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मिट्टी तथा पाषाण भरित बांधों में क्लेश व दोष निवारण  
के उपाय — मार्गदर्शी सिद्धान्त

*Indian Standard*

**DISTRESS AND REMEDIAL MEASURES IN EARTH  
AND ROCKFILL DAMS — GUIDELINES**

ICS 93.160

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**BUREAU OF INDIAN STANDARDS**  
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG  
NEW DELHI 110002

## FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Dams and Reservoirs Sectional Committee had been approved by the Water Resources Division Council.

Conservation of water is the most important prerequisite for proper management of water resources and hence, large number of earth and rockfill dams have been constructed in India, most of them after independence. While these dams have contributed to the development of the nation, some of them also pose as potential hazard because of catastrophic damage which can take place if the reservoir water stored behind the dam is suddenly released due to any failure or accident. The safety of the dam is thus of paramount importance and any deterioration or disorder observed in the dam, therefore, warrants immediate suitable strengthening. Strengthening may sometimes be necessary to restore the stipulated utility of the dam and reservoir. Strengthening may also be required for upgrading the stability of the dam due to inadequacies in original design, deficiencies in construction, ageing, increase in storage/spillway capacity/seismicity or modification in codal design requirement. However, remedial measures imply restoration of original state and stability of dam after it has experienced some distress like breach, slope failure, settlements, crack formation, piping, subsidence/upheaval etc.

The main object of strengthening the dam through remedial measures is not only to improve its safety alone but also to restore it fully to meet the designed requirements and estimated benefits.

There is no ISO standard on the subject. This standard has been prepared based on indigenous manufacturers' data/practices prevalent in the field in India.

The composition of the committee responsible for formulating this standard is given in Annex A.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

## *Indian Standard*

# DISTRESS AND REMEDIAL MEASURES IN EARTH AND ROCKFILL DAMS — GUIDELINES

### 1 SCOPE

This standard deals with the various causes of distress, detecting methods and implementation of the remedial measures for earth and rockfill dams. The distress and remedial measures pertaining to concrete/asphalt faced rockfill dams are not covered in this standard. The remedial measures for the works relating to increase in spillway capacity and construction of fuse plug or breaching section are also not covered in this standard.

### 2 REFERENCES

The following Indian Standards contain provisions which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

<i>IS No.</i>	<i>Title</i>
6066 : 1994	Pressure grouting of rock foundations in river valley projects — Recommendations ( <i>second revision</i> )
7894 : 1975	Code of practice for stability analysis of earth dams
8826 : 1978	Guidelines for design of large earth and rockfill dams
9296 : 1979	Guidelines for inspection and maintenance of dam and appurtenant structures ( <i>first revision</i> )

### 3 GENERAL

The remedial measures best suited for a dam depend upon many factors. The type of treatment should be selected/adopted on the basis of techno-economic considerations to ensure the safety and restoration of embankment within stipulated period. The types of treatments discussed in the standard are overall and general and should be considered together with specific instructions that might have been stipulated during design, construction or maintenance.

### 4 CAUSES FOR DISTRESS IN DAMS

4.1 An evaluation of the existing rules of the art and any modification of the criteria used to evaluate the

safety may result in disagreement with standard actually followed in design and construction of the dam.

4.2 Distress in the dam generally takes place on account of the following:

- a) Natural factors like ageing, earthquake, unprecedented rains and floods, etc;
- b) Design inadequacies and deficiency;
- c) Imperfections and deficiencies during construction, operation and maintenance;
- d) Incorrect estimation of design parameters such as density, shear parameter, permeability, etc; and
- e) Non-observance of design requirements with regard to construction of structures on upstream and downstream within specified zones.

### 5 TYPES OF DISTRESS IN DAMS

5.1 Types of distress most frequently observed in embankment dams are as follows:

- a) Distress due to deteriorations in the foundations, and
- b) Distress due to deteriorations in the dam body.

#### 5.2 Distress Due to Deteriorations in the Foundations

##### 5.2.1 Percolation and Internal Erosion

The main cause of the deficient behaviour is due to (a) inadequacies of existing-seepage control system, namely seepage barriers and drainage system; and (b) excessive pore pressure or degradation in the foundation.

##### 5.2.2 Loss of Shear Strength

Saturation of the soil may result in high value of pore-pressure and reduction in shear strength of the foundation which create disorders in and the form of downstream slips degradation of foundation material etc.

##### 5.2.3 Deformation and Subsidence

Differential settlement in the foundation may lead to excessive seepage, high exit gradient through the strata of the foundation itself or opening/cracks development in the cut-off.

### 5.3 Distress Due to Deteriorations in the Dam Body

#### 5.3.1 Percolation and Internal Erosion

The distress is mostly associated with the following:

- a) Deficiency in construction with respect to moisture content control, earth placement and compaction particularly at junctions of zones and method dealing with frost effects;
- b) Unsatisfactory and sub-standard construction of the impervious core and other water barrier systems; and
- c) Use of undesirable construction materials without proper compliance to design parameters and without adequate precautions, in respect of fine clays, organic clay, dispersive clays, silt and fine uniform sands, soluble soils with boulders, decomposed rocks, weathered rocks, soils with unsuitable grain-size-distribution, etc; and
- d) Inadequacies of drainage system and filters.

#### 5.3.2 Slope Protection Works

The distress in the slope protection works is generally attributed to:

- a) material decomposition or weathering;
- b) unforeseen actions or actions of exceptional magnitude such as precipitation or waves in reservoir;
- c) differential movements and/or slips of the protection measures at upstream;
- d) inadequate protective drainage filter layers below revetment and improper packing of revetments;
- e) splashing due to wave action, in case of inadequate free board, resulting in the downstream slope erosion; and
- f) Presence of too small size of stones.

#### 5.3.3 Differential Movements

The differential movements including uneven load transfer, cracking, arching and hydraulic fracture in the dam body are liable to occur due to unsuitable embankment materials, improper construction methods, poor compaction and heterogeneity in foundation strata.

#### 5.3.4 Interface Between Embankments and Concrete/Masonry/Steel Structures/Adjoining Embankments

Improper contact at interface leads to:

- a) Preferential path of seepage associated with

internal erosion; and

- b) Differential movements.

#### 5.3.5 Upstream Slips

The upstream slips are mostly associated with the following:

- a) Inadequate shear strength of the foundation;
- b) Inadequate strength of the embankment materials;
- c) Poor construction;
- d) Excessive pore pressure;
- e) Sudden drawdown; and
- f) Liquefaction.

#### 5.3.6 Downstream Slips

The downstream slips are mostly associated with the following:

- a) Inadequate shear strength of the foundation;
- b) Inadequate strength of the embankment materials;
- c) Poor construction;
- d) Excessive pore pressure;
- e) Percolation and/or internal erosion;
- f) Liquefaction; and
- g) Saturation due to sustained rainfall.

## 6 DETECTION METHODS

### 6.1 Direct Observation and Monitoring

Direct observation is one of the most effective methods of detecting the following deteriorations in foundation and dam body:

- a) Deformation and land subsidence;
- b) Excessive seepage and internal erosion;
- c) Slope protection;
- d) Differential movements;
- e) Upstream slips; and
- f) Downstream slips.

Embankment dam should be monitored and examined for cracks, leakages, saturated areas or wet spots, springs, sinkholes, evidence of piping, erosion, excessive growth of vegetation, frost, heave, crest alignment, bulging or depression of slopes and berms, animal burrows, and deterioration of rip-rap or other

slope protection materials. The major areas needing attention in inspection have been listed in IS 9296 which may be referred to for guidance.

#### 6.1.1 Under-Water Observation

Under-water observations with video equipment and remotely operated vehicles ( ROV ) or divers for inspecting inaccessible areas under-water may be used for detecting the deterioration in foundation and reservoir side of dam.

#### 6.2 Measurement

Periodic and systematic measurements in respect of seepage, phreatic level, uplift, pore pressure, turbidity, horizontal displacement, vertical displacement and rainfall may also be used in detecting the deterioration in foundation and dam body.

#### 6.3 Investigation

Test results on soil samples from dam and foundation and chemical and physical analysis of seepage can be used to investigate the deterioration in respect of shear strength, seepage and internal erosion of the foundation and dam body.

### 7 REMEDIAL MEASURES

7.1 Strengthening, repairs and remedial measures are not amenable to standardization and should be carefully selected depending upon (a) the risk element as influenced by the height of the dam, reservoir volume and potential loss to life and properties, etc, (b) the economic value of water stored, (c) nature of foundation stratum, and (d) materials and methods used in construction of the dam. Measures generally used are as follows:

- 1) Monitoring distress level;
- 2) Seepage control measures;
- 3) Construction and/or repair of drains filters and relief wells;
- 4) Strengthening by grouting or other methods;
- 5) Filling of fractures, cavities and sink holes;
- 6) Construction or repair of slope protection;
- 7) Reconstruction of deteriorated zones;
- 8) Upstream stabilization methods;
- 9) Downstream stabilization methods;
- 10) Raising of dam;
- 11) Increase in spillway capacity;
- 12) Construction of fuse plug/breaching section; and
- 13) Lowering of reservoir level.

Construction methods which may be used for rehabilitation are given in 7.2 to 7.10.

#### 7.2 Treatment for Control of Excessive Seepage

The main objective of treatment is to restore the water tightness of the dam and foundation. The method of treatment may differ for foundation, dams with upstream membrane, dams with impervious core and homogeneous dams.

##### 7.2.1 Foundation

###### 7.2.1.1 Rock

Depending upon the nature of rock, grouting may be done either from the upstream or top of the dam ensuring the formation of continuous barrier in the rock along with core. The grouting may be carried out with ordinary portland cement or chemicals ( see IS 6066 ).

###### 7.2.1.2 Soil

During the service time of reservoir it is usually impractical to provide a positive cut-off or open partial cut-off through out the length of the dam as a remedial measure. However, a full cut-off may be adopted by way of providing any one of the following:

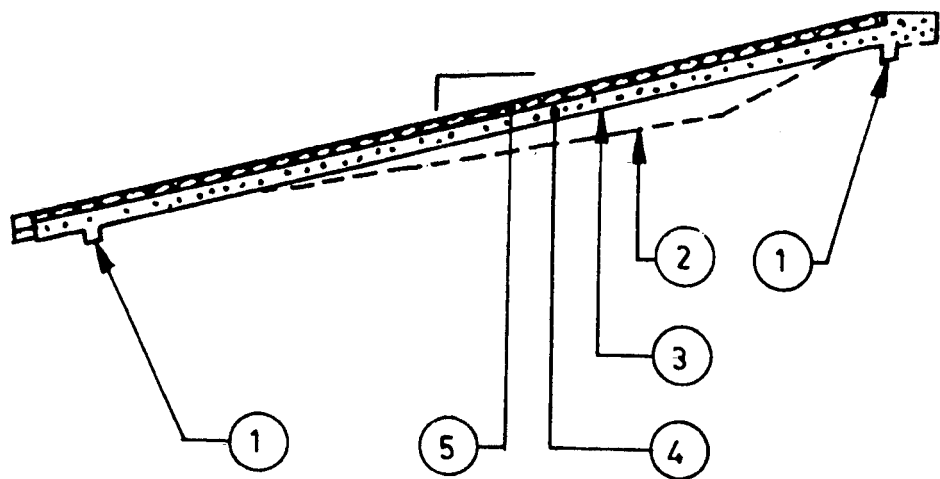
- a) R.C.C. diaphragm;
- b) Plastic diaphragm;
- c) Sheet piles; and
- d) Alluvial grouting.

Sometimes clay blanket constructed by suitably spreading impervious material upstream under minimum water condition in the reservoir combined with downstream relief wells may be the most appropriate solution.

##### 7.2.2 Dams with Impervious Core and Homogeneous Dams

Problems related with seepage through the dam body having homogeneous section or core may be effectively tackled using the following measures:

- a) The seepage at about FRL and above is mainly as a result of siphon effect over the dam body and may be eliminated by extension of core up to at least one metre above MWL by open excavation and construction of continuous additional core above the existing one according to specification,
- b) Seepage through homogeneous section may be reduced by providing upstream geo-membrane lining with suitable cover of protective layer ( see Fig. 1 ),



1. Anchoring of LDPE Film in Trenches

2. Existing Slope Profile

3. LDPE Film 350 Micron Thickness
4. 90 cm Thick Earth Cover

5. 30 cm Thick Stone Pitching

FIG. 1 TYPICAL DETAIL OF LAYING OF LDPE FILM ON THE UPSTREAM SLOPE

- c) Construction of a cement-bentonite/plastic or concrete diaphragm wall through or adjacent to the core of the dam,

d) Cement-bentonite or chemical grouting, and  
NOTE — Proper care is to be exercised to avoid reduction in the efficiency of downstream filter arrangements due to grouting.

e) Removing and rebuilding the damaged parts of the dam including core with generously provided filter layers with very precise specifications in respect of the filter.
- c) Providing an inclined chimney filter and transverse filter drain for the seepage in downstream and covering the chimney section by constructing additional downstream section of dam (*see Fig. 3*),

d) Providing filter and rock toe at the downstream toe and improve drainage, and

e) Combination of above measures may also be adopted on account of safety and economic grounds.

7.3 Drains and Filter Construction or Repair

The main aim of the remedial measure is to collect the seepage water inside the dam and through foundation and provide it a safe exit through the drainage system.

7.3.1 Perched Water

To drain the perched water or high phreatic lines at different places leading to local slushiness in the downstream slope or piping, the following methods may be adopted:

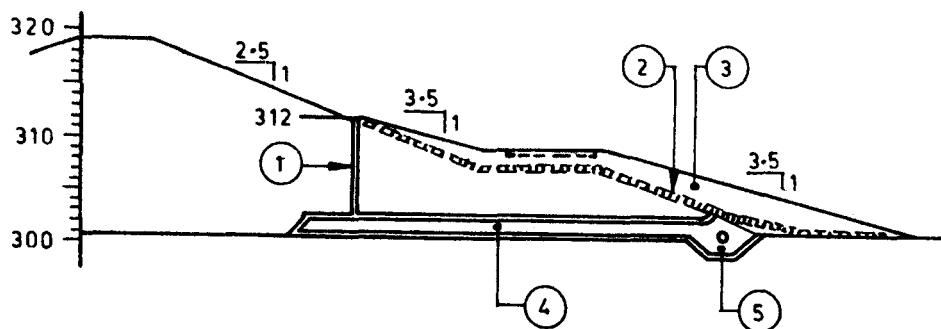
- a) Constructing vertical drains in the downstream slope of the dam section going down and joining the extended horizontal filters. This will drain the perched water into the existing downstream drainage system of the dam section (*see Fig. 2*),
- b) Providing a new filter section with berm at the appropriate level of the downstream section covering the entire area of seepage. This section will serve the purpose of downstream loading and safe exit to the seeping water,

7.3.2 Sand Boils and Slushy Conditions on Downstream of Dam

The main cause of sand boils and slushy conditions on the downstream of dam is the excess hydrostatic pressure and seepage through deep pervious strata underlying the dam. The severity of under-seepage both in respect of excessive hydrostatic pressure and seepage-flow is dependent upon head of water, permeability of substratum and characteristics of the upper strata of downstream portion. This problem may be tackled by properly designed and constructed downstream loading berm with suitable inverted filter, drainage trench, upstream clay blanket with or without relief wells or their suitable combination.

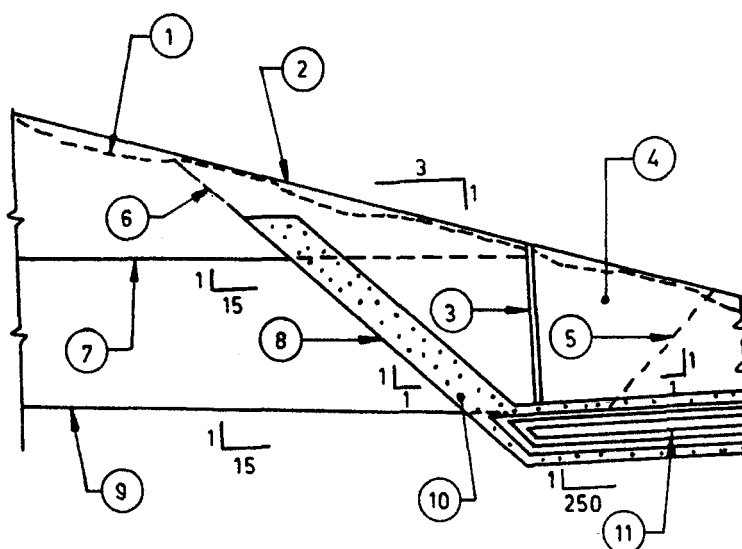
7.4 Strengthening by Grouting

Multiple-row-grout-curtain may be used for sealing deep permeable alluvium in foundation. However, dam body grouting may also be done if need arises. Special care has to be taken in working out the allowable grouting pressure and grout intake to avoid the possibility of further cracks in the core and rise of pore water pressure within the dam endangering its



- |                    |  |
|--------------------|--|
| 1. Vertical Drains | 4. Extended Horizontal Filter          |
| 2. Filter          | 5. Existing Downstream Drainage System |
| 3. Clean Gravel    |  |

FIG. 2 TYPICAL DETAILS OF VERTICAL DRAINS IN THE DOWNSTREAM SLOPE



- |                                   |   |
|-----------------------------------|---|
| 1. Existing Profile               | 7. Hydraulic Gradient Line with Water Level ( for Reservoir Condition A ) |
| 2. Proposed Profile               | 8. Stable Slope Suitable to Site Conditions                               |
| 3. Vertical Stand Pipe Piezometer | 9. Hydraulic Line with Water Level ( for Reservoir Condition B )          |
| 4. Earthfill Compacted in Layers  | 10. 1.5 m Thick Sand Filter   |
| 5. Cut Line                       | 11. Cross Filter Drains   |
| 6. Cut Line                       |   |

FIG. 3 TYPICAL DETAIL OF INCLINED CHIMNEY FILTER IN THE DOWNSTREAM SLOPE

safety. Grouts, usually clay-cement-bentonite mixtures with certain additives and reagents, have to be adjusted to suit varying local conditions based on extensive laboratory and field tests to optimise the mix proportions with regard to stability, bleeding, fluidity, lubricity and strength. Clay-gels and silica-gels may be used but resins which are too expensive should be used judiciously depending on the necessity.

### 7.5 Filling in Fractures and Cavities

The main reasons for fractures and cavities are poor

quality materials used for construction and defective placing of embankment or inefficient drainage system. The methods described in 7.5.1 to 7.5.3 are generally employed for strengthening.

**7.5.1** Removing the zone of cavities by open excavation and refilling the cavities with the dam material by placing, dumping, spreading, moistening and compacting as per specification adopted for dam construction.

**7.5.2** Filling the cracks with thick slurry consisting

primarily of natural clayey soil. Thoroughly mixed slurry is pumped with low head pump under gravity head. Before pumping any slurry, the cracks are washed with water under pressure. Slurry filled into the cracks are allowed to dry for several days/weeks. In case of appreciable shrinkage of the slurry due to drying, the process is repeated. Finally the cracks should be sealed at the surface by trenching filling and recompacting with appropriate soil to a depth of 0.3 to 0.6 m.

7.5.3 Sealing of sink holes in the reservoir or in the upstream of dam section by encircling the area by sheet piling and filling the hole with dense mixture of appropriate materials such as sand, gravel, pebble, boulder and rock fragments etc and then compacting as per specifications adopted for dam construction.

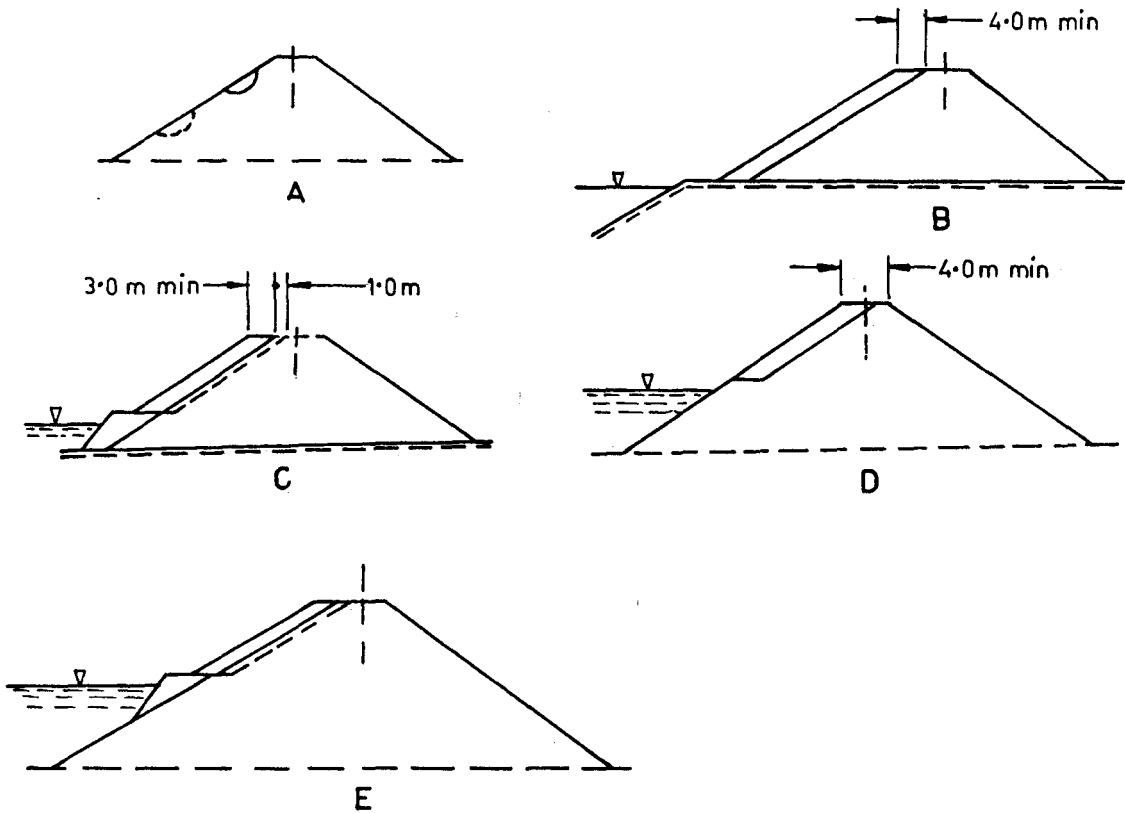
7.6 Repair of Slope Protection

7.6.1 The following measures are generally adopted to repair slope protection (see Fig. 4):

- a) Partial repair with the same material and methods as adopted in the original dam construction,
- b) Enlarging the upstream protection by dumping selected rockfill along the entire upstream slope,
- c) Enlarging the upstream protection zone by dumping selected rockfill over the platform constructed out of dumped coarse fractioned rockfill,
- d) Replacement of slope protection, and
- e) Partly enlarging the upstream protection from dumped coarse fractioned rockfill.

7.7 Reconstruction of Deteriorated Zones

Some times it becomes inevitable to reconstruct the dam section in part or whole length due to severe rain



- A. Partial Repair
- B. Enlarging
- C. Enlarging from Dumped Coarse Fractioned Rockfill
- D. Replacement of Slope Protection
- E. Partly Enlarging from Dumped Coarse Fractioned Rockfill

FIG. 4 DIFFERENT WAYS OF REPAIRING AND STRENGTHENING UPSTREAM SLOPE PROTECTION



cuts, bulges, slope slides, settlement, unwarranted human and animal activities etc. In such cases, a fresh dam section based on IS 8826 and IS 7894, be evolved and fitted over the existing dam section in most economical methods.

### 7.8 Upstream Slope Stabilization Methods

Following methods may be employed for upstream slope stabilization:

- a) Flattening of the slope and/or reloading on the upstream toe. This may be done by constructing large width rockfill berm at lower level. Properly designed flatter slope can then be constructed from this lower level berm to the top of the dam,
- b) Stabilizing the upstream slope by grouting with sand cement grout,
- c) Restoration of failed slopes using geogrids, and
- d) Providing additional earthfill with horizontal filters within.

### 7.9 Downstream Slope Stabilization Methods

The following methods may be employed for downstream stabilization:

- a) Installing drainage system,
- b) Flattening of slope,
- c) Reinforcing of earth,
- d) Stone pitching,
- e) Providing an effective rain-water drainage system,
- f) Providing good and effective turfing, and
- g) Employing any other treatment suggested in 6.3.

### 7.10 Raising of Dam Crest

Raising of dam crest may be required on free board consideration. For raising a dam crest, strengthening of the profile by downstream loading may be done. While taking up the upstream strengthening for raising the dam crest, necessary precautions should be taken in respect of maintaining the reservoir outlet, removal of embankment protection, possible presence of sediments etc. In case of a zoned dam, the prolongation and strengthening of the core should be given due consideration.

## 8 PLANNING, DESIGN AND EXECUTION OF REMEDIAL WORKS

### 8.1 Design Procedure

For any enlargement, alteration, rehabilitation, repair or abandonment of existing structures or facilities, the original design documents and all available construction and operation records should be carefully studied.

If the rehabilitation would require substantial structural modification or if basic assumptions and environmental conditions which form the basis of the original design have considerably changed, the whole structure should undergo a new stability analysis.

### 8.2 Principles and Criteria of Design

Designing of any part or whole of any component of the embankment dam should be done as per current relevant Indian Standards. Before starting detailed design work, the actual condition of those parts or components of the structures to be enlarged, modified or repaired should be carefully surveyed and documented.

**8.3** A close watch should also be kept to study the effectiveness of the treatment. All necessary data and procedures adopted should be properly documented. Regular inspection of the distressed area, depending upon its importance, should be carried out.

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**Amendments Issued Since Publication**

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