



**Government of India  
Ministry of Water Resources  
Central Water Commission**

**Guidelines  
for  
Safety Inspection of Dams**

**New Delhi  
June 1987 (Revised)**

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*Compiled by*  
**Dam Safety Organization**

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## **C O N T E N T S**

Chapter	I	Introduction	4
Chapter	II	General Requirements	6
Chapter	III	Phase I Investigation	9
Chapter	IV	Phase II Investigation	15
Chapter	V	Reports	31
Chapter	VI	Acknowledgements	33
Appendix	I	Format for Engineering Data	34
Appendix	II	Inspection Items	36
Annexure	I	Definition of Terms associated with Durability of Concrete	44
Appendix	III	Structures, Features, Events and Evidence to be examined during Inspections	48

## Chapter I

### **INTRODUCTION**

- 1.1 The dams are national property – constructed for the development of the national economy and in which large investments and other resources have been deployed.
- 1.2 The safety of the dam is a very important aspect for safeguarding the national investment and the benefits derived by the nation from the project. In addition, an unsafe dam constitutes a hazard to human life and property in the downstream reaches.
- 1.3 The safety of the dams and allied structures is an important aspect to be examined for ensuring public confidence in the continued accrual of benefits from the national investment made and to protect the downstream area from any potential hazard.
- 1.4 This document provides guidelines for the inspection and evaluation to determine the safety of dams and allied structures.
- 1.5 The procedures and guidelines outlined in this document apply to the inspection and evaluation of all dams / barriers together with appurtenant works which impound or divert water and which (1) are 8 metres or more in height or (2) have an impounding capacity of six hectare metres or more. Barriers which are 2 metres or less in height regardless of storage capacity or barriers which have a storage capacity at maximum water storage elevation of 2 hectare metres or less regardless of height are exempted.
- 1.6 Authority : “Resolution VI – Dam Safety Service” adopted at the First Conference of State Ministers of Irrigation held at New Delhi on 17-18 July 1975 reads thus “The Conference recommends that in view of the increasing number of large dams in India, the Government of India may constitute an Advisory Dams Safety Service to be operated by the Central Water Commission.” Accordingly, the Government of India constituted Dam Safety Organization in the Central Water Commission during June 1979 to assist the State Governments to locate causes of potential distress affecting safety of dams and allied structures and to advise / guide the State Governments in providing suitable remedial measure. The Dam Safety Organization, Central Water Commission issues these guidelines in pursuant to the above resolution and constitution of the service.

- 1.7 The guidelines outline principal factors to be weighed in the determination of existing or potential hazards and define the scope of activities to be undertaken in the safety inspection of dams. The establishment of rigid criteria of standards is not intended. Safety must be evaluated in the light of peculiarities and local conditions at a particular dam and in recognition of the many factors involved, some of which may not be precisely known. This can only be done by competent & experienced engineering judgement, which the guidelines are intended to supplement and not supplant. The guidelines are intended to be flexible, and the proper flexibility must be achieved through the employment of experienced engineering personnel.
- 1.8 The guidelines provide for two phases of investigations since the scope and completeness of each investigation depend upon the availability and suitability of engineering data, the validity of original design assumptions and the physical condition of the dam. Phase I would be an inspection to assess the general condition of the dam and determine the need for any additional engineering investigations and analyses. It would consist of a visual examination of the dam and a review of available engineering data, including operating records. It is not intended that costly explorations or analyses would be performed during a Phase I inspection.
- 1.9 Phase II investigations would be performed where the results of the Phase I inspection indicate the need for additional investigations and studies. Phase II would include, as required, all additional visual examinations, measurements, foundation exploration & testing, materials testing, hydraulic & hydrologic analyses and structural stability analyses deemed essential to evaluate the safety of the dam.
- 1.10 The guidelines present only procedures for investigating and evaluating existing conditions. Their scope does not encompass the studies and engineering required for project modification to correct deficiencies found by the investigation.

## Chapter II

### **GENERAL REQUIREMENTS**

#### **Classification of dams**

- 2.1 Dams should be classified in accordance with size and hazard potential in order to formulate a basis for selecting dams to be included in the inspection programme and their priority and also to provide compatibility between guideline requirements and involved risks.
- 2.1.1 Size: The classification for size based on the height of the dam and storage capacity should be in accordance with Table I. The height of the dam is established with respect to the maximum storage potential measured from the natural bed of the stream or watercourse at the downstream toe of the barrier. For the purpose of determining dam size, the maximum storage elevation may be considered equal to the top of dam elevation. Size classification may be determined by either storage or height, whichever gives the large size category.

TABLE I

Size Classification

<b>Category</b>	<b>Storage (Hectare Metres)</b>	<b>Height (Metres)</b>
Minor	<125 and $\geq 6$	<12 and $\geq 8$
Medium	$\geq 125$ and <6250	$\geq 12$ and <30
Major	$\geq 6250$	$\geq 30$

- 2.1.2 Hazard Potential : The classification for potential hazards should be in accordance with Table II. The hazards pertain to potential loss of human life or property damage in the area downstream of the dams in the event of failure or misoperation of the dam or appurtenant facilities. Dams conforming to criteria for the low hazard potential category generally will be located in the rural or agricultural areas where failure may damage farm buildings, limited agricultural land or township and country roads. Significant hazard potential category structures will be those located in predominantly rural or agricultural areas where failure may damage isolated homes, secondary highways or minor railroads or cause interruption of use or service of relatively important public utilities. Dams in the high hazard potential

category will be those located where failure may cause serious damage to homes, extensive agricultural, industrial and commercial facilities, important public utilities, main highways or railroads.

Table II

Hazard Potential Classification

<b>Category</b>	<b>Loss of Life (Extent of Development)</b>	<b>Economic Loss (Extent of Development)</b>
Low	None expected (non-permanent structures for human habitation)	Minimal (undeveloped to occasional structures or agriculture)
Significant	Few (no urban developments and no more than a small number of inhabitable structures)	Appreciable (notable agriculture, industry or structures)
High	More than few	Excessive (extensive community, industry or agriculture)

### **Selection of dams to be investigated**

2.2 The selection of dams to be investigated should be based upon an assessment of existing developments in flood hazard area. Those dams possessing a hazard potential classified high or significant as indicated in Table II should be given first and second priorities, respectively, in the inspection programme. Inspection priorities within each category may be developed from a consideration of factors such as size classification and age of the dam, the population size in the downstream flood area, and potential developments anticipated in flood hazard areas.

### **Technical investigations**

2.3 A detailed, systematic, technical inspection and evaluation should be made of each dam selected for investigation in which the hydraulic and hydrologic capabilities, structural stability and operational adequacy of project features are analysed and evaluated to determine if the dam constitutes a danger to human life or property. The investigation should vary in scope and completeness depending upon the availability and suitability of

engineering data, the validity of design assumptions and analyses and the condition of the dam. The minimum investigation will be designated Phase I, and an in-depth investigation designated Phase II should be made where deemed necessary. Phase I investigations should consist of a visual inspection of the dam, abutments and critical appurtenant structures and a review of readily available engineering data. It is not intended to perform costly explorations or analyses during Phase I. Phase II investigations should consist of all additional engineering investigations and analyses found necessary by results of the Phase I investigation.

### **Qualification of investigators**

- 2.4 The technical investigation should be conducted under the direction of competent professional engineers experienced in the investigation, design construction and operation of dams, applying the disciplines of hydrologic, hydraulic, soils & structural engineering and engineering geology. All field inspections should be conducted by qualified engineers, engineering geologist and other specialists, including experts on mechanical and electrical operation of gates and controls, knowledgeable in the investigation, design, construction and operation of dams.



## Chapter III

### **PHASE I INVESTIGATION**

#### **Purpose**

- 3.1 The primary purpose of the Phase I investigation programme is to identify expeditiously those dams which may pose hazards to human life or property.

#### **Scope**

- 3.2 The Phase I investigation will develop an assessment of the general condition with respect to safety of the project based upon available data and a visual inspection, determines any need for emergency measures and conclude if additional studies, investigation and analyses are necessary and warranted. A review will be made of pertinent, existing and available engineering data relative to the design, construction and operation of the dam and appurtenant structures, including electrical and mechanical operating equipment and measurement from inspection and performance instruments and devices and a detailed systematic visual inspection will be performed of those features relating to the stability and operational adequacy of the project. Based upon the findings of the review of engineering data and the visual inspection, an evaluation will be made of the general condition of the dam, including where possible the assessment of the hydraulic and hydrologic capabilities and the structural stability.

#### **Engineering data**

- 3.3 To the extent feasible the requisite engineering data listed in Appendix I relating to the design, construction and operation of the dam and appurtenant structures, should be collected from existing records and reviewed to aid in evaluating the adequacy of hydraulic and hydrologic capabilities and stability of the dam. Where the necessary engineering data are not available, inadequate or invalid, a listing should be made of these specific additional data deemed necessary by the engineer in charge of the investigation and included in the Phase I report.

#### **Field inspections**

- 3.4 The field inspection of the dam, appurtenant structures, reservoir area and downstream channel in the vicinity of the dam should

be conducted in a systematic manner to minimize the possibility of any significant feature being overlooked. A detailed checklist should be developed and followed for each dam inspection to document the examination of each significant structural and hydraulic feature, including electrical and mechanical equipment for operation of the control facilities that affect the safety of the dam. Model checklist in a generalized form for embankment (earth and rockfill), concrete dam and ancillary works is given in Appendix II. The checklist can be altered to suit the characteristics of the particular project or structure. The "Special Items" category listed at the end of each major heading as for listing those items which are specific to the structure but have not been included in the general checklist items.

- 3.4.1 Particular attention should be given to detecting evidence of leakage, erosion, seepage, excessive wetness or slushiness in the areas downstream of dam, presence of sand boils, change in water table conditions downstream, slope instability, undue settlement, displacement, tilting, cracking, deterioration and improper functioning of drains and relief wells. If the dam is instrumented, look for any evidence of excessive pore pressure conditions. It may be examined whether there had been any encroachment on the free board allowance made in the design. The adequacy and quality of maintenance and operating procedures and operation of control facilities should be examined as they pertain to the safety of the dam.
- 3.4.2 Photographs and drawings should be used freely to record conditions in order to minimize descriptions.
- 3.4.3 The field inspection should include appropriate features and items, including but not limited to those listed in Appendix III, which may influence the safety of the dam or indicate potential hazards to human life or property.

### 3.5 **Evaluation of hydraulic and hydrologic features**

#### 3.5.1 Design data

Original hydraulic and hydrologic design assumptions obtained from the project records should be assessed to determine their acceptability in evaluating the safety of the dam. All constraints on water control such as block entrances, restrictions on operation of spillway and outlet gates, inadequate energy dissipater or restrictive channel conditions, significant reduction in reservoir capacity by sediment deposition and other factors

should be considered in evaluating the validity of discharge ratings, storage capacity hydrographs, routings and regulation plan. The discharge capacity and / or storage capacity should be capable of safely handling the recommended spillway design flood.

The Indian Standard IS : 11223 – 1985 “Guidelines for fixing spillway capacity” gives the criteria for inflow design flood as under:

The dams may be classified according to size by using the hydraulic head (from normal or annual average flood level on the downstream to the maximum water level) and the gross storage behind the dam as given below. The overall size classification for the dam would be greater of that indicated by either of the following two parameters:

<b>Classification</b>	<b>Gross Storage</b>	<b>Hydraulic Head</b>
Small	Between 0.5 & 10 million m <sup>3</sup>	Between 7.5 m & 12 m.
Intermediate	Between 10 & 60 million m <sup>3</sup>	Between 12 m & 30 m.
Large	Greater than 60 million m <sup>3</sup>	Greater than 30 m.

The inflow design flood for safety of the dam would be as follows:

<b>Size as determined in classification</b>	<b>Inflow design flood for safety of dam</b>
Small	100 year flood
Intermediate	SPF
Large	PMF

Floods of larger or smaller magnitude may be used if the hazard involved in the eventuality of a failure is particularly high or low. The relevant parameters to be considered in judging the hazard in addition to the size would be:

- (i) distance to and location of the human habitations on the downstream after considering the likely future developments.
- (ii) Maximum hydraulic capacity of the downstream channel at a level at which catastrophic damage is not expected.

For more important projects, dam break studies may be done as an aid to the judgement in deciding whether PMF needs to be used. Where the studies or judgement indicate an imminent danger to present or future human settlements, the PMF should be used. Any departure from the general criteria as above on account of larger or smaller hazard should be clearly brought out and recorded.

Each site is individual in its local conditions and evaluation of cause and effects. While, therefore, the norms mentioned above may be taken as general guidelines, the criteria could be varied in special cases where the same are justifiable on account of local conditions and keeping in view the hazard potential.

When a dam capable of impounding large quantity of water is constructed above an area having extensive community, industry and agriculture, a distinct hazard from a possible failure is created. The failure of a dam so located would have disastrous effects. In addition to loss of life, loss to property, loss of revenue from the project, the deliberate acceptance of a calculated risk in the spillway design and free board would reduce the public confidence in the safety of similar structures.

The spillway capacities and free board allowances of such a dam should be adequate to insure against failure of the dam during the most severe flood or sequence of floods considered reasonably possible, irrespective of the apparent infrequency of occurrence of controlling conditions.

In determining the spillway capacity of relatively low dams and which do not have large storage capacity, where possible failure would not result in serious danger to life and property, (taking into account future development) a less severe condition may be adopted. The selection of spillway capacity would be governed by overall economic considerations, such as cost of replacing the dam, maintenance and loss of revenue when the project is impaired. The margin of safety may be made consistent with economic analysis.

### 3.5.2 Experience data

In some cases where design data are lacking, an evaluation of overtopping potential may be based on watershed characteristics and rainfall and reservoir records. An estimate of the probable maximum flood may also be developed from a conservative, generalized comparison of the drainage area, size and the

magnitude of recently adopted probable maximum floods for dam sites in comparable hydrologic regions. Where the review of such experience data indicates that the recommended spillway design flood would not cause overtopping, additional hydraulic and hydrologic determinations will be unnecessary.

### **3.6 Evaluation of structural stability**

The Phase I evaluations of structural adequacy of project features are expected to be based principally on existing conditions as revealed by the visual inspection, together with available design and construction information and records of performance. The objectives are to determine the existence of conditions which are hazardous, or which with time might develop into safety hazards, and to formulate recommendations, pertaining to the need for any additional studies, investigations or analyses. The results of this phase of the inspection must rely very substantially upon the experience and judgement of the inspecting engineer.

#### **3.6.1 Design and construction data**

The principal design assumptions and analyses obtained from the project records should be assessed. Original design and construction records should be used judiciously, recognizing the restricted applicability of such data as material strengths and permeabilities, geological factors and construction descriptions. Original stability studies and analyses should be acceptable if conventional techniques and procedures were employed, provided that review of operational and performance data confirm that the original design assumptions were adequately conservative. The need for such analyses, where either or none exist or the originals are incomplete or unsatisfactory, will be determined by the inspecting engineer, based upon other factors such as condition of structures. Design assumptions and analyses should include all applicable loads, including earthquake and indicate the structure's capability to resist overturning, sliding and overstressing with adequate factors of safety. In general, seepage and stability analysis comparable to the requirements of paragraph 4.4 should be on record for all dams in the high hazard category and large dams in the significant hazard category. This requirement for other dams will be subject to the option with the inspecting engineer.

### 3.6.2 Operating records

The performance of structures under maximum loading conditions should in some instances provide partial basis for stability evaluation. Satisfactory experience under loading conditions not expected to be exceeded in the future should generally be indicative of satisfactory stability, provided adverse changes in physical conditions have not occurred. Instrumentation, observation of forces, pressures, loads, stresses, strains, displacements, deflections or other related conditions should also be utilized in the safety evaluation. Where such data indicate abnormal behaviour, unsafe movement or deflections, or loadings which adversely affect the stability or functioning of the structure, it should find place conspicuously in the report.

### 3.6.3 Post construction changes

Data should be collected on changes which have occurred since project construction that might influence the safety of the dam such as road cuts, quarries, mining and groundwater changes and changes in the upstream watersheds.

### 3.6.4 Seismic stability

An assessment should be made of the potential vulnerability of the dam to seismic events and a recommendation developed with regard to the need for additional seismic investigation. The seismic zones together with appropriate coefficients for use in such analysis are given in IS : 1983-84 "Criteria for Earthquake Resistant Design of Structures." All high hazard category dams in zone V should have a stability assessment based upon knowledge of regional and local geology engineering seismology, in-situ properties of materials and appropriate dynamic, analytical and testing procedures. The assessment should include the possibility of physical displacement of the structures due to movements along active faults. Departure from this general guidance should be made whenever, in the judgement of the investigating engineer, different seismic stability requirements are warranted because of local geological conditions or other reasons.

## Chapter IV

### **PHASE II INVESTIGATION**

#### **Scope**

- 4.1 The Phase II investigation will be supplementary to Phase I and should be conducted when the results of the Phase I investigation indicates the need for additional in-depth studies, investigations or analyses.
- 4.1.1 The Phase II investigation should include all additional studies, investigations and analyses necessary to evaluate the safety of the dam. Included, as required, will be additional visual inspections, measurements, foundation exploration and testing, materials, testing hydraulic and hydrologic analysis and structural stability analyses.

#### **Hydraulic and Hydrologic Analysis**

- 4.2 Hydraulic and hydrologic capabilities should be determined using the following criteria and procedures. Depending on the project characteristics, either the spillway design flood peak inflow or the spillway design flood hydrograph should be the basis for determining the maximum water surface elevation and maximum outflow. If the operation or failure of upstream water control projects would have significant impact on peak flow or hydrograph analyses, the impact should be assessed.
- 4.2.1 Maximum water surface based on SDF peak inflow

When the total project discharge capability at maximum pool exceeds the peak inflow of the spillway design flood (SDF) and operational constraints would not prevent such a release at controlled projects, a reservoir routing is not required. The maximum discharge should be assumed equal to the peak inflow of the spillway design flood. Flood volume is not controlling in this situation and surcharge storage is either absent or is significant only to the extent that it provides the head necessary to develop the release capability required.

In the case of structures like bridges, weirs, barrages, where no absorptive capacity is allowed for, the flood peak has to be passed down without any moderation and, therefore, determination of the peak value becomes important.

On the other hand, in the flood control and the storage projects where full flood absorptive capacity is provided, the aspect of volume is of greater importance.

#### 4.3 **Peak for Standard Project Flood**

When the SPF flood is applicable under the provisions of Table III and data are available, the spillway design flood peak inflow may be determined by usual conventional methods. Flow frequency information from regional analysis is generally preferred over a single station results when available and appropriate. Rainfall runoff techniques may be necessary when there are inadequate runoff data available to make a reasonable estimate of flow frequency.

##### 4.3.1 Peak for PMF

The unit hydrograph – infiltration loss technique is generally the most expeditious method computing the spillway design flood peak for most projects. This technique is discussed in the following paragraph.

##### 4.3.2 Maximum water surface based on SDF Hydrograph

Both peak and volume are required in this analysis. Where surcharge storage is significant, or where there is insufficient discharge capability at maximum pool to pass the peak inflow of the SDF, considering all possible operational constraints, a flood hydrograph is required. When there are upstream hazard areas that would be imperiled by fast rising reservoir levels, SDF hydrographs should be routed to ascertain available time for warning and escape. Determination of probable maximum precipitation of SPF or 100 year precipitation, whichever is applicable, and unit hydrographs or runoff models will be required, followed by the determination of the PMF or SPF or 100 year flood. Conservative loss rates (significantly reduced by antecedent rainfall conditions where appropriate) should be estimated for computing the rainfall excess to be utilized with unit hydrographs. Rainfall values are usually arranged with gradually ascending and descending rates with the maximum rate late in the storm. When applicable, conservatively high snow melt runoff rates and appropriate releases from upstream project should be assumed. The maximum water surface elevation and spillway design flood outflow are then determined by routing the inflow hydrograph through the reservoir surcharge storage, assuming a starting water surface at the bottom of surcharge



storage, or lower when appropriate. For projects where the bottom of surcharge space is not distinct or the flood control storage space (exclusive of surcharge) is appreciable, it may be appropriate to select starting water surface elevations below the top of the flood control storage for routings. Conservatively high starting levels should be estimated on the basis of hydrometeorological conditions reasonably characteristic for the region and flood release capability of the project. Necessary adjustment of reservoir storage capacity due to existing or future sediment or other encroachment may be approximated when accurate determination of deposition is not practicable.

#### 4.3.3 Acceptable procedures

Techniques for performing hydraulic and hydrologic analyses are generally available from publications prepared by Central / State agencies involved in water resources development or text books written by the academic community. Some of these procedures are rather sophisticated and require expensive computational equipment and large data banks. While results of such procedure are generally more reliable than simplified methods, their use are generally not warranted in studies connected with this programme unless they can be performed quickly and inexpensively. There may be situations where more complex techniques have to be employed to obtain reliable results. However, these cases will be exceptions rather than the rule. Whenever the acceptability of procedures is in question, the advice of competent experts should be sought. Such expertise is generally available in the Central Water Commission, India Meteorological Department and National Institute of Hydrology.

#### 4.3.4 Freeboard allowances

Guidelines on specific minimum freeboard allowances are not considered appropriate because of the many factors involved in such determinations. The investigator will have to access the critical parameters for each project and develop its minimum requirements. Many projects are reasonably safe without freeboard allowances because they are designed for overtopping, or other factors minimize possible overtopping. Conversely, freeboard allowance of several feet may be necessary to provide a safe condition. Parameters that should be considered include the duration of high water levels in the reservoir during the design floods, the effective wind fetch and reservoir depth available to support wave generation; the probability of high wind speed occurring from a critical direction; the potential wave run-

up on the dam based on roughness and slope; and the ability of the dam to resist erosion from overtopping waves.

The present day practice is to check the freeboard allowance in earth / rockfill dam by Savillie's method which takes into account the effective fetch, reservoir depths, wave generation, wind speed, wave run-up depending upon the roughness and slope of embankment face.

For final selection of freeboard, the hazard potential of dam should also be taken into consideration.

#### **4.4 Stability investigations**

The Phase II stability investigations should be compatible with the guidelines of this paragraph.

##### **4.4.1 Foundation and material investigations**

The scope of the foundation and material investigation should be limited to obtaining the information required to analyse the structural stability and to investigate any suspected condition which would adversely affect the safety of the dam. Such investigations may include borings to obtain concrete, embankment, soil foundation and bedrock samples; testing specimens from these samples to determine the strength and elastic parameters of the materials, including the soft seams, joints, fault gouge and expansive clays or other critical materials in the foundation, determining the character of the bedrock, including joints, bedding planes, fractures, faults, voids & caverns and other geological irregularities; and installing instruments for determining movements, strains, suspected excessive internal seepage, pressure seepage gradients and uplift forces. Special investigations may be necessary where suspect rock type such as limestone, gypsum, salt, basalt, claystone, shales or others are involved in foundations or abutments in order to determine the extent of cavities, piping or other deficiencies in the rock foundation. A concrete core drilling programme should be undertaken only when the existence of significant structural cracks is suspected or the general qualitative condition of the concrete is in doubt. The tests of materials will be necessary only where such data are lacking or are outdated.

#### 4.4.2 Stability assessment

Stability assessments should utilize in-situ properties of the structure and its foundation and pertinent geologic information. Geologic information that should be considered includes groundwater and seepage conditions, lithology, stratigraphy and geologic details disclosed by borings, available records & geologic interpretation, maximum past overburden at site as deduced from geologic evidence of bedding, folding & faulting; joints & joint systems; weathering; slickensides, and field evidence relating to slides, faults, movements and earthquake activity. Foundations may present problems where they contain adversely oriented joints, slickensides or fissured material, faults, seams of soft materials or weak layers. Such defects and excess pore water pressures may contribute to instability. Special tests may be necessary to determine physical properties of particular materials. The results of stability analyses afford a means of evaluating the structure's existing resistance to failure and also the effect of any proposed modifications. Results of stability analyses should be reviewed for compatibility with performance experience when possible.

##### 4.4.2.1 Seismic stability

The inertial forces for use in the conventional equivalent static force method of analysis should be obtained by multiplying the weight by the seismic coefficient and should be applied as a horizontal force at the centre of gravity of the section or element. Seismic stability investigations for all high hazard category dams located in Seismic Zone 5 and high hazard dams of the hydraulic fill type in Zone 4 should include suitable dynamic procedures and analyses. Dynamic analyses for other dams and higher seismic coefficients are appropriate if in the judgement of the investigating engineer they were warranted because of proximity to active faults or other reasons. Seismic stability investigations should utilize "state-of-the-art" procedures involving seismological and geological studies to establish earthquake parameters for use in dynamic stability analyses and, where appropriate, the dynamic testing of materials. Stability analyses may be based upon either time-history or response spectra techniques. The results of dynamic analyses should be assessed on the basis of whether or not the dam would have sufficient residual integrity to retain the reservoir during and after the greatest or more adverse earthquake which might occur near the project location.

A study of the seismic events that have occurred in the past may be made and compared with the seismic events occurring during the period after construction for any particular variations in the pattern and intensity in the earthquake occurrence and their impact on the reservoir and dam stability.

#### 4.4.2.2 Clay shale foundation

Clay shale is a highly over consolidated sedimentary rock comprised predominantly of clay minerals, with little or no cementation. Foundations of clay shales, particularly those containing montmorillonite, may be highly susceptible to expansion and consequent loss of strength upon unloading. The shear strength and the resistance to deformation of clay shales may be quite low and high pore water pressures may develop under increase in load. The presence of slickenside in clay shales is usually an indication of low shear strength. Prediction of field behaviour of clay shales should not be based solely on results of conventional laboratory tests since they may be misleading. The use of peak shear strengths for clay shales in stability analysis may be unconservative because of non-uniform stress distribution and possible progressive failures. Thus, the available shear resistance may be less than if the peak shear strengths were mobilized simultaneously along the entire failure surface. In such cases, either greater safety factors or residual shear strength should be used.

#### 4.4.2.3 Karstic foundation

'Karst' is a general term for terrain in which surface and subsurface features, especially the relief and the drainage are directly related to the existence of bed rocks that are notably soluble in water. Karstic foundation can start creating problems even after dam construction. In Karstic and limestone region, it is essential to investigate whether the seepage losses are large so as to defeat the purpose of the project and also whether the water seeping around and beneath the dam itself does not imperil the safety of the structure. Observations for development in such foundation, like chemical analysis of seepage water downstream of the dam for lime content etc., may be carried out.

#### 4.4.3 Embankment dams

##### 4.4.3.1 Liquefaction

The phenomenon of liquefaction of loose, saturated sands and silts may occur when such materials are subjected to shear deformation or earthquake shocks. The possibility of liquefaction must presently be evaluated on the basis of empirical knowledge supplemented by special laboratory tests and engineering judgment. The possibility of liquefaction in sands diminishes as the relative density increases above approximately 70 percent. Hydraulic fill dams in Seismic Zones 4 and 5 should receive particular attention since such dams are susceptible to liquefaction under earthquake shocks.

#### 4.4.3.2 Shear failure

Shear failure is one in which a portion of an embankment or of an embankment and foundation moves by sliding or rotating relative to the remainder of the mass. It is conventionally represented as occurring along a surface and is so assumed in stability analyses, although shearing may occur in a zone of substantial thickness. The circular arc or the sliding wedge method of analyzing stability, as pertinent, should be used. The circular arc method is generally applicable to essentially homogeneous embankments and to soil foundations consisting of thick deposits of fine grained soil containing no layers significantly weaker than other strata in the foundation. The wedge method is generally applicable to rockfill dams and to earth dams on foundations containing weak layers. Other methods of analysis such as those employing complex shear surfaces may be appropriate depending on the soil and rock in the dam and foundation. Such methods should be in reputable usage in the engineering profession.

#### 4.4.3.3 Loading conditions and safety factors

The loading conditions for which the embankment structures should be investigated are:

1. Construction condition with or without partial pool (for upstream and downstream slopes).
2. Reservoir partial pool (for upstream slope).
3. Sudden drawdown (for upstream slope).
4. Steady seepage (for downstream slope).
5. Steady seepage with sustained rainfall (for downstream slope).
6. Earthquake condition (for upstream and downstream slopes).

The various design condition of analysis along with the minimum values of factors of safety to be aimed at and use of type of shear strength for each condition of analysis is given in I.S.:7894 – 1975 Code of Practice for Stability Analysis of Earth Dams and reproduced at Table III.

#### 4.4.3.4 Safety factors

Safety factors for embankment dam stability studies should be based on the ratio of available shear strength to developed shear strength,  $S_D$  :

$$S_D = \frac{C}{F.S.} + \frac{\sigma \tan \phi}{F.S}$$

$C$  = cohesion

$\phi$  = angle of internal friction

$\sigma$  = normal stress

The factors of safety listed in Table III are recommended as minimum acceptable. Final accepted factors of safety should depend upon the degree of confidence the investigating engineer has in the engineering data available to him. The consequences of a failure with respect to human life and property damage are important considerations in establishing factors of safety for specific investigations.

#### 4.4.3.5 Seepage failure

A critical uncontrolled under seepage or through seepage condition that develops during a rising pool can quickly reduce a structure which was stable under previous conditions, to a total structural failure. The visually confirmed seepage conditions to be avoided are (1) the exit of the phreatic surface on the downstream slope of the dam, (2) development of hydrostatic heads sufficient to create in the area downstream of the dam sand boils that erode materials by the phenomenon as "piping" and (3) localized concentrations of seepage along conduits or through previous zones. The dams most susceptible to seepage problems are those built of or on semi pervious materials of uniform fine particle size, with no provisions for an internal drainage zone and / or no under seepage controls.

Table III

**Minimum Desired Values of Factors of Safety**

[as per Code IS 7894 of 1975]

<b>Code No.</b>	<b>Loading Conditions</b>	<b>Slope most likely to be critical</b>	<b>Pore Pressure Assumption</b>	<b>Type of shear strength test to be adopted</b>	<b>Minimum desired factor of safety</b>
I	Construction condition with or without partial pool. *	Upstream & downstream	To be accounted for the Hilf's method.	QR *	1.0
II	Reservoir partial pool.	Upstream	Weights of material in all zones above phreatic line to be taken as moist and those below as buoyant.	RS +	1.3
III	Sudden drawdown				
(a)	Max.head water to min.with tail water at max.	Upstream	As given in 5.4.2 **	RS +	1.3
(b)	Max.tail water to min. with reservoir full	Downstream	As given in 5.4.5 **	RS +	1.3
IV	Steady seepage with reservoir full	Downstream	As given in 5.5.2 **	RS +	1.5
V	Steady seepage with sustained rainfall	Downstream	As given in 5.6.1 **	RS +	1.3
VI	Earthquake condition:				
(a)	Steady seepage	Downstream	As given in Case IV	RS +	1.0 Ψ
(b)	Reservoir full	Upstream	As given in Case II	RS +	1.0 Ψ

Note: These factors of safety are applicable for the method of analysis mentioned in the Code.

\* Where the reservoir is likely to be filled immediately after completion of dam, construction pore pressure would not have dissipated and these should be taken into consideration. This is to be adopted for failure planes passing through impervious foundation layer.

+ S Test may be adopted only in cases where the material is cohesionless and free draining.

Ψ Values are according to IS:1893-1984 "Criteria for earthquake resistant design of structures (3<sup>rd</sup> rev.).

\*\* These refer to the Code.

Q Test = Unconsolidated undrained test  
 R Test = Consolidated undrained test and  
 S Test = Consolidated drained test.

#### 4.4.3.6 Seepage analyses

Review and modifications to original seepage design analyses should consider conditions observed in the field inspection and piezometer instrumentation. A seepage analysis should consider the permeability ratios resulting from natural deposition and from compaction placement of materials with appropriate variation between horizontal and vertical permeability. An under seepage analysis of the embankment should provide a critical gradient factor of safety for the maximum head condition of not less than 1.5 in the area downstream of the embankment.

$$\text{F.S.} = \frac{i_c}{i} = \frac{H_c / D_b}{H / D_b} = D_b \frac{(\gamma_m - \gamma_w)}{H \gamma_w} \dots\dots(2)$$

- $i_c$  = Critical gradient
- $i$  = Design gradient
- $H$  = Uplift head at downstream toe of dam measured above tailwater.
- $H_c$  = The critical uplift
- $D_b$  = The thickness of the top impervious blanket at the downstream toe of the dam.
- $\gamma_m$  = The estimated saturated unit weight of the material in the top impervious blanket
- $\gamma_w$  = The unit weight of water

Where a factor of safety less than 1.5 is obtained, the provision of an under seepage control system is indicated. The factor of safety of 1.5 is a recommended minimum and may be adjusted by the responsible engineer based on the competence of the engineering data.

#### 4.4.4 Concrete dams and appurtenant structures

##### 4.4.4.1 Requirements for stability

Concrete dams and structures appurtenant to embankment dams should be capable of resisting overturning, sliding and overstressing with adequate factors of safety for normal and maximum loading conditions.

##### 4.4.4.2 Loads

Loadings to be considered in stability analyses include the water load on the upstream face of the dam; the weight of the structure, internal hydrostatic pressures (uplift) within the body of the dam, at the base of the dam and within the foundation;



earth and silt loads; ice pressure, seismic and thermal loads, and other loads, as applicable. Where tailwater or backwater exists on the downstream side of the structure, it should be considered, and assumed uplift pressures should be compatible with drainage provisions and uplift measurements, if available. Where applicable, ice pressure should be applied to the contact surface of the structure at normal pool elevation. Till specific reliable procedures become available for assessment of ice pressure, it may be provided for at the rate of 250 k Pa applied to the face of the dam (IS 6512-1984). Normally, ice thickness should not be assumed greater than 2/3 m. Earthquake forces should consist of the inertial forces due to the horizontal acceleration of the dam itself and hydrodynamic forces resulting from the reaction of the reservoir water against the structure. Dynamic water pressures for use in conventional methods of analysis may be computed as per IS 1893-1984 "Criteria for earthquake resistant design of structures" or similar method.

#### 4.4.4.3 Strength

The concrete strength should be based on in-situ properties of concrete which varies with age, the kind of cement and other ingredients and their proportions.

##### Comprehensive strength

As per Indian Standard IS : 6512-1984, the compressive strength of concrete and masonry shall conform to the following requirements:

- (a) Concrete: Concrete strength is determined by compressing to failure 150 mm cubes. The strength of concrete should satisfy early load and construction requirements and at the age of one year it should be four times the maximum computed stress in the dam or  $14 \text{ N/mm}^2$ , whichever is more. The allowable working stress in any part of the structure shall not also exceed  $7\text{N/mm}^2$ .
- (b) Masonry: The compressive strength of masonry is determined by compressing to failure 75 cm cubes of the masonry fabricated and cured at temperatures approximating to those expected in the structures (or 45 x 90 cm cylinders cored out of the structures or blocks made for the purpose). This strength should satisfy early load and construction requirements and at one year it should be

five times the maximum computed stress on the dam or  $12.5 \text{ N/mm}^2$ , whichever is more.

Note: For the purpose of quality control, correlation between the strength of mortar and that of masonry may be established in suitable smaller size specimen.

#### Tensile strength

- (a) No tensile stress shall be permitted at the upstream face of the dam for load combination B. Nominal tensile stresses, however, may be permitted in other load combinations and their permissible values shall not exceed the values given below:

#### **Values of permissible tensile stress in concrete and masonry**

<u>Load combination</u>	<u>Permissible Tensile Stress</u>	
	<u>Concrete</u>	<u>Masonry</u>
C	0.01 $f_c$	0.005 $f_c$
E	0.02 $f_c$	0.01 $f_c$
F	0.02 $f_c$	0.01 $f_c$
G	0.04 $f_c$	0.02 $f_c$

Where  $f_c$  is the cube compressive strength of concrete / mortar for masonry.

- (b) Small values of tension on the downstream face may be permitted since it is very improbable that a fully constructed dam is kept empty and downstream cracks which are not extensive and for limited depths from the surface may not be detrimental to the safety of the structure.

#### 4.4.4.4 Overtuning

A gravity structure should be capable of resisting all overturning forces. It can be considered safe against overturning if the resultant of all combinations of horizontal and vertical forces, excluding earthquake forces, acting above any horizontal plane through the structure or at its base is located within the middle third of the section. When earthquake is included, the resultant should fall within the limits of the plane or base, and foundation

pressures must be acceptable. When these requirements for location of the resultant are not satisfied, the investigating engineer should assess the importance to stability of the deviations.

#### 4.4.4.5 Sliding

Sliding of concrete gravity structures and of abutment and foundation rock masses for all types of concrete dams should be evaluated by the shear friction resistance concept. The available sliding resistance is compared with the driving force which tends to include sliding to arrive at a sliding stability safety factor. The investigation should be along all potential sliding paths. The critical path is that plane or combination of planes which offers the least resistance.

##### 4.4.4.5.1 Sliding resistance

Sliding resistance is a function of the unit shearing strength at no normal load (cohesion) and the angle of friction on a potential failure surface. It is determined by computing the maximum horizontal driving force which could be resisted along the sliding path under investigation. The following general formula is obtained from the principles of statics and may be derived by resolving forces parallel and perpendicular to the sliding plane:

$$R_R = V \tan (\phi + \alpha) + \frac{CA}{\cos \alpha (1 - \tan \phi \tan \alpha)} \dots\dots\dots(3)$$

where

$R_R$  = Sliding Resistance (maximum horizontal driving force which can be resisted by the critical path).

$\phi$  = Angle of internal friction of foundation material or, where applicable, angle of sliding friction.

$V$  = Summation of vertical forces (including uplift).

$C$  = Unit shearing strength at zero normal loading along potential failure plane.

$A$  = Area of potential failure plane developing unit shear strength "C"

$\alpha$  = Angle between inclined plane and horizontal (positive for uphill sliding).

for sliding downhill, the angle  $\alpha$  is negative and equation (1) becomes:

$$R_R = V \tan (\phi - \alpha) + \frac{CA}{\cos \alpha (1 + \tan \phi \tan \alpha)} \dots\dots\dots(4)$$

when the plane of investigation is horizontal, and the angle is zero and equation (4) reduced to the following:

$$R_R = V \tan \phi + CA$$

#### 4.4.4.5.2 Downstream resistance

When the base of a concrete structure is embedded in rock or the potential failure plane lies below the base, the passive resistance of the downstream layer of rock may sometimes be utilized for sliding resistance. Rock that may be subjected to high velocity water scouring should not be used. The magnitude of the downstream resistance is the lesser of (a) the shearing resistance along the continuation of the potential sliding plane until it daylights or (b) the resistance available from the downstream rock wedge along an inclined plane. The theoretical resistance offered by the passive wedge can be computed by a formula equivalent to formula (3) :

$$P_P = W \tan (\phi + \alpha) + \frac{CA}{\cos \alpha (1 - \tan \phi \tan \alpha)} \dots\dots\dots(5)$$

$P_P$  = Passive resistance of rock wedge

$W$  = Weight (buoyant weight, if applicable) of downstream rock wedge above inclined plane of resistance, plus any superimposed loads.

$\alpha$  = Angle of internal friction or, if applicable, angle of sliding friction.

$\alpha$  = Angle between inclined failure plane and horizontal.

$C$  = Unit shearing strength at zero normal load along failure plane.

$A$  = Area of inclined plane of resistance.

When considering cross-bed shear through a relatively shallow, competent rock strut, without adverse jointing or faulting,  $W$  and  $\alpha$  may be taken as zero and  $45^\circ$  respectively, and an estimate of passive wedge resistance per unit width obtained by the following equation:

$$P_p = 2CD$$

where  $D$  = Thickness of the rock strut.

The shear friction safety factor is obtained by dividing the resistance  $R_R$  by  $H$ , the summation of horizontal loads to be applied to the structure:

$$S_{s-f} = \frac{R_R}{H} \quad \text{.....(8)}$$

When the downstream passive wedge contributes to the sliding resistance, the shear friction safety factor formula becomes:

$$S_{s-f} = \frac{R_R + P_p}{H} \quad \text{.....(9)}$$

The above direct superimposition of passive wedge resistance is valid only if shearing rigidities of the foundation components are similar. Also, the compressive strength and buckling resistance of the downstream rock layer must be sufficient to develop the wedge resistance. For example, a foundation with closely spaced, near horizontal, relatively weak seams might not contain sufficient buckling strength to develop the magnitude of wedge resistance computed from the cross-bed shear strength. In this case, wedge resistance should not be assumed without resorting to special treatment (such as installing foundation anchors).

#### 4.4.4.5.3 Factors of safety against sliding

The IS 6512-1984 states that the factor of safety against sliding may be calculated on the basis of partial factor of safety in respect of friction ( $F_\phi$ ) and partial factor of safety in respect of cohesion ( $F_c$ ) as given in the next page:

### Partial factors of safety against sliding

Sl. No.	Loading Condition	F <sub>f</sub>	F <sub>c</sub>		
			For dams and the contact plane with foundation	For foundation	
				Thoroughly investigated	Others
(i)	A,B,C	1.50	3.60	4.00	4.50
(ii)	D,E	1.20	2.40	2.70	3.00
(iii)	F,G	1.00	1.20	1.35	1.50

The factor of safety against sliding shall be computed from the following equation and shall not be less than 1.0.

$$F = \frac{(w - u) \tan \phi}{F_{\phi}} + \frac{CA}{F_c} P_p$$

where

F = factor of safety against sliding.

w = total mass of the dam

u = total uplift force

$\tan \phi$  = coefficient of internal friction of the material

C = cohesion of the material at the plane considered

A = area under consideration for cohesion

$F_{\phi}$  = partial factor of safety in respect of friction

$F_c$  = partial factor of safety in respect of cohesion, and

P = total horizontal force

The value of cohesion and internal friction may be estimated for the purpose of preliminary designs on the basis of available data on similar or comparable materials. For final designs, however, the value of cohesion and internal friction shall be determined by actual laboratory and field tests.

The IS: 6512-1984 does not take into consideration the passive wedge contribution.

## Chapter V

### REPORTS

- 5.1 The first report on the project evaluation would be compilation of information in the format given at Appendix I.
- 5.2 The study of the data and the classification of the dam in respect of its hazard potential form the second report. In case the hazard potential of a dam is classified as high, the same should be reported immediately to the project authority, State Government, Central Water Commission (Dam Safety Organization).
- 5.3 Phase – I Report
  - 5.3.1 The Phase I report is an investigation report after a study of the design data and behaviour of the dam and a detailed inspection of the site. Appendix II gives the guidelines for performing field inspection and can serve as a basis for developing a detailed checklist to suit the characteristics of the particular project or structure. The fundamental objective of the inspection is the detection of any existing or developing structural or hydraulic weakness. Appendix III indicates the structures, features, events and evidence which should be looked for.
  - 5.3.2 The Phase I report should contain a summary of existing engineering data, including geological maps and information, results of inspections and photographs.
  - 5.3.3 Evaluation of operational adequacy of reservoir regulation and maintenance of dam and operating facilities and features that pertain to the safety of the dam.
  - 5.3.4 Description of warning system in effect, if any. Evaluation of the hydraulic and hydrological assumptions and structural stability.
  - 5.3.5 An assessment of the general condition of the dam with respect to safety based upon the findings of the visual inspection and review of engineering data. Where data on the original design indicate significant departures from or non-conformance with guidelines contained herein, the engineer-in-charge of the investigation will give his opinion of the significance, with regard to safety, of such factors. Any

additional studies, investigations and analyses considered essential to assessment of the safety of the dam should be listed, together with an opinion about the urgency of such additional work.

5.3.6 Possible remedial measures or revisions in operating and maintenance procedures which may (subject to further evaluation) correct deficiencies and hazardous conditions found during the investigations.

#### 5.4 Phase – II Report

5.4.1 Phase II investigations which are supplementary to Phase I investigation are conducted when the results of the Phase I investigations indicate the need for additional in-depth studies, investigations or analysis.

5.4.2 Phase II report should describe the detailed investigations and should supplement Phase I report. They should contain the following information:

5.4.2.1 Summary of additional engineering data obtained to determine the hydraulic and hydrologic capabilities and / or structural stability.

5.4.2.2 Results of all additional studies, investigations and analyses performed.

5.4.2.3 Technical assessment of dam safety, including deficiencies and hazardous conditions found to exist.

5.4.2.4 Indicate alternative possible remedial measures or revision in maintenance and operating procedures, which may (subject to further evaluation), correct deficiencies and hazardous conditions found during the investigation.



## Chapter VI

### **ACKNOWLEDGEMENTS**

The following references have been made use of in compilation of the guidelines:

1. Recommended guidelines for safety inspection of dams – Department of the Army – Office of the Chief Engineers, Washington DC, USA.
2. The Evaluation of Dam Safety – Engineering Foundation Conference Proceedings.
3. Selection of Design Flood – by Fennil Mosonyi and Werner Buchi.
4. Guide for Making a Condition Survey of Concrete in Service – Reported by ACI Committee 201 – Journal of the American Concrete Institute – November 1968, No.11, Proceedings V.65.
5. Developments in Geotechnical Engineering – Dams, Dam Foundations and Reservoir Sites – by Ernest E.Wahlstrom.
6. Criteria for Design of Solid Gravity Dams – IS 6512-1984.
7. Guidelines for Fixing Spillway Capacity – IS 11223-1985.
8. Criteria for Earthquake Resistant Design of Structures IS 1893 -1984.
9. Code of Practice for Stability Analysis for Earth Dams – IS 7894 – 1975.

## Appendix I

### **Format for ENGINEERING DATA**

#### **(A) GENERAL**

1. Name of the Dam - Project
2. Location – River, Sub-basin, Basin, Village/Tehsil/District/State
3. Type of Dam
4. Year of completion
5. Height of Dam (Elevations: Deepest foundation, River bed, FRL, MWL, Top of Dam)
6. Impounding capacity at F.R.L., at M.W.L.
7. Index map showing location of dam, catchment area, downstream area subject to potential damage due to failure of dam or failure of operating equipment
8. Nearest downstream city, town, village which can be located on the map. Its distances from dam and population
9. Extent of economic development in downstream area

#### **(B) PROJECT FEATURES**

1. Salient features
2. Construction drawings indicating plans, elevation and sections of the dam and appurtenant structures including the details of the discharge facilities such as outlet works, spillways and operating equipment
3. Emergency preparedness – Communications Downstream Warning Systems Auxiliary power – Remote Operation – Security of the site

#### **(C) HYDROLOGY**

1. Description of Drainage basin – Drainage area and basin runoff characteristics
2. Design flood-design assumptions and analysis, storage of flood control zone
3. Spillway capacity and flood routing criteria

4. Area capacity curves
5. Elevation of crest, type, width, crest length, location of spillway and number size and type of gates
6. Type, location, capacity entrance and exit levels of other outlet works
7. Emergency drawdown capacity
8. Type, location, observations and records of hydrometeorological data

**(D) GEOLOGY AND FOUNDATION**

1. Rock types, logs of borings of geological maps profiles and cross-section location and special problems (fault, shear zones, solutions, channels etc.)
2. Effects of geology on design
3. Adequacy of investigation
4. Foundation treatment-grouting-drainage etc.
5. Cut-off

**(E) Construction History-including diversion scheme, construction sequence, construction problems, alterations, repairs**

**(F) Operation and regulation plan under normal conditions and during floods and other emergency conditions. Flood Warning Systems**

**(G) Operation record-experiences during past major floods**

**(H) Stability and stress analysis of the dam, spillway and appurtenant structures and features including the assumed properties of materials and all pertinent applied loads**

**(I) Instrumentations and records of performance observations**

**(J) Any known deficiency that may pose a threat to the safety of the dam or to human life and property**

## Appendix II

### **INSPECTION ITEMS**

This appendix provides guidance for performing field inspections and may serve as the basis for developing a detailed checklist for each dam.

#### **1. CONCRETE STRUCTURES IN GENERAL**

(a) Concrete Surfaces

The condition of the concrete surfaces should be examined to evaluate the deterioration and continuing serviceability of the concrete. Descriptions of concrete conditions should conform with the appendix to "Guide for making a conditions survey of concrete in service", American Concrete Institute (ACI) Journal, Proceedings Vol.65, No.11, November 1968 pages 905-918 vide Annexure I.

(b) Structural Cracking

Concrete structures should be examined for structural cracking resulting from overstress due to applied loads, shrinkage and temperature effects or differential movements.

(c) Movement – Horizontal and Vertical Alignment

Concrete structures should be examined for evidence of any abnormal settlements, heaving, deflections or lateral movements.

(d) Junctions

The condition at the junction of the structure with abutments or embankments should be determined.

(e) Drains – Foundation, Joint, Face

All drains should be examined to determine that they are capable of performing their design function.

(f) Water Passages

All water passages and other concrete surface subject to running water should be examined for erosion, cavitation, obstructions, leakage or significant structural cracks.

(g) Seepage or Leakage

The faces, abutments and toes of the concrete structures should be examined for evidence of seepage or abnormal leakage, and records of flow of downstream springs reviewed for variation with reservoir pool level. The sources of seepage should be determined, if possible.

(h) Monolith Joints – Construction Joints

All monolith and construction joints should be examined to determine the condition of the joint and filler material, any movement of joints, or any indication of distress or leakage.

(i) Foundation

Foundation should be examined for damage or possible undermining of the downstream toe.

(j) Abutments

The abutments should be examined for sign of instability or excessive weathering.

## **2. EMBANKMENT STRUCTURES**

(a) Settlement

The embankments and downstream toe areas should be examined for any evidence of localized or overall settlement, depressions or sink holes.

(b) Slope Stability

Embankment slopes should be examined for irregularities in alignment and variances from smooth uniform slopes, unusual changes from original crest alignment and elevation, evidence of movement at or beyond the toe, and surface cracks which indicate movement.

(c) Seepage

The downstream face of abutments, embankment slopes and toes, embankment-structure contacts and the downstream valley areas should be examined for evidence of existing or past seepage. The sources of seepage should be investigated

to determine cause and potential severity to dam safety under all operating conditions. The presence of animal burrows and tree growth on slopes which might cause detrimental seepage should be examined.

(d) Drainage Systems

The slope protection should be examined to determine whether the systems can freely pass discharge and that the discharge water is not carrying embankment or foundation material. Systems used to monitor drainage should be examined to assure they are operational and functioning properly.

(e) Slope Protection

The slope protection should be examined for erosion-formed gullies and wave-formed notches and benches that have reduced the embankment cross-section or exposed less wave resistant materials. The adequacy of slope protection against waves, currents and surface run-off that may occur at the site should be evaluated. The condition of vegetative cover should be evaluated where pertinent.

### **3. SPILLWAY STRUCTURES**

Examination should be made of the structures and features, including bulkheads, flash-boards and fuse plugs of all service and auxiliary spillways which serve as principal or emergency spillways for any condition, which may impose operational constraints on the functioning of the spillway.

(a) Control Gates and Operating Machinery

The structural members, connections, hoists, cables and operating machinery and the adequacy of normal and emergency power supplies should be examined and tested to determine the structural integrity and verify the operational adequacy of the equipment where cranes are intended to be used for handling gates and bulkheads, the availability, capacity and condition of the cranes and lifting beams should be investigated. Operation of control systems and protective & alarm devices such as limit switches, sump high water alarms and drainage pumps should be investigated.

(b) Unlined Saddle Spillways

Unlined saddle spillways should be examined for evidence of erosion and any conditions which may impose constraints on the functioning of the spillway. The ability of the spillway to resist erosion due to operation and the potential hazard to the safety of the dam from such operation should be determined.

(c) Approach and Outlet Channels

The approach and outlet channels should be examined for any conditions which may impose constraints on the functioning of the spillway and present a potential hazard to the safety of the dam.

(d) Stilling Basin (Energy Dissipators)

Stilling basins, including baffles, flip buckets or other energy dissipators should be examined for any conditions which may pose constraints on the ability of the stilling basin to prevent downstream scour or erosion which may create or present a potential hazard to the safety of the dam. The existing condition of the channel downstream of the stilling basin should be determined.

#### **4. OUTLET WORKS**

The outlet works examination should include all structures and features designed to release reservoir water below the spillway crest through or around the dam.

(a) Intake Structure

The structure and all features should be examined for any condition which may impose operational constraints on the outlet works. Entrances to intake structure should be examined for conditions such as silt or debris accumulation which may reduce the discharge capabilities of the outlet works.

(b) Operating and Emergency Control Gates

The structural members, connections, guides, hoists, cables and operating machinery, including the adequacy of normal and emergency power supplies should be examined and tested to determine the structural integrity and verify the operational

adequacy of the operating and emergency gates, valves, bulkheads and other equipments.

(c) Conduits, Sluices, Water Passages, etc.

The interior surfaces of conduits should be examined for erosion, corrosion, cavitation, cracks, joint separation and leakage at cracks or joints.

(d) Stilling Basin (Energy Dissipator)

The stilling basin or other energy dissipater should be examined for conditions which may impose any constraints on the ability of the stilling basin to prevent downstream scour or erosion which may create or present a potential hazard to the safety of the dam. The existing condition of the channel downstream of the stilling basin should be determined by soundings.

(e) Approach and Outlet Channels

The approach and outlet channels should be examined for any conditions which may impose constraints on the functioning of the discharge facilities of the outlet works, or present a hazard to the safety of the dam.

(f) Drawdown Facilities

Facilities provided for drawdown of the reservoir to avert impending failure of the dam or to facilitate repairs in the event of stability or foundation problems should be examined for any conditions which may impose constraints on their functioning as planned.

## **5. SAFETY AND PERFORMANCE INSTRUMENTATION**

Instruments which have been installed to measure behaviour of the structures should be examined for proper functioning. The available records and readings of the installed instruments should be reviewed to detect any unusual performance of the instruments or evidence of unusual performance or distress of the structure. The adequacy of the installed instrumentation to measure the performance and safety of the dam should be determined.



(a) Headwater and Tailwater Gauges

The existing records of the headwater and tailwater gauges should be examined to determine the relationship between other instrumentation measurements such as stream flow, uplift pressures, alignment and drainage system discharge with the upper and lower water surface elevations.

(b) Horizontal and Vertical Alignment Instrumentation (Concrete Structures)

The existing records of alignment and elevation surveys and measurements from inclinometers, inverted plumb bobs, gauge points across cracks and joints, or other devices should be examined to determine any change from the original position of the structure.

(c) Horizontal and Vertical Movement, Consolidation and Pore-water Pressure Instrumentation (Embankment Structures)

The existing records of measurements from settlement plates or gauges surface should be examined to determine the movement history of the embankment. Existing piezometer measurements should be examined to determine if the pore-water pressures in the embankment and foundation would under given conditions impair the safety of the dam.

(d) Uplift Instrumentation

The existing records of uplift measurements should be examined to determine if the uplift pressures for the maximum pool would impair the safety of the dam.

(e) Drainage System - Instrumentation

The existing records of measurements of the drainage system flow should be examined to establish the normal relationship between pool elevations and discharge quantities and any changes that have occurred in this relationship during the history of the project.

(f) Seismic Instrumentation

The existing records of seismic instrumentation should be examined to determine the seismic activity in the area and the response of the structures to past earthquakes.

## 6. RESERVOIR

The following features of the reservoir should be examined to determine to what extent the water impounded by the dam would constitute a danger to the safety of the dam or a hazard to human life or property.

(a) Shore Line

The land forms around the reservoir should be examined for indications of major active or inactive landslide areas and to determine susceptibility of bedrock stratigraphy to massive landslides of sufficient magnitude to significantly reduce reservoir capacity or create waves that might overtop the dam.

(b) Sedimentation

The reservoir and drainage area should be examined for excessive sedimentation of recent developments in the drainage basin which could cause a sudden increase in sediment load thereby reducing the reservoir capacity, with attendant increase in maximum outflow and maximum pool elevation.

(c) Potential Upstream Hazard Areas

The reservoir area should be examined for features subject to potential back-water flooding resulting in loss of human life or property at reservoir levels upto the maximum water storage capacity including any surcharge storage.

(d) Watershed Runoff Potential

The drainage basin should be examined for any extensive alternations to the surface of the drainage basin such as changed agriculture practices, timber clearing, railroad or highway construction or real estate developments that might extensively affect the runoff characteristics. Upstream projects that could have impact on the safety of the dam should be identified.

## **7. DOWNSTREAM CHANNEL**

The channel immediately downstream of the dam should be examined for conditions which might impose any constraints on the operation of the dam or present any hazards to the safety of the dam. Development of the potential flooded area downstream of the dam should be assessed for compatibility with the hazard classification.

## **8. OPERATION AND MAINTENANCE FEATURES**

### (a) Reservoir Regulation Plan

The actual practices in regulating the reservoir and discharges under normal and emergency conditions should be examined to determine if they comply with the designed reservoir regulation plan and to assure that they do not constitute a danger to the safety of the dam or to human life or property.

### (b) Maintenance

The maintenance of the operating facilities and features that pertain to the safety of the dam should be examined to determine the adequacy and quality of the maintenance procedures followed in maintaining the dam and facilities in safe operating condition.

## Annexure I

### **Definition of Terms Associated with Durability of Concrete**

- A.1 **Cracks:** An incomplete separation into one or more parts with or without space between.
- A.1.1 **Cracks will be classified by direction, width & depth:** The following adjectives can be used: Longitudinal, transverse, vertical, diagonal and random. Three width ranges are suggested as follows: fine – generally less than 1 mm; medium – between 1 & 2mm; and wide – over 2 mm.
- A.1.2 **Pattern cracking:** Fine openings on concrete surfaces in the form of a pattern, resulting from a decrease in volume of the material near the surface or increase in volume of the material below the surface, or both.
- A.1.3 **Checking:** Development of shallow cracks at closely spaced but irregular intervals on the surface of mortar or concrete.
- A.1.4 **Hairline cracking:** Small cracks of random pattern in an exposed concrete surface.
- A.1.5 **D-cracking:** The progressive formation on a concrete surface of a series of fine cracks at rather close intervals, often of random patterns, but in highway slabs paralleling edges, joints & cracks and usually curving across slab corners.
- A.2 **Deterioration:** Deterioration in any adverse change of normal mechanical, physical and chemical properties either on the surface or in the whole body of concrete generally through separation of its components.
- A.2.1 **Disintegration:** Deterioration into small fragments or particles due to any cause.
- A.2.2 **Distortions:** Any abnormal deformation of concrete from its original shape.
- A.2.3 **Efflorescence:** A deposit of salts, usually white, formed on a surface, the substance having emerged from below the surface.
- A.2.4 **Exudation:** A liquid or viscous gel-like material discharged through a pore, crack or opening in the surface.

- A.2.5      **Incrustation:** A crust or coating generally hard formed on the surface of concrete or masonry construction.
- A.2.6      **Pitting:** Development of relatively small cavities in a surface due to phenomena such as corrosion or cavitation, or in concrete, localized disintegration.
- A.2.7      **Popout:** The breaking away of small portions of a concrete surface due to internal pressure which leaves a shallow, typical & conical depression.
- A.2.7.1    **Popouts, small:** Popouts leaving holes upto 1 cm in diameter, or the equivalent.
- A.2.7.2    **Popouts, medium:** Popouts leaving holes between 1 and 5 cm in diameter, or the equivalent.
- A.2.7.3    **Popouts, large:** Popouts leaving holes greater than 5 cm in diameter, or the equivalent.
- A.2.8      **Erosion:** Deterioration brought about by the abrasive action of fluids or solids in motion.
- A.2.9      **Scaling:** Local flaking or peeling away of the near surface portion of concrete or mortar.
- A.2.9.1    **Peeling:** A process in which thin flakes of mortar are broken away from a concrete surface; such as by deterioration or by adherence of surface mortar to forms as forms are removed.
- A.2.9.2    **Scaling, light:** Loss of surface mortar without exposure of coarse aggregate.
- A.2.9.3    **Scaling, medium:** Loss of surface mortar upto ½ to 1 cm in depth and exposure of coarse aggregate.
- A.2.9.4    **Scaling, severe:** Loss of surface mortar ½ to 1 cm in depth with some loss of mortar surrounding aggregate particles 1 to 2 cm in depth so that aggregate is clearly exposed and stands out from the concrete.
- A.2.9.5    **Scaling, very severe:** Loss of coarse aggregate particles as well as surface mortar and mortar surrounding aggregate, generally greater than 2 cm in depth.

- A.2.10 **Spall:** A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the large mass.
- A.2.10.1 **Small Spall:** A roughly circular or oval depression, generally not greater than 2 cm depth nor greater than 15 cm in any dimension, caused by the separation of a portion of the surface concrete.
- A.2.10.2 **Large Spall:** May be a roughly circular or oval depression, or in some cases an elongated depression over a reinforcing bar, generally 2 cm or more in depth and 15 cm or greater in any dimension, caused by a separation of the surface concrete.
- A.2.11 **Joint Spall:** Elongated cavity along a joint.
- A.2.12 **Dummy area:** Area of concrete surface which gives off a hollow sound when struck.
- A.2.13 **Stalactite:** A downward pointing formation, hanging from the surface of concrete, shaped like an icicle.
- A.2.14 **Stalagmite:** As stalactite, but upward formation.
- A.2.15 **Dusting:** The development of a powdered material at the surface of hardened concrete.
- A.2.16 **Corrosion:** Disintegration or deterioration of concrete or reinforcement by electrolysis or by chemical attack.
- A.3 **Textural Defects**
- A.3.1 **Bleeding channels:** Essentially vertical localized open channel caused by heavy bleeding.
- A.3.2 **Sand streak:** Streak in surface of formed concrete caused by bleeding.
- A.3.3 **Water pocket:** Voids along the underside of aggregate particles or reinforcing steel which formed during the bleeding period. Initially filled with bleeding water.
- A.3.4 **Stratification:** The separation of overwet or over-vibrated concrete into horizontal layers with increasingly lighter materials towards the top: water, laitance, mortar and coarse aggregate will tend to occupy successively lower positions in

that order; a layered structure in concrete resulting from placing of successive batches that differ in appearance.

- A.3.5 **Honeycomb:** Voids left in concrete due to failure of the mortar to effectively fill the spaces among coarse aggregate particles.
- A.3.6 **Sand pocket:** Part of concrete containing sand without cement.
- A.3.7 **Segregation:** The differential concentration of the components of mixed concrete, resulting in non-uniform proportions in the mass.
- A.3.8 **Discolouration:** Departure of colour from that which is normal or desired.

## Appendix III

### **STRUCTURES, FEATURES, EVENTS AND EVIDENCE TO BE EXAMINED DURING INSPECTIONS**

#### **1 GENERAL**

The performance of dams and appurtenant structures is controlled by

- (1) their designs,
- (2) the characteristics of their constituent materials,
- (3) the nature of their foundations, and
- (4) their regional settings.

The fundamental objective of dam safety inspections is the detection of any existing or developing structural or hydraulic weakness. In searching for weaknesses, dam inspectors must recognize and understand the inter-relationship of the demands which control performance.

#### **2. CHANGES IN THE CHARACTERISTICS OF MATERIALS**

2.1 General : Observe for defective, unsuited or deteriorated materials. A variety of different materials makes up the different types of dams and appurtenances. The quality and durability of these materials must always be determined in every instance and the need for such critical examination and what to look for as listed in this section are not normally repeated in the sections on specific structures.

##### 2.2 Concrete

- (1) Alkali – aggregate reaction, pattern of crushing and cracking.
- (2) Leaching
- (3) Abrasion
- (4) Spalling
- (5) General deterioration
- (6) Strength loss

##### 2.3 Rock

- (1) Degradation
- (2) Softening
- (3) Dissolution



## 2.4 Soils

- (1) Degradation
- (2) Dissolution
- (3) Loss of plasticity
- (4) Strength loss
- (5) Mineralogical change

## 2.5 Soil - Cement

- (1) Loss of cementation
- (2) Crumbling

## 2.6 Metals

- (1) Loss of cementation
- (2) Corrosion
- (3) Stress-corrosion
- (4) Fatigue
- (5) Tearing and rupture
- (6) Galling

## 2.7 Timber

- (1) Rotting
- (2) Shrinkage
- (3) Combustion
- (4) Attack by organisms

## 2.8 Rubber

- (1) Hardening
- (2) Loss of elasticity
- (3) Heat deterioration
- (4) Chemical degradation

## 2.9 Joint sealers

- (1) Loss of plasticity
- (2) Shrinkage
- (3) Melting

## **3 GENERIC OCCURRENCES**

3.1 General : Observe occurrences for their characteristics, locations and recency. These occurrences are of a universal nature

regardless of structure type of foundation class. The details of what to look for in observing these occurrences, actual or evidential, are not repeated in the sections on specific structures.

### 3.2 Seepage and leakage

- (1) Discharge – stage relationship
- (2) Increasing or decreasing
- (3) Turbidity and piping
- (4) Colour
- (5) Dissolved solids
- (6) Location and pattern
- (7) Temperature
- (8) Taste
- (9) Evidence of pressure
- (10) Boils
- (11) Recency and duration

### 3.3 Drainage

- (1) Obstructions
- (2) Chemical precipitates and deposits
- (3) Unimpeded cutfall
- (4) Sump pump facilities
- (5) Bacterial growth

### 3.4 Cavitation

- (1) Surface pitting
- (2) Sonic evidence
- (3) Vapour pockets

### 3.5 Stress and strain : Evidence and clues

- (1) In concrete-cracks, crushing, displacements, offsets, shears & creep
- (2) In steel-cracks, extensions, contractions, bending & buckling
- (3) In timber crushing, buckling, bending, shears, extensions & compressions
- (4) In rock and soils-cracks, displacements, settlement, consolidation, subsidence, compression, zones of extension & compression.

### 3.6 Stability, evidence and clues

- (1) In concrete and steel structures – tilting, tipping, sliding & over-turning
- (2) In embankment structures, cutslopes natural slopes – bulging, sloughing, slumping, sliding, cracks & escarpments
- (3) In rock cutslopes, foundation and unlined tunnels – slumps, slides, rockfalls, bulges & cracks

## **4. OPERATION AND MAINTENANCE**

### 4.1 Service reliability of outlet, spillway sump pump mechanical – electrical features

- (1) Broken or disconnected lift chains and cables
- (2) Test operation including auxiliary power sources
- (3) Reliability and service connections of primary sources
- (4) Verification of operators understanding and ability to operate
- (5) Case and assurance of access to control stations
- (6) Functioning of lubrication systems

### 4.2 Gate chamber, galleries, tunnels and conduits

- (1) Ventilation and heat control of damp, corrosive environment of mechanical-electrical equipment.

### 4.3 Accessibility and visibility

- (1) Obscuring & vegetal overgrowth
- (2) Galleries-access ladders & lighting
- (3) Access roads and bridges
- (4) Communication and remote control lines, cables and telemetering systems

### 4.4 Control of vegetation and burrowing animals

- (1) Harmful vegetation in embankments-oversize & dead root channels
- (2) Harmful vegetation in structural concrete joints
- (3) Obstructing vegetal growth in hydraulic flow channels
- (4) Ground squirrels, rats and beavers

## **5. BEHAVIOUR**

- 5.1 Every attempt should be made to anticipate and have engineer-observers present on site at items of large spillway and outlet

discharge. Resident operational personnel can often supply valuable information and may be the only available observers (during earthquakes) for example.

## 5.2 Warning, safety and performance instrumentation

- (1) Piezometers, flow recorders, accelerometers, seismoscopes, joint meters & gauge points, strain meters, stress meters, inclinometers, direct & inverted plumb lines, surface reference monuments, stage recorders, extension meters.
- (2) Serviceability
- (3) Access to readout stations
- (4) Type and location suitable for conditions being observed
- (5) Need for recalibration
- (6) Faulty readings, sources and reasons
- (7) Alarm systems operable and at appropriate set points
- (8) Random check readings during inspections
- (9) Quiz operators to determine their understanding of purpose and functioning of instruments.

## 5.3 During and after large floods

- (1) Drift marked high waterlines
- (2) Evidence of taxed spillway capacity
- (3) Undesirable or dangerous spillway flow patterns directly observed or deduced from flow strains, erosion trails, swept vegetation & deposition of solids.

## 5.4 During and after large outlet releases

- (1) Undesirable or dangerous spillway flow patterns, dynamic pressures, vibrations & cavitation sonics.

## 5.5 After earthquakes

- (1) Cracks, displacements, offsets in structural features
- (2) Cracks, slumps, slides, displacements, settlements in embankments, cut slopes and fill slopes.
- (3) Broken stalactites in galleries, tunnels & chambers.
- (4) Toppled mechanical equipment
- (5) Sand boils.

## 6. CONCRETE DAMS

(Any of these observations are applicable also to reservoir impounding power intake structures, spillway control structures, lock walls).

### 6.1 Stress and strain : Evidence and clues

- (1) Cracks, crushing, displacements, offsets in concrete monoliths, buttresses, face slabs, arch barrels visible on exterior surfaces and in galleries, valve & operating chambers and conduit interior surfaces.
- (2) Typical stress and temperature crack patterns in buttresses, pilasters, diaphragms and arch barrels.
- (3) Retention of design forces in post tensioned anchorages and tendons.

### 6.2 Stability : Evidence and clues

- (1) Excessive or maldistributed uplift pressures revealed by piezometers, pressure spurts from foundation drain holes, construction joints and cracks.
- (2) Differential displacements of adjacent monoliths, buttresses and supported arch barrels or face slabs.
- (3) Disparities in region near the interface between arches and thrust blocks.
- (4) Movement along construction joints.
- (5) Uplift on horizontal surfaces revealed by seepage on downstream face and in galleries at construction lift elevations.

### 6.3 Hillsides and river channels adjacent to the abutments and river section foundation along the downstream toe of the dam.

- (1) Leakage
- (2) Seepage
- (3) Stability
- (4) Boils

### 6.4 Special attention to stability and seepage control at discontinuities and junctures.

- (1) Embankment wraparound sections
- (2) Waterstops in monoliths and face slabs
- (3) Reservoir impounding backfill at spillway control sections and retaining walls.

## 6.5 Foundation

- (1) Piping of weathering products from old solution channels and rock joint structure.
- (2) Efficiency of foundation seepage control systems – drains, drainage holes, grout curtains, cutoffs & drainage tunnels.
- (3) History of shear zones, faults & cavernous openings.
- (4) Zones of varying permeability
- (5) Orientation of stratification and bedding planes – effect on permeability, uplift & foundation stability.
- (6) Subsurface erosion and piping.
- (7) Thin weaker interbeds – effect on stability.

## **7. EMBANKMENT – TYPE DAMS**

### 7.1 Stress and strain : Evidence and clues

- (1) Settlement
- (2) Consolidation
- (3) Subsidence
- (4) Compressibility
- (5) Cracks, displacements, offsets, joint opening changes in concrete facing on rockfills
- (6) Loss of freeboard from settlement
- (7) Zones of extension and compression visible along dam crest or elsewhere
- (8) Crushing of rock points of contact
- (9) Differential settlement of embankment cross sectional zones visible along dam crest, indicating stress transfer along region of zone interface (increases possibility of hydraulic fracturing).

### 7.2 Stability : Evidence and clues

- (1) Cracks, displacements, openings, offsets, sloughs, slides, bulges, escarpments on embankment crest and slopes and on hillsides adjacent to abutments.
- (2) Sags and misalignments in parapet walls, guardrails, longitudinal conduits or other linaments parallel to embankment axis.
- (3) Irregularities in alignment and variances from smooth, uniform face planes.
- (4) Bulges in ground surfaces beyond toes of slopes.

### 7.3 Inadequate seepage control : Evidence and clues

- (1) Wet spots

- (2) New vegetal growth
- (3) Seepage and leakage
- (4) Boils
- (5) Saturation patterns on slopes, hillsides and in streambed
- (6) Depressions and sinkholes
- (7) Evidence of high escape gradients.

#### 7.4 Erosion control

- (1) Loss, displacement & deterioration of upstream face riprap, underlayment and downstream face slope protection.
- (2) Leaching

#### 7.5 Foundation

- (1) See 6.5 also
- (2) Consolidation
- (3) Liquefaction

#### 7.6 Other endangerments

- (1) Utility pressure conduits on, over or through embankments.
- (2) Diversion ditches along abutment hillsides.

### **8 SPILLWAYS**

#### 8.1 Approach channel

- (1) Obstructions
- (2) Slides slumps and cracks & cutslopes

#### 8.2 Log booms

- (1) Submergence
- (2) Uncleared accumulated drift
- (3) Parting
- (4) Loss of anchorage
- (5) Inadequate slock for low reservoir stages.

#### 8.3 Hydraulic control structure

- (1) Stability
- (2) Retention of capacity rating
- (3) Erosion at toe
- (4) Unauthorized installations on crest, raising storage level and decreasing spilling capacity.

- (5) Gate piers
- (6) Trash control systems
- (7) Nappe and crotch aeration
- (8) Siphon prime settings

#### 8.4 Headwater control (gates, flashboards, fuse plugs)

- (1) Unauthorized position
- (2) Wedging
- (3) Gate trunnion displacements
- (4) Loss of gate anchorage post-tensioning
- (5) Undesirable eccentric loads from variable positions of adjacent gates.
- (6) Gate-seal
- (7) Erosive seal leakage
- (8) Failure of system
- (9) Availability of bulkhead facilities for unwatering, and of cranes and lifting beams.

#### 8.5 Operating deck and hoists

- (1) Broken or disconnected lift chains and cables
- (2) Unprotected exposure of electrical-mechanical equipment to weather, sabotage, vandalism.
- (3) Structural members and connections.

#### 8.6 Shafts, conduits and tunnels

- (1) Vulnerability to obstruction
- (2) Evidence of excessive external overloading-pressure jets contorted cross-sections, cracks, displacements & circumferential joints.
- (3) Serviceability of linings (concrete and steel), materials deterioration, cavitation & erosions.
- (4) Rockfalls
- (5) Severe leakage about tunnel plugs
- (6) Support system for pressure conduits in walk-in tunnels.

#### 8.7 Bridges

- (1) Possibility of collapse with consequent flow obstruction.
- (2) Serviceability of operational and emergency equipment transport.



## 8.8 Discharge carrier (open channel or conduit)

- (1) Vulnerability to obstruction
- (2) Evidence of excessive external sidewall loading – large wall deflections, cracks, differential deflections at vertical joints.
- (3) Invert anchorage and foundation support – dummy soundings, buckled lining & excessive uplift.
- (4) Observation of evidence of dangerous hydraulic flow patterns – cross water, inadequate freeboard, wall climb, unwetted surface, uneven distribution, ride up on horizontal curves, negative pressures at vertical curves & pressure flow deposition.
- (5) Drain system serviceable
- (6) Air injection and expulsion
- (7) Tendency for jump formation in conduits
- (8) Buckling & slipping of slope lining
- (9) Erosion of unlined channels.

## 8.9 Terminal structures

- (1) Inadequate dissipation of energy
- (2) Jump sweepout
- (3) Undercutting
- (4) Retrogressive erosion
- (5) Loss of foundation support for flip bucket substructure
- (6) Unsafe jet trajectory and impingement
- (7) Erosive endangerment of adjacent dam or other critical structures.

## 8.10 Return channels

- (1) Impaired outfall
- (2) Obstructions
- (3) Slides, slumps & cracks in cutslopes.
- (4) Erosion of deposition creating dangerous tailwater elevations or velocities.
- (5) Evidence of destructive eddy currents.

## **9. OUTLETS**

- 9.1 General : Many of the observations made of outlet components are similar in nature and purpose to these made for spillway components, stilling basins for example.

- 9.2 Approach channels (may seldom be directly visible and may require underwater inspection).
- (1) Siltation
  - (2) Underwater slides and slumps.
- 9.3 Intake structure (including appended, inclined and free standing towers with wet and dry).
- (1) Lack of dead storage
  - (2) Siltation
  - (3) Potential for burial by slides and slumps
  - (4) Damage or destruction of emergency and service bulkhead installation facilities
  - (5) Availability of bulkhead, cranes & lifting beams
  - (6) Serviceability of access bridges
- 9.4 Trash racks and raking equipment
- (1) Clogging of bar spacing
  - (2) Lodged debris on horizontal surfaces
  - (3) Collapse
- 9.5 Gate chambers, gates, valves, hoists, controls, electrical equipments, air demand ducts.
- (1) Accessibility to control station under all conditions
  - (2) Ventilation
  - (3) Unauthorized gate or valve positions
  - (4) Binding of gate seals
  - (5) Seizing
  - (6) Erosive seal leakage
  - (7) Failure of lubrication system
  - (8) Drainage arc sump pump serviceability
  - (9) Vulnerability to flooding under reservoir pressure through conduits, by-passes and gate bonnets surfacing in chamber.
- 9.6 Conduits and tunnels
- (1) See 8.6 also
  - (2) Seepage or leakage along external periphery of conduit
  - (3) Extension strains in conduits extending through embankments
  - (4) Capacity and serviceability of air relief and vacuum valves on conduits.
- 9.7 Terminal structures  
See 8.9
- 9.8 Return channels  
See 8.10

## **DAM SAFETY DIRECTORATE**

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