RATING OF DAM SAFETY DEFECTS

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1 Introduction

1.1 Background

Svenska Kraftnät (the central authority on dam safety in Sweden) in co-operation with Svensk Energi (the Swedish electricity production, transmission and distribution industry association) have established a proposal for a standardised rating scheme for dam safety defects. The system is intended to be utilised by dam owners in their monitoring of dam safety in conjunction with activities such as comprehensive dam safety evaluations (design reviews) and in-depth inspections. This system could furthermore be utilised to evaluate defects, malfunctions, and other changes detected outside regular monitoring activities. The scheme provides a common terminology that should, among other things, facilitate communications between various parties concerned with dam safety.

This scheme is to be utilised when evaluating defects related to a dam facility. Application instructions have been produced for this purpose. An evaluation of the scheme itself will be carried out in the winter of 2005, before the inspections of 2006 begin.

The initial ambition was to create a scheme for the classification of technical performance defects as well as organisational non-conformances and incidents affecting dam safety. During the outlining of this rating scheme it was realised that although organisational issues may have an important influence on dam safety, it was not appropriate to evaluate them according to the same scheme as performance defects. It has also been realised that incidents could usually be related to a defect and therefore could also be evaluated according to this standardised rating scheme, if caused by a performance defect. Consequently this rating scheme has been limited to technical performance defects only.

Section 1 of this document provides a short description of the structure and utilisation of the rating scheme.

1.2 Application of the rating scheme

Regardless of how a functional defect has been detected, it should be thoroughly documented. It is then important to determine if the defect affects **dam safety**. If it does not, but could have other impacts such as work-place safety or maintenance issues, then it should not be classified according to this scheme.

Application of the rating scheme begins with the assessment of each deficiency, and subsequent classification of each deficiency into one of five established evaluation categories (A1 to A5) according to a 5-grade rating scale. Establishment of a dam safety rating begins with determination of the extent of the deficiency in accordance with criterion A.

- A - The degree to which the defect results in a discrepancy between the existing condition and the desired or intended condition

Rating of a defect according to criterion A takes into consideration the extent to which the defect results in a discrepancy from the intended condition or performance of the component or system in question.

The extent of the discrepancy is evaluated according to a 5-grade scale, A1 – A5, with A5 being the most serious deficiency. The extent of the observed deficiency is established

through an evaluation performed by a qualified individual, with attention being given to causative connections and the risk of progressive deterioration. This evaluation could be made either for defects of individual components, or for combined defects affecting a certain system or part of a dam.

A	Extent of discrepancy
A5	Very large discrepancy
A4	Large discrepancy
A3	Moderate discrepancy
A2	Small discrepancy
A1	Very small discrepancy/no remarks

The next step is to consider three supplementary evaluation criteria; B, C, and D as defined below:

- B – The importance of the component/subsystem for the proper performance of the dam

Rating of the defect according to criterion B takes into consideration the importance of the function of the affected component with respect to preserving the proper function of the dam, and its discharge facilities. Furthermore built-in safety barriers and redundant systems, such as various reserve systems, should be considered.

- C – Frequency of loading

Rating of the defect according to criterion C takes into consideration how often loads, or other related circumstances, could occur that may lead to a dam safety problem as a result of the defect.

- D – Possibility to monitor the deterioration process and to take measures against progression to dam failure

Rating of the defect according to criterion D takes into consideration the possibility of monitoring the status of the defect, and/or the progression of deterioration that may result from the defect. This criterion also includes consideration of the possibility of implementing actions to prevent dam failure.

Each of these three supplementary evaluation criteria is considered according to a 5-grade rating scale, 1 – 5, with 5 being the most serious from a dam safety point of view. For all of these criteria a rating of 1 implies that the defect does not, considering the particular circumstances, constitute a dam safety problem.

The rating of a defect, based on A1-A5, is then combined with the supplementary criteria ratings, B1-B5, C1-C5 and D1-D5, to produce a dam safety rating BK1-BK5 (in Swedish; "**b**edömnings**k**lass"). The rating BK5 is the most serious from a dam safety point of view and BK1 the least serious.

BK	Dam safety rating
BK5	Very large importance to dam safety
BK4	Large importance to dam safety
BK3	Moderate importance to dam safety
BK2	Small importance to dam safety
BK1	Very small importance to dam safety

Initially the determination of the dam safety rating is based on criterion A. The further evaluation of criteria B, C and D allows determination of whether there are extenuating circumstances which would justify the possible downgrading of the initial dam safety rating. An evaluation key provides guidance as to the extent of a possible reduction of the dam safety rating, as justified by the supplementary evaluation criteria B, C and D.

1.3 Notes regarding a simplified application of the scheme

In some cases a simplified application of the scheme for the establishment of dam safety ratings could be used. According to this simplified application, the extent of the deficiency based on criterion A would lead directly to a dam safety rating BK. The possible reductions based on supplementary criteria B, C and D are not considered, thus leading to the same effect as a presumption that there are no extenuating circumstances.

As an example, this simplified application could be used on A1 and A2 deficiencies when a deeper analysis regarding the significance of a defect for dam safety is not justified. Similarly the simplified method can be used if the result of an overestimation of the dam safety rating of the defect has no significance. Deficiencies noted in the yearly report to the County Administrative Board (Länsstyrelsen) ought to be based on a detailed evaluation according to the complete scheme.

2 Application instructions for rating of functional defects

2.1 General

The concept “functional defects” is henceforth used as a generic term for:

- physical defects or flaws, i.e. deviations from an intended status or a status free of physical defects.
- deviations from guidelines and standards, i.e. conditions not corresponding to current requirements, which are sometimes more stringent than earlier requirements. Even if the installations have no physical defects or flaws, guidelines or standards could have been changed, implying that the installations no longer comply with requirements.

Functional defects are evaluated relative to the desired or intended status according to requirements, guidelines and established practices applicable at the time of the inspection. Evaluation of a functional defect according to the standardised rating scheme is carried out according to the steps below.

2.2 Describe the observed defect and related circumstances

The description of the observed defect should comprise documentation as to its location, the extent of the damage, possible causes and effects, as well as other pertinent information. Photographs and sketches could be attached to the description, when applicable. The progression of the damage is described, using reports from the latest in-depth inspection or any previous condition monitoring, and supplementary documents.

2.3 State in what way the defect has, or could have, significance

- Dam safety
- Other impacts such as work-place safety, economy, aesthetics, environment, or operation and maintenance not related to dam safety

Defects that affect dam safety should be evaluated relative to this standardised rating scheme. If it is not clear whether or not the defect could affect dam safety, then the defect should be classified in accordance with this scheme.

2.4 Evaluate the extent of the discrepancy from intended status or function

Evaluate the extent to which the defect produces a discrepancy from intended status or function of the component or subsystem in question. The extent of deficiency should express the extent of the gap between intended and actual status. The evaluation should consider:

- how far the deterioration has progressed: is it in an initial phase or has it progressed far, does the damage in its present state pose a threat to proper function, or could it over time develop into a threat to proper function?
- the extent of the damage: is it local or does it cover large areas?
- the cause of the defect: is it a normal degradation process or is it a process requiring more attention?

The extent of the discrepancy is evaluated according to a 5-grade scale, with 1 representing "very small" and 5 representing "very large" discrepancies.

Guidance for evaluation of the extent of the discrepancies is given in *Table 1*. Examples of the evaluation of functional defects related to embankment dams, concrete dams and discharge installations are provided in *Appendix 1, Examples*.

Table 1. Extent of discrepancies caused by functional defect

A	Discrepancy extent	Functional defect description
A5	Very large discrepancy	Very large deviation from requirements, far-progressed damage covering large areas, non-existent safety margins (safety factor about 1); also comprises systems out of function, lacking prerequisites for intended functioning or in a "state of decay."
A4	Large discrepancy	Large deviation from requirements, major damage covering large area, limited safety margins (safety factor slightly above 1), status unsatisfactory as to guidelines and standards.
A3	Moderate discrepancy	Moderate deviation from requirements, moderately progressed damage, but proper functioning could be increasingly affected in the long run; safety margins below expectations but considerably over 1.
A2	Small discrepancy	Small deviation from requirements, damage in early stage and limited, but proper functioning could be affected in the long run; safety margins slightly below requirements
A1	Very small discrepancy/ no remark	Insignificant influence on function, adequate safety margins, status generally in accordance with requirements and intentions

2.5 Evaluate significance of defect from a dam safety point of view

When the extent of discrepancy resulting from the defect has been established, its significance to dam safety should be evaluated. The evaluation should be made either for individual defects, or combined for a specific part of the dam or a system. This is carried out according to the instruction in section *2.6 Complete scheme* or according to *2.7 Simplified application of the scheme*. In the complete scheme, in addition to the extent of deficiency, other circumstances, so-called supplementary evaluation criteria, are also considered. The combined effects of the extent of deficiency based on criterion A considered together with the supplementary evaluation criteria results in a dam safety evaluation rating. In the simplified application, an evaluation rating is determined directly from the extent of the deficiency based solely on criterion A.

BK	Dam safety ratings
BK5	Very large importance to dam safety
BK4	Large importance to dam safety
BK3	Moderate importance to dam safety
BK2	Small importance to dam safety
BK1	Very small importance to dam safety

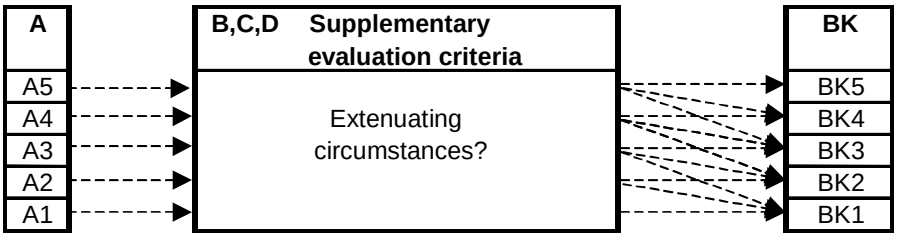
The complete scheme is designed in such a manner that application of the supplementary criteria will result either in a reduced rating (less serious) or in an unaltered rating. The

simplified application could be considered when a deeper analysis of the importance of the defect is not justified or when the potential overestimation that could result from the simplified method is of no significance.

In section *3 Examples* some examples describe how a rating could be carried out for some hypothetical defects using both the complete scheme, and the simplified application.

2.6 The complete scheme for establishment of dam safety ratings

Establishment of a dam safety rating begins with determination of the extent of the deficiency in accordance with criterion A. Using the three supplementary evaluation criteria B, C and D it is evaluated whether there are extenuating circumstances which justify a downgrading of the importance of the deficiency from that determined according to criterion A. The supplementary evaluation criteria can only result in an unaltered or less serious evaluation rating, compared to that resulting from the extent of the deficiency in accordance with criterion A.



The supplementary evaluation criteria relate to the following aspects:

B. The importance of the component/subsystem for the proper functioning of the dam - Rating of the defect according to criterion B takes into consideration the importance of the function of the affected component with respect to preserving the proper function of the dam and its discharge facilities. Furthermore built-in safety barriers and redundant systems, such as various reserve systems, should be considered. If there are safety barriers, additional functional defects must occur simultaneously to make the observed defect result in a dam safety problem.

C. Frequency of loading - Under criterion C the frequency of loads or other related circumstances that could result in the observed defect leading to a dam safety problem is considered.

D. Possibility to monitor the deterioration process and to take measures against progression to dam failure - Rating of the defect according to criterion D takes into consideration the possibility of monitoring the status of the defect, and/or the progression of deterioration that may result from the defect. This criterion also includes consideration of the possibility of implementing actions to prevent dam failure. The problems could be monitored for example by using instruments, or during inspections. Examples of preventive measures could include the lowering of the water level of the reservoir, reinforcement of the dam, or auxiliary opening of floodgates using hoisting cranes. The monitoring and preventive measures required to avoid a dam failure should be documented in the operation manual or emergency plan of the dam.

These three supplementary evaluation criteria are evaluated according to 5-grade scales, see *Tables 2 to 4*.

Table 2. Importance of the component/subsystem for the proper functioning of the dam

B	Importance of the component/subsystem for the proper functioning of the dam
B5	The component/subsystem is part of the dam itself or its discharge facilities and necessary for its proper functioning, and there are no built-in safety barriers or redundant systems
B4	The component/subsystem is part of the dam itself or its discharge facilities and necessary for its proper functioning, but there are built-in safety barriers or redundant systems
B3	The component/subsystem is part of a supporting or monitoring system connected to the dam or discharge facilities, but there are no built-in safety barriers or redundant systems
B2	The component/subsystem is part of a supporting or monitoring system connected to the dam or discharge facilities, and there are built-in safety barriers or redundant systems
B1	The component/subsystem normally is of no importance to the proper functioning of the dam or the discharge facilities

Table 3. Frequency of loading

C	Frequency of loading and other relevant conditions
C5	Loads and conditions occurring at least once/5 years
C4	Loads and conditions occurring once/5 years – once/50 years
C3	Loads and conditions occurring once/50 years – once/500 years
C2	Loads and conditions occurring less than once/500 years
C1	Loads and conditions normally not considered dam safety issues

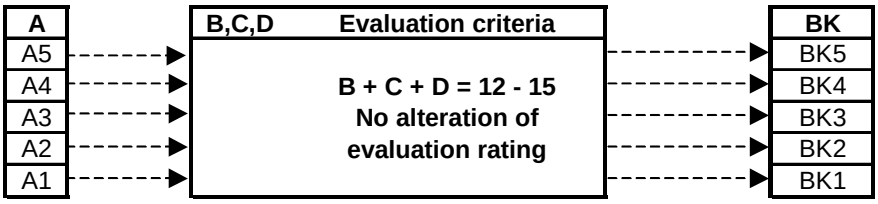
Table 4. Possibility to monitor the deterioration process and to take measures against progression to dam failure

D	Possibility to monitor the deterioration process and to take measures against progression to dam failure
D5	Damage may develop into a dam failure without being detected. Means to prevent a dam failure not available.
D4	Progress of damage difficult to detect in time and/or difficult to counteract. The possibility to prevent a dam failure exists only if favourable conditions are present.
D3	Conditions to detect progress of damage in time and/or take measures to prevent a dam failure are present
D2	Favourable conditions exist for early detection of damage and/or taking measures to prevent progress of damage.
D1	Preventive action not necessary; corrective measures normally taken when the situation arises

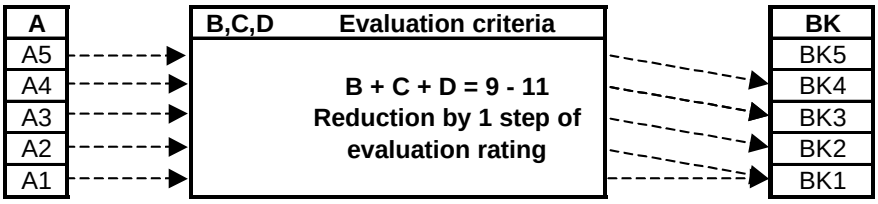
Criteria A-D are to be evaluated individually and the ratings that are assigned should be clearly justified. When adequate information for making a clear evaluation is not available, scale values could be stated as an interval. When making an evaluation it is recommended that the same information not be used as justification for more than one evaluation criterion. The extent of the deficiency, A1-A5, combined with the observations according to B, C and D, will result in a dam safety evaluation rating.

The summation of scale values 1-5 for evaluation criteria B, C and D will decide whether a **reduction** of the dam safety rating according to criterion A is allowed, or if the dam safety rating will remain the same. When establishing the evaluation rating, the following evaluation key for the summation of B, C and D is utilised.

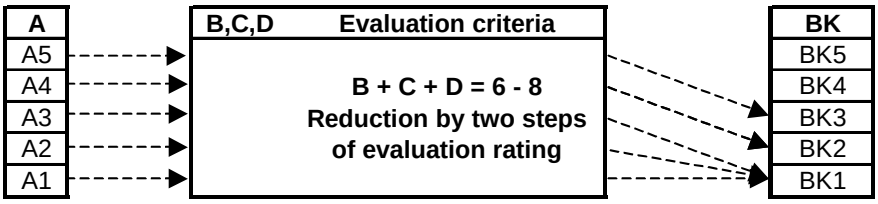
– A summation of 12-15 for B, C and D combined allows no reduction of the dam safety rating



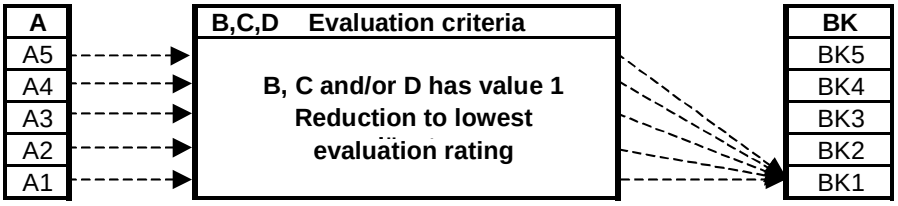
– A summation of 9-11 for B, C and D combined will allow reduction of the rating by one step



– A summation of 6-8 for B, C and D combined will allow a reduction of the rating by two steps



– If the evaluation of any one of the supplementary criterion B, C or D results in a scale value 1, then the dam safety rating is automatically reduced to BK1. The deviation may however have other impacts such as work-place safety of maintenance issues.



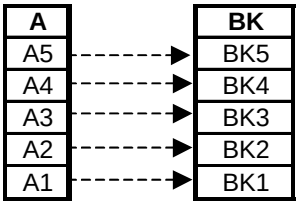
Documentation of the defects together with the individual criteria ratings and the resulting dam safety ratings can be summarized as shown in *Table 5*.

Table 5 Documentation of defects and ratings

Description of dam safety defect and justification for ratings A, B, C and D	A 1-5	B 1-5	C 1-5	D 1-5	Total B+C+D	BK 1-5

2.7 Simplified application of the scheme

When using the simplified application, the defect is placed in the same dam safety rating category (BK) as the rating according to criterion A.



Documentation of the resulting dam safety ratings can be summarized as shown in *Table 6*.

Table 6 Documentation of defects and ratings according to the simplified application

Description of dam safety defect and justification for rating A	A 1-5	B 1-5	C 1-5	D 1-5	Total B+C+D	BK 1-5
		X	X	X	X	
		X	X	X	X	
		X	X	X	X	

Defects reported to the County Administrative Board in the yearly report should be carefully evaluated according to the complete scheme.

3 Application examples

3.1 Example 1. Corroding steel cables in the hoisting gear of an outlet

3.1.1 Assumptions

The dam facility is an embankment dam with a hydropower station and a spillway. There are two gates at the spillway, one radial gate and one vertical lift gate. The radial gate hoisting gear consists of a winch with two steel cables attached to the upstream side of the gate. Preparations allowing the gate to be hoisted by a mobile crane have been made through the installation of eyebolts on the gate complete with lifting straps. The hoisting machinery of the vertical lift gate is a hydraulic cylinder.

The freeboard from maximum water level to the spillway crest and to the crest of the core in the embankment dam is 1 metre. The reservoir area is large, as compared to the catchment area. At the design flood inflow and no discharge the reservoir level will rise by 15 centimetres per 24 hours.

During an inspection it is observed that the steel cables are affected by corrosion and beginning to fray. There is no documentation as to when they were last replaced. The inspector concludes that their condition is a major deviation from requirements and that the safety margin is small. Based on this description the defect is evaluated as an A4 deficiency.

3.1.2 Establishing the dam safety rating

The following ratings are made with respect to the four evaluation criteria:

- A4 according to the previous description
- B4 considering that the gate is part of the discharge facility and that there is some redundancy in the system –the gate could be hoisted using a mobile crane if it is feared that the cables would break when it becomes necessary to use the gate to permit major discharge.
- C4 considering that a normal water inflow (5-year flood) could be handled by the vertical lift gate, but that the radial gate must be utilised at a 50-year flood.
- D2 taking into account that the rate of rise of the reservoir level is considered slow enough to allow replacement of the steel cables in case of a cable break, alternately to call up a mobile crane and have it hoist the gate.

According to the simplified application, the defect would be evaluated as having a dam safety rating of BK4 – very important to dam safety.

According to the complete scheme a review of extenuating circumstances under criteria B, C and D would result in a summation of B+C+D = 10. According to the evaluation key, the evaluation rating will be reduced by one step from the criterion A rating. The A4 rating combined with the total of 10 according to B, C and D would then result in the defect being evaluated as having a dam safety rating of BK3 – moderate importance to dam safety.

3.2 Example 2. Abnormal leakage in an embankment dam foundation

3.2.1 Assumptions

The dam facility is an embankment dam with a core of moraine and supporting fill of sandy gravel. The foundation is laid on a deep deposit of pervious granular soil and therefore an impervious blanket has been constructed on natural ground upstream of the dam. The regulating amplitude of the dam is considerable.

The monitoring system comprises v-notch weirs and open standpipe piezometers; with a measurement interval of once a week when the reservoir water level is high. Maximum possible drawdown rate is about 5 centimetres per hour. There is no contingency plan for sudden leakage and no local storage of reserve filling material.

Over the years seepage and water level measurement variations have been observed in the downstream area. The upstream impervious blanket has been extended and additional gravel fill has been placed on downstream areas where artesian water pressure has been observed.

During routine operational monitoring a significant increase of leakage is noticed in a v-notch weir, in addition a rise in water levels is observed in nearby in the standpipes. The leakage water is not turbid. The reservoir water level was normal at the time.

3.2.2 Establishing the dam safety rating

The following ratings are made with respect to the four evaluation criteria:

- A4 considering it is a major discrepancy from intended conditions, abnormal quantities of leakage (although not turbid) and high pore water pressure in the ground; the situation is monitored, although not continuously.
- B5 since the ability of the foundation to control the leakage is an indispensable part of the dam; there are no built-in redundancy systems.
- C5 considering the load is normal (normal reservoir water level)
- D4 since it is uncertain whether contingency action could halt the progress of the damage; the damage could escalate quickly (days) and at normal operational monitoring intervals, it could take a week before it is detected that the situation has grown worse; there is no contingency plan and a major lowering of the reservoir would take several days, up to weeks.

According to the simplified application, the defect would be evaluated as having a dam safety rating of BK4 – very important to dam safety.

Using the complete scheme a check of extenuating circumstances B, C and D would result in a summation of B+C+D = 14. According to the evaluation key, the evaluation rating will not be reduced from the criterion A rating. The A4 rating combined with the total of 14 according to B, C and D would then result in the defect being evaluated as having a dam safety rating of BK4 – Large importance to dam safety.

RATING OF DAM SAFETY DEFECTS

Appendix 1 Examples – extent of discrepancy

Introduction

The following examples illustrate how an evaluation of the extent of a discrepancy resulting from a defect may be rated relative to criterion A with regard to some functional defects on embankment dams, concrete structures, and discharge facilities. When utilising the scheme, a qualified individual should evaluate current conditions. It should be stressed that the following examples are only suggestion, and that actual situations must be evaluated relative to the existing conditions.

An evaluation of the scheme itself will be carried out in the winter of 2005, before the inspections of 2006 begin. During this evaluation, this collection of examples will also be reconsidered.

Example 1 - Erosion in the upstream slope of an embankment

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	Extensive damage, very large areas of rip-rap washed away and underlying transition zone, or shoulder material is exposed, or significantly undersized rip-rap where extensive damage could be expected in the event of a storm Extensive damage to the crest caused by large-scale wave run-up, or significant lack of freeboard where wave run-up could be expected to cause extensive damage in the event of a storm
A4	Large discrepancy	Major damage, rip-rap washed away, and underlying transition zone or shoulder material exposed in large areas, or undersized rip-rap where major damage could be expected in the event of a storm Major damage to the crest caused by wave run-up, or lack of freeboard where wave run-up could be expected to cause major damage to the crest in case of a storm
A3	Moderate discrepancy	Moderate damage to rip-rap or undersized rip-rap where moderate damage could be expected in the event of a storm Spray and some wave run-up, or lack of freeboard where some wave run-up could be expected in the event of a storm
A2	Small discrepancy	Small damage and movement of stones in the rip-rap Rip-rap or freeboard somewhat below requirement
A1	Very small discrepancy/ no remarks	Insignificant changes in rip-rap, acceptable conditions

Example 2 – Embankment dam leakage

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	Abnormal leakage with transport of material
A4	Large discrepancy	Abnormal leakage without transport of material
A3	Moderate discrepancy	Seepage not monitored
A2	Small discrepancy	Wet areas developing in downstream area
A1	Very small discrepancy/ no remarks	Normal, monitored seepage

Example 3 – Lack of stability in concrete dam

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	Non-existing safety margin (safety factor about 1)
A4	Large discrepancy	Large discrepancy from desired safety margins (safety factor slightly above 1)
A3	Moderate discrepancy	Safety margins lower than desired but clearly over 1
A2	Small discrepancy	Safety margins somewhat under desired level but very clearly over 1
A1	Very small discrepancy/ no remarks	Safety margins fulfils requirements

Example 4 – Damage to concrete structures

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	Exposed strength reinforcement in supporting parts of structure
A4	Large discrepancy	Exposed reinforcement in large area
A3	Moderate discrepancy	Moderate deterioration of concrete in large area, or cracks with leakage
A2	Small discrepancy	Surficial concrete damage or cracks that do not affect the carrying capacity of the structure
A1	Very small discrepancy/ no remarks	Insignificant concrete damage such as shallow surficial damage to the concrete, small cracks with lime depositing, micro-cracks in concrete surface

Example 5 –Discharge facility deficiency

(NB: When establishing the dam safety evaluation ratings it is advisable to make an evaluation of the combined impacts of defects affecting components or subsystems that are part of the same overall functional system.)

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	The defect is of very large importance to the ability to open the gate as intended during conditions when the system or component is put into action - gate or hoisting equipment with non-existing safety margins, significant corrosion in load-carrying parts, risk of a failure - disaster protection system not functional - auxiliary hoist not functional – gate de-icing systems and gate-sealing not functional, resulting risk of inoperable gate due to freezing
A4	Large discrepancy	Defect of large importance to the ability to open the gate as intended during conditions when the system or component is put into action – gate or hoisting equipment undersized (small safety margins), corrosion in load-carrying parts – mechanical parts insufficiently lubricated – large risk of hoisting gear cabin being hit by traffic, causing serious damage to gate manoeuvring system – large risk of unprotected equipment being tampered with by unauthorised persons – fuses under-sized for hoist machinery power supply
A3	Moderate discrepancy	Defect of moderate importance to the ability to open the gate as intended during conditions when the system or component is put into action - some degree of corrosion on load-carrying parts, function may be affected in the long run - gate heating system not satisfactory, low-temperature alarm missing – unsatisfactory location of cables, risk of damage
A2	Small discrepancy	Defect of small importance to the ability to open the gate as intended - corrosion in non load-carrying parts - unsatisfactory lighting - no fire and burglary alarm at the facility
A1	Very small discrepancy/ no remarks	Component or subsystem with functional defect or deviation from requirements which is insignificant in magnitude, functioning seen as satisfactory

Example 6 – Inadequate discharge capacity

	Extent of discrepancy	**Description of functional defect**
A5	Very large discrepancy	Very large deviation from requirements – discharge capacity less than 50% of required
A4	Large discrepancy	Large deviation from requirements – discharge capacity about 50-75% of required
A3	Moderate discrepancy	Moderate deviation from requirements – discharge capacity about 75-90% of required
A2	Small discrepancy	Small deviation from requirements – discharge capacity larger than 90% but less than required
A1	Very small discrepancy/ no remarks	Insignificant deviation from requirements – short, insignificant overflowing required to comply with discharge capacity requirements