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INSPECTION OF CONCRETE AND MASONRY DAMS

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INTRODUCTION

Safety evaluation of an existing concrete or masonry dam consists of a) a thorough review of records pertaining to the structural and hydraulic design, site geology, construction procedures, structural behavior based on instrumentation, and operation and maintenance, then b) an onsite inspection of the dam, followed by c) appropriate analysis of any unresolved issues. This discussion addresses the onsite inspection of concrete and masonry dams and presents information with regard to the recognition of potential dam safety concerns.

Visual examination is an essential tool by which the engineer, technician, owner or other responsible party can ascertain, first hand, indications of excessive stresses, strains, seepage, materials deterioration, and signs of foundation or structural instability. However, the presence of any of the deficiencies discussed does not necessarily indicate that there is a dam safety problem. Judgment is required based on an understanding of the deficiency, its cause, the short and long term effects, and how these might endanger the dam. Remember, an examination is not usually made under maximum loading conditions, thus an examiner must visualize how these more severe conditions could aggravate any concerns that are observed. The presence of any deficiency should be documented, and if there is any doubt about the effect of the condition on the dam, further investigation should be recommended.

TYPES OF CONCRETE DAMS

In examining concrete dams and evaluating their condition with regard to dam safety, it is also important to know the different types of dams and to understand how each is designed to function structurally. There are basically four types of concrete dams.

- Gravity dams depend on their own weight for structural stability. The foundation for a gravity dam is most important - sound rock is best, but smaller dams have performed well on soft foundations. Instability can occur by either overturning or sliding along the foundation contact or along horizontal cracks or even construction lift lines. Uplift pressures are very important to stability. Surface deterioration of the concrete is less of a concern because of thick cross-sections.

- Arch dams are less massive than gravity structures. The hydrostatic load sustained by an arch dam is transmitted to the abutments, therefore the abutments should be of sound rock capable of receiving the load from the reservoir. Foundation conditions and uplift pressures are not as critical for arch dams, but foundation seepage gradients are higher because of the relatively thin cross-section. Weak or deteriorated concrete could have a greater affect on the stability of an arch dam because of the thinner cross-section.

- Buttress dams have a water supporting face that transmits the reservoir load to a series of buttresses that then transfer the load to the foundation. Therefore, the competency of the foundation is important as with gravity dams. The stability of a buttress dam is achieved largely by the vertical force of the reservoir water acting over the sloping upstream face. Because of the space between the buttresses, uplift pressures are not as critical, but foundation seepage gradients are usually high. Concrete deterioration ray be of concern because of the thin structural elements.

- Composite dams, as the name implies, are combinations of the foregoing types, or a gravity or buttress section combined with an embankment section. In addition to the previously mentioned concerns for the particular types of dams, the contacts between the different types of dams is also of concern.

PRIMARY CAUSES OF FAILURE OF CONCRETE DAMS

It is important to understand what the primary causes of failure of concrete and masonry dams are, because understanding the causes lends insight into how a particular deficiency could ultimately lead to failure. The primary causes of failure could be grouped into the following categories:

- Weak foundation or abutment rock unable to handle imposed loads resulting in excessive movement, over stressing of the dam, and failure. Included in this category is the weakening of the foundation or abutment caused by seepage. Low foundation or abutment strength, stability, and water tightness and other foundation deficiencies are the leading cause of concrete dam failures. Foundation rock may undergo disintegration, decomposition, or solutioning and lose the ability to support the dam. Seepage erosion of material from rock joints, movement along faults or shear zones and sliding along bedding planes can also contribute to failure. Thus, inspection of the foundation and abutments is vitally important.

- Structurally weak concrete due to initial low strength concrete or subsequent concrete degradation that leads to an inability of the dam to sustain imposed loads and failure. Low-strength mortar can lead to plains of weakness within a masonry dam or to the masonry blocks becoming dislodged from the matrix.

- Inadequate freeboard leading to overtopping and the potential subsequent erosion of the supporting foundation and/or abutments which may precipitate failure by overturning or sliding. Overtopping of a masonry dam can lead to the masonry blocks being dislodged precipitating a collapse of the dam.

- Instability of a concrete or masonry dam can be caused by changes in design loading conditions brought about by such things as improper operation of the dam or unauthorized modifications to the spillway which result in higher than intended reservoir levels. Flashboards on spillway gates are an example of a modification that should be analyzed regarding the potentially higher reservoir loading that may result.

ONSITE IINSPECTION

Inspections should be scheduled for alternately high and low reservoir conditions. The effects of near-maximum loading can be observed with a full reservoir; conversely the upstream face, groins and perhaps the downstream foundation, if discharges are not being made, are visible under a low reservoir.

All exposed surfaces of a concrete dam and adjacent areas should be examined during a dam safety inspection. These areas can be grouped into the following:

- Abutment and foundation areas are often difficult to inspect. Steep abutments may necessitate the use of field glasses for a preliminary look, and the use of high scaling equipment later if a problem is suspected. The inspection of the abutments and foundation includes the determination of whether any foundation movements or seepage is occurring. The possibility of piping or solutioning of the abutment and foundation materials should be investigated if seepage is present.

- Upstream and downstream faces of the dam should be examined for indications of distress or signs of movement. Areas of seepage on the downstream face should be investigated to determine the source of the water. The faces of the structure can be examined from the top of the dam, the abutments, and other upstream and downstream observation points. The faces can be examined first from a distance with field glasses and then more closely if necessary by the use of movable scaffolding or a skip suspended from the top of the dam. Indications of deficiencies such as weathering, chemical, or physical attack can be observed on the faces before they become a dam safety problem.

- Galleries (including instrumentation and drains) in a concrete dam give an indication of the leakage that is present as well as give the examiner a view of any cracking or movement that has occurred within the structure. Evidence of a reactive aggregate condition may also be observed in the walls of the gallery system. The examination of the foundation and formed drains may indicate changes in flow and potential safety of dams problems. Galleries contain instrumentation pertinent to dam safety such as weirs, plumblines, uplift pressure gages, foundation movement gages, etc. This instrumentation should be examined for evidence of serviceability, and the readings should be compared with previous readings to determine if unsafe changes or trends are occurring.

- Crest of a concrete dam is easily accessible and may reveal many dam safety problems. Differential movements, settlement, and the effects of weathering, chemical and physical attack are problems which may be identified. The differential movement or settlement between dam monoliths can be readily observed by sighting along the parapets or continuous metalwork. The deterioration of the concrete surfaces may be the first indication of chemical attack occurring within the concrete.

CONCRETE DAM DEFICIENCIES

Modern concrete technology has been the result of a gradual evolution, in many cases as a result of serious problems which have occurred in existing structures. Thus, many of today's practices for designing and constructing strong, durable concrete may have been unknown or poorly understood at the time an older dam was built.

There are several different kinds of deficiencies that can adversely affect concrete dams:

- Low concrete strength or durability affects the capability of the dam to withstand imposed loads and to resist the effects of weathering, chemical or physical attack. All surfaces of the dam should be inspected for evidence of low concrete strength and durability.

- Freeze-thaw damage occurs when susceptible concrete is subjected to freezing and thawing cycles and internal stresses are produced in the cement paste matrix and aggregate as a result of expansion and contraction of the freezing water. The effects of freeze-thaw damage are pattern cracking and progressive surface deterioration. Mix design practices before 1942 did not account for freeze-thaw action. Air entrainment in modern mix designs has largely mitigated freeze-thaw damage.

- Sulphate attack can result when low sulphate-resistant cement concrete is exposed to naturally occurring sulphate in adjacent soil or ground water. The results of sulphate attack are swelling that causes surface spalling. Mix design prior to 1930 did not recognize sulphate attack. Where this is a potential problem, sulphate-resistant type III or IV cement is now used.

- Alkali-aggregate reaction (AAR) is a two-part reaction that occurs when alkalies in the cement react with siliceous aggregate to form a silica gel, which then absorbs water and expands. The effects of alkali-aggregate reaction can be severe cracking, distortion and loss of strength of the concrete mass. Damage is most evident near the surface, where the concrete is unconfined. Visible evidence of AAR is pattern cracking and often the appearance of a white precipitate on the surface of the concrete, which is by product of the reaction. The selection of cement and aggregate combinations to avoid AAR was not employed until about 1940.

- Structurally weak concrete and mortar can also be the result of poor mix design or construction practices.

Unbonded lift lines in a concrete dam may lead to instability. Seepage and vegetative growth along a lift line would be an indication of such a condition.

Cracks in concrete are an indicator of stress. Cracks in the crest or dam faces or galleries should be monitored to determine if movement is continuing. Simple scribe marks across a crack can provide a simple visual tool for monitoring potential movement.

Differential movement between blocks or parapet wall segments on the crest of a dam is an indication of structural distress.

Excessive leakage into or through a concrete dam is a sign that excessive stress is occurring in the dam and has caused cracking, or that bonding has not occurred between lift lines and blocks. The location and apparent pressure of seeps into the dam should be noted. Flow in gallery gutters should also be monitored to determine if it is increasing.

Controlled seepage through foundation drains should be maintained or dangerous hydrostatic pressures on the dam may result. A regular cleaning program should be initiated for drains susceptible to clogging.

It should be stressed again that the mere presence of any of the problems mentioned does not automatically indicate that the dam is in trouble. Neither does the magnitude of the problem symptoms always accurately portray the magnitude and the risk to the dam. Many cases of foundation failures have finally occurred suddenly after only inconspicuous and subtle symptoms. Conversely, there are a number of concrete dams which suffer from chemical or physical attack and exhibit an unsightly and alarming appearance, but are serving their function quite well. The point is that judgment in visualizing the process at work with regard to functioning of a dam is essential to a successful dam safety examination and evaluation.