DESIGN PRINCIPLES OF EARTH DAMS

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ADVANTAGES OF EMBANKMENT DAMS

1. Any given Foundation
2. Locally available material
3. More resistant to seismic forces
4. Less time of construction
5. Cheaper
*As Good Dam Sites are exhausted, the embankment dam with its flexible requirements remains almost the only choice.*

*More than 90% of high dams planned or constructed in the country since 1950 are embankment dams*
Basic criteria for satisfactory design

Foundation is adequately water tight
Stability to prevent excess uplift pressures, piping, instability, sloughing and removal of material by erosion.
Allowance for settlement by camber and 0.01H
Surplussing arrangement to prevent overtopping
Freeboard to prevent overtopping
u/s & d/s protection works to prevent erosion.
STABILITY ANALYSIS

STATIC Stability analysis
Dynamic Stability analysis
Static Stability Analysis

Design studies for slope stability include consideration

Loading conditions
Material properties
Pore Pressures
Factor of Safety requirement under various loading conditions
• Loading conditions:
  To be *safe* and *stable* during all phases of *construction* and *operation*.
  Analysis to be done for *most critical combination of forces* likely to occur.

Construction condition (u/s and d/s slopes)- UCUD
Reservoir partially full (u/s slope) - CU test
Sudden Drawdown (u/s slope) - CU test
Steady seepage (d/s slope) - CU Test
Steady seepage with sustained rainfall(d/s slope) - CU test
Earthquake condition (u/s & d/s slopes) - CU Test
Design parameters selection

Shear strength parameters are obtained from Triaxial tests of borrow area.

Analysis procedure

Determining Driving and Resistant Forces involves Assumption of
1. Tentative section of dam
2. Possible circular failure surface
• Then

  Division of the slip circle mass into a number of slices
  Calculation of forces on each slice
  Summation of the forces
DYNAMIC ANALYSIS

• Necessary for detailed design of all important dams

Deformation Analysis
To obtain response of the structure to earthquake ground motion.

Liquifaction Analysis
Serious loss of strength under cyclic loading
Classification according to height and storage capacity

- **Large dams (IS:8826-1978)**
  i) Dams exceeding height more than 15m height and
  ii) a dam between 10 m and 15m height providing volume of earth work exceeds 0.75 million m3 and
    Storage capacity exceeds 1 million m3 or
  iii) Max.flood discharge exceeds 2000 cusecs

- **Small Dams (IS:12169-1987)**
  i) Dam not satisfying the criteria of a large dam
## Data required for design of Earth dams

- Index plan along with latitude and longitude
- Net level plan
- Longitudinal section of dam
- FRL and MWL contour Plan
- Trail Pit particulars along L. S of dam
- Test results of Borrow soils and Foundation soils from APERL
- Geological Report of GSI
- General layout of Plan
### Record of Boring - BH NO. 1

**Project:** Drilling of bore holes for collection of core samples and proserving in core boxes.

**RALLA VAGU RESERVOIR**

<table>
<thead>
<tr>
<th>Dia Bore Hole: 150MM &amp; 75MM (NX)</th>
<th>Total Depth of BH: 10.2 m</th>
<th>Chainage No: 0.100 KM</th>
<th>Type of Drilling: Rotary</th>
<th>GL: 307.375</th>
<th>Date: 27-11-2016 TO 29-11-2016</th>
</tr>
</thead>
</table>

**Use of Bore:** Daimond bit  
**Location:** RALLA VAGU

**Length of casing:** 4.0 m

**Ground Water Level:**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Length of Run (m)</th>
<th>Description</th>
<th>Log of Bore</th>
<th>Depth</th>
<th>0-15</th>
<th>15-30</th>
<th>30-45</th>
<th>N</th>
<th>Details of Rock core</th>
</tr>
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<tbody>
<tr>
<td>0.0</td>
<td>1.0</td>
<td></td>
<td></td>
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</table>

**MORAI WITH BOLDERS**

**SOIL WITH BOLDERS**
<table>
<thead>
<tr>
<th>S.No</th>
<th>Lab Ref. No</th>
<th>Location</th>
<th>ATTERBERG LIMITS</th>
<th>GRADATION ANALYSIS</th>
<th>B.S.I Classification</th>
<th>Differential Free Swell</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid Limit (W.L.) %</td>
<td>Plastic Limit (W.P.) %</td>
<td>Plasticity Index</td>
<td>Shrinkage Limit %</td>
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<tr>
<td>1</td>
<td>69</td>
<td>Ch. 500m along the axis</td>
<td>68</td>
<td>20</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>Ch. 200m along the axis</td>
<td>Left Non Plastic</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Note: The soil samples are collected and sent by the party.
<table>
<thead>
<tr>
<th>S.No</th>
<th>Lab Ref No</th>
<th>Chainage (Meters)</th>
<th>Lab Permeability $K \times 10^6$ cm/sec</th>
<th>Specific Gravity (Assumed)</th>
<th>FDD gr/cc</th>
<th>FMC/%</th>
<th>Void Ratio</th>
<th>Saturated Moisture content</th>
<th>Shear Parameters of soil passing 4.75 mm size sieve</th>
<th>Un-Consolidated Un-drained Triaxial Shear (Quick) test without Pore Pressure measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td>FDD/ FMC</td>
<td>FDD/ SMC</td>
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<td></td>
<td>C Kg/cm$^2$ $\Phi$ (Deg) C Kg/cm$^2$ $\Phi$ (Deg)</td>
<td>C Kg/cm$^2$ $\Phi$ (Deg) C Kg/cm$^2$ $\Phi$ (Deg)</td>
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<tr>
<td>1</td>
<td>69</td>
<td>Ch. 500m along axis</td>
<td>23.88976</td>
<td>2.70</td>
<td>1.649</td>
<td>6.8</td>
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<td>23.6</td>
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<tr>
<td>2</td>
<td>70</td>
<td>Ch. 200m along axis</td>
<td>permeable</td>
<td>2.68</td>
<td>1.764</td>
<td>4.9</td>
<td>0.52</td>
<td>19.4</td>
<td>--</td>
<td>0.15 15</td>
</tr>
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</table>

Note: The soil samples are collected and sent by the party.
Free Board Requirements

- **FRL Condition:**
  Normal Free board should not be less than 2.0 m over FRL

- **MWL Condition:**
  The free board should be minimum of 1.5 m over MWL
Factors considered for Free board

• Wave Characteristics:
  Wave height and Wave length

• Slope of dam

• Roughness of pitching
COMPUTATION OF EFFECTIVE FETCH

\[ F_e = \frac{\sum X_i \cos \alpha \cos \alpha }{\sum \cos \alpha} \]

\[
\begin{array}{|c|c|c|c|}
\hline
\cos \alpha & X_i & X_i \cos \alpha & X_i \cos \alpha \cos \alpha \\
\hline
0.743 & 2.08 & 1.55 & 1.151 \\
0.809 & 2.29 & 1.85 & 1.499 \\
0.866 & 4.73 & 4.10 & 3.550 \\
0.914 & 4.32 & 3.95 & 3.610 \\
0.951 & 4.26 & 4.05 & 3.851 \\
0.978 & 5.11 & 5.00 & 4.890 \\
0.995 & 5.68 & 5.65 & 5.621 \\
1.000 & 6.00 & 6.00 & 6.060 \\
0.995 & 5.18 & 5.15 & 5.124 \\
0.978 & 3.37 & 3.30 & 3.277 \\
0.951 & 2.95 & 2.80 & 2.662 \\
0.914 & 2.90 & 2.65 & 2.422 \\
0.866 & 2.77 & 2.40 & 2.078 \\
0.809 & 3.09 & 2.50 & 2.023 \\
0.733 & 3.16 & 2.35 & 1.746 \\
\hline
\end{array}
\]

\[ \Sigma = 13.512 \quad \Sigma = 19.454 \]

\[ F_e = \frac{\sum X_i \cos \alpha \cos \alpha }{\sum \cos \alpha} = \frac{49.354}{13.512} = 3.66 \text{ km} \]
Components of Embankment dams

• Cut-Off
• Core
• Casing cover
• Internal drainage system and foundations
• Slope Protection arrangements
• Surface drainage

On special cases, the following components are provided:

• Impervious blanket
• Relief Wells
Classification according to materials used

- Homogeneous earth dams
- Zoned earth dams
1. Selected Earth Fill
2. Impervious Fill
3. Foundation
4. Imperious Sub-Stratum
5. Sand Filter
6. Rock Toe
7. Rubble Pitching
8. Tee Drain

FIG. 1  CROSS-SECTION OF MODIFIED HOMOGENEOUS EARTH DAM
1. Positive Cut-off
2. Grout Curtain
3. Central Impervious Core
4. Upstream Casing
5. Downstream Casing

6. Inclined and Horizontal Filter
7. Rock Toe and Toe Drain
8. Riprap with Filter
9. Catch Water Drain

Note — Horizontal filter at intermediate levels are sometimes placed in the upstream casing zone where casing material is of Impervious nature.

2A Embankment Dam with Central Core and Positive Cut-Off
**Cut-off**

**Functions of Cut-Off:**
- To reduce loss of stored water through foundation and abutments
- To prevent subsurface erosion by piping

**Type of Cut-off:**
Type of Cut-off should be decided on the basis of detailed geological investigation (Positive Cut-off or Partial cut-off)
- The centre line of cut-off should be within the base of impervious core.
- Cut-off should be fixed at least 0.4m into continuous impervious or inerodible rock formation in case of positive cut-offs
Cut-off

Bottom width of Cut-Off:
• Provide sufficient working space for compaction equipments
• Working space to carryout curtain grouting
• Provide safety against piping.

Minimum width of Cut-off:
• A Minimum width of 4.0 m is recommended.
• A bottom width of 10 to 30 % of hydraulic head may be provided

Side slopes of Cut-off:
• 1:1 or flatter for overburden soils
• 0.5:1 for soft rock
• 0.25 :1 for hard rock
Core

The core provides an impermeable barrier within the body of the dam.

- The minimum top width of core should be 3m.

- Thickness of core shall not be less than 30% (preferably 50%) of maximum head of water acting at that section.

- The top level of the core should be fixed at 0.5m above MWL.
Casing cover

• The function of casing is to impart stability and protect the core
• Relatively pervious materials, which are not subject to cracking on direct exposure to the atmosphere are suitable for casing
Internal Drainage system

Internal drainage system comprises

• an inclined or vertical filter
• a horizontal filter
• A rock toe
• A toe drain
Internal Drainage system

Inclined or Vertical sand filter:

- It is desirable to be provided especially to protect silty core material
- Where head of water is 3m or less, it may not be necessary to provide blanket or chimney filter. Adequate toe protection shall be provided
Slope Protection (IS: 12169-1987)

Up stream slope:
• U/s slope protection is ensured by providing riprap
• A minimum of 300 mm thick rip rap over 150 mm thick filter layer may be provided.

Down stream slope:
• D/s slope protection is ensured by providing riprap or turfging
• To protect the d/s slope from raincuts by providing suitable turfging on entire slop.
Surface Drainage(IS:12169-1987)

Down stream slope protection:
• Turfing
• Chute drains at 90 m c/c to drain water
• Longitudinal drains

Rock toe:
• Max. and Min. height of rock toe shall be 6m and 1.5 m
• However, rock toe height shall be 0.2 H shall be considered.
Impervious blanket and Relief Wells
(IS:12169-1987)

Impervious blanket:
• Horizontal u/s impervious blanket is provided to increase the path of seepage when full cut-off is not practicable
• Min. thickness of blanket shall be 1m and
• Min. length of blanket shall be 5 times the max. water head.

Relief Wells:
• Relief wells are provided after construction earth dam when seepage is found.
Embankment dams are to ensure:

- Safety against overtopping
- Stability
- Safety against internal erosion

**Stability analysis:**

- Embankment height more than 10m, stability analysis may not be necessary
- Embankment height more than 10m, stability analysis may be carried out as per IS: 7894-1975.
Basic Design Requirements
(IS:12169-1987)

Top Width:
• Crest width of dam should be fixed according to the working space required at the top
• No dam should have crest width of less than 6m

Settlement allowance:
• 1 to 2% of the embankment height above the designed top level may be provided to account for both embankment and foundation settlements of earth dam
Basic Design Requirements (IS:12169-1987)

Berms:

- To break the continuity of the slopes
- To provide level surface for construction and maintenance operations
- A min. berm width of 3m is recommendable.
- However, 5 to 6m width is desirable.
## Basic Design Requirements

(IS:12169-1987)

<table>
<thead>
<tr>
<th>Case</th>
<th>Condition Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-1</td>
<td>U/s Sudden draw down condition</td>
</tr>
<tr>
<td>Case-2</td>
<td>U/s Sudden draw down condition with earth quake</td>
</tr>
<tr>
<td>Case-3</td>
<td>D/s Steady seepage Condition</td>
</tr>
<tr>
<td>Case-4</td>
<td>D/s Steady seepage condition with earth quake</td>
</tr>
</tbody>
</table>
### Table 1: General Guidelines for Embankment Sections

(Clause 5.1.2.3)

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Description</th>
<th>Weight Up to 5 m</th>
<th>Height Above 5 m and Up to 10 m</th>
<th>Height Above 10 m and Up to 15 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Homogeneous section/Modified homogeneous section</td>
<td>Zoned section/Modified homogeneous section</td>
<td>Zoned section/Modified homogeneous section</td>
</tr>
<tr>
<td>i)</td>
<td>Type of section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii)</td>
<td>Slopes</td>
<td>Upstream</td>
<td>Downstream</td>
<td>Upstream</td>
</tr>
<tr>
<td></td>
<td>a) Coarse grained soil (GW, GP, SW, SP)</td>
<td>Not suitable</td>
<td>Not suitable</td>
<td>Not suitable</td>
</tr>
<tr>
<td></td>
<td>b) Coarse grained soil (GC, GM, SC, SM)</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 2:1</td>
</tr>
<tr>
<td></td>
<td>c) Fine grained soil (CL, ML, CL, MI)</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 2:5:1</td>
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<tr>
<td></td>
<td>d) Fine grained soil (CH, MH)</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 2:1</td>
<td>(H) (V) 3:75:1</td>
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<tr>
<td>iii)</td>
<td>Hearting zone</td>
<td></td>
<td></td>
<td>May be provided</td>
</tr>
<tr>
<td></td>
<td>a) Top width</td>
<td></td>
<td></td>
<td>3 m</td>
</tr>
<tr>
<td></td>
<td>b) Top level</td>
<td></td>
<td></td>
<td>0:5 m above MWL</td>
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<tr>
<td>iv)</td>
<td>Rock toe height</td>
<td></td>
<td>Necessary</td>
<td>Necessary</td>
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<tr>
<td></td>
<td></td>
<td>3 m height, 1 m height of rock toe may be provided</td>
<td>Necessary</td>
<td>Necessary</td>
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<td>v)</td>
<td>Berms</td>
<td></td>
<td>Not necessary</td>
<td>Not necessary</td>
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</table>
3A EMBANKMENT SECTION SHOWING SLICES

3B ANALYSIS OF THE FORCES ACTING ON SLICE 5

Fig. 3 Circular Arc Method (Method of Slices)
\[ FS = \frac{\sum S}{\sum T} = \frac{\Sigma \left[ C + (N - U) \tan \phi \right]}{\Sigma W \sin \alpha} \]

where

\[ FS = \text{factor of safety}, \]
\[ S = \text{resting or stabilizing force}, \]
\[ T = \text{driving or actuating force}, \]
\[ C = c \times \frac{b}{\cos \alpha}, \]
\[ N = \text{force normal to the arc of slice}, \]
\[ U = \text{pore water pressure}, \]
\[ \phi = \text{angle of shearing resistance}, \]
\[ W = \text{weight of the slice}, \]
\[ \alpha = \text{angle made by the radius of the failure surface with the vertical at the centre of slice}, \]
\[ c = \text{unit cohesion, and} \]
\[ b = \text{width of slice}. \]
E-2. ANALYSIS

E-2.1 The factor of safety for earthquake condition shall be worked out from the following formula:

\[
FS = \frac{\Sigma [ C + (N - U) \tan \phi ] - \Sigma (W1 \sin \alpha \tan \phi \times AH)}{\Sigma W \sin \alpha + \Sigma W1 \cos \alpha \cdot AH}
\]

where

- \( FS \) = factor of safety;
- \( C \) = cohesive resistance of the slice;
- \( N \) = force normal to the arc of slice;
- \( U \) = pore water pressure;
- \( N-U \) = effective normal force acting on the failure surface of slice;
- \( \phi \) = angle of internal friction;
- \( W1 \) = saturated weight of the slice if it is below phreatic line and moist weights (or drained weights, if it is freely draining) if it is above it;
- \( \alpha \) = angle between the centre of the slice and radius of failure surface;
- \( AH \) = horizontal seismic coefficient; and
- \( W \) = weight of the slice considered for driving force.
## Permissible Factor of Safeties:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Permissible F.O.S</th>
</tr>
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<tbody>
<tr>
<td>u/s Sudden draw down condition</td>
<td>1.30</td>
</tr>
<tr>
<td>U/s Sudden draw down condition with earth quake</td>
<td>1.00</td>
</tr>
<tr>
<td>d/s steady seepage condition</td>
<td>1.50</td>
</tr>
<tr>
<td>d/s steady seepage condition with earth quake</td>
<td>1.00</td>
</tr>
</tbody>
</table>
THATIPUDI RESERVOIR
**BENEFITS:**

- Irrigation to 2.91Lakh ha. (7.2 lakh Acres);

- Hydro Power with installed capacity of 960 MW;

- Diversion of 80 TMC of water to Krishna River;

- Supply of 23.44 TMC of water for Visakhapatnam city;

- Drinking water facility to 540 villages (28.5 Lakh population).
List of I.S Codes

i) IS:10635-1993 : Free Board Requirements in Embankment dams-Guidelines

ii) IS:12169-1987 : Criteria for design of Small embankment dams

iii) IS: 8826-1978 : Guidelines for design of large earth and rock fill dams


v) IS: 9429-1999: Drainage system for earth and rock fill dams

vi) IS: 8237-1985 : Code of practice for Protection of slope for Reservoir Embankment