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Applying the DER Rating System for the Visual Assessment of Defects on Concrete Dams

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Abstract

NamWater is responsible for the management and maintenance of Namibia's main dams, amongst the many other infrastructure assets under their ownership. They have, as a result, devised asset management policies and practices with the aim of reaping the benefits of asset management. Additionally, they have aligned themselves with the current approaches to dam safety management in managing the dams. These current approaches do however not provide for a guided and standard approach when it comes to the visual assessment of surface defects on the dam elements. This may result in varying assessment outcomes from different individuals based on their differences in training and experience.

The DER rating system used for the rating of defects on road structures, as input into the STRUMAN BMS used by SANRAL and other entities, provides for a standard approach to visually assessing the defects on these road structures. A study by Gombele (2017:79) has also demonstrated the possibility of using the DER rating system for the assessment of defects on cooling towers in a power generation environment. Additionally, the rating of defects can also play a role in dam risk determination, as demonstrated in the CIRIA 1 Project RP568 risk assessment methodology (Morris, Hewlett and Elliott, 2000:15). In quest for a standard and guided approach for visually assessing surface defects on dam elements, this study applied the DER rating on selected elements of three NamWater dams. The approach was by initially identifying dam elements that are deemed equivalent to the bridge items in the TMH19: Part A. There are variations in the design and functions of the dam elements versus those of bridge elements and thus the relevance of the defects may also vary for the two structure types. Thus, the focus of this study was on using the DER rating system to only assess the surface defects on the dam elements. This may be useful for the initial phase of a condition assessment for dams whereby it can provide a quantifiable indication of durability issues.

While the study was able to demonstrate the possibility of using the DER rating system to assess defects such as cracks, spalling and erosion on the surfaces of dam elements, gaps where identified in its applicability. Only 33% of the bridge items in the TMH19: Part A were deemed relevant for the visual assessment of the dam items, coupled with the significant amount of U (unable to inspect) ratings given during the assessment. Furthermore, of the identified defects, a significant amount was given a low Relevancy rating (R) meaning that they are of a low relevance to the structural integrity of the dam structure. This may be due to the fact that the guiding tables used are originally for bridge items and thus not entirely suitable for dams. For the DER rating system to be applied extensively to dam items, defects that are specific to dam elements will therefore need to be incorporated into the guiding tables. Additionally, the weighting of the ratings for certain defects would need to be revised to specifically align with the consequence of the

defect on the dam item. This process may require the compilation of a database of historical defects, guided by expert engineering judgement, to provide for guiding tables that are specific to dams. Assessment of more dams that vary in age, type, and performance may also be required to get a more diversified outcome of the applicability of the DER rating system on dams.

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List of acronyms

ACI	American Concrete Institute
BMS	Bridge Management System
CIRIA	Construction Industry Research and Information Association
DEP	Pennsylvania Department of Environmental Protection
DER-U	Degree, Extent, Relevance – Urgency (Ratings given to defects based on DER system as guided by the TMH19)
DWA	South African Department of Water Affairs
GPS	Global Positioning System
KPI	Key Performance Indicator
KDSMS	Dam Safety Management System developed by Kwater in Korea
Kwater	Korea Water Resources Corporation
LHS	Left Hand Side
NamPort	Namibia Ports Authority
NamWater	Namibia Water Corporation Limited
RHS	Right Hand Side
SA	South Africa
SANCOLD	South African National Committee on Large Dams
SANRAL	The South African National Roads Agency SOC Ltd
SWOT	Strength-Weakness-Opportunity-Threats Analysis
TMH	Technical Methods for Highways
UK	The United Kingdom
WRM	Water Resource Management

1. Introduction

1.1. Background

The Namibia Water Corporation Limited (NamWater) is a state owned enterprise that was established by an act[1] of parliament in 1997. Its main function is to commercially supply water in bulk to industries, local authorities and the directorate of rural water supply of the Ministry of Agriculture, Water and Forestry, in Namibia. NamWater is thus entrusted with the provision, maintenance and the management of the infrastructure used for the supply of water. This infrastructure includes water retaining structures such as dams and reservoirs. Dams and reservoirs play a major role in the functioning of NamWater. The dams are used for the collection and storage of raw water prior to purification. Most of the major dams were constructed in the pre-independence era (between 1960 and 1990) and the concrete may be deteriorating due to aging. These dams are also located at vast distances from each other and their management thereby demands more of the organisation's human and financial resources. The implementation of asset management is thus of relevance for NamWater to effectively manage these dams.

A major component of infrastructure asset management is the inspection, monitoring and maintenance of the infrastructure. These processes are carried out to ensure positive returns on investments and to avert adversely affecting the level of service due to the deterioration of the infrastructure, as well as to ensure the safety and structural integrity of the structures. Visual inspection of civil infrastructure such as bridges is often associated with a rating system that enables the prioritisation of repairs and maintenance activities, in addition to the budget allocations for the identified repair and maintenance activities (Gombele, 2017:45). The DER (Degree, Extent and Relevance) rating system, which is used for the rating of defects on bridge structures as well as serving as input into the STRUMAN BMS (Bridge Management System) used for the management of bridges in South Africa, is one such example of a defects rating system.

The DER rating system has proven to be effective for bridges in South-Africa and is also being implemented by the Roads Authority of Namibia, who also uses the STRUMAN BMS. It has further been tested for the rating of defects on cooling tower foundations in a power generating environment and has been implemented for under-water structures of NamPort in Namibia (Gombele, 2017:79). This applicability of the DER rating system across the various structure types

[1] Namibia Water Corporation Act 12 of 1997: To establish the Namibia Water Corporation Limited; to regulate its powers, duties and functions; to provide for a more efficient use and control of water resources; and to provide for incidental matters.

that are made of similar material to that of concrete dams is an indication of the possibility of applying it for the visual assessment of surface defects on dams.

Rating systems such as the DER rating system are however not commonly used for the visual assessment of dam defects in dam safety management. If applicable, the DER rating system has the potential to serve as a guided and standard approach for the initial stage of the condition assessment process for dams, which should be followed by detailed investigations. The outcomes of the visual assessment of dam elements done using the DER rating system can potentially be used in prioritising further assessments, repair and maintenance activities across various dam structures, in light of limited human and financial resources. However, in its original form, The DER rating system is likely to have limitations in its applicability to dam elements due to the differences in functionality and varying failure mechanisms of dams and bridges. It thus remains to be seen how applicable the DER rating system can be for the rating of surface defects on dam structures.

1.2. Problem statement

Defects rating systems such as those used for the visual assessment of surface defects on bridge elements are not common for dams. The visual assessment of dam surface defects is generally based on their descriptive evaluation by the inspector without attaching any rating to it. The result is the absence of a systematic and guided approach for the visual assessment of dam surface defects. This may lead to visual assessment results varying from individual to individual (based on different educational backgrounds and/or experiences) across the various dams inspected, which can ultimately affect decision making regarding, for instance, the prioritisation of repair and rehabilitations.

1.3. Research Objectives

The main objective of this study is to assess the applicability of the DER rating system to NamWater's concrete dams as a potential standard guiding approach for visually assessing surface defects across various dams. This objective is broken down into the following sub-objectives:

- Review literature on asset management, dam structures, dam defects rating and dam safety concepts.
- Review of NamWater's asset management practice.
- Review of international approaches to dam safety management.
- Review of the dam safety management approaches currently used by NamWater.

- Apply the DER rating systems for the rating of surface defects on elements of concrete dams to assess its applicability, limitations and to identify potential areas of improvement.

1.4. Research Questions

The main research questions for this study emanating from the research objectives are as indicated below:

- What is the status-quo of NamWater's asset management in comparison to infrastructure asset management requirements?
- What are the international best practice approaches to dam safety management?
- What dam safety approaches are currently used by NamWater and how do they compare with the current international best practice approaches?
- How applicable is the DER rating system for rating of surface defects on concrete dam components?
- What are the potential improvements/modifications that can be made to the DER rating system to make it more suitable for use in visually assessing dam surface defects?

1.5. Conceptual Framework

The study intends to touch on various concepts that are related to the topics of asset management and the safety of structures, with particular focus on the DER rating system used for the rating of defects. The conceptual framework for this study is indicated in **Figure 1**. The grey boxes indicate the main concepts of the study and the interrelation between the concepts is shown by the blue arrows.

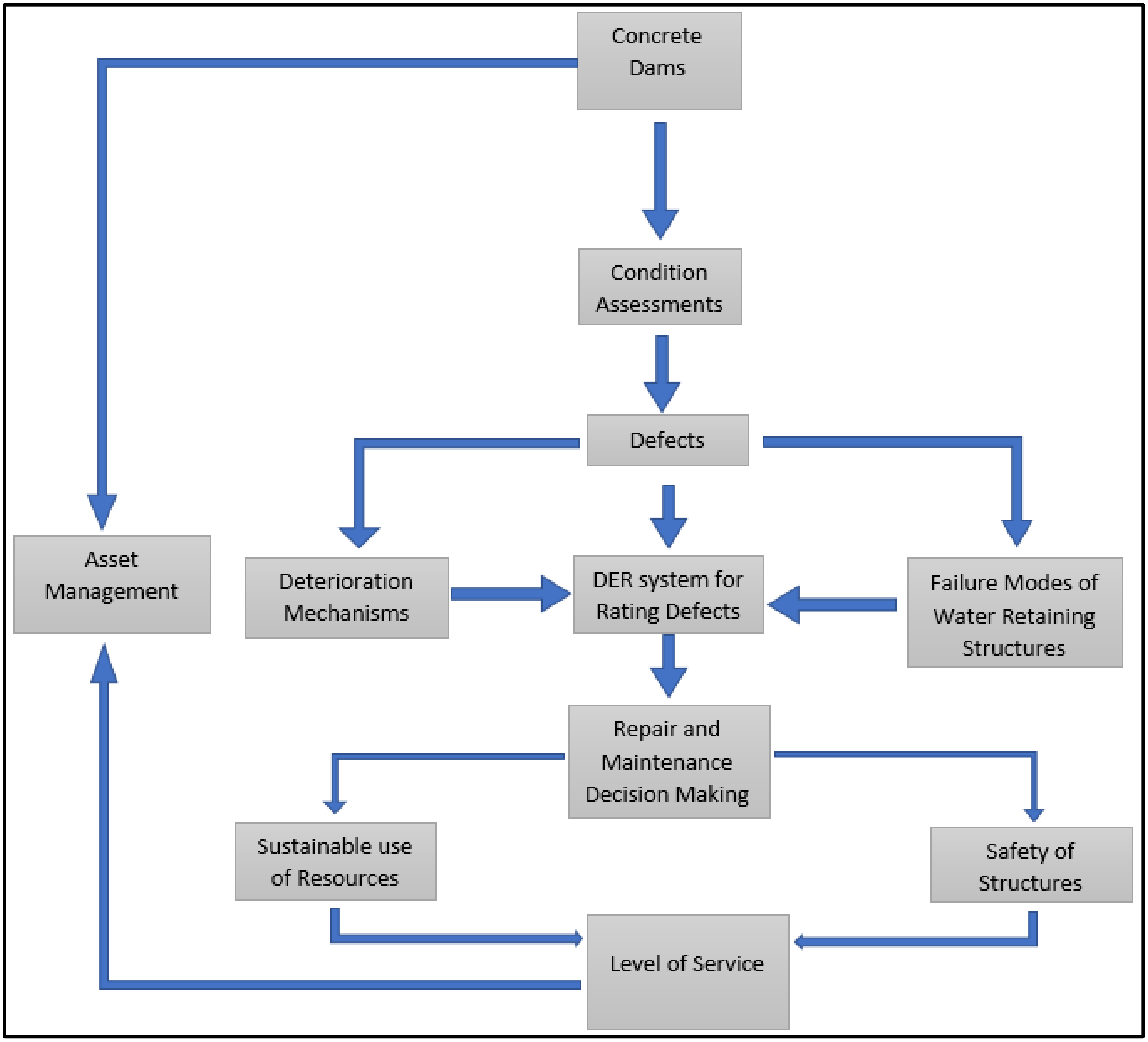


Figure 1: Research Conceptual Framework

2. Research methodology

The research methodology for the study was split into two main parts, namely the literature review and the part whereby the DER rating system is applied to the surface defects of dams. The methodology undertaken for these two parts is described in the following sub-sections.

2.1. Literature review

A part of this study looked into the literature on asset management and its relevance to organisations that manage important infrastructure such as NamWater. This part also reviewed the asset management processes implemented by NamWater and how these align with the general practice as stipulated in recognised asset management guidelines. The effective implementation of asset management practices will pave the way for implementation of rating systems such as the DER, which is the subject of this research, hence the importance of reviewing asset management literature. This section further reviewed literature on dams and dam safety, dam defects and visual inspection of concrete structures, the DER rating system, as well as the various approaches to dam safety management.

2.2. Application of the DER rating system to dam defects

This is the part of the study that focused on the actual application of the DER rating system on concrete dams to assess its applicability. Various steps had to be undertaken prior to the actual assessment of the dam surface defects using the DER rating system. The procedure carried out under this section is as follows:

2.2.1. Identify bridge items in the TMH19 equivalent to dam elements

Bridge items in the TMH19: Part A (Committee of Transport Officials, 2016a) deemed similar in material, construction, loading and surface defects to the dam items were identified. A side by side comparison was done between the equivalent dam item and the identified bridge items. The rating of defects on the bridges using the DER rating system is usually associated with the guiding tables under TMH19: Part B. Since these guiding tables are specifically for bridge items, there is likely to be limitations in their applicability to dam items due to variations in design, functionality and relevance of defects of the two structure types. The guiding tables in TMH19: Part B were thus reviewed under this section to see how reasonably they can be applied to the equivalent dam items.

2.2.2. Visual Inspection of dams

Visual Inspections were carried out on the Oanob, Hardap and Otjivero dams. The procedure followed was as follows:

1. Desktop study

This involved reviewing the existing drawings and reports for the dams to be inspected prior to going to site.

2. Visual assessments

The approach was to identify with the eye the surface defects on the identified equivalent dam components. Pictures were captured and crack widths measurements taken where possible. The following basic tools (**Figure 2**) where used for the condition assessment on site:

- Crack width ruler
- Camera
- Mobile phone camera
- Tape measure
- Hammer
- Hand-held GPS

Figure 2: Tools used for the Visual Condition Assessment

2.2.3. Apply the DER rating to the identified defects

An attempt was made to apply the DER rating system to the identified defects. This involved rating of the worst defect identified on each inspection item by following the process elaborated in the TMH19: Part A.

2.3. Research limitations

The focus of the study is on applying the DER rating for the visual assessment of surface defects on dam elements. The research limitations were as follows:

1. Even though there is need for the improvement of risk analysis methods in dam engineering (National Research Council, 1983:41), this study is by no means an attempt to replace current best practice approaches to dam safety management. It merely aims to assess the applicability of the DER rating system as a potential tool for visually assessing surface defects on dams.
2. Although other rating systems do exist for bridges worldwide (as indicated by Gombele (2017:26)), this study focused on the DER rating system since it is the one used in South-Africa (SANRAL) and Namibia (The Roads Authority of Namibia and NamPort). Additionally, the study by Gombele (2017:79) also found the DER rating system to be more suitable for use on structure types other than bridges because of its greater flexibility, simplicity of approach and clarity of the process compared to the other rating systems.
3. This approach does not disregard the fact that components of the dams and bridges may have different functions, failure modes and impacts due to failure. Consequently, there is likely to be limitations in the use of the guiding tables in the TMH19: Part B when applying these to dam elements. The idea was however to focus on the surface defects as an initial indicator of durability issues on concrete dams.
4. Whilst the focus is on concrete dam elements, non-concrete items whose deterioration or failure may pose risk to the structural integrity of the concrete elements were also considered merely for the purpose of assessing the applicability of the DER rating system on dams. This includes items such as erosion and scour protection works.
5. Assessment of the dam defects was limited to only 3 dams in Namibia under this study. The main limitations for choosing only 3 dams is the time for carrying out the study as well as the financial resources required, particularly the logistical costs. The three selected structures were however deemed sufficient for the purpose of this study. The selection of the three dams to be inspected was done so as to ensure that all three dams are of a different type for a more diverse application of the DER rating system
6. Restrictions in access to various parts of the dam structures due to the presence of water prevented the inspection of certain items. As a result, assessment of some of the defects often relied on the quality of the photos taken from a distance.

3. Literature review

Literature relating to the concepts indicated in the conceptual framework of **Figure 1** was reviewed under this chapter.

3.1. Concrete dams

Most of the dams under the management and maintenance of NamWater are made primarily of concrete or earth embankments and in some cases, a combination of both. This study is focused only on the dams with concrete structures or components. The concrete dams come in many different forms and the choice of dam structure is largely influenced by how it transfers the loads imposed on it, amongst other factors. **Figure 3** shows the common loads on a concrete dam section.

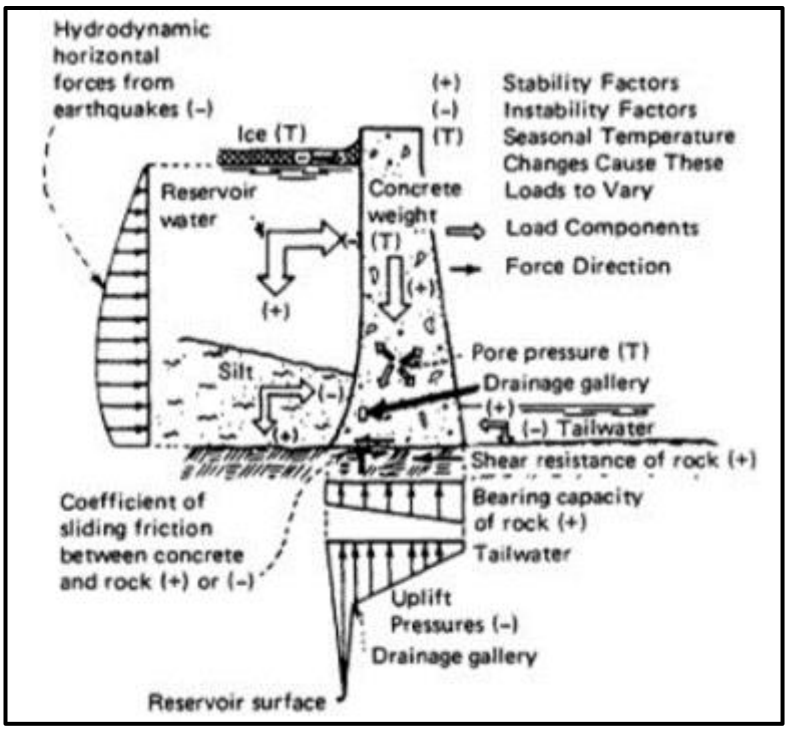


Figure 3: Typical loads on concrete dam (National Research Council, 1983:205)

Most of NamWater's concrete dams are gravity, arch and buttress dams, as well as a combination of the different types. A general description of the dam types most common in NamWater is presented in the following sections.

Gravity Dams

A gravity dam is a dam type that depends primarily on its weight to withstand the forces imposed on it and is commonly chosen because it is relatively simple to design and build (National Research Council, 1983:183). These types of dams are generally constructed of mass concrete cast in blocks and should primarily resist overturning and sliding. Overturning of the gravity dams is usually caused by the uplift forces on the dam structures, while sliding of the dam commonly results from the horizontal forces acting on the dam. A typical cross-section of a gravity dam is shown in **Figure 4**. The section in **Figure 4** is a non-overflow section. Gravity dams often contain both an overflow (spillway) and non-overflow section (Jansen, 1988:467).

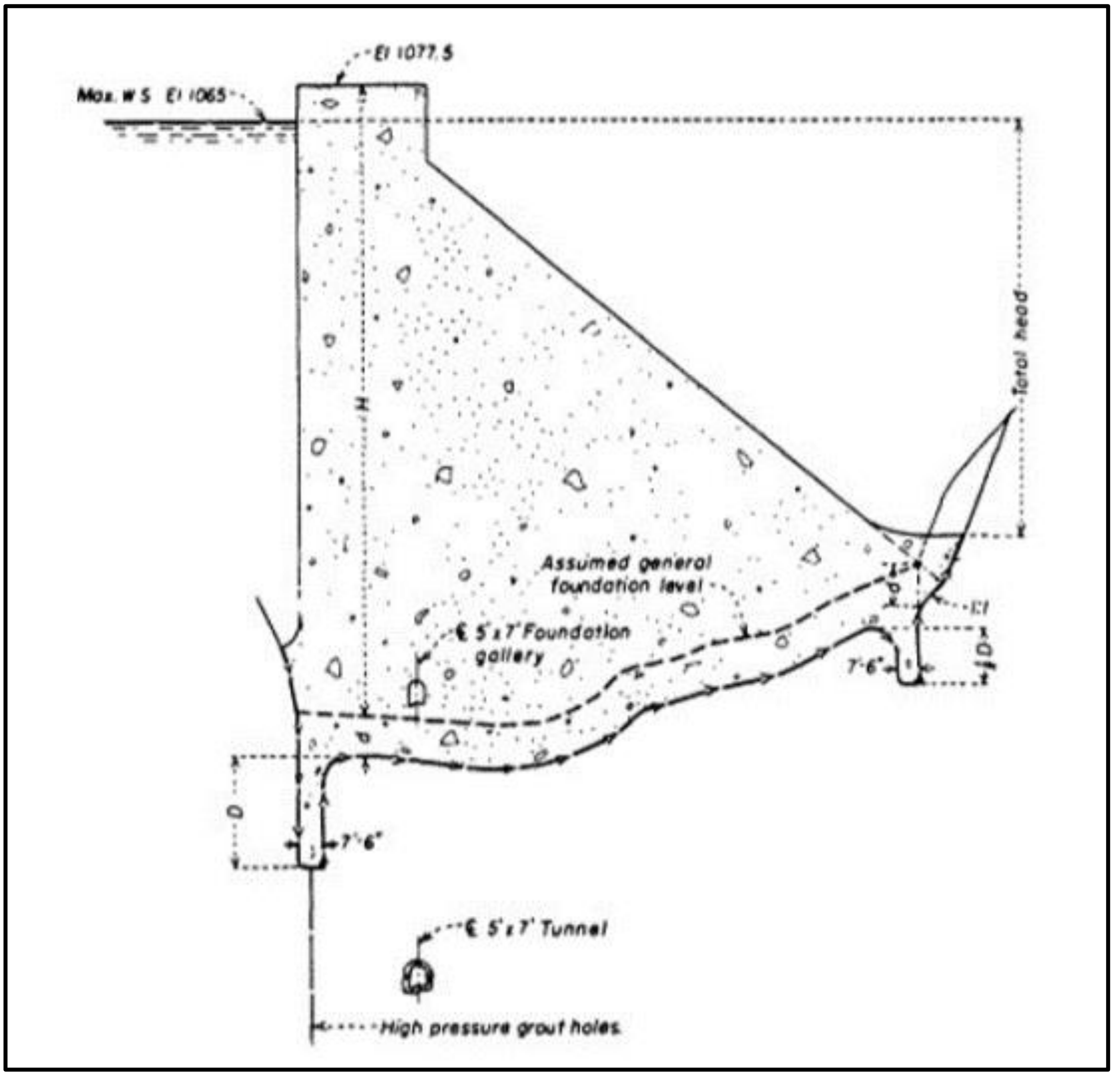


Figure 4: Gravity dam section (National Research Council, 1983:184)

Arch Dams

An arch dam is a concrete dam whose shape resembles that of a portion of a circle, is relatively slender compared to a gravity dams, and unlike a normal gravity dam, the foundations are designed to only carry the weight of the structure whilst the imposed forces are for the most part carried into the abutments (National Research Council, 1983:185). A typical arch dam is shown in **Figure 5**.

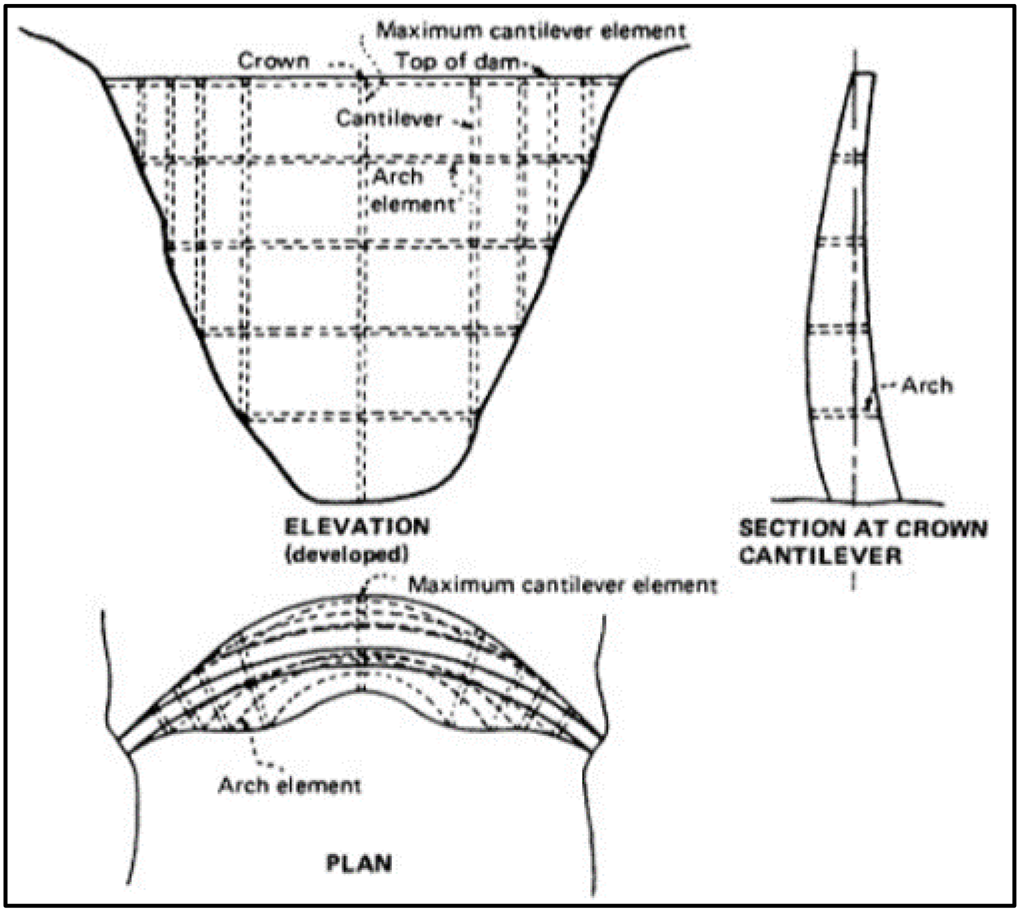


Figure 5: Arch dam (National Research Council, 1983:186)

Buttress Dams

The buttress dam consists of a sloping slab supported on vertical buttresses, with the distribution of the forces being the same as for the gravity dam (National Research Council, 1983:184). However, one important difference between the buttress dam and a traditional gravity dam is that, in addition to using its own weight, the buttress dam uses the weight of the water over the upstream face to provide stability (Jansen, 1988:466). However, excessive deterioration, pitting or spalling of the face slab on the buttress should be avoided as it can decrease its strength due to its slender nature (National Research Council, 1983:184). The typical cross-section of a buttress dam can be seen in **Figure 6**.

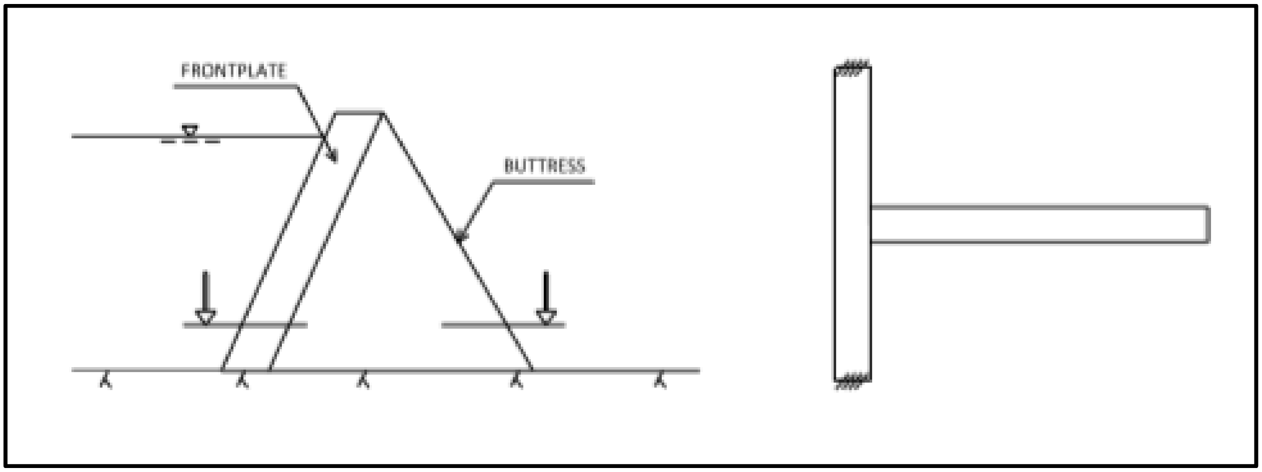


Figure 6: Buttress Dam (Broberg and Thorwid, 2015:7)

NamWater's main dams are depicted in **Table 1** and their locations shown in **Figure 7**. Notably, most of these dam structures where build as far back as the 1970s and are approaching their expected useful life. As can be seen from **Figure 7**, these dams are vastly spaced from each other and managing them effectively may be demanding on the human and/or financial capacity of an organisation.

Table 1: NamWater's main dams

Dam Name	Type of Embankment	Year Completed
Hardap Dam	Rock fill with a watertight upstream bituminous concrete blanket with concrete main spillway	1962
Oanob Dam	Concrete double curvature arch with a gravity section in each flank	1991
Naute Dam	Concrete gravity arch	1972
S. Von Bach Dam	Rock fill with upstream watertight bituminous concrete blanket	1971
Swakoppoort Dam	Concrete double curvature arch	1978
Omatako Dam	Earth embankment with clay core	1983
Otjivero Main Dam	Multi buttress gravity arch	1984
Friedenhau Dam	Concrete gravity Wall	1971
Dreihuk Dam	Vertical reinforced concrete curtain with rock fill embankment on one side	1975
Nauaspoort Dam	Earth fill with clay core	1975
Olushandja Dam	Earth fill with clay core	1975
Omdel Dam	Earth fill with clay core	1995
Neckertal Dam	Roller Compacted Concrete Gravity	Under construction since 2013

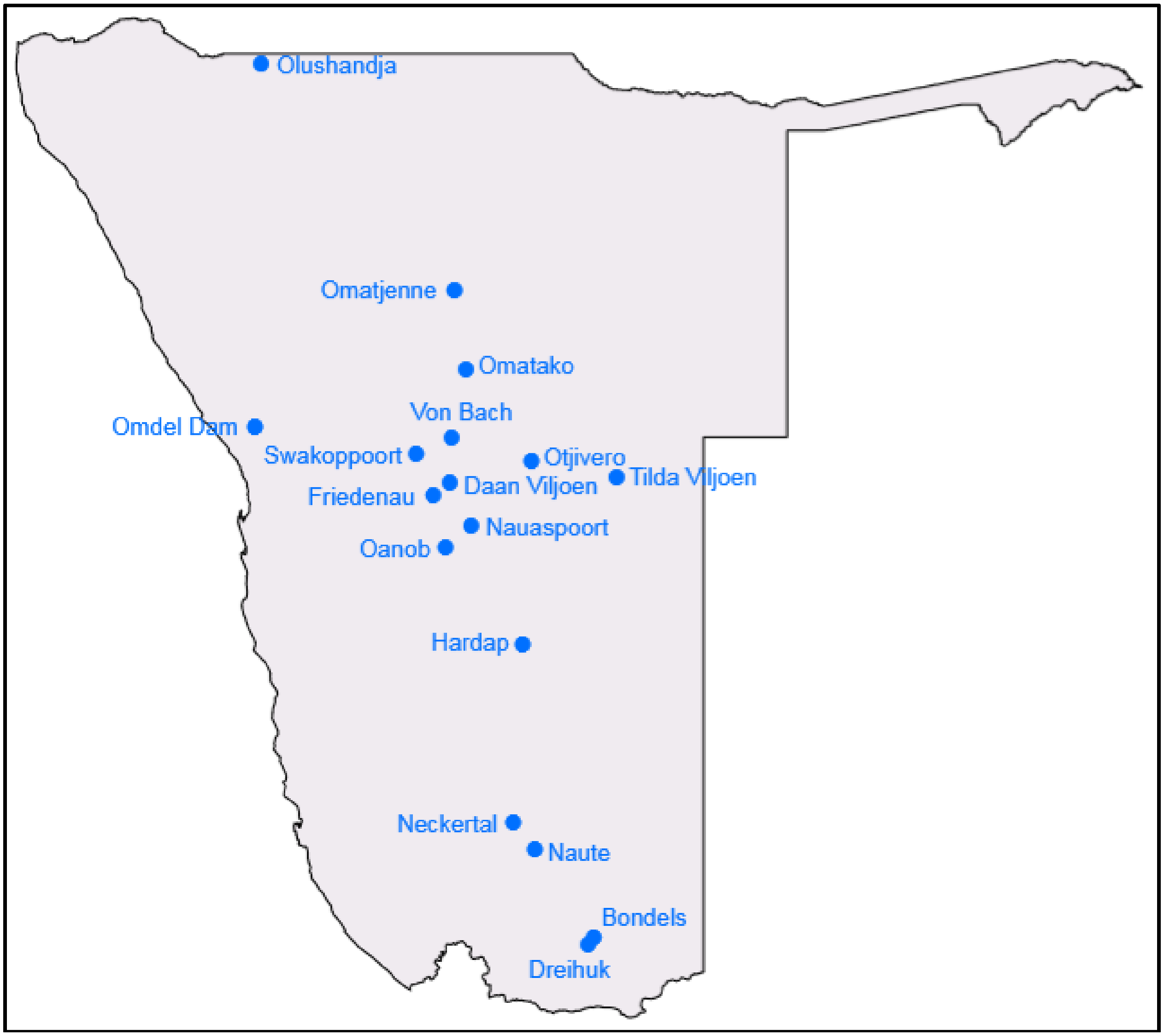


Figure 7: Locatility of Main Dams in Namibia

3.2. Defects on concrete dams

Despite the fact that concrete as a construction material has high durability characteristics (Bhuyan, 2001:651), concrete structures still undergo deterioration under various loading and environmental conditions. This often happens while the structure is still in use before the end of its lifespan. As a result, continual repair and maintenance of the structure is often the most feasible option to keep the structure in operation rather than constructing new structures. The concrete gravity dams under the management of NamWater are also subjected to defects typical for concrete elements and repair and maintenance is often required. However, according to Ramesh (2017:1), it is foremost essential to accurately determine the underlying cause of deterioration or damage, the extent of deterioration, as well as the deterioration mechanisms, in order to successfully repair concrete structures. Wrongful diagnosis of concrete defects may lead to applying wrong repair and maintenance techniques and strategies. The ultimate implication will be the inappropriate allocation of an organisation's limited resources whilst the problem is not solved. It is thus important to carry out a detailed investigation on the concrete defects identified on deteriorating structures to avoid wasting resources and to ensure the safety of the structures.

Deterioration of concrete structures results from changes in the physical, chemical and/or mechanical properties of concrete (Courard, Treviño and Bissonnette, 2011:17). According to Nixon (2013:61), deterioration mechanisms may be classified as chemical, physical and thermal. The defects due to these deterioration mechanisms are discussed as follows:

3.2.1. Defects due to chemical deterioration mechanisms

Generally, chemical deterioration of concrete results from chemical reactions between chemical substances that ingress the concrete from the environment and chemical components within the concrete. This ultimately causes distortion of the chemical properties of the concrete, resulting in the disintegration of the components of the concrete. Chemical deterioration mechanisms may result from acid attacks, sulfate attacks, microbial attack, Alkili-Silica Reaction (ASR) as well as chloride induced deterioration. The most common chemical deterioration noticed on NamWater's dams is the Alkali-Silica Reaction (ASR) which, according the compiled dam safety evaluation reports, can be seen on the Oanob, Naute and Von Bach dam as symbolized by the crack patterns on these dam walls. The ASR cracks may be an indication of a possible reduction in stresses within the dam concrete structure and where reinforcement is provided; the cracks may provide passage for corrosive agents to the embedded steel. Calcite stains/lime leaching is also common on most of NamWater's dams, particularly on the horizontal lift joints and through cracks where water seeps through the openings from the upstream. The porosity of cement based materials such as concrete may be increased by the leaching of calcium ions which may ultimately result in durability issues on concrete structures such as dams (Cheng, Chao and Lin, 2013:1851).

3.2.2. Defects due to physical deterioration mechanisms

These deterioration mechanisms are as a result of physical attack by physical external objects, resulting in the distortion of the physical properties of the concrete. The may be due to abrasion, erosion and freeze-thaw damage. Most common physical deterioration on NamWater's dams is the erosion of concrete. Erosion of the concrete is defined as a special form of abrasion caused by the abrasive actions of fluids, suspended solids and wind borne sand particles (Ballim, Alexander and Beushausen, 2009:207). This is particularly common on the spillways and apron slabs of the dams. Dislodging of concrete aggregates on the surface may be caused by this action which can reduce the cover concrete depth, resulting in inadequate protection for the embedded steel. The erosion of the concrete may also result in cross-section loss, reduced weight and the reduction of allowable stresses on the concrete dam elements.

3.2.3. Defects due to thermal deterioration

Thermal deterioration is caused by the effect of temperature changes within the concrete and results into the formation of cracks. As the temperature of the concrete rises and falls, the concrete expands and contracts accordingly, which results in cracks (Nixon, 2013:63). These evolution of thermal cracks may also be influenced by the gradual non-linear distribution of the temperature profile due to the development of heat of hydration of cement at the early ages of mass concrete such as that used in concrete gravity dams (Embaby, Abdelrahman and Sayed-Ahmed, 2014:467). The use of expansion joints helps control the cracking due to thermal changes in the concrete. Cracks due to thermal expansion are common on NamWater's dams, especially those with inadequate expansion joints.

3.2.4. Shrinkage Cracks

NamWater's concrete dams are also associated with shrinkage cracks. Shrinkage is the reduction in volume of newly casted concrete as it loses moisture from its capillary and pore micro-structure due to exposure to drying conditions during the setting and hardening stages (Muazu, Wei and Wang, 2016:1026). Restraint to this shrinkage of the concrete induces tensile stresses which results in cracks when the tensile strength of the concrete is exceeded (Muazu, Wei and Wang, 2016:1026). These cracks are known as shrinkage cracks.

Whilst common on most NamWater dams, according to National Research Council (1983:19), most cracks caused by shrinkage and temperature during the early period after construction are not a threat to the dam's stability as they do not penetrate deeply enough into the concrete. The monolithic behaviour of the dam may however be affected by cracking at greater depths which can result in higher stress concentrations, as well as allowing water pressure freer access to the interior of the dam, resulting in higher pore pressures (National Research Council, 1983:19). This may ultimately affect the dam stability. Also, albeit not being common amongst the dams in Namibia and classified as being part of physical deterioration, the freeze thaw damage to concrete is accelerated by the presence of cracks (National Research Council, 1983:19).

Despite the focus of this study being on investigating the applicability of the DER rating system for the visual inspection of surface defects on dams, the relevance of the defects on the structure may vary for a bridge versus on a dam. For instance, since the main bridge components are made of reinforced concrete, ingression of corrosive agents may have an effect on the corrosion of the embedded steel. However, this may not necessarily be the case for gravity dams which are less likely to have reinforcement embedded in the main dam wall as they are primarily made of mass concrete. Furthermore, there is a significant amount of defects on dams that, while they may be of low relevance to bridges, have a great effect on the functionality and structural integrity of the dams. For instance, defects such as the inoperability of gates on dams, leakages, reservoir slides, and siltation will significantly affect the functionality and stability of dams. The defects identifiable with concrete dam structures, as well as their causes and the effects they can have on the structures, are summarized in **Table 2** and **Table 3**, as derived from National Research Council (1983:190). These defects can be identified by carrying out a visual inspection of the structures, usually as the initial stage of any investigation of the structural condition of the structure. Other diagnostic methods are often used to supplement and/or substantiate the results of the visual inspections in determining the deterioration mechanism that caused the defect (Ramesh, 2017:1).

Table 2: Common defects on concrete dams (National Research Council, 1983:190)

No.:	Indicator/defect	Possible Causes	Possible Effects
1	On Concrete (General) (Shallow Cracking, Crazing and Spalling)	Freeze-thaw cycling, Reactivity, Sulfate Attack, Leaching, Aging	Accelerated deterioration, Reduction of allowable stresses, Reduction of effective section, Increased stresses, loss of weight, Increased leakage
2	On Concrete (Local) (Spalling and cracking)	Stress concentrations, Freeze-thaw action, Differential movement	Progressive deterioration, Increase leakage, Loss of section, Stress concentrations
3	On Concrete Deep cracking	Excessive loading, Overstress, Uplift, Shrinkage (usually occurs early in life), Expansion, Foundation Movement, Seismic activity, Loss of strength, Concrete creep	Increased leakage, Accelerated deterioration, Progressive cracking, Stress redistribution, Increased stresses, Reduced stability, Differential movement
4	Leakage (moist or wet surfaces on concrete)	Cracks, Deteriorated Concrete, Porous Concrete	Increased rate of deterioration, Leaching, Loss of Weight, Loss of Strength, Increased leakage
5	Leakage (Concentrated through concrete)	Cracks, Differential movement, Open joints, High uplift, Leaking pipes and conduits, Plugged drains, Erosion or cavitation of concrete, Leaching	Loss of concrete matrix, Loss of Structural Integrity, Increased uplift
6	Leakage (through concrete (notice-able change))	Self-sealing of cracks, Plugged drains, Broken drains, Differential movement, Concrete failure	Increased uplift, Loss of concrete, Stress redistribution
7	Leakage (Foundations and abutments)	Foundation deterioration, Inadequate drains, Opening of joints, seams, shears, etc., Movement	Foundation weakening with potential failure, Piping through foundation, Increased uplift, Loss of stability, Differential movement of dam, Loss of revenue/water, Loss of storage
8	Movement	Foundation settlement or heave, Abutment movement, Seismic activity, Overtopping, Excessive loading or uplift, Concrete expansion due to chemical action	Increased leakage, Inoperable appurtenances, Severe cracking, Stress redistribution, Reduction in stability, Anomalous changes in section or plan

Table 3: Common defects on concrete dams (continued) (National Research Council, 1983:190)

No.:	Indicator/defect	Possible Causes	Possible Effects
9	Development of offsets	Foundation movement, Differential movement, Seismic activity, Unforeseen loads	Increased cracking and spalling, Increased leaks, Binding of gates and operators
10	Erosion and loss of foundation at toe or at outlets and spillway	Inadequate channel capacity, Channelization of water (spills or stream flow), Lack of protection, Overtopping, Poor energy dissipation, Poor foundation, Piping or leakage, Poor drainage, Normal weathering	Undermining, Loss of Stability, Complete failure of appurtenances
11	Inoperability of gates and valves	Failed Parts, Corrosion, Build-up of mineral deposits, Blockages, Debris, Silt deposits, Ice, Differential movements	Inability to operate, Reduced capacity of spillways/outlets, Increased probability of overtopping
12	Reservoir Slides	Unstable geology, Saturation, High runoff, Sloughing	Sudden high waves with resultant overtopping, Siltation, Blockage of outlets and spillways, Increased loading, reduction of reservoir capacity
13	Siltation	Geology, Normal or abnormal inflow, Cultivation upstream, Vegetation removal	Increased loads, Reduced stability, Plugging of outlets, Reduction of reservoir capacity
14	Debris	Floods, Logging, Vegetation	Plugging of Spillways, Plugging of outlets, Damage to trash racks and equipment
15	High waves	Wind Reservoir slides	Overtopping, damage to equipment, Undermining of banks
16	Ice	Cold weather	Accelerated deterioration, Blockage of spillways and outlets, Damage to piping and equipment, Misoperation of gates, Damage to trash racks, Parapet damage, Increased loading

3.3. General procedure for the visual assessment of concrete defects on dams

According to Bukenya et al. (2014:235), the structural integrity of dam structures is traditionally determined by visual inspections carried out by experienced engineers who then make recommendations on the most suitable rehabilitation methods. The general process for the visual assessment of concrete defects, particularly in the initial stages, involves carrying out site inspections of the concrete elements with the eye and very simple tools. The visual inspections should identify changes and/or damages and defects on the structural elements such that a pre-liminary judgement of the impact of identified defects on structural integrity and service life of the structure can be determined (Nordström et al., 2019:1683). For dams with concrete elements, the same general approach of inspecting concrete structures should apply. This traditional method of determining the structural integrity of dam structures may however have shortcomings on the surveillance or inspection of critical parts of the infrastructure (Bukenya et al., 2014:235). Safety monitoring instruments are thus useful for identifying hidden defects, as well as providing warning signals against imminent disaster, particularly when linked to some form of network. Institutions like the Kwater in Korea have as a result implemented a dam safety management system (the KDSMS) that incorporates dam performance monitoring through instrumentations and monitoring system (Jeon et al., 2009:560).

A general procedure for the visual inspections is shown in **Figure 8** (as deduced from Nordström et al. (2019:1683)).

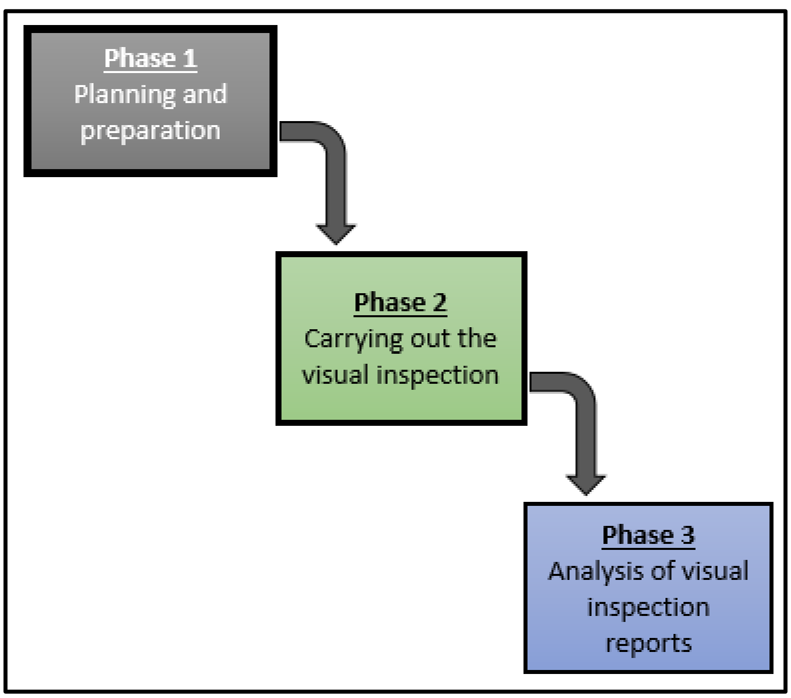


Figure 8: General procedure for visual assessment of concrete structures

The idea behind phase 1 of this procedure is to ensure the inspector is familiar with the structure's design and its previous condition prior to carrying out the inspections. This involves studying of existing drawings and previous reports by the inspector. An inspection form/checklist should then be prepared for the collection of information during the visual inspection on site. The ACI201.1R-08 (American Concrete Institute, 2008:201.1R-14) provides a checklist (see Appendix A) which can be used when collecting the above information for all concrete structures in general.

Phase 2 involves the inspector visiting the site and visually identifying as much as is possible the various defects on the structure. The techniques and equipment to be used may be governed by the type of dam being inspected and accessibility to various components. The capturing of photographs is a very important part of any visual inspection and this should be of high quality to give a good documentation of the defects (Nordström et al., 2019:1684). Modern day technologies such as drones can be used to capture photos of areas that are difficult to access. The checklist in the ACI201.1R-08 (Appendix A) also makes provision for the recording of defects in a manner similar to the TMH19 bridge inspection forms, albeit the fact that theTMH19 forms are specific for bridges. The major difference however is that the TMH19 forms makes provision for the rating of bridge defects using the DER rating system whereas the checklist in ACI201.1R-08, while making provision for both quantitative and qualitative recording of defects (i.e., crack width, location, pattern etc.), it does not make provision for any defects rating. During the visual inspection, special equipment and ladders are often needed (Ellsworth and Ginnado, 1991:44). Common tools used during the visual inspection of concrete structures are indicated in **Table 4**, as stated by (Ellsworth and Ginnado, 1991:46). The items in **Table 4** are more or less the same as those indicated in the TMH19 Manual for the visual assessment of road structures (**Table 5**). These inspection tools can also be used during the visual inspection on concrete dams.

Table 4: Inspection tools (Ellsworth and Ginnado, 1991:46)

Standard Tools	Special Equipment
100-foot measuring tape and folding rule	Ladder
Inspection mirror with a swivel head	"cherry picker"
Callipers	
Plumb bob	
Straight edge	
feeler gauges	
Binoculars	
Camera and film	
Screwdriver	
Heavy duty pliers	
Flashlight	
Pocket knife	
Wire brush	
Magnifying glass	
Crack comparator	
Level	
Clipboard	
Chalk	

Table 5: Inspection equipment and material (Committee of Transport Officials, 2016a:7-6)

Equipment/Material
Clipboard, pencil and eraser
Notebook
As-built drawings (if available)
Torch
Binoculars
Digital camera (GPS enabled)
Handheld GPS device (minimum of 5m accuracy; WGS84 format)
Access equipment, e.g. 6 m ladder
Gumboots (for culvert inspections)
Laser distance meter
Crack width gauge
Tape measure
Measuring wheel
High-visibility vest
Non-skid shoes/boots
Amber flashing light

The reports of the visual inspection are to be compiled by the inspector. The third phase of the procedure involve identifying the various elements that may either require immediate remedial action or further in depth investigations. In-depth investigations may take the form of sampling of existing concrete and testing in laboratory, assessment of defects using special equipment such as radar or the installation of specialised monitoring equipment. In many instances, human and financial resources are limited and as result decisions have to be made as to which dams to prioritise for either further investigations or remedial works. Using a system like the DER rating system will significantly help in this decision-making process.

3.4. Asset management in general

3.4.1. Principles

An asset intensive organisation like NamWater may need to implement asset management practices to effectively manage their vast and diverse asset portfolio. Additionally, the DER rating system, which is the focal point of this study, is highly based on an asset management approach to bridge management. It is therefore an important component of this study to review key asset management concepts. A general overview of asset management concepts is given under this sub-section.

Many publications define asset management in many synonymous ways. According to the international infrastructure management manual (IIMM) (IPWEA and NAMS, 2006:xiii), asset management is the cost effective life cycle management of assets through which an organisation’s activities and practices are coordinated in a systematic way to enable the optimal and sustainable deliverance of the organisations objectives. It is also defined as an organisation’s coordinated activity to realize value from its assets (International Organization for Standardization, 2014:14). A more extensive definition of asset management, which is similar to that of the IIMM, is that it is “systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organisational strategic plan“ (The Institute of Asset Management, 2008:v). To effectively manage infrastructure assets, a significant amount of information and data about the asset is required. This is substantiated by Halfawy, Newton and Vanier (2006:222), who define asset management as being essentially “a set of data-intensive decision making processes.” Furthermore, Park, Park and Lee (2016:711) define asset management as the rational decision making process intended to satisfy the level of service demanded on assets (i.e., roads, railroads, harbours, dams, airports, and other infrastructures) while simultaneously minimizing costs and maximizing effects of the asset on level of service. Even though only physical assets are given as an example in this definition, asset management is also applicable to other assets. Hence, asset management standards like the ISO 5000 are also applicable to all other asset types. The different asset classes are shown in **Figure 9**. Physical assets belong to the group of tangible assets and can be either movable or immovable.

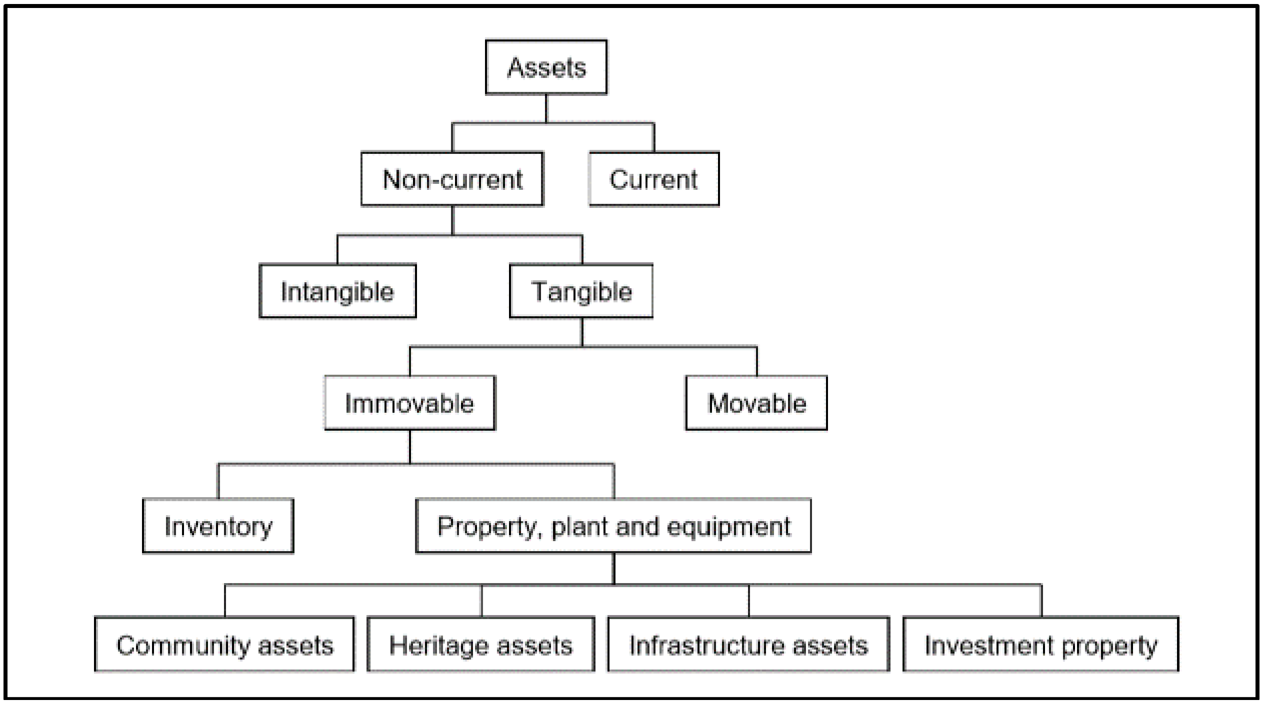


Figure 9: Classification of Assets (Von Holdt, 2006:20)

Even though there are other various categories of assets within NamWater, such as human assets, financial assets and assets that are intangible, this study is only concerned with physical engineering infrastructure asset management. It is thus imperative to narrow down the definition of asset management to the context of engineering Infrastructure asset management. Infrastructure assets are defined as the stationary systems forming a network and serving whole communities, whereby it is intended to maintain the system indefinitely at a particular level of service potential by continually replacing and refurbishing its components (IPWEA and NAMS, 2006:xiv). According to the Australian Asset Management Collaborative Group (AAMCoG) as quoted by Mahmood et al. (2014:287), engineering asset management (EAM) is "the process of organising, planning, and controlling the acquisition, care, refurbishment, and disposal of infrastructure and engineering assets."

It is however important that asset management be implemented in line with the strategic plan of the organisation. A strategic plan, in business terms, is a document that an organisation uses to communicate its organisational goals and the actions required to achieve these goals, as well as all other critical elements developed during the strategic planning process (Maleka, 2014:15). Aligning asset management with the organisational strategic plan requires the compilation of the asset management policy which is deduced from the organisation strategic plan. The asset management policy outlines the requirements of managing the assets within the organisation, as well as outlining the guiding principles. After the compilation of an asset management policy, there should be some form of approach as to how the asset management principles and requirements are to be instilled. This is where an asset management strategy and the asset management objectives come into play. An asset management strategy may be defined as the long term approach that an organisation takes in relation to the management of its assets. The asset management objectives are compiled in parallel to the asset management strategy and they are measureable and specific outcomes of an organisation's asset management. In essence, asset management objectives are a requirement for the successful implementation of the asset management strategy and policy. It now leaves a question of what actions needs to be taken to ensure the implementation of asset management. This is where an asset management plan comes into play. An asset management plan is defined as the document that contains the specific activities, resources, responsibilities and timescales required for successfully implementing the asset management strategy in order to meet the asset management objectives (The Institute of Asset Management, 2008:2). The asset management plan (AMP) should cater for the long term infrastructure needs of the organisation as well as identifying areas of infrastructure improvement, maintenance and regulatory requirements (Stinson, 2014:12).

The asset management policy, strategy, objectives and plans discussed in sub-section 3.4.1 collectively constitute an asset management system. An asset management system is often perceived to be computer software that an organisation uses to manage its assets. While the terms asset management software and asset management systems are often used interchangeably, asset management software is merely a tool used for the management of assets. A comprehensive definition of an asset management system is given by the PAS 55-1:2008 (The Institute of Asset Management, 2008:2) as:

"The organisation's **asset management policy**, **asset management strategy**, **asset management objectives**, **asset management plan(s)** and the activities, processes and organisational structures necessary for their development, implementation and continual improvement."

An asset management system's definition and how it is related to the other asset management terms is schematically illustrated in **Figure 10**. **Figure 11** shows the interrelationship between the asset management components within the asset management framework.

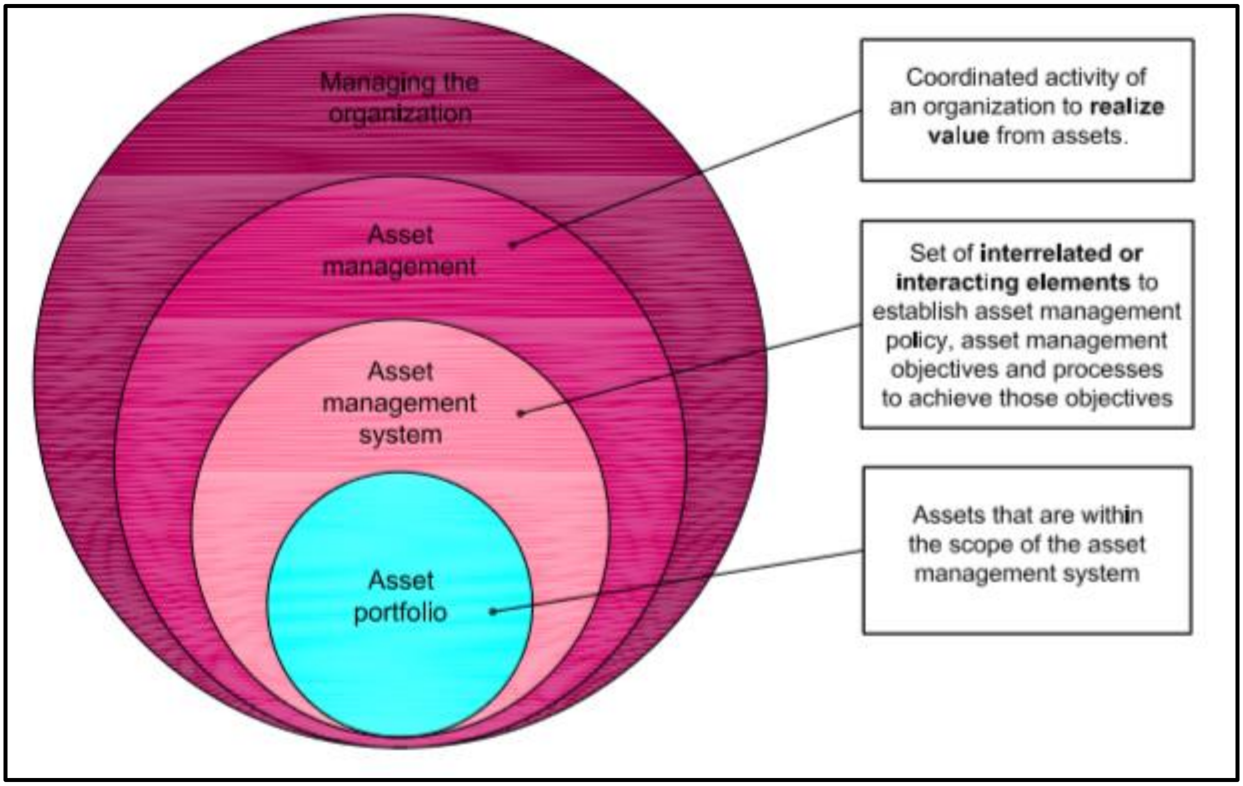


Figure 10: Relationship between key asset management terms (International Organization for Standardization, 2014:4)

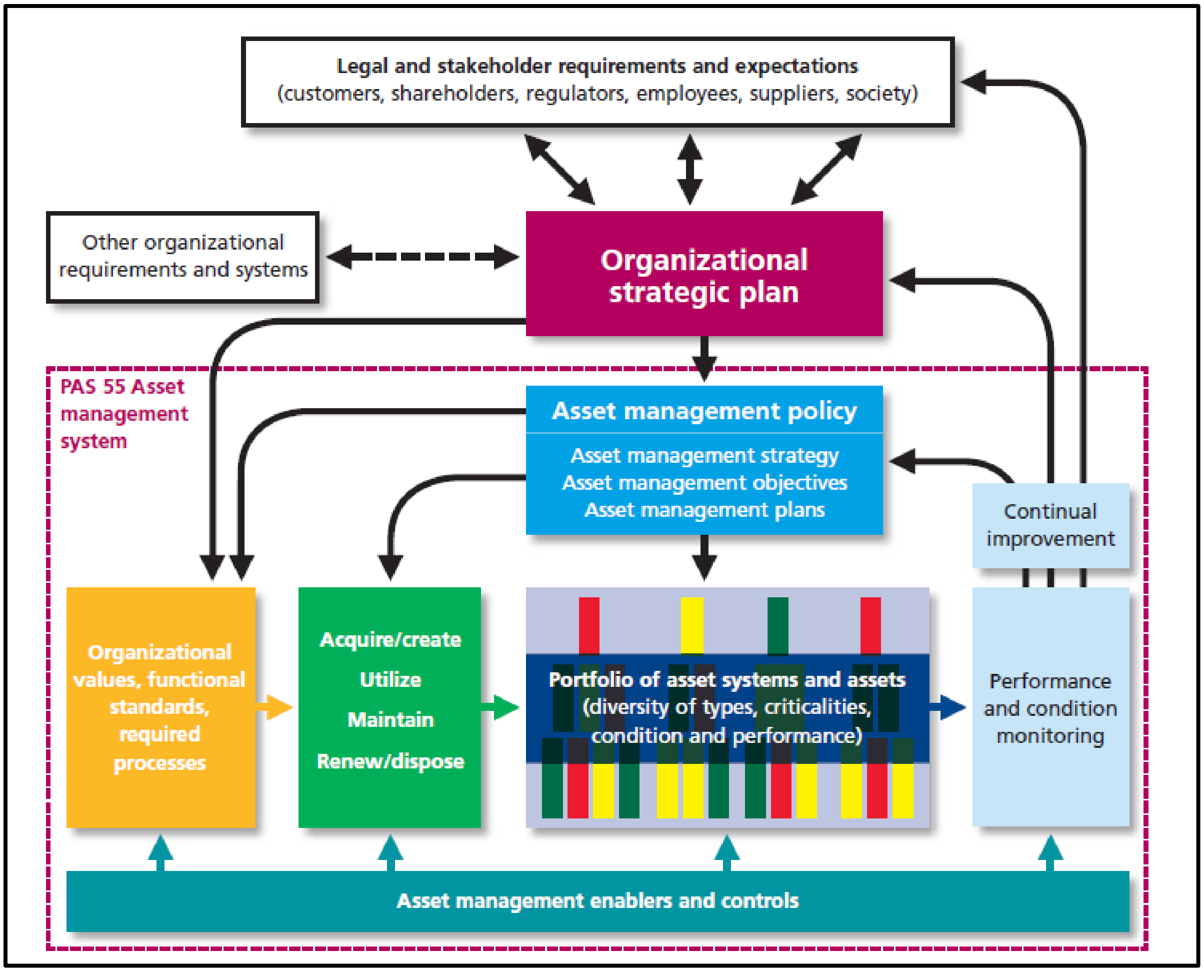


Figure 11: Interrelationship between Asset Management System Components (The Institute of Asset Management, 2008:viii)

3.5. Background to NamWater's asset management

A review of the asset management framework implemented by NamWater is done under this section. This includes a comparison of this framework with the general asset management practices as discussed in the previous sub-section. NamWater has over the last couple of years given considerable attention to the concept of asset management. Since 2012, projects have been undertaken by NamWater to establish the required asset management documentation in order to ensure the implementation of the practice of asset management. It is commendable that key documents that comprise the asset management system, as per the definition in PAS 55-1:2008 have now been established by NamWater. These key documents are reviewed in the following sub-sections:

3.5.1. The asset management policy

NamWater's asset management policy was established and approved in 2012. It is stated that the purpose of NamWater's asset management policy is to define the corporation's vision and intent regarding all aspects of asset management. NamWater's asset management policy is derived from the NamWater strategic corporate framework as per the guidelines of the PAS 55-1:2008. The focal aspects of NamWater's Asset Management Policy regarding the physical assets comprises the asset provision, asset operation, asset care and the external factors that may affect the performance of the physical assets. The overall asset management framework of NamWater is based on 17 key performance areas (KPAs) aligned with the PAS55-1:2008 elements. These KPAs are adopted as the framework for the asset management policy and strategy. The KPAs are shown in **Table 6**, including their corresponding PAS 55-1:2008 elements. The asset management policy refers to these KPAs as the asset management policy elements and gives descriptions of each, as well as the target maturity level and the expected benefits of each of these elements on the organisation's asset management. Being the document that defines the "what" of asset management, NamWater's asset management policy is intended to remain unchanged over time. The desired end state for NamWater's asset management is described by the asset management policy and this asset management policy is seen as a significant contributor to the organisation's strategic objectives and the stakeholders' expectations.

Table 6: The 17 KPIs (NamWater, 2012:4)

PAS 55 element	Asset Management KPAs
AM policy and strategy, with management reviews	a. Strategy Management
AM enablers and controls	b. Information Management c. Technical Information d. Organisation and Development e. Contractor Management f. Financial Management g. Risk Management h. Environment. Health and Safety
Implementation of AM plans	i. Asset Care Plans j. Work Planning and Control k. Operator Asset Care l. Material Management m. Support Facilities and Tools n. Life Cycle Management o. Project and Shutdown Management
Performance Assessment and Improvement	p. Performance Measurement q. Focused Improvement

3.5.2. The Asset management strategy

An asset management maturity assessment was carried out and used in compiling the asset management strategy for NamWater. The focal areas for NamWater's asset management strategy are based on the same 17 KPAs that are identified as the main elements of the asset management policy (**Table 6**). These KPAs are however split into three priority areas namely, the high priority KPAs, medium priority KPAs and the low priority areas. The high priority KPAs where to be implemented during the first 12 months of establishing the asset management strategy, while the implementation of the medium priority areas would be effected in the subsequent 12 months. It was required to rather just maintain the maturity level of the low priority KPAs as they did not require a change in maturity for the first 12 months of establishing the asset management strategy.

The asset management strategy developed for NamWater looks at each of these 17 KPAs/identified elements in the strategy, by identifying the gaps on the best practice items of each element and then allocating the corresponding improvement initiatives. Timescales and the responsible parties are also assigned to these improvement initiatives, as is the requirement of any asset management strategy. The AM strategy also indicates the expected benefits of each element to NamWater's asset management, as well as its implementation risks. Unlike the asset management policy which is unchanged over time, the asset management strategy ought to be updated periodically in order to indicate the maturity progression with respect to the NamWater asset management policy.

3.5.3. Asset management objectives

As per the conclusions in the asset management policy of NamWater, one of the subsequent steps after compiling the policy is to quantify the asset management objectives in terms of the asset management KPIs, with targets. This is in line with the definition of asset management objectives, which indicates that the objectives must be specific and quantifiable (The Institute of Asset Management, 2008:2). However, by looking at NamWater's asset management strategy, the improvement initiatives proposed for each best practice of each element are quite reminiscent of what an objective would be for each identified item. As a result, the asset management objectives seem to be in the asset management strategy and not stipulated in their own document. It may however not be exactly wrong to include the asset management objectives in the asset management strategy document since they both fall under one element of the asset management system, as indicated in **Figure 11**.

3.5.4. Asset management plans

There is an asset management master plan derived from the asset management strategy of NamWater. This asset management master plan is derived for only a one-year horizon, unlike the strategy, which is a long term approach to asset management. The one-year horizon implies that the AM master plan needs to be reviewed and updated annually. NamWater's asset management strategy identifies asset care plans as one of the 17 KPAs. Asset care plans comprises maintenance strategies such as the usage based and the condition based maintenance (Carstens and Vlok, 2013:59). This may be described as detailed asset specific activities that focus on the maintenance of that specific asset. According to NamWater's asset management policy, regarding asset care plans, the maintenance of the asset will either be tactical or non-tactical based, whereby tactical maintenance is based on or driven by the maintenance plan. This approach is pro-active and can assist in averting disasters before they occur, particularly where there is no redundancy. Alternatively, non-tactical maintenance, is based on the equipment's performance, whereby response is usually reactive or due to a breakdown. The different maintenance tactics specified in the asset management policy of NamWater regarding asset care plans are shown in **Figure 12**. As can be seen from **Figure 12**, tactical maintenance takes control of the equipment being maintained whereas for non-tactical maintenance, it all depends on the equipment.

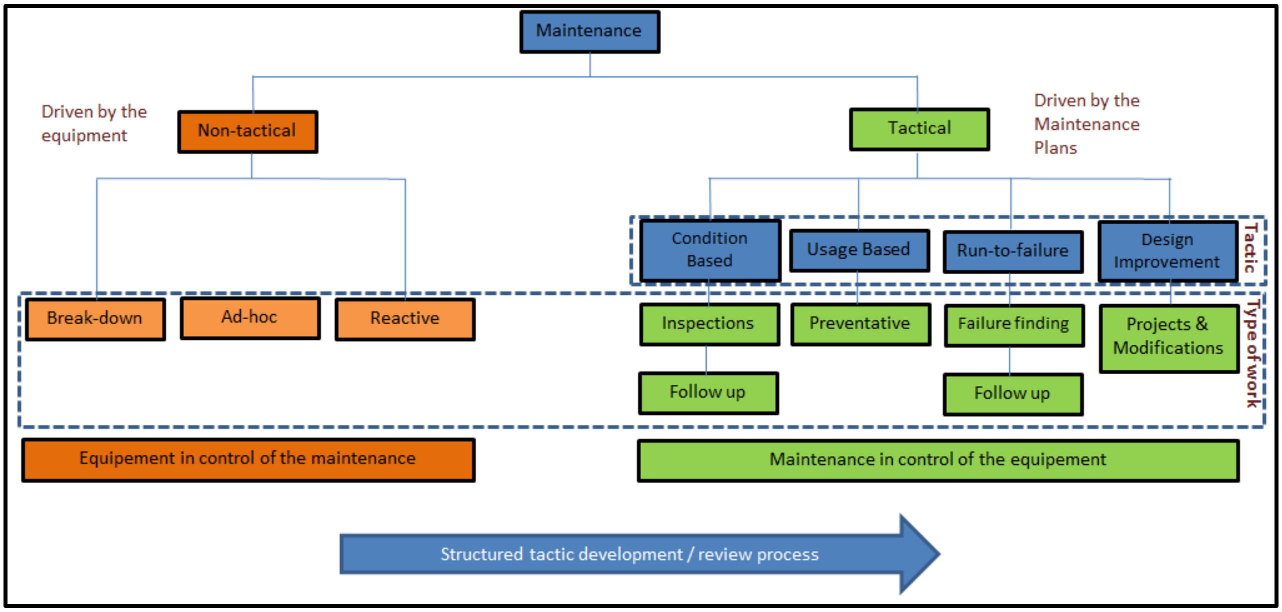


Figure 12: Maintenance Mix Showing the Maintenance Tactics (NamWater, 2012:19)

3.5.5. NamWater's asset management tools

NamWater is in possession of an asset management tool known as SAP Plant Maintenance (SAP PM) which is a module within the SAP ERP system. The key activities contained in the SAP PM Module includes inspection, notifications, corrective and preventative maintenance, repairs and other measures to ensure an ideal technical system and it manages all maintenance activities (SAP PM Tutorial, 2018). The SAP PM established for NamWater is not asset specific and is intended for the management of all physical asset types ranging from large infrastructure like dams and reservoirs to smaller equipment and appurtenances. It therefore falls under the category of general purpose software rather than asset specific software. However, there is no clear correlation between the rating of defects by dam inspectors and the inputs into SAP PM and it seems the approach is merely to create maintenance plans for selected defective structures guided by decisions emanating from discussion meetings on the dam safety evaluation reports.

3.6. Dam safety management

3.6.1. Overview of international approaches to dam safety management

The historical and catastrophic impact of dam failure to people and the environment is proof of the risks associated with dam failure (Sidek et al., 2014:583). Dam safety management should thus ensure minimal risk to life, property, essential services and the environment (Victoria State Government, 2019). Whilst the importance of asset management cannot be overstated, "risk-based techniques are growing in popularity amongst dam professionals worldwide as a device for defining risks that may have been otherwise overlooked and to prioritize implementation of dam safety remedial works to best protect the public" (Donnelly, 2006). A risk may be defined as the change in the condition of the asset that will sufficiently cause a change in the service to be delivered (Mian et al., 2011:2). In simpler terms, this risk is the consequence of asset failure, which may include any loss to life and/or property and is not necessarily only the related to ultimate limit state failure. This seems relevant for dam risk, for which a risk to life downstream may in some instances be attributed to the opening of flood gates rather than the structural or ultimate limit state failure of the dam structure. The main purpose of risk assessment is to provide a formal, consistent approach for evaluating the likelihood of occurrence of various adverse outcomes (National Research Council, 1983:41). Various risk assessment techniques and methodologies have thus been developed to assist the owners of dams and/or reservoirs (Morris, Hewlett and Elliott, 2000:1) in this regard. Harvey, as cited by Morris, Hewlett and Elliott (2000:7), states that in the UK, the benefits of risk assessment have been realised in the industries that have a major hazard potential. The focus seems to be on the facilities that are associated with hazardous materials and processes. This may explain the reason why, for instance, facilities or infrastructure such as bridges are not assessed via a risk based approach.

While a risk based approach is becoming more popular for dam safety management compared to traditional engineering approaches, a risk assessment methodology for the safety assessment of reservoirs in the UK developed under CIRIA 1 Project RP568 (Morris, Hewlett and Elliott, 2000:1) does take into consideration the engineering approach as well. The assessment methodology proposed under the CIRIA 1 Project RP568 is comprised of two stages defined as follows:

Stage 1. Impact Assessment

This stage of the methodology is primarily focused on identifying and quantifying the impact posed by failure of the dam. A rating is given for a particular dam based on the impact it has on the downstream as well giving special consideration to any impact that results in the loss of life. The following seven key impacts are evaluated for each dam being assessed:

- Residential
- Non-Residential
- Transportation
- Recreational
- Industrial
- Utilities
- Agriculture

The procedure is such that a rating is allocated for each of the seven key impacts followed by combining all the impact rating including the potential loss, culminating into an impact score for the dam in question. The combining of the impact scores is based on weighting values based on engineering judgment and expertise and were developed through a risk discussion workshop. An impact assessment summary sheet (**Figure 13**) was developed for combining the impact scores based on the weighted values. In summary, the procedure for carrying out stage 1 of the risk assessment methodology is as shown in **Figure 14** and it starts with collation of information and visiting the site, through the process of predicting the resulting flood water levels, up until the point of determining a single impact score for the dam. It is important to note that at this stage of the assessment methodology, there is no talk of any dam inspections and identification of dam defects, as would be the case with, for instance, using the DER rating system. The importance of the impact scores becomes clear when there are a variety of dam structures in the more often than not situation of limited financial and/or human resources. Similar to the objective of the DER rating system, the impact score rating of various structures can be used to rank various dams in order of priority for further, more detailed risk assessment and or rehabilitation works.

Table 5 - Reservoir Impact Assessment Summary Sheet	Date:
Site	By:

NEAR VALLEY ASSESSMENT		IMPACT Impact Score (0 - 4)	IMPACT Weight	IMPACT Score (Score x Weight)	PEOPLE AT RISK PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		---
Impact 6	Utilities		0.25		---
Impact 7	Agriculture / Habitats		0.05		---
		Total Near Valley Score[1] =			Total PAR =
					Pot^n loss of life[2] = (0.5 x PAR)

FAR VALLEY ASSESSMENT		IMPACT Impact Score (0 - 4)	IMPACT Weight	IMPACT Score (Score x Weight)	PEOPLE AT RISK PAR Value
Impact 1	Residential Properties		0.15		
Impact 2	Non Residential Properties		0.15		
Impact 3	Transportation Infrastructure		0.10		
Impact 4	Recreational Sites		0.05		
Impact 5	Industrial Sites		0.25		---
Impact 6	Utilities		0.25		---
Impact 7	Agriculture / Habitats		0.05		---
		Total Far Valley Score[3] =			Total PAR =
					Pot^n loss of life[4] = ($PAR^{0.6}$)

Combined Impact Score	Score	Factor	Total
Near Valley Score[1]		100	
Near Valley Pot^n Loss of Life[2]		1	
Far Valley Score3		30	
Far Valley Pot^n Loss of Life[4]		1	
Reservoir Impact Score =			

Figure 13: Impact Assessment Summary Sheet (Morris, Hewlett and Elliott, 2000:14)

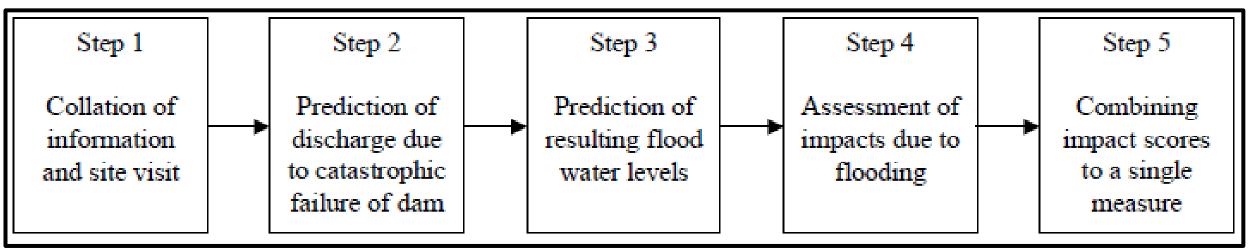


Figure 14: Impact Assessment Steps (Morris, Hewlett and Elliott, 2000:10)

Stage 2. Risk Assessment

According to Morris, Hewlett and Elliott (2000:1), this stage of the assessment methodology is based on an approach that applies sound engineering knowledge by considering the various components of a dam. This is particularly true when compared with the stage 1 approach that is more focused on the impact of failure. The stage 2 approach involves the scoring of the various components of the dam based on consequence of failure, likelihood of failure and the confidence of the consequence of failure and likelihood of failure scores.

The scoring of the dam components based on the abovementioned scores, as proposed under CIRIA 1 Project RP568 (for dams and reservoirs in the UK), is guided by a database of previous dam incident records, in conjunction with site specific details and engineering judgement. This approach is analogous to using the guiding tables provided in the TMH 19 for rating various defects based on the DER system used in South-Africa for road structures. Stage 2 of the assessment proposed under CIRIA 1 Project RP568 is a *Failure Mode, Effect and Criticality Analysis* (FMECA) type and is based on the LCI diagram (**Figure 15**). The L relates to the location of a component at the dam, the C for the cause of failure and the I for indications of failure (Morris, Hewlett and Elliott, 2000:14). The LCI diagram allows for a standardised approach to undertaking the assessment of the dam components. Again, this compares reasonably well to the TMH 19 bridge inspection form (Appendix B) in that it makes provision for rating of various defects on selected dam components. After the completion of the LCI diagrams, criticality and risk scores are computed which then plays a vital role in the ranking of the dam components in terms of risks. Consequently, as in the case with the DER rating system, this will assist in identifying and prioritising the components for which remedial works and/or further investigations are required. This prioritisation procedure is demonstrated in **Figure 16**. Furthermore, the DER rated visual inspection data entered into the STRUMAN BMS has to be validated to ensure its integrity and completeness (Committee of Transport Officials, 2016a:2-3). Similarly, for the assessment methodology in question, a review of the scoring and justification of the high risk elements by the assessor is required after the identification and prioritisation of key risk elements, to ensure that the appropriate measures for managing the risks are taken.

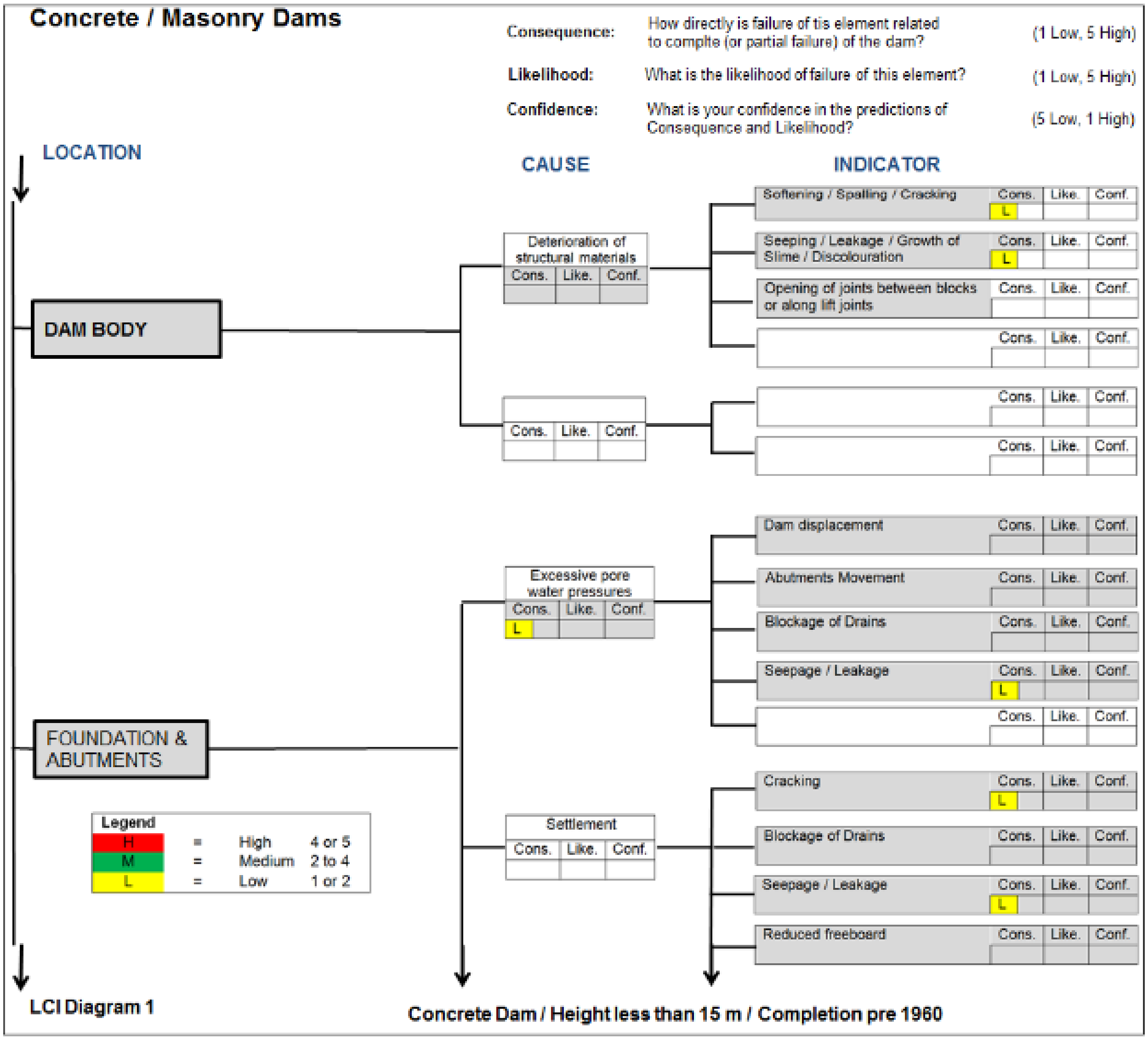


Figure 15: Example of a part of an LCI diagram (Morris, Hewlett and Elliott, 2000:15)

Table 7 – Risk Summary Table											
Site: Test Case #1									Date: Sept 99		
Sheet 1 of 4									By: mwm		
Element Ref.											Impact Score = 1,215
Location	*Cause / Indicator*	Criticality Score	Crit. Rank		Cons. X Like.	C x S Rank		Conf. Score	Conf. Rank		Risk Score (Impact x Criticality)
Spillway and Components	Seepage / leakage	48	1		3 x 4 = 12	1		4	1		58,320
Dam body	Internal erosion Wet patches. Springs, sinkholes	40	2		2 x 5 = 10	2		4	2		48,600
Inlet / outlet works	Pipework damaged Seepage / leakage	30	3		2 x 5 = 10	3		3	4		36,450
Dam body	Settlement Cracking	24	4=		2 x 3 = 6			4	3		29,160
Dam body	Settlement Internal erosion	24	4=		4 x 2 = 8			3			
Dam body	Internal erosion Piping	24	4=		4 x 2 = 8			3			
Dam body	Settlement Seepage / leakage	18	5=		3 x 3 = 9	4		2			21,870

Figure 16: Example of Dam Risk Prioritisation Table (Morris, Hewlett and Elliott, 2000:17)

3.6.2. Dam safety management in Namibia (and South-Africa)

Many countries world-wide have developed laws and regulations applied to dam safety activities (Jeon et al., 2009:555) and guidelines used by engineers when monitoring the structural integrity of the dam structures (Bukenya et al., 2014:235). In Namibia, dam safety is governed by Part 17 (Dams, dam safety and flood management) of the Water Resource Management Act 11 of 2013 (WRM Act). There is however no gazetted dam safety regulations supplementing this act such as, for instance, the Regulations Regarding the Safety of Dams under Section 123(1) of the National Water Act, 1998, of the South African government (DWA dam safety regulations). The absence of dam safety regulations in Namibia results in various shortcomings when it comes to dam safety management. For example, in classifying dam classes/categories, the DWA dam safety regulations gives guidance based on dam size (wall height) and the hazard potential (which considers potential loss of life, potential economic loss and potential impact on resource quality). The WRM Act (Water Resources Management Act, No. 11 of 2013, 2013:58) on the other hand simply just refers to 'categorisation of dams with a safety risk as described and declared by the Minister, by notice in the Gazette.' Furthermore, the WRM Act does not offer much in terms of guidance and regulations when it comes to the safety evaluation of existing dams. Institutions that manage large dams such as NamWater have often, as a result, resorted to using the DWA dam safety regulations in compiling their dam safety evaluation reports. According to the DWA dam safety regulations, the dams are classified into categories I to III based on their safety risks. The process for dam categorisation starts with identifying whether the dam has a safety risk or not, as defined under clause 1 (7) of the DWA dam safety regulations. According to the DWA dam safety regulations (National Water Act, No.36 of 1998. Regulation, 2009:7), a dam with a safety risk is defined as follows (In addition to declaration under section 118(2) and 118(3)(a) of the Act):

“Any dam which can contain, store or dam more than 50 000 cubic metres of water, whether that water contains any substance or not, and which has a wall of a vertical height of more than five metres, measured as the vertical difference between the lowest downstream ground elevation on the outside of the dam wall and the non-overspill crest level or the general top level of the dam wall”

This is then followed by classifying the dam based on its size (**Table 7**) as well as based on its hazard potential (**Table 8**). The classifications of **Table 7** and **Table 8** are combined to give a category for the dam (**Table 9**). According to the DWA dam safety regulations, the categorisation of the dams is done to determine the level of control over the safety of the structure. Whilst the classification of dams based on their size is a relatively straightforward exercise, given the geometric information of the dam, the classification based on hazard potential on the other hand is strongly based on the impact of the flood on the downstream of the dam. Consequently, most guidelines on the risk assessment of dams are focused on determining the maximum/peak design floods and then modelling their impact should a dam failure occur. DWA has developed a risk-based model whereby the risks are evaluated against a multiple acceptability criteria on five impact diagrams to assess the economic, social, socio-economic and environmental impacts of dam failure as well as to assess the risk to human life (Reynolds and Barnardo-Viljoen, 2014:14). The aim of this approach is to identify the unacceptable risks so as to guide the recommendation and prioritisation of the rehabilitation works in order to improve dam safety. However, the approach for evaluating dam risks and ranking dams based on their risks seems to mostly focus on the impact of dam failure and the contribution of dam defects in risk determination is hardly mentioned. This is despite the fact that the DWA dam safety regulations do require the inspection of dam elements to identify defects. The methodology proposed under CIRIA 1 Project RP568 for dams in the UK, by contrast, involves using the rating of dam defects in the overall risk calculation and risk ranking of the dams as described earlier.

The DWA dam safety regulations, despite requiring regular inspections of the dams, do not provide a proper and/or standardized guide for evaluating the surface defects, which could make it both easier and more time efficient for dam inspectors. The approach is simply to rely on the judgement of the approved professional persons as they assess dam item by item and rehabilitation decisions are consequently based on their recommendations. According to the SANCOLD guidelines on safety in relation to floods (SANCOLD, 1991:1), the failure of a dam in executing its function may be through inadequate provision of storage or inadequacy of spillway capacity or through the structural failure. Whilst the structural failure of dams is occasionally mentioned in most guidelines on dam safety assessments, such as SANCOLD, it appears these guidelines do not specifically mention the rating of concrete defects on the dam elements as being a compulsory input to a calculation of the overall dam risk. The DWA dam safety regulations stipulate that dam safety evaluation reports are to be compiled for dams with a safety risk. NamWater has previously embarked on projects to carry out dam safety evaluation reports for a number of selected dams. Since Namibia has not yet produced dam safety regulations of their own (Hattingh, 2015:2), DWA dam safety regulations were used as a guide in undertaking the dam safety evaluations. The dam safety evaluation report compiled for the Oanob dam is a good example of dam safety evaluation based on the DWA dam safety regulations. From the Oanob dam safety evaluation report, it can be seen that significant effort is put in determining the dam risk based on the impact that dam failure may have on the downstream. Furthermore, whilst there is an indication that the structural behaviour of the dam as observed during the inspection was taken into account for determining the probability of failure of the dam, the approach does not involves giving weighted ratings for the identified defects. It seems the approach was merely based on engineering judgement by the approved professional person carrying the dam safety evaluation and visual inspection, as outlined in clause 35 (4) (b) (ii) of the DWA dam safety regulations. There is however not much quantitative information given about the observed defects (Such as crack widths, extend, frequency). Additionally, there seem to be no standardised approach that relates the identified defects to the calculated dam risk. When there is a need to compare with other dams, an additional exercise may potentially be carried out that may require rating of these defects based on quantified information. A recognised defects rating system similar to the DER rating system, or as the one proposed in the CIRIA 1 Project RP568 risk assessment methodology, would possibly provide such a standardised approach that all dam professionals may use.

Table 7: Dam Size Classification (National Water Act, No.36 of 1998. Regulation, 2009:51)

Size class	Maximum Wall Height in Metres (m)
Small……	More than 5 m but less than 12 m
Medium…	Equal to or more than 12 m but less than 30 m
Large……	Equal to or more than 30 m

Table 8: Hazard Potential Classification (National Water Act, No.36 of 1998. Regulation, 2009:51)

Hazard Potential Rating	Potential Loss of Life	Potential Economic loss	Potential Impact on Resource Quality
Low………………	None………………….	Minimal	Low
Significant………	Not more than ten…..	Significant	Significant
High……………..	More than ten………	Great	Severe

Table 9: Category Classification of Dams with a Safety Risk (National Water Act, No.36 of 1998. Regulation, 2009:51)

Size Class	Hazard Potential Rating		
	Low	Significant	High
Small…………	Category I…..	Category I…..	Category I…
Medium………	Category II….	Category II….	Category II...
Large…………	Category III…	Category III…	Category III..

3.6.3. Decision making regarding repair and maintenance of dam structures

After a thorough evaluation of the dams has been conducted and dam safety evaluation reports furnished, repair and maintenance activities have to be produced for the identified defects. In an environment where an organisation manages a large number of dam structures, such as is the case with NamWater, there may be a need to prioritise repairs on certain dams based on various factors such the extent of defects, urgency of the defect as well the criticality of the structure. The ultimate aim of prioritising repair and maintenance of various structures is to ensure the sustainable use of limited resources within public organisations that manages a large number of these important infrastructures. These limited resources may take the form of both qualified personnel and financial resources. This is empathized by Zamarrón-Mieza, Yepes and Moreno-Jiménez (2017:218), who indicates that the allocation of limited financial, human and material resources to ensure adequate operating conditions of dams is a significant challenge to the institutions that owns the dams, particularly with aging dams. Whilst there may be merit in management making repair and maintenance decisions by simply relying on the dam safety evaluation reports, particularly when considering the limited availability of resources, there are definitely areas that can be improved to help in this decision making. Making a decision based on the criticality (or redundancy) of a structure may be more straight forward compared to when one has to evaluate various defects on numerous dams. This is because an asset of high criticality is easier to pick than to zoom in on all identified defects and singling out the most urgent defects. Asset criticality is defined as the impact that an asset has on the overall system in order to meet the asset management objectives of an institution. When going the route of using defects for decision making, one will have to look at all defects of the asset and identify their extent and relevance prior to making repair decisions. The challenge with this approach is that the way in which defects vary from structure to structure in terms of degree, extend and relevance makes it very difficult to decide on which structure to attend to (in the space of limited resources). A solution to this approach could be the use of a rating system which takes into consideration the more detailed information about the defect and assigning degree, extent and relevance ratings, thereby providing a quantifiable approach to allocating resources for repairs and maintenance of the defective structures. It is for reasons like these that many institutions worldwide have established defects rating systems used for the prioritisation of repair and maintenance of defects on structures. However, the use of such rating systems is highly advanced in the transportation industry, particularly with bridges, and is not so commonly associated with dams and other structure types. This situation has prompt studies to look into how the defects rating systems used for bridge structures can be applied to other types of structures. An example of such a study is the one by Gombele (2017), who did a study on the applicability of the DER-U defects rating system in a power generating environment, whereby the DER-U rating system was tested for the rating of defects on structural elements of a cooling tower.

3.6.4. Summary

Currently, the common approach to dam safety management is risk based. As a result, and as can be seem from most dam safety guidelines and regulations, the impact of failure is given significant weighting when prioritising dams based on risks over the effect that identified defects may have on dam risk. Under this approach, dams with significant defects but low impact of failure may be overlooked when for instance, prioritising repairs and maintenance. Additionally, whilst most of this guidelines and regulations do indicate the importance of visually inspecting dams to identify defects, an approach that mentions the rating of dam defects as input to dam safety management or risk analysis is hardly mentioned. Such approach could be used to include dam defects as part of dam risk determination.

3.7. The DER rating system

As previously stated, rating systems are commonly used for the rating of defects on road structures such as bridges and culverts. These rating systems are intended for use in a bridge management system (BMS) (Gombele, 2017:26) for the rating and evaluation of the identified defects or the condition of the structure. There are many different defects rating systems worldwide used for bridge structures. The DER rating system is one such rating system used in South-Africa (and some neighbouring countries). The DER rating system is used in the STRUMAN BMS, which is the BMS used by most provinces in South Africa for the management of their bridge maintenance and rehabilitation. According to Nell, Nordengen and Newmark (2008:2), the STRUMAN BMS consists of the following modules:

1. The Inventory Module

   This module consists of the list of all structures of the road network with detailed information pertaining to their type, location, construction materials, dimensions etc. (Committee of Transport Officials, 2016a:2-1).
2. Inspection Module

   It is under this module where inspection data is entered into the BMS. According to (Committee of Transport Officials, 2016a:2-1), inspections are carried out using standard inspection forms which contains a list of inspection items per structure type.
3. The Condition Module

   The condition of the structure is evaluated in the condition analysis module of the BMS after the input of the inspection data, based on various indices.
4. Budget module

   This module focusses on the optimised costs of the identified remedial activities for the defects identified on the structures.

The DER-U rating system used in the STRUMAN BMS is a defects rating system based on rating of the defects of a structural element according to its degree (D), extent (E), and relevancy (R). The urgency rating (U) is based on the urgency of the assigned remedial work activity. According to the (Committee of Transport Officials, 2016a:4-1), the severity of the defect is defined by the degree rating. The extent rating expresses how extensive the identified defect is spread out on the element being inspected. The relevancy rating quantifies how relevant the defect is regarding the user safety as well as the structural and functional integrity of the structure (Nell, Nordengen and Newmark, 2008:5). The use of the DER rating system (and any other rating systems for that matter) is for the eventual production and prioritisation of the repairs and maintenance activities, in addition to the allocation of budgets for these activities in order to optimise the asset life cycle (Gombele, 2017:37).

Once understood, the DER rating system is fairly easy to use, even though the visual inspection is still mostly recommended only for experienced inspectors. The defects, extent and relevancy of a defect is based on a four point scale starting from 1 to 4, as shown in **Table 10**.

Table 10: Allowable DER values (Committee of Transport Officials, 2016a:4-2)

Rating	D (Degree)	E (Extent)	R (Relevancy)	
X	Not applicable			
U	Unable to inspect			
0	No visible defects			
1	Minor	Local	Minimum	No structural integrity or safety issues
2	Moderate	More than local	Moderate	Some possible structural integrity or safety issues
3	Warning	Less than general	Major	Structural integrity or safety compromised
4	Severe	General	Critical	Potentially a serious impact on structural integrity and/or user safety

As can be seen from **Table 10**, it is a must to have a degree rating for all items inspected. However, where the X, U, and 0 ratings are used for the degree rating, the E and R ratings should not be given. Additionally, there are various restrictions on the DER rating system. For instance, certain combinations of the D and R are not valid. **Table 11** summarizes the various combinations of D and R that are not valid.

Table 11: DER ratings requirements (Committee of Transport Officials, 2016a:4-3)

D&R	R=1	R=2	R=3	R=4
D=1	1-1	1-2	Not valid	Not valid
D=2	2-1	2-2	2-3	Not valid
D=3	3-1	3-2	3-3	3-4
D=4	4-1	4-2	4-3	4-4

Figure 17 gives a summary of the procedure for the rating of defects using the DER rating system, as derived from TMH19A (Committee of Transport Officials, 2016a:4-3). As can be seen from **Figure 17**, the DER ratings are only applied to the worst defect as this is usually the defect with the highest relevancy. That is why, particularly for the relevancy rating, inspectors with appropriate design and rehabilitation experience are required. The inspector should understand how the structure behaves and how the defect will interfere with the load path of the structure and the impact the defect will have on the safety of the users of the structure (Committee of Transport Officials, 2016a:4-1) in order to make a reasonable rating of the relevancy. It is however

recommended that the rest of the defects on the inspection item are recorded merely for the purpose of repair and maintenance.

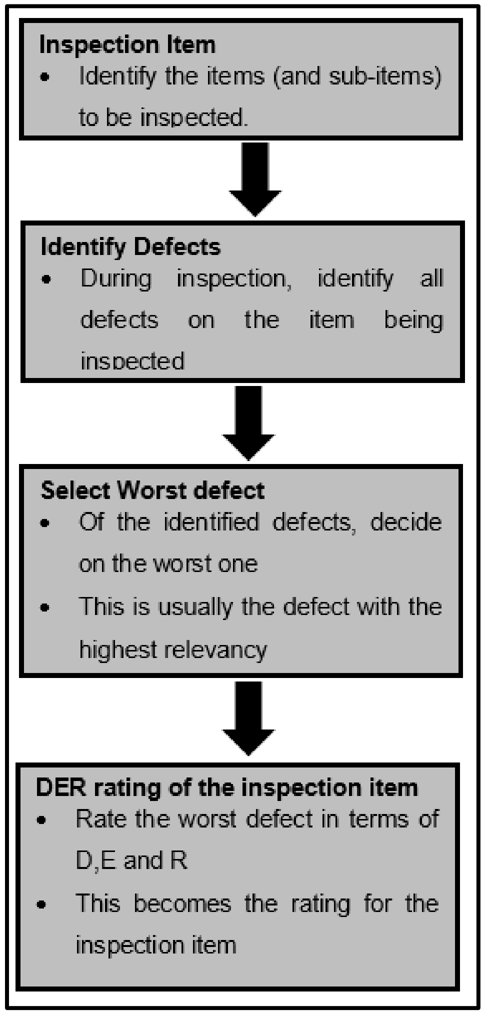


Figure 17: Procedure for rating defects using the DER system

Despite being a rating system for rating defects on a structure, the DER rating system is not intended to have the bridge inspector rate the condition of the inspection item or the structure as a whole, but rather to focus on the identified defects (Committee of Transport Officials, 2016a:4-1). From the above descriptions of the DER rating system, it seems logical to assume that it may be applicable to defects on any concrete structure. It is for this reason, and it's potential to improve decision making and prioritisation of the repair and maintenance of dam structures which may consequently contribute to the overall improvement of asset management within NamWater, that this study intends to assess its applicability for assessing surface defects on concrete dams.

4. Applying the DER rating system on dam elements

In an attempt to apply the DER rating system for the rating of defects on dam elements, the following was carried out under this study:

4.1. Identifying equivalent dam elements for applying the DER rating system

With the DER rating system, the bridge inspectors may use the tables in TMH 19 developed for the various components of the different bridge structures as a guide for rating the identified defects. The inspector will identify the different components of the structure to be inspected and may use the tables in the TMH19 as a guide in giving ratings to the identified defects. Additionally, the TMH19 has standard inspection forms per inspection item of a selected structure that the inspector can use. However, with dam elements, templates that make provision of rating identified defects are not common. The approach in this study identified equivalent dam components similar in material, loading, construction and defects to the bridge items from the tables in TMH19. Whilst the focus of the study is on the concrete defects, the DER rating system allows for the evaluation of defects such as scour protection works, which, if not well maintained, may result in structural issues for the concrete elements. As a result, and for an extended assessment of the DER ratings system on dams, some of these defects have been considered. Since this study is just a rough attempt at developing or using rating systems for dams, detailed assessments and modifications on the quantifications of the measurable defects (i.e., scour depth or crack width for a particular degree rating) for the various ratings do not form a part of this study. This may be done in follow up researches or through discussions by task groups. The review of the equivalent bridge items from TMH19 tables was mainly guided by a combination of the researcher's own engineering judgement, literature and the descriptions of the dam defects identified in **Tables 2** and **3.** The following dam elements were identified for application of the DER rating system and a comparison with their equivalent bridge items is shown in the following sub-sections:

4.1.1. Dam apron slab and spillway section

The apron slabs for both the bridge and dam are made of concrete and primarily loaded with their self-weight. The dam apron slab however serves the purpose of protecting the dam wall against erosion and undermining of the foundations due to overtopping of the wall and may be subjected to overtopping flows with massive energy. Since the apron slab is in most cases downstream of the spillway section, it was decided to evaluate its defects in combination with those of the spillway section. The bridge items indicated in **Table 12**, were reviewed as per **Table 13**, **Table 14** and **Table 15**. The defects items deemed reasonable for application to dams from **Tables 13** to **15** were combined into **Table 16**, which was then used for the evaluation of the equivalent dam elements.

Table 12: Dam Apron Slab and Spillway Section Comparison to Equivalent TMH19 items

TMH19 Bridge Item(s)	Dam Equivalent Item
Apron Slab and Cut-off Wall (Item 1, Table 2.2, TMH19) Scour Protection Works in Waterways (Item 3, Table 2.2, TMH19) and Dam Abutment Defects (Item 6, Table 2.1)	**Dam Apron Slab/Spillway Section**
Item Description: For bridges, an apron serves the very purpose of protecting the bridge elements against scour.	**Item Description:** The dam apron slab is used for dissipating the energy due to the pressure from the released flood water and for protection against scour and undermining in waterways (i.e., downstream of spillways).
Material(s): Concrete	**Material(s):** Concrete
Typical Loads: Self-weight	**Typical Loads:** Mostly Self weight and pressure from the flood water.
Typical Deterioration/defects: Cracks, Scour, spalling etc. (See item 6, table 2.1 and items 1 and 3 from table 2.2 of TMH19)	**Typical Deterioration/defects:** Erosion or loss foundation at outlets and spillways, cracks, spalling
<u>Item Picture:</u> 	**<u>Item Picture:</u>** 

Table 13: Apron Slab and Cut-Off Wall Defects

Item 1: Apron Slab and Cut Off Wall Defects (From Table 2.2, (Committee of Transport Officials, 2016b:2-43))			
Defects	**Observations**	**D**	**Comments on Applicability to Dam Elements**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1	Shrinkage and restraint cracks are the most common type of cracks in mass concrete due to stresses caused by restraint to volumetric changes (Bellport, 1979). AAR is also a serious deterioration mechanism on concrete dams (Bai *et al.*, 2018:341) that causes cracks in the concrete and may compromise the safety of the dam. While observations of leakages may be a possibility on the spillway sections since they are usually part of the impounding structure, observations for reinforcement corrosion may not be as common with these items as they are primarily constructed of mass concrete. This defect is however still deemed relevant for concrete elements of the dams and will be applied to the spillways and apron slabs in this study.
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3	
	Crack is greater than 0.6 mm	4	
Scour of outlet structures	Local scour at outlet is shallow. Scour has not exposed base of cut off wall or apron slab.	1	The dam apron slabs are meant for mitigating against scouring and/or erosion downstream of the dam wall/spillway due to spillway flow (URS Greiner Woodward Clyde, 2002:38). Scour or erosion has the potential to cause undermining and loss of stability of the dam structure (**Table 3**, as derived from National Research Council (1983:190)). However, the depth of scour at which local collapse will happen for the dam aprons and the dam wall may not be the same as that of a bridge outlet structures. For the purpose of assessing the application of the DER ratings under this study, these defect ratings will be applied to the dam apron slab as is.
	Local scour at outlet is shallow. Scour has partly exposed base of cut off wall or apron slab.	2	
	Local scour at outlet has exposed cut off wall or apron slab. Scour has exposed erodible founding material of outlet structures and some structural damage of cut off wall or apron slab has occurred.	3	
	Scour has exposed erodible founding material of outlet structures. Severe structural damage has occurred. Further scour may cause collapse of culvert.	4	

Table 14: Scour Protection Works (In Waterways) Defects

Item 3: Scour Protection Works (In Waterway) Defects (From Table 2.2, (Committee of Transport Officials, 2016b:2-47))			
Defect	**Observations**	**D**	**Comments on Applicability to Dam Elements**
Scour or erosion of waterway	Scour or erosion is shallow. There is no possibility of local collapse.	1	The item "scour of outlet structures' has already been considered for the defects rating of the apron slab scour (**Table 13**).
	Scour or erosion is shallow. Sides appear stable. There is a small possibility of local collapse.	2	
	Scour or erosion is deep. There is a possibility of local collapse.	3	
	Scour or erosion is deep. Sides are vertical or overhanging. Sides appear unstable. There is a real possibility of local collapse, which would endanger the roadway.	4	
Flood debris accumulation	Loose debris accumulating on piers or bridge decks.	1	The accumulation of debris on the spillways or flood gates and apron slabs of dams may result in plugging of spillways and outlets (**Table 3**, as derived from National Research Council (1983:190)). These defect ratings will thus be considered for the purpose of this study.
	Debris accumulation in the form of small branches on piers or on bridge decks.	2	
	Debris accumulation in the form of large branches or small trees on piers or on bridge decks.	3	
	Debris accumulation in the form of large trees on piers or on bridge decks.	4	
	Siltation significantly reducing capacity of floods at bridge.	2-4	
Defective scour protection works.	Scour protection materials can comprise: - • Gabion mattresses and/or boxes • Stone pitching • Grouted stone pitching • Interlocking concrete paving blocks • Concrete slabs • Precast concrete retaining blocks • Geocells • Vegetation • Interlocking cellular concrete grass blocks General defects include:-		The apron slab downstream of a dam wall/spillway may be provided with scour protection works, which if not provided, may result in undermining and potential collapse. These protection works may also serve the purpose of transitioning flow to the stream channel (URS Greiner Woodward Clyde, 2002:40). As a result, and for the purpose of assessing the applicability of the DER rating to dams under this study, these ratings will be applied to the scour protection works on the dam apron slabs.
	Vegetation within the protection works to a lesser or larger degree can cause damage to the protection works and is aesthetically a problem.	1-3	
	Portions of the protection works are missing; they may have been removed by vandals or have eroded away.	2-3	
	Protection works were never provided or have been completely removed. In river bridges the abutment stability may be compromised.	3-4	

Table 15: Abutment Defects

Item 6: Abutment Defects (From Table 2.1, (Committee of Transport Officials, 2016b:2-11))			
Defects	**Observations**	**D**	**Comments on Applicability to Dam Elements**
Spalling (All loose concrete must be broken away to expose extent of spall)	Spalling is shallow and reinforcement is not visible.	1	The defect of spalling is relevant to concrete dams as indicated in **Table 2**. As such the ratings for this defect will be applied to the concrete surface defects of the spillway and apron slab, especially where the concrete is reinforced, for the purpose of this study.
	Spalling is shallow. Reinforcement is partly exposed. Minor signs of corrosion. Thus spalling not attributable to corrosion.	2	
	Reinforcement is partially or fully exposed and corrosion is a problem	3	
	Reinforcement is exposed and significantly corroded. Prestress duct is exposed. Section loss.	4	
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1	This defect has already been considered under **Table 13**.
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3	
	Crack is greater than 0.6 mm	4	

Table 16: Dam Apron Slab and Spillway Section Equivalent Guiding Table

Dam Item 2: Dam Apron Slab and Spillway section		
Defect	**Observations**	**D**
Spalling (All loose concrete must be broken away to expose extent of spall)	Spalling is shallow and reinforcement is not visible.	1
	Spalling is shallow. Reinforcement is partly exposed. Minor signs of corrosion. Thus spalling not attributable to corrosion.	2
	Reinforcement is partially or fully exposed and corrosion is a problem	3
	Reinforcement is exposed and significantly corroded. Prestress duct is exposed. Section loss.	4
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3
	Crack is greater than 0.6 mm	4
Scour or erosion of waterway	Scour or erosion is shallow. There is no possibility of local collapse.	1
	Scour or erosion is shallow. Sides appear stable. There is a small possibility of local collapse.	2
	Scour or erosion is deep. There is a possibility of local collapse.	3
	Scour or erosion is deep. Sides are vertical or overhanging. Sides appear unstable. There is a real possibility of local collapse, which would endanger the roadway.	4
Flood debris accumulation	Loose debris accumulating on piers or bridge decks.	1
	Debris accumulation in the form of small branches on piers or on bridge decks.	2
	Debris accumulation in the form of large branches or small trees on piers or on bridge decks.	3
	Debris accumulation in the form of large trees on piers or on bridge decks.	4
	Siltation significantly reducing capacity of floods at bridge.	2-4
Defective scour protection works.	Scour protection materials can comprise:- • Gabion mattresses and/or boxes • Stone pitching • Grouted stone pitching • Interlocking concrete paving blocks • Concrete slabs • Precast concrete retaining blocks • Geocells • Vegetation • Interlocking cellular concrete grass blocks General defects include:-	
	Vegetation within the protection works to a lesser or larger degree can cause damage to the protection works and is aesthetically a problem.	1-3
	Portions of the protection works are missing; they may have been removed by vandals or have eroded away.	2-3
	Protection works were never provided or have been completely removed. In river bridges the abutment stability may be compromised.	3-4

4.1.2. Dam wall (downstream or upstream)

The bridge abutment and the dam wall are both concrete vertical members primarily transferring lateral loads. While they may exhibit similar surface defects in the concrete material such as cracks due to shrinkage, ASR, spalling etc., the relevance of the defects may vary for the two structure types. However, as alluded to earlier, for the purpose of this study these two items are deemed equivalent. A comparison of the two items is shown in **Table 17**. The bridge item 6 was reviewed as per **Table 15**, resulting in **Table 18,** which is was used as a guide for applying the DER rating to the Dam Wall defects.

Table 17: Dam Wall (Upstream and Downstream) Comparison to Equivalent TMH19 items

TMH19 Bridge Item(s)	Dam Equivalent Item
Abutment Defects (Item 6, Table 2.1, TMH19)	**Dam Wall (Downstream or Upstream)**
Item Description: Structural element at the bridge ends carrying the bridge superstructure and transferring the loads from the approach.	**Item Description:** A wall constructed across a stream to retain the water upstream for various reasons such as storage, flood mitigation etc.
Material(s): Concrete	**Material(s)** Concrete
Typical Loads: Lateral loads from approach earth backfill and loads from superstructure	**Typical Loads:** Lateral hydrostatic loads from the upstream water, self-weight
Typical Deterioration/defects: Cracks, spalling (see item 6, table 2.1 TMH19)	**Typical Deterioration/defects:** Cracking, crazing and spalling, leakage, movement, development of off-sets, settlement
Item Picture: 	**Item Picture:** 

Table 18: Dam Wall (Upstream/Downstream) Defects Equivalent Guiding Table

Dam Item 3: Dam Wall (Upstream/Downstream) Defects		
Defect	**Observations**	**D**
Spalling (All loose concrete must be broken away to expose extent of spall)	Spalling is shallow and reinforcement is not visible.	1
	Spalling is shallow. Reinforcement is partly exposed. Minor signs of corrosion. Thus spalling not attributable to corrosion.	2
	Reinforcement is partially or fully exposed and corrosion is a problem	3
	Reinforcement is exposed and significantly corroded. Prestress duct is exposed. Section loss.	4
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3
	Crack is greater than 0.6 mm	4

4.1.3. Dam wall foundations (downstream or upstream)

The abutment foundations transfer the loads from the abutment wall to the founding material. This is the same as the purpose of the dam wall foundations, which is used to transfer the loads on the dam wall to the founding material. They are both made of concrete and as can be seen from **Table 19**, the surface defects for both these items are similar barring the fact that leakages may be more prominent to the dam wall foundations due the dam's primary purpose of retaining water. Additionally, the relevance of these surface defects may vary for the two structure types. The assessment done on the relevance of the abutment foundation defects to the dam wall foundations is as shown in **Table 20** and **Table 21** and as a result, **Table 22** will be used for testing the applicability of the DER rating system on the dam wall foundations.

Table 19: Dam Wall Foundations Comparison to Equivalent TMH19 items

TMH19 Bridge Item(s)	Dam Equivalent Item
Abutment Foundation Defects(Item 5, Table 2.1, TMH19)	**Dam Wall Foundations**
Item Description: Base of the abutment walls	**Item Description:** Base of the dam wall
Material(s): Concrete	**Material(s):** Concrete
Typical Loads: Loads from superstructure and lateral loads from approach via the abutment wall.	**Typical Loads:** Loads from dam wall
Typical Deterioration/defects: Cracks, spalling (see item 5, table 2.1 of TMH19)	**Typical Deterioration/defects:** Cracking, spalling, leakage, movement, settlement
Picture: 	**Picture:** 

Table 20: Abutment Foundation Defects

Defects	Observations	D	Comments on Applicability to Dam Elements
Item 5: Abutment Foundation Defects (From Table 2.1, (Committee of Transport Officials, 2016b:2-9))			
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1	Shrinkage and restraint cracks are the most common type of cracks in mass concrete due to stresses caused by restraint to volumetric changes (Bellport, 1979). AAR is also a common deterioration mechanism on concrete dams (Bai *et al.*, 2018:341) that causes cracks in the concrete and may compromise the safety of the dam. Observations of leakages may be a possibility on the dam wall foundations since they are part of the impounding structure, but observations for reinforcement corrosion may not be as common since the foundations are primarily constructed of mass concrete. This defect is however still deemed relevant for the dam wall foundations and the ratings will be applied as is for the purpose of this study.
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3	
	Crack is greater than 0.6 mm	4	
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is visible of the order of 0.1 to 0.2 mm and there are no signs of water leakage or corrosion of reinforcement.	1	Shear failure in concrete gravity dams tend to appear at the base of the dam as it resist the horizontal forces (National Research Council, 1983:183). Where the cracks identified in the dam wall foundations are associated with shear failure, this item may be applicable. Observations of corroding reinforcement may not be as common as the dam structures are made primarily of mass concrete. However, signs of water leakages may be a possibility since the foundations are part of the impounding structure. For the purpose of this study, this defect will thus be applied to the dam wall foundations as is.
	Crack is greater than 0.2 mm but smaller or equal to 0.4 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is greater than 0.4 mm with no signs of water leakage or corrosion of reinforcement.	3	
	Crack is greater than 0.5 mm and there are signs of water passing through crack and/or evidence of corrosion of reinforcement.	4	
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1	This defect is more suitable for the foundations of bridges such as those with pile caps. For the purpose of this study, it shall however remain as is to be used where the cracks identified in the dam wall foundations may be associated with bending failure.
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3	
	Crack is greater than 0.6 mm	4	

Table 21: Abutment Foundation Defects (continued)

Item 5 Abutment Foundation Defects (continued) (From Table 2.1, (Committee of Transport Officials, 2016b:2-9))			
Defects	**Observations**	**D**	**Comments on Applicability to Dam Elements**
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	Honeycombing is shallow and reinforcement is not visible.	1	Honeycombing is caused by concrete mortar not filling the spaces between the course aggregate particles resulting in voids between these particles (Singh and Kaur, 2012). While honeycombing may not directly compromise the structure, it can provide passage for corrosive agents to the reinforcement in reinforced concrete, as well moisture into the concrete that may promote AAR. Even though dams are primarily made of mass concrete, these defect ratings will be considered for the purpose of assessing the DER rating on dams under this study and will be applied to the dam wall foundations as is.
	Honeycombing is shallow. Reinforcement is partly exposed. No signs of corrosion.	2	
	Reinforcement is fully exposed, with some signs of corrosion; or reinforcement is partly exposed and corroded. Prestress duct is partly exposed.	3	
	Reinforcement is exposed and corroded. Prestress duct is exposed.	4	
Scour of foundations	Local scour at pier foundation is shallow. Scour has not exposed base of foundation.	1	Scour or erosion has the potential to cause undermining and loss of stability (**Table 3**) and potentially destabilise the dam wall. Even though the type of foundations for dams may differ from those of bridges, for the purpose of this study, these defect ratings will be applied to the dam foundations as is.
	Local scour at pier foundation is shallow. Scour has partly exposed base of foundation or piles of piled foundation.	2	
	Local scour at pier founded on piles has exposed the piles. Scour has exposed erodible founding material of a spread footing on a small portion of the perimeter of footing.	3	
	Scour has exposed erodible founding material of a spread footing which might cause the footing to collapse or settle.	4	

Table 22: Dam Wall Foundations Equivalent Guiding Table

Dam Item 4: Dam Wall Foundations		
Defect	**Observations**	**D**
Spalling (All loose concrete must be broken away to expose extent of spall)	Spalling is shallow and reinforcement is not visible.	1
	Spalling is shallow. Reinforcement is partly exposed. Minor signs of corrosion. Thus spalling not attributable to corrosion.	2
	Reinforcement is partially or fully exposed and corrosion is a problem	3
	Reinforcement is exposed and significantly corroded. Prestress duct is exposed. Section loss.	4
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3
	Crack is greater than 0.6 mm	4
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3
	Crack is greater than 0.6 mm	4
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	Honeycombing is shallow and reinforcement is not visible.	1
	Honeycombing is shallow. Reinforcement is partly exposed. No signs of corrosion.	2
	Reinforcement is fully exposed, with some signs of corrosion; or reinforcement is partly exposed and corroded. Prestress duct is partly exposed.	3
	Reinforcement is exposed and corroded. Prestress duct is exposed.	4
Scour of foundations	Local scour at pier foundation is shallow. Scour has not exposed base of foundation.	1
	Local scour at pier foundation is shallow. Scour has partly exposed base of foundation or piles of piled foundation.	2
	Local scour at pier founded on piles has exposed the piles. Scour has exposed erodible founding material of a spread footing on a small portion of the perimeter of footing.	3
	Scour has exposed erodible founding material of a spread footing which might cause the footing to collapse or settle.	4

4.1.4. Dam crest

A dam crest is the top part of the dam wall and may be comprised of an overflow section and a non-overflow section or both. The non-overflow section of a dam wall is often used for vehicular access to the dam crest. The bridge deck slab is identified to be the equivalent component. While surface defects such as cracks and spalling may be found on both the dam crest and the deck slab of a bridge, the relevance of these defects will vary for the for two items due to the differences in their design and functionality. There are however some cases whereby the dam crest is compost of a bridge over the spillway or sluice gates, in which case this bridge or deck may exhibit defects similar to those of a road bridge. A comparison of the equivalent items is shown in **Table 23**. A review of the TMH19 bridge defects items for the deck slab is shown in **Table 24**. Based on this assessment, **Table 25** was to be used for assessing the dam crest defects.

Table 23: Dam Crest Comparison to Equivalent TMH19 items

TMH19 Bridge Item(s)	Dam Equivalent Item
Deck & Slab Defects (Item 20, Table 2.1, TMH19)	**Dam Crest**
Item Description: Concrete superstructure of the bridge carrying the deck/surface of the bridge.	**Item Description:** Top part of dam wall.
Material(s): Concrete	**Material(s):** Concrete
Typical Loads: Traffic loads, thermal loads	**Typical Loads:** Traffic loads, thermal loads
Typical Deterioration/defects: Cracks, spalling (see items 11,17 & 20, table 2.1 TMH19)	**Typical Deterioration/defects:** Cracking, crazing and spalling, leakage, movement, development of off-sets, settlement
Item Picture: 	**Item Picture:** 

Table 24: Deck and Slab Defects

Item 20: Deck & Slab Defects (From Table 2.1, (Committee of Transport Officials, 2016b:2-39))			
Defects	**Observations**	**D**	**Comments on Applicability to Dam Elements**
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1	Dams such as the Hardap dam in Namibia are constructed with decks over the spillways which contains structural members for which the presence of bending or flexural cracks is a possibility. As a result, these defect ratings will be applied to such instances where the dam crest is comprised of decks that may exhibit flexural cracks under this study.
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3	
	Crack is greater than 0.6 mm	4	
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is visible of the order of 0.1 to 0.2 mm and there are no signs of water leakage or corrosion of reinforcement.	1	Same as with the comments on the bending cracks, these defect ratings will be applied if the cracks identified on the dam crest or deck over dam crest are associated with shear failure under this study.
	Crack is greater than 0.2 mm but smaller or equal to 0.4 mm with no signs of water leakage or corrosion of reinforcement.	2	
	Crack is greater than 0.4 mm with no signs of water leakage or corrosion of reinforcement.	3	
	Crack is greater than 0.5 mm and there are signs of water passing through crack and/or evidence of corrosion of reinforcement.	4	
Lack of cover to reinforcement	There are sporadic signs of slight discolouration of concrete face indicating start of reinforcement corrosion due to lack of cover.	1	Like with any reinforced concrete member, a lack of cover concrete may expose the reinforcement in the reinforced components of the dam crest to corrosive agents. These defect ratings are thus deemed relevant for the dam crest and will remain as is for the purpose of this study.
	There are clear signs of discolouration of concrete face along length of reinforcement bar with small cracks.	2	
	Cracks are visible along the length of the reinforcement but with more significant cracks.	3	
	Local spalling and extensive cracking and staining due to corrosion of reinforcement.	4	
Spalling (All loose concrete must be broken away to expose extent of spall)	Spalling is shallow and reinforcement is not visible.	1	Spalling occurs when fragmented material breaks loose from the surface of the structure due to impact or internal stresses and also due the incursion of moisture into the concrete elements (Hoang, Nguyen and Xuan Linh, 2019:2). This defect is relevant to concrete elements of the dams as indicated in **Table 2**. The ratings may thus be applied to the dam crest components, particularly where reinforced concrete is used.
	Spalling is shallow. Reinforcement is partly exposed. Minor signs of corrosion. Thus spalling not attributable to corrosion.	2	
	Reinforcement is partially or fully exposed and corrosion is a problem	3	
	Reinforcement is exposed and significantly corroded. Prestress duct is exposed. Section loss.	4	

Table 25: Dam Crest Equivalent Guiding Table (Overspill and Non-overspill)

Dam Item 5: Dam Crest (Overspill and Non-Overspill)		
Defect	**Observations**	**D**
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is of the order of 0.3 mm with no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.3 mm but smaller or equal to 0.6 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is of the order of 0.6 mm and there are signs of water passing through crack and evidence of corrosion of reinforcement.	3
	Crack is greater than 0.6 mm	4
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is visible of the order of 0.1 to 0.2 mm and there are no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.2 mm but smaller or equal to 0.4 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is greater than 0.4 mm with no signs of water leakage or corrosion of reinforcement.	3
	Crack is greater than 0.5 mm and there are signs of water passing through crack and/or evidence of corrosion of reinforcement.	4
Lack of cover to reinforcement	There are sporadic signs of slight discolouration of concrete face indicating start of reinforcement corrosion due to lack of cover.	1
	There are clear signs of discolouration of concrete face along length of reinforcement bar with small cracks.	2
	Cracks are visible along the length of the reinforcement but with more significant cracks.	3
	Local spalling and extensive cracking and staining due to corrosion of reinforcement.	4
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	Crack is visible of the order of 0.1 to 0.2 mm and there are no signs of water leakage or corrosion of reinforcement.	1
	Crack is greater than 0.2 mm but smaller or equal to 0.4 mm with no signs of water leakage or corrosion of reinforcement.	2
	Crack is greater than 0.4 mm with no signs of water leakage or corrosion of reinforcement.	3
	Crack is greater than 0.5 mm and there are signs of water passing through crack and/or evidence of corrosion of reinforcement.	4

Discussion

There are 21 inspection items associated with the bridge structure in the TMH19: Part A (Table 8). However, only seven items (33%) where deemed relevant and applicable to the dams. Of this 7 items, only three (namely, the Abutment wall, abutment foundation and the deck and slab defects) were considered for this study. For a more extensive assessment of the DER rating, two more dam equivalent inspection items where obtained from Table 9 in the TMH19: Part A. this gives a total of 5 defect items considered under this study. Even though the items from Table 9 of the TMH19: Part A are primarily for smaller bridges compared to those in Table 8, there are some reasonable similarities in their functioning, material and defects to certain dam items. An example is the apron slab and cut-off wall, which compares well to the typical defects on a dam apron slab, as indicated in **Table 12**. Furthermore, not all of the identified bridge defects are on the concrete elements. However, these defects are relevant to the adjacent dam elements and may, if they are not well maintained, have an effect on the structural integrity of the dam or a part of it. The scour protection works defects may be reasonably applied to the protection works at the apron slab which, if left unprotected, may be subjected to erosion and consequently have an effect on the stability of the dam wall. It was further noticed that the bridge items identified as equivalent to the dam elements do not cover all the possible dam defects. An example is the bridge abutment, which does not capture all potential defects on a dam wall such as leakages, settlement and off-sets (**Table 2**). The allocation of the ratings for a particular value of measurable defect may also need to be adjusted to make the ratings more suitable to dams. However, such assessments and modifications are beyond the scope of this study. Additionally, even though it is not the subject of this study, NamWater is also in possession of concrete potable water storage reservoirs with deteriorating concrete. Rating of concrete surface defects such as the spalling, shear cracks, bending cracks and lack of cover to reinforcement on the potable water storage reservoirs is likely to yield successful ratings compared to dams without major changes. This is because the potable water storage reservoirs, similar to bridges, are primarily made of reinforced concrete as opposed to mass concrete used for the dams. This can also be explored in follow-up researches since this study is only focused on the major concrete dams of NamWater.

4.2. Selecting concrete structures to be assessed

Three of the concrete dams in **Figure 7** in the vicinity of the central area of Namibia were chosen for assessment of the DER rating system. The 3 dams chosen for this study are described as follows:

4.2.1. Oanob dam

The Oanob dam (**Figure 18** and **Figure 19**) is a double curvature arch dam with gravity flanks that kinks upstream, located in the Hardap region, upstream of the town of Rehoboth. The dam height above the riverbed is 52.9 m and is categorised as a class III dam, accordingly to the DWA dam safety regulations. The dam was constructed in 1991 and its capacity is estimated at 34 million m^3. The dam spillway is provided on a separate location and not on the main dam wall, even though the main dam wall is provided with some outlet pipes (**Figure 20**). This study however only focused on the components at the main dam wall of the Oanob dam.

Figure 18: Oanob Dam Main Wall

Figure 19: Oanob Dam Components

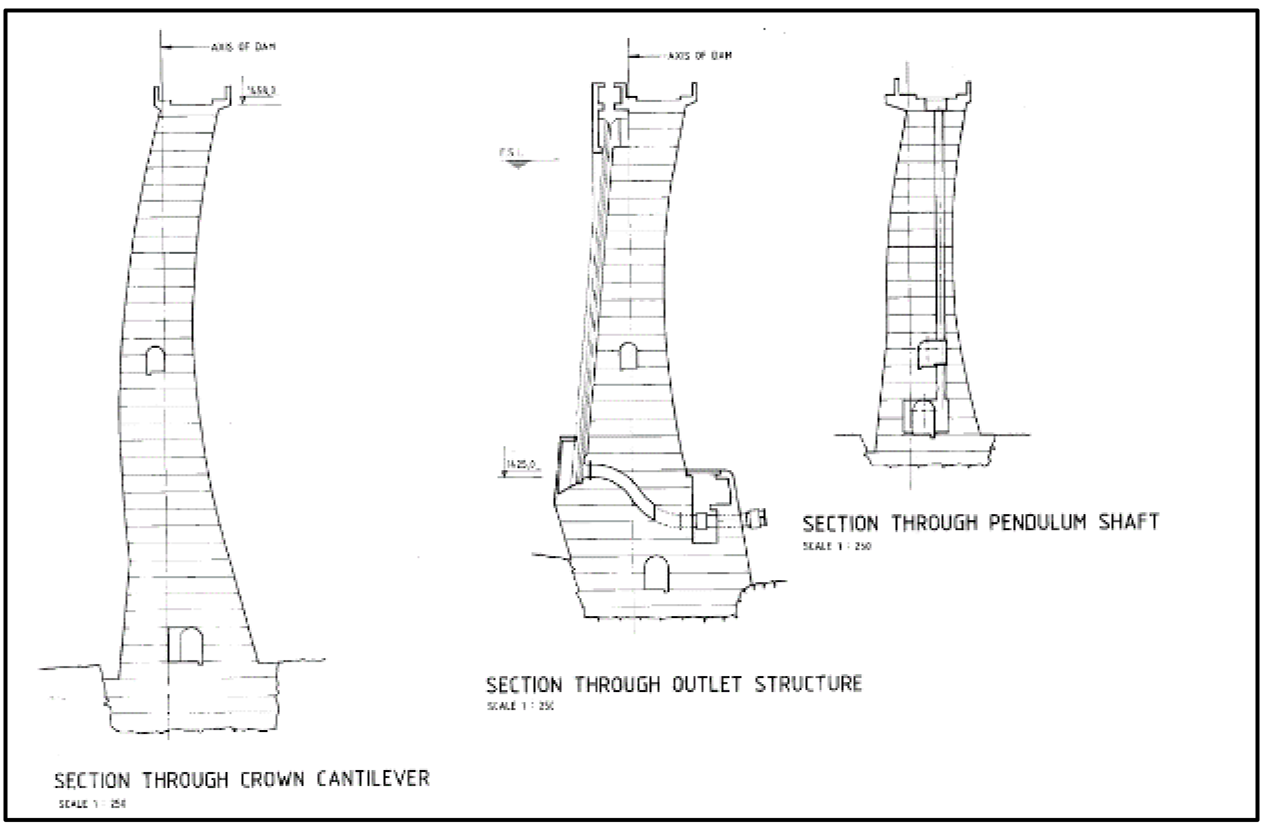


Figure 20: Cross-Sections through Oanob Dam Wall (Hattingh, 2015)

4.2.2. Hardap dam

The Hardap dam is situated in southern Namibia in the Hardap Region (**Figure 7**) on the Fish River Canyon, upstream of the town of Mariental. It was constructed in 1962 and is primarily an asphalt-concrete faced rock filled embankment dam with a gravity concrete spillway section. In addition to the main components described above, the dam also consists of three additional embankments and an auxiliary spillway (**Figure 21**).The overall height of the dam is 35.9 m and it has a capacity of 295 million m^3 at full supply and is classified as a class III dam according to the DWA dam safety regulations. The spillway section is compost of 4 openable radial flood gates (**Figure 22**). The crest of the spillway section connects the two rock embankment crest via a bridge like deck slab above the flood gates (**Figure 23**). More detailed information about the Hardap dam may be found in the First Dam Safety Evaluation Report of the Hardap Dam by Denys (2013).This study was only focused on the assessment of the main concrete spillway of the Hardap dam.

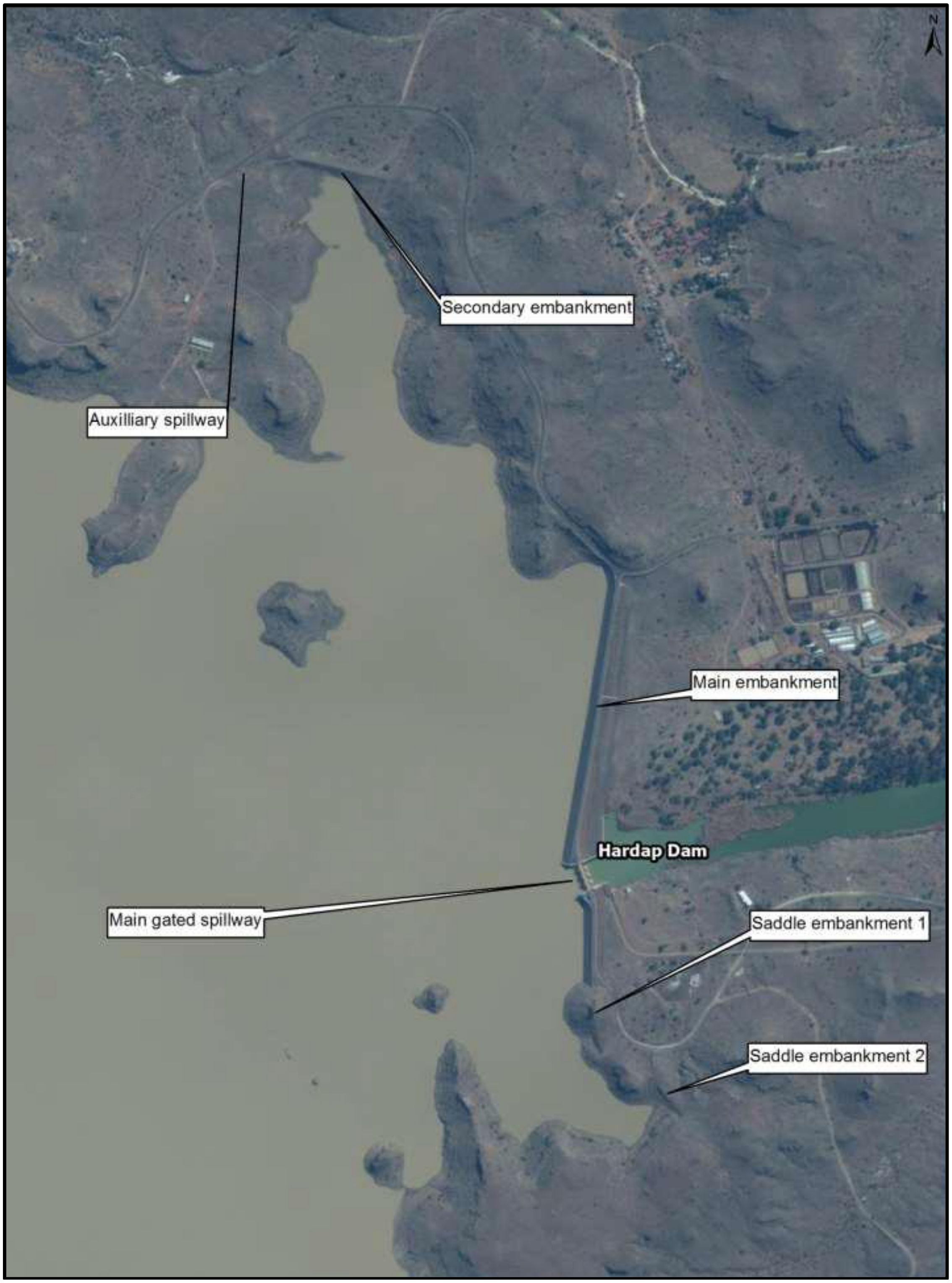


Figure 21: Various Components of the Hardap Dam (Denys, 2013)

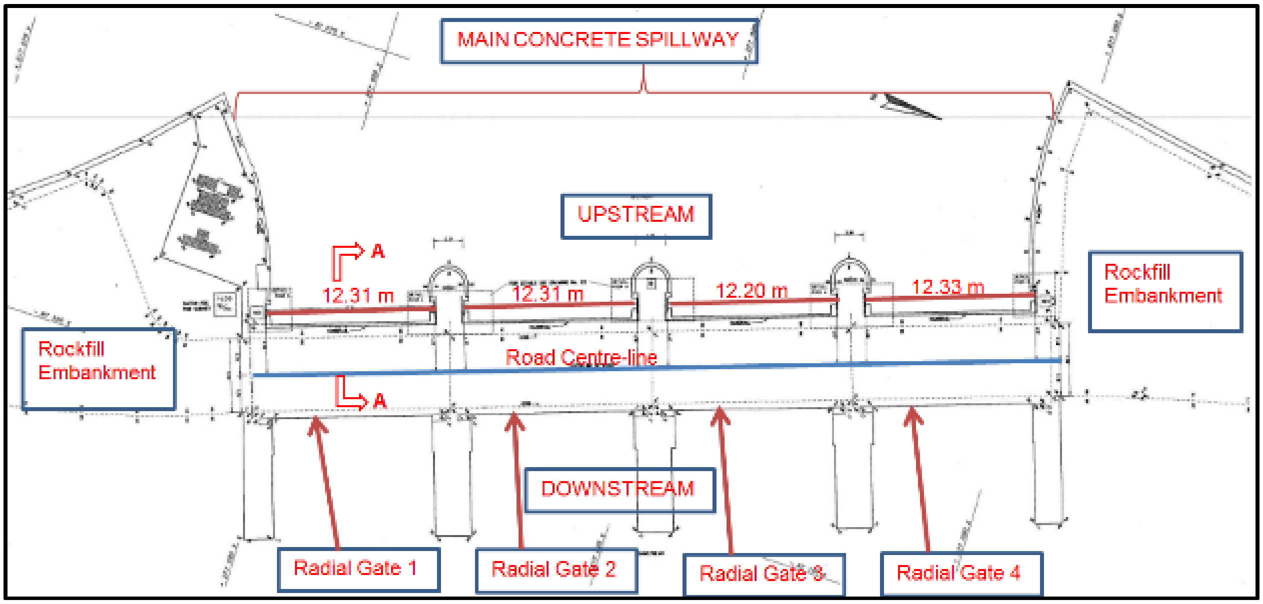


Figure 22: Hardap Dam Main Spillway Section and Adjoining Abutments (Denys, 2013)

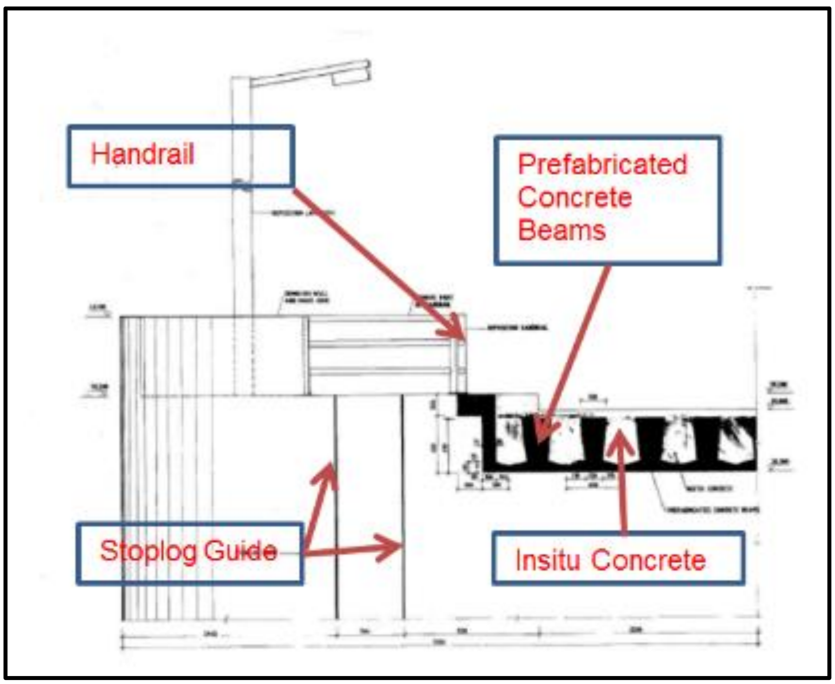


Figure 23: Typical Section through Main Spillway Showing Deck Slab (Denys, 2013)

4.2.3. Otjivero dam

The Otjivero dam (**Figure 24**) is a mass concrete multiple arch buttress dam, completed in 1984 and its main purpose is to impound water on the white Nossob River for the domestic use of Gobabis. It is located about a 100 km west from the town of Gobabis in the Otjozondjupa Region. An aerial view of the Otjivero dam is shown in **Figure 25**. The main dam wall is composed of an uncontrolled spillway in the middle, between an accessible non-overspill crest (**Figure 26**). The total height of the dam is 16 m and its capacity is estimated at 18 million m^3. A concrete apron Slab is provided at the dam toe (**Figure 27**).

Figure 24: Otjivero Dam Wall

Figure 25: Otjivero Dam Components

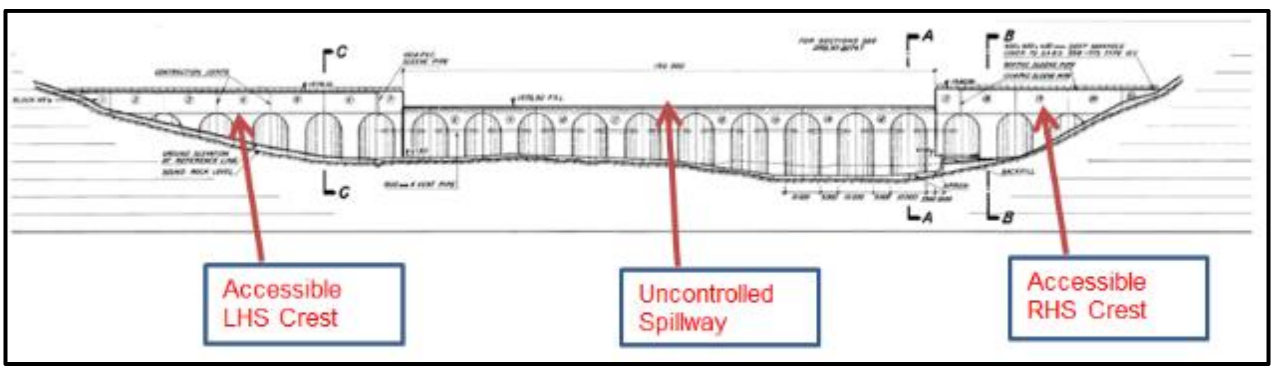


Figure 26: Otjivero Dam Downstream Elevation

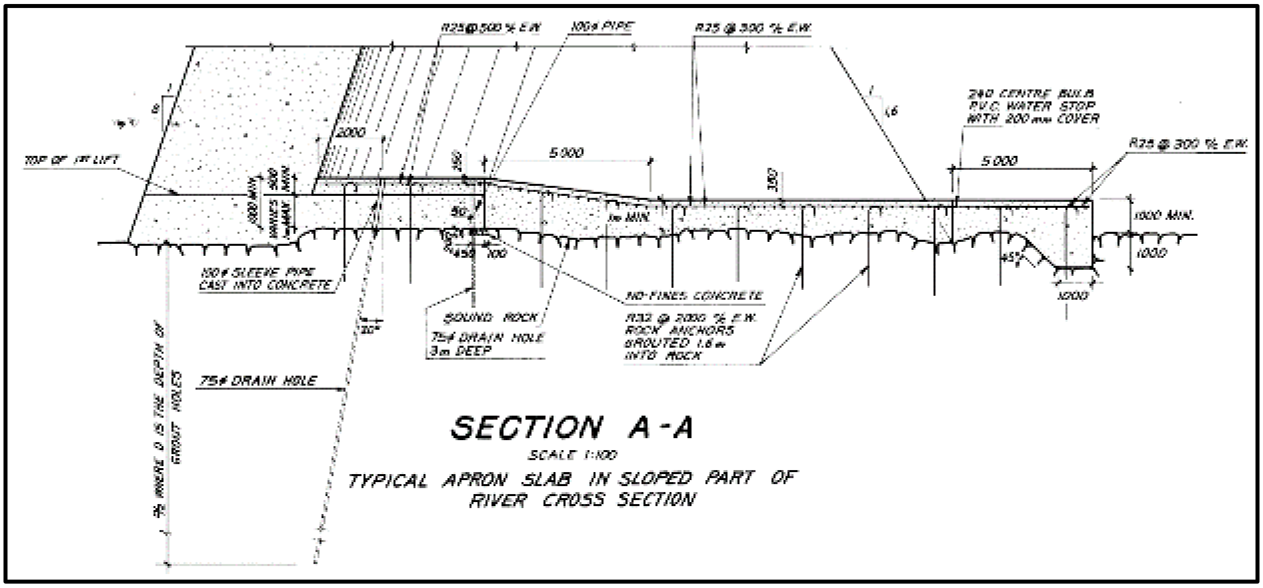


Figure 27: Otjivero Dam Apron Slab Cross-Section

4.3. Rating of dam surface defects using the DER rating system

Visual inspections were carried out for the three dams identified. The guiding tables devised in section 4.1 were then used for rating the various items inspected. The rating of the identified defects using the DER rating system for the selected dams is as follows:

4.3.1. Oanob dam

4.3.1.1. Spillway section and apron slab

For this dam, there is no spillway section at the main dam wall as can be seen from the dam cross-section drawing (**Figure 20**), which only shows the dam foundation extends. This is because the spillway section is provided elsewhere away from the dam. As a result, there is also no apron slab on the downstream, and even if there was an apron slab on the downstream, inspecting it was not going to be possible due to ponding on the downstream. As a result, the DER rating for the bridge equivalent of the spillway section and apron slab was purely going to be a U rating.

4.3.1.2. Dam wall (downstream)

Table 26: Oanob Dam: Dam Wall (downstream) DER Ratings

Dam Item 3: Dam Wall (Downstream)			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)		No clear visible signs of spalling could be identified on the dam. There was however some lime leaching, especially between the horizontal lift joints.
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(2, 2, 1 - 0)		Random cracks of varying widths (range 03-06mm) on downstream dam wall. May be attributed shrinkage and potentially ASR.

4.3.1.3. Dam wall (upstream)

Table 27: Oanob Dam: Dam Wall (upstream) DER Ratings

Dam Item 3: Dam Wall (Upstream)			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)	 	No clear visible signs of spalling could be identified on the dam.
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(1, 1, 1 - 0)		Minor Random hairline cracks on downstream dam wall. May be attributed shrinkage during construction stage

4.3.1.4. Dam wall foundations

Table 28: Oanob Dam: Dam Wall Foundations DER Ratings

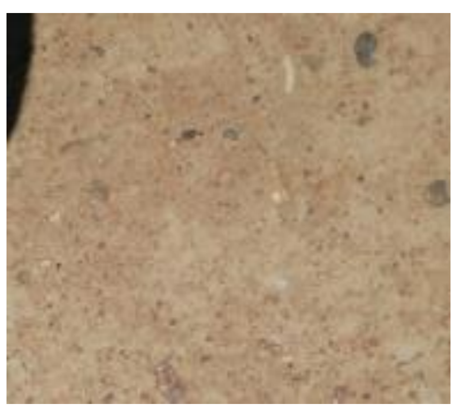
Dam Item 4: Dam Wall Foundations			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)	 	Unable to inspect due to the fact that the foundations are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect due to the fact that the foundations are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect due to the fact that the foundations are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream construction stage

Table 29: Oanob Dam: Dam Wall Foundations DER Ratings (Continued)

Dam Item 4: Dam Wall Foundations			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(U, , - R)		Unable to inspect due to the foundation are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream construction stage
Scour of foundations	(0, , - R)		No visible signs of scouring of foundations as the abutment-dam interface protection works are properly covering the foundations.

4.3.1.5. Dam crest

Table 30: Oanob Dam: Dam crest (Top of Crest) DER Ratings

Dam Item 5: Dam Crest (Top of Crest)			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(4, 3, 1 - 0)	 	Crack along the centreline of road of large width. Depth to be ascertained by further tests. Intersecting cracks at the middle of expansion joints may indicate inadequate expansion joint spacing
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(0, , - R)		No visible signs of honey-combing
Lack of cover to reinforcement	(0, , - R)		No visible signs of exposed reinforcement
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)		No visible signs of spalling even though abrasion/weathering of the concrete due to water is visible by the exposed aggregate stones

A crack is visible along the centreline of the crest with intersecting transverse cracks at half the distance between the joints. The transverse cracks may be attributed to expansion due to insufficient spacing of joints between the concrete blocks. However, on the other hand, major cracks are also identifiable within the gallery at fairly regular intervals (**Figure 28**). It could not be ascertained if the transverse cracks noticed on the dam crest are the ones protruding all the way through to the gallery or not, as their depth could not be ascertained.

Figure 28: Cracks within the Oanob Dam Gallery

Discussion on the inspection of the Oanob dam:

For the Oanob dam, of a possible 13 identifiable defects from the guiding tables, four (30%) where deemed as either inapplicable to the dam items or could not be inspected and where thus given a U or X rating. There are six defects items (46% of the total identified defects) that were given a 0 rating as no defects could be identified. As a result, there were only three defect items for which quantifiable ratings could be applied. However, these three defects all had a relevancy rating of one or less, which means that the relevance of these defects to the structural integrity of the dam is insignificant. This may however be misleading. For instance, despite there being no visible signs of major defects from the visual inspection of the dam-abutment interface that would have resulted in movements of the dam wall, the various diagonal cracks identified in the gallery may indicate some movement in the foundations of the structure. An addition to the guiding tables that would allow for the assessment of defects within the gallery would have covered this gap that results in such valuable defect information being missed. One may thus also attribute the low relevancy of the identified defects to the fact that the guiding tables used are meant for bridges and will thus require modification to ensure all dam defects rated appropriately.

4.3.2. Hardap dam

4.3.2.1. Spillway section and apron slab

Due to the ponding of water downstream, it was not possible to inspect the apron slabs. Additionally, despite being able to view the spillway from the top, a close up view of the concrete was not possible due to difficulty in accessibility. Thus the visual inspection of the spillway is highly reliant on the quality of the pictures taken from the top. Further inspection may be required possibly by capturing close up images with the use of drone technology.

Table 31: Hardap Dam: Spillway Section and Apron Slab DER Ratings

Dam Item 2: Spillway Section and Apron Slab			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)		No visible signs of spalling even though abrasion/weathering of the concrete due to water is visible by the exposed aggregate stones
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(0, , - R)		Due to accessibility restrictions, the item was inspected from a distance and the photos were also taken from a distance. As a result, and as evident from the photograph taken, there was no visible signs of shrinkage or AAR cracks
Scour or erosion of waterway	(U, , - R)		Unable to inspect due to downstream water/ponding
Flood debris accumulation	(0, , - R)		No visible signs of the accumulation of flood debris
Defective scour protection works	(U, , - R)		Unable to inspect due to downstream water/ponding

Whilst no major defects could be identified on the spillway section, there is however some growth of grass on the spillway section.

4.3.2.2. Dam wall (downstream and upstream)

The Hardap dam is primarily an embankment dam with the concrete part being only the spillway section (**Figure 29**). The spillway section has been evaluated under sub-section 5.4.2.3. Additionally, no defects were identified on the upstream side of the concrete spillway (**Figure 30**).

Figure 29: Hardap Dam Spillway and Embankments

Figure 30: Hardap Dam Upstream of Spillway Section

4.3.2.3. Dam wall foundations

Table 32: Hardap Dam: Dam Wall Foundations DER Ratings

Dam Item 4: Dam Wall Foundations			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect as the foundations are r fully submerged in water both on the upstream and downstream
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect due
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(U, , - R)		Unable to inspect
Scour of foundations	(U, , - R)		Unable to inspect due

4.3.2.4. Dam crest

Table 33: Hardap Dam: Dam Crest (Top of Crest) DER Ratings

Dam Item 5: Dam Crest			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(4, 3, 2 - 0)	  	Random cracks of widths greater than 0.6mm across dam slab on dam crest. Primarily attributed to Shrinkage and possibly AAR.
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(0, , - R)		No visible signs of honey-combing
Lack of cover to reinforcement	(0, , - R)		No visible signs of exposed reinforcement
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)		No visible signs of spalling

Random cracks are all over the slab over the sluice gates and have large widths as measured on the surface. Additional investigations such as core drilling may be required to ascertain the depth of these cracks. Whilst the imminent risk to structural failure is low, the continuous monitoring may be required as this may be attributed to ASR or Thermal loads. Additionally, the dam structure is more than 50 years old and some of the defects are possibly due to aging.

Discussion on the inspection of the Hardap dam:

Of the total identifiable defects in the devised dam equivalent guiding tables, seven (50%) were given a U or X rating as they either could not be inspected or were deemed inapplicable for the Hardap dam. Six of them (42%) were given a 0 rating as no visible defects were identified. This means that only one identifiable defects, the cracks on the deck slab of the dam crest, was given a quantifiable rating for the Hardap dam. It was also observed that none of the identifiable defects for the Hardap dam had a relevancy rating higher than 0, signifying the low relevance of the defects on the structural integrity of the dam. Again, as with the Oanob dam, this may give a perception that there are no major defects on the Hardap dam elements.

4.3.3. Otjivero dam

4.3.3.1. Spillway section and apron slab

Table 34: Otjivero Dam: Spillway Section and Apron Slab DER Ratings

Dam Item 2: Spillway Section and Apron Slab			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(4, 4 ,1 - R)		Longitudinal crack at mid-span of each apron slab panel highly attributed to inadequate expansion joint spacing.
Scour of Outlet Structures	(2, 2 , 1- 1)		Unable to inspect due to the fact that the foundations are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream
Scour or erosion of waterway	(1, 2 , 2- 1)		Unable to inspect due to the fact that the foundations are either fully covered by the stone pitching on the abutment-dam interface or fully submerged in water both on the upstream and downstream

Table 35: Otjivero Dam: Spillway Section and Apron Slab DER Ratings (continued)

Dam Item 2: Spillway Section and Apron Slab			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Flood debris accumulation	(0, , - 0)		Other than the loose rocks on the outlet of the apron slab, there is no accumulation of flood debris
Defective scour protection works	(3, 2 , 1- 0)		Despite the absence of scour protection works, the scour defects are minimal due to the loose rocks and the underlying rock formation

4.3.3.2. Dam wall (downstream)

Table 36: Otjivero Dam: Dam Wall (downstream) DER Ratings

Dam Item 3: Dam Wall Downstream			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Spalling (All loose concrete must be broken away to expose extent of spall)	(1, 1, 1 - 0)		Minor spalling/delamination identified on the wall particularly at the vertical joints, associated marks reminiscent of leakages or leaching of substances.
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(2, 4, 1 - 0)	  	Vertical cracks of varying widths (range 0.4-0.6mm) on downstream dam wall. May be restraint cracks and potentially AAR. The inadequacy in expansion joints spacing may be a contributing factor. This is exhibited on almost all the buttress sections.

4.3.3.3. Dam wall (upstream)

Table 37: Otjivero Dam: Dam Wall (upstream) DER Ratings

Dam Item 3: Dam Wall Upstream			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Spalling (All loose concrete must be broken away to expose extent of spall)	(U, , - R)		Unable to do a proper visual inspection due the presence of water on the upstream. However, visible from a distance, there are no clear visible signs of spalling identified on the dam.
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect due the presence of water on the upstream

4.3.3.4. Dam wall foundations

Table 38: Otjivero Dam: Dam Wall Foundations DER Ratings

Dam Item 4: Dam Wall Foundations			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , - R)		Unable to inspect as the foundations are covered by the apron slabs downstream and the water upstream
Shear cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , -)		Unable to inspect as the foundations are covered by the apron slabs downstream and the water upstream
Bending cracks (Crack should be cleaned. Its width and if possible its depth ascertained)	(U, , -)		Unable to inspect as the foundations are covered by the apron slabs downstream and the water upstream
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(U, , -)		Unable to inspect as the foundations are covered by the apron slabs downstream and the water upstream
Scour of foundations	(0, , - R)		Unable to inspect as the foundations are covered by the apron slabs downstream and the water upstream

4.3.3.5. Dam crest

Table 39: Otjivero Dam: Dam Crest (Top of Crest) DER Ratings

Dam Item 5: Dam Crest			
Defect	**Rating (D,E,R-U)**	**Picture**	**Comment(s)**
Shrinkage and restraint cracks including AAR (Crack should be cleaned. Its width and if possible its depth ascertained)	(4, 3, 2 - 0)	 	A longitudinal crack is visible along the non-overspill crest. Needs further investigation.
Honeycombing (If possible, areas of honeycombed concrete must be removed to expose full extent of damage)	(U, , - R)		No visible signs of honey-combing
Lack of cover to reinforcement	(0, , - R)		No visible signs of exposed reinforcement
Spalling (All loose concrete must be broken away to expose extent of spall)	(0, , - R)		No visible signs of spalling

A crack is visible along the centreline of the eastern dam crest. Even though the crack looks dormant, its cause and depth could not be ascertained. Further investigation may be required to ascertain the actual cause and how deep it penetrates into the dam crest.

Discussion on the inspection of the Otjivero Dam:

For the Otjivero dam, seven (38%) of the identifiable defects indicated in the guiding tables devised for the dam equivalent items were given a U or X rating as they either could not be inspected or were deemed not applicable. Another three (16%) were assigned a 0 rating since no such defects were identified. As a result, only eight identifiable defects were given quantifiable ratings, which is ±88% more than was the case for the Oanob dam and ±63% more than the Hardap dam. This is a possible indication that applying the DER rating on more dam structures of varying size and type may give a more diversified and informed idea about its applicability. However, as with the other dams inspected, the relevance of the majority of the identified defects on the structural integrity of the dam is very low. This may also be attributed to the fact the guiding tables in the TMH19: Part B that were used are devised specifically for bridges. Differences in the design, functionality and relevance of defects between dams and bridges make these tables less suitable for application to dams in their original form.

4.3.4. SWOT Analysis of the DER rating System on dam surface defects

The SWOT analysis shown in **Table 40** gives a concluding summary on the applicability of the DER rating system on the surface defects of the assessed dams.

Table 40: SWOT Analysis of DER rating system on dams

Strengths	Weakness	Opportunities	Threats
1. Ease of applicability	1. Unable to accommodate all dam defects in its original state	1. Can potentially result in a time efficient and unbiased approach for visually assessing the surface defects on dams, particularly in the initially stage	1. Acceptance by dam professionals who may be comfortable with the existing way of doing things
2. Standard approach to assessing the defects that is able to offer guidance to the inspector.	2. Weighting of the ratings have to be relevant to the dam defects to ensure defects of relevance are considered	2. Has the potential for the inclusion of dam surface defects in dam risk determination.	
3. Flexibility in applying to dams of various designs.	3. Most of the defects items in the TMH19 guiding tables are not relevant to the dam elements	3. Has the potential for improving the prioritization of the various dam structures for maintenance and repairs as well as prioritization of further investigations.	
		4. Can potentially be applied on other NamWater structures such as the concrete potable water storage reservoirs made of reinforced concrete.	

5. Conclusions

NamWater has established an asset management framework that includes the asset management policy, asset management strategy, asset management objectives and the asset management plans. This should pave the way for the implementation of asset management tools such as the use of the rating systems for the visual assessment of the dam surface defects.

NamWater's current approach to dam safety is in line with international best practice approaches, mostly due to their alignment to the South African DWA dam safety regulations. This approach is highly risk based and is focused on dam risk determination based on probability of failure and impact of failure. The current approach employed by NamWater is primarily the undertaking of dam safety evaluations for the major dams. The dam safety evaluations involve conducting visual inspections to identify defects on the dam elements by approved dam inspectors, who then make recommendations on repair and maintenance to be considered by the decision makers. Whilst the current dam safety management approach used by NamWater may have performed well over the years, there is however no standardised and guided approach to executing the visual inspections other than evaluating the dam items on the dam inspection checklist, to the discretion of the inspector. As a result, this study assessed the applicability of the DER rating system on three of NamWater's concrete dams.

The Oanob dam had 46% of the defects given a 0 (none or no defects) rating, meaning these defects were not identified on the respective dam inspection items. These defects include the spalling of the concrete, honeycombing and lack of cover to reinforcement. The reason for not finding such defects may be attributed to the fact that Oanob dam is primary made of mass concrete rather than the reinforced concrete for which most bridge structural elements are composed of. Defects on the dam wall foundations were not inspected since the foundations were covered by water both on the upstream and downstream of the dam wall. This defects were thus given a U rating. The most severe defects identified on the Oanob dam was the shrinkage and restraint cracks on the concrete components of the dam wall. However, these defects have a low relevance to the overall stability of the dam structure, hence the low relevancy (R) rating.

Shrinkage and restraint cracks on the dam crest were the most successfully rated defect on the Hardap dam wall. The rest of the surface defects were mostly either unidentifiable, inapplicable or the dam item could not be inspected. The unidentified defects include the spalling, shrinkage and the non-concrete defects such as scour, debris accumulation and defective scour protection works on the dam spillway for which a 0 rating was given. The inability to identify most of these defects was due to restrictions in accessibility to the dam spillway, which resulted in the inspection being undertaken from a distance. The bulk of the defects which were given a U (unable to inspect) rating are on the dam wall foundations and the apron slab. These items could not be inspected due to the pool of water on the downstream and upstream sides of the dam wall. The relevancy ratings for most of the defects on the Hardap dam are however very low, with the most relevant defect being the restrain cracks on the deck-slab of the dam crest.

For the Otjivero dam, 38% of the identifiable defects indicated in the guiding tables used for the dam equivalent items were given a U or X rating as they either could not be inspected or were deemed not applicable. Defects with these ratings on the Otjivero dam includes the spalling and shrinkage cracks on the upstream face of the dam wall. The lack of access to the upstream face of the dam wall by the inspector due to the impounded water was the main reason for the U or X ratings. On the downstream face of the dam wall with better accessibility, the spalling and shrinkage cracks were successfully assessed and given quantifiable ratings. The foundations on the Otjivero dam are covered by the apron slab on the downstream side and by the pool of water on the upstream and could thus not be inspected for defects such as the shrinkage, shear, bending and honeycombing, hence the U or X defects ratings. While the most severe defects identified on the Otjivero dam is the shrinkage and restraint cracks, they had low relevancy ratings compared to the non-concrete defect items such as the scour of the outlets structures or the defective scour protection works.

This study was able to demonstrate the possibility of applying the DER rating to the visual assessment of dam defects. It was however found that, for the three dams considered under this study, most of the identified surface defects have a low relevance on the structural integrity of these structures. This is particularly true for most of the concrete surface defects such as the spalling, honeycombing, lack of cover to reinforcement, shear and bending cracks have in general produced low degree and relevancy ratings across the three dams assessed. The fact that the original guiding tables used are derived specifically for bridge items may be the reason, as they may not cover all the defects that are specific for dams. Furthermore, the weighting of the DER ratings in the TMH19 guiding tables are not entirely suitable for the actual defects on the equivalent dam items, in line with their relevance. For instance, a certain scour depth on a bridge outlet structure may have a greater effect on the bridge structure than the effect that the same amount of scour depth will have on the dam apron slab or the dam wall.

For the DER rating system to be fully applicable for dam defects, there is thus a need to review and devise the inspection items in the TMH19 guiding tables to suit the dam items in terms of the defects and the weighting of the ratings. A database of dam defects collected over time may contribute meaningfully to the development of guiding tables specific for dam elements, coupled with the traditional engineering judgement from experienced dam inspectors. This could then be used for assessing and rating defects in the same vein as the tables in TMH19 used for the DER rating system. There is also some general indication that testing the DER rating on more dam structures of varying size and type may give a more diversified evaluation of its applicability as can be seen from the varying rating outcomes for the three dams assessed.

The ratings for non-concrete defects such as the scour of outlets, accumulation of flood debris and defective scour protection works do however yield higher relevancy ratings for the three dams assessed than the concrete defects. If the DER rating system can be modified and refocussed to include the specific defects of the dam elements, then it may as well contribute to the condition of assessment of dam surface defects for NamWater as a standard approach to inspecting dam surface defects. Due to the inevitable possibility of varying ratings from different assessors, the validation of DER rated dam inspection data may still be required to ensure its integrity and completeness, similar to when used on bridges. As a result, dam expertise and experience will still be required when the DER rating system is to be used for dams. The use of the DER rating system does however have the potential to reduce such variations since the assessors are using guiding tables.

Furthermore, the concrete surface defects such as spalling, shear cracks, bending cracks and lack of cover to reinforcement are common on NamWater's other structures such as the potable water storage reservoirs. Chances are that the applicability of the DER rating system to NamWater's concrete reservoirs, particularly in the coastal areas where they are prone to chloride attacks, may yield more successful ratings of these defects. This is due to the fact the reservoirs are for the most part constructed with reinforced concrete than would a gravity concrete dam, for which mass concrete is the primary material used.

6. Recommendations

The research recommends as follows:

- A study should be considered for the creation of a historical dam defects database and the development of guiding tables similar to those in TMH19 that are specific for dam defects.
- Revisiting of the weighting of the DER ratings to suit the defects on dams based on their potential modes of failure is recommended. This should be guided by expert engineering judgement through discussions in task groups or through follow up research.
- Assessment of more dams with varying defects using the DER rating system to get a more diversified evaluation of its applicability. This assessment should go as far as investigating the performance of using the DER rating system for dam safety management.
- The outcome of this study should serve as a stepping stone to devising the DER rating system to be fully usable for the visual assessment of dam defects and eventually the prioritisation of repair and maintenance work.
- A study that focuses on applying the DER rating for assessing concrete surface defects on NamWater's potable storage reservoirs should also be considered. This is likely to yield more successful ratings on the concrete surface defects since the potable water storage reservoirs are primarily made of reinforced concrete as opposed to the mass concrete used on the dams under this study. This is in consideration of the fact that DER rating system was originally devised for bridges, for which the structural elements are primarily made of reinforced concrete.

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8. Appendices

Appendix A: ACI 201.1R-08 Visual Inspection Form

1. GENERAL	Report number		
	Purpose of inspection		
	Inspector's name(s)		
1A. DESCRIPTION OF THE STRUCTURE	Name		
	Location		
	Type		
	Size		
	Owner		
	Project engineer		
	Contractor		
	Date(s) of construction		
	Photographs	General view	
		Detailed close-up of condition of area	
	Sketch map orientation indicating sunny and shady areas and well and poorly drained regions		
1B. MATERIALS USED (if known)	Concrete	Normal weight aggregate type	
		Aggregate size	
		Admixture type	
		Mixture proportion	
		Compressive strength	
		Modulus of elasticity	
2. NATURE OF ENVIRONMENTAL AND LOADING CONDITIONS	Exposure	Environment (arid, subtropical, marine, freshwater, industrial, etc.)	
		Weather (July and Jan. mean temperatures, mean annual rainfall, and months in which 60% of rainfall occurs)	
		Freezing and thawing	
		Wetting and drying	
		Drying under dry atmosphere	
		Chemical corrosion and attack (sulfates, acids, bases, chloride, gases)	
		Abrasion, erosion, cavitation, impact	
		Electric conductivity	
		Deicing chemicals that contain chloride ions	
		Heat from adjacent sources	
	Drainage	Flashing	
		Joint sealants	
		Weepholes	
		Contour	
		Elevation of drains	
	Loading conditions	Dead	
		Live	
		Impact	
		Vibration	
		Traffic	
		Seismic	
		Other	
	Soils (foundation conditions)	Expansive soil	
		Compressible soil (settlement)	
		Evidence of pumping	

3. DISTRESS INDICATORS	Cracking			
	Staining			
	Surface deposits and exudations			
	Leaking			
4. PRESENT CONDITION OF STRUCTURE	Overall apparent alignment of structure	Settlement		
		Deflection		
		Expansion		
		Contraction		
	Surface condition of concrete	General condition: good, satisfactory, poor		
		Formed and finished surfaces	Smoothness	
			Bug holes (Surface air voids)	
			Sand streaks	
			Honeycomb	
			Soft areas	
			Cold joints	
			Staining	
		Cracking	Location and frequency	
			Crack map	
			Width and pattern	
			Leaching, stalactites	
			Working versus nonworking (dormant)	
		Scaling	Area, depth	
			Type	
		Spalls and popouts	No., size, and depth	
			Type	
		Stains, efflorescence		
		Exposed reinforcement: corrosion		
		Curling and warping		
		Erosion	Abrasion	
			Cavitation	
		Previous patching or other repair		
		Surface coatings, protective systems, linings, toppings	Type and Thickness	
			Bond to concrete	
			Condition	
		Penetrating sealers	Type	
			Effectiveness	
			Discoloration	

Appendix B: Inspection form B1: Bridge (General)

ROAD AUTHORITY	STRUCTURE TYPE	BRIDGE NUMBER	LOCATION SKETCH
	BRIDGE - GENERAL		
		BRIDGE NAME	

INSPECTION INFORMATION			
Inspection Type	Inspector Name	Firm	Date (dd/mm/yyyy)

GPS COORDINATES - START					
Latitude (South)			Longitude (East)		
DD	MM	SS.s	DD	MM	SS.s

GPS COORDINATES - END					
Latitude (South)			Longitude (East)		
DD	MM	SS.s	DD	MM	SS.s

VERTICAL CLEARANCES (road-over-road bridges only)						
Position/Span No						
Min height (m)						

LOCATION DETAIL					
Road No.	Road km	Road Name	Feature Crossed	Feature Name/Road No.	Region/Depot

STRUCTURE INFORMATION						
No. of Spans	Structure Orientation	Overall Length	Overall Width	Year Constructed	Bridge Type	

INSPECTION RATINGS

INSPECTION ITEM		1. APPROACH EMBANKMENT			2. GUARDRAIL			3. WATERWAY			4. APPROACH EMB. PROT WORKS			5. ABUTMENT FOUNDATIONS			6. ABUTMENTS			7. WING / RETAINING WALLS			8. SURFACING			9. SUPER-STRUCT. DRAINAGE		
POSITION		D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	D	E	R
Abut																												
Abut																												

INSPECTION ITEM	10. KERBS / SIDEWALKS			11. PARAPET / HANDRAIL			21. MISC. ITEMS		
	D	E	R	D	E	R	D	E	R

INSPECTION ITEM		12. PIER PROTECTION WORKS			13. PIER FOUNDATIONS			14. PIERS & COLUMNS			15. BEARINGS			16. SUPPORT DRAINAGE			17. EXPANSION JOINTS			INSPECTION ITEM		18. LONGITUDINAL MEMBER			19. TRANSVERSAL MEMBERS			20. DECK SLAB		
POSITION		D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	D	E	R	POSITION		D	E	R	D	E	R	D	E	R
Abut																				Span										
Abut																				Span										
Pier																				Span										
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ITEM	POSITION	ACTIVITY CODE or DESCRIPTION	QTY	Unit	U	Make safe	REMARKS	Rpt. Photo	Mon freq

Inspector's assessment and further comments:

FURTHER INSPECTION REQUIRED ? Y/N		IF FURTHER INSPECTION REQUIRED IS "Y" Then please indicate any special requirements ie. 6m Ladder, Bush cutting, UBIU, better weather etc. If nothing please state "none"	
Was UBIU used ? Y/N			
Is the UBIU needed for future inspections? Y/N			

D - DEGREE							E - EXTENT				R - RELEVANCY				U - URGENCY					
Not Applic-able	Unable to inspect	None	Minor	Mode-rate	Warning	Severe	Local	More than local	Less then general	General	Min	Moderate	Major	Critical	Record only	Monitor only	Routine	< 10 yrs	< 5 yrs	ASAP
X	U	0	1	2	3	4	1	2	3	4	1	2	3	4	R	0	1	2	3	4