights with the specified power supply) mounted on a backing board which is:				
		(i)	900mm wide x 150mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(ii)	1200mm wide x 200mm high	number (No.)	2	R 15 000,00	R 30 000,00
		(c)	Illuminated road sign – R & TR series (1200mm diameter)	number (No.)	4	R 15 000,00	R 60 000,00
		(d)	Illuminated road sign – TW series (1800 x 1200mm)	number (No.)	4	R 15 000,00	R 60 000,00
		(e)	Mobile variable message sign	number (No.)	2	R 15 000,00	R 30 000,00
	C1.5.7.6		Maintenance of illuminated traffic signs:				
		(a)	Sign mounted flashing amber lights (a pair of two lights mounted on a separate backing board)	month	2	R 2 500,00	R 5 000,00
		(c)	Illuminated road sign – R & TR series (diameter indicated)	month	2	R 2 500,00	R 5 000,00
		(d)	Illuminated road sign – TW series (length of sides indicated)	month	2	R 2 500,00	R 5 000,00
		(e)	Mobile variable message sign	month	2	R 2 500,00	R 5 000,00
C1.5.8			Traffic safety officer	man-month	2	R 4 650,00	R 9 300,00
C1.5.9			Traffic safety vehicle	month	2	R 500,00	R 1 000,00
C1.5.12			Additional traffic accommodation facilities ordered by the Engineer:				
	C1.5.12.1		Provision of additional traffic accommodation facilities	provisional sum	Prov	Sum	R 20 000,00
	C1.5.12.2		Handling cost, profit and all other charges in respect of item C1.5.12.1	percentage (%)	R 20 000,00	10,00%	R 2 000,00
TOTAL CARRIED FORWARD TO SUMMARY							R 310 140,00

C9.1

ASPHALT LAYERS

ITEM			DESCRIPTION	UNIT	QTY	RATE	AMT
C9.1.15			Milling of bridge decks and keys adjacent to bridge decks				
	C9.1.15.1		Provision of an appropriate sized milling machine	number (No)	lump sum		R 15 000,00
	C9.1.15.2		Milling of bridge decks and keys to bridge deck approaches	cubic metre (m³)	50	1436	R 71 800,00
	C9.1.15.3		Cleaning of milled surfaces	square metre (m²)	557	140	R 77 980,00
TOTAL CARRIED FORWARD TO SUMMARY							R 164 780,00

C14.1

ACCESS FOR BRIDGE
REHABILITATION

ITEM		DESCRIPTION	UNIT	QTY	RATE	AMT
C14.1.1		Temporary access structures and work platforms				
	C14.1.1.1	(a) Access and platforms to locations as described as well as dismantling and removal at completion (heights assessed by contractor)				
		(i) Bridge deck and parapets	lump sum	1		R 7 110,00
		(ii) Beams	lump sum	1		R 7 110,00
TOTAL CARRIED FORWARD TO SUMMARY						R 14 220,00

C14.3

DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK

ITEM		DESCRIPTION	UNIT	QTY	RATE		AMT
C14.3.1		Demolition of concrete members					
	C14.3.1.1	Full demolition of:					
		(i) Parapets	cubic metre (m³)	31,9	R	451,70	R 14 409,23
		(ii) Deck	cubic metre (m³)	105,3	R	451,70	R 47 564,01
		(iii) Beams	cubic metre (m³)	117	R	451,70	R 52 848,90
TOTAL CARRIED FORWARD TO SUMMARY							R 114 822,14

C20.1**TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP**

ITEM				DESCRIPTION	UNIT	QTY	RATE	AMT
C20.1.2				Special tests requested by the Engineer				
	C20.1.2.2			Employer's contribution to other special tests				
		(a)		Any special test requested by Engineer	prime cost (PC) sum	Prime	Cost	R 25 000,00
			(i)	Handling costs and profit in respect of item C20.1.2.2(a)	percentage (%)	R 25 000,00	15%	R 3 750,00
TOTAL CARRIED FORWARD TO SUMMARY								R 28 750,00

SUMMARY OF PRICING SCHEDULE

GENERAL

C1.2	GENERAL REQUIREMENTS AND PROVISIONS	R	151 102,00		
C1.3	CONTRACTOR'S SITE ESTABLISHMENT AND GENERAL OBLIGATIONS	R	231 000,00		
C1.4	FACILITIES FOR THE ENGINEER	R	18 600,00		
C1.5	ACCOMMODATION OF TRAFFIC	R	310 140,00	R	710 842,00

ASPHALT LAYERS

C9.1	ASPHALT LAYERS	R	164 780,00	R	164 780,00

REPAIR AND REHABILITATION OF STRUCTURES

C14.1	ACCESS FOR BRIDGE REHABILITATION	R	14 220,00		
C14.3	DEMOLITION AND REMOVAL OF STRUCTURAL CONCRETE AND STEELWORK	R	114 822,14	R	129 042,14

QUALITY ASSURANCE

C20.1	TESTING MATERIALS AND JUDGEMENT OF WORKMANSHIP	R	28 750,00	R	28 750,00

SUBTOTAL A

R	1 033 414,14

VALUE ADDED TAX:

15% of Subtotal	R	155 012,12

TOTAL CARRIED TO C.1.1.1 : FORM OF OFFER

R	1 188 426,26

ETHICS APPLICATION FORM

Please Note:

Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: <http://www.ebe.uct.ac.za/ebe/research/ethics1>

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Samuel Ndeutapo
Department		Civil Engineering
Preferred email address of applicant:		ndtsam002@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	MSc
	Credit Value of Research: e.g., 60/120/180/360 etc.	120
	Name of Supervisor (if supervised):	Professor Pilate Moyo
If this is a research contract, indicate the source of funding/sponsorship		
Project Title		<i>An economic evaluation on FRP for bridge construction in South African coastal areas</i>

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Samuel Ndeutapo		17/05/2021
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Pilate Moyo		17 May 2021

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).	Prof. Alphose Zingoni		18/06/2021
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.			