Design of Earth Dams

Earth Dam Components

<table>
<thead>
<tr>
<th>No</th>
<th>Component name</th>
<th>Purpose of component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Foundation</td>
<td>support dam and restrict underseepage</td>
</tr>
<tr>
<td>2</td>
<td>Cutoffs</td>
<td>reduce seepage through foundation</td>
</tr>
<tr>
<td>3</td>
<td>Blanket</td>
<td>alternative to cutoff for deep foundation</td>
</tr>
<tr>
<td>4</td>
<td>Core</td>
<td>prevent leakage through the dam</td>
</tr>
<tr>
<td>5</td>
<td>Filters</td>
<td>prevent particle migration and piping</td>
</tr>
<tr>
<td>6</td>
<td>Shells</td>
<td>provide gravity fill and structural support</td>
</tr>
<tr>
<td>7</td>
<td>Freeboard</td>
<td>prevent overtopping and provide storage</td>
</tr>
<tr>
<td>8</td>
<td>Rip-rap</td>
<td>prevent wave and water erosion</td>
</tr>
<tr>
<td>9</td>
<td>Crest</td>
<td>provide access and increase stability</td>
</tr>
</tbody>
</table>
Design Requirements

Basic design requirements for earth dams may be listed, following the U.S. Corps of Engineers (1968) as:

(a) Embankment slopes must be stable under all construction and operating conditions, including reservoir drawdown.

(b) The embankment must not impose excessive stresses on the foundation or abutments.

(c) Seepage flow through the embankment, foundation and abutments must be controlled so that piping, sloughing, or removal of material by solution does not occur. Seepage flow quantities may also be limited by storage considerations.

(d) Spillways, outlet capacities and freeboard must be sufficient to prevent overtopping. Freeboard must include allowances for post construction embankment and foundation settlements.

Types of Earth Dams

[Diagrams showing various types of earth dams]

a. Homogeneous dam with internal drainage on impervious foundation
b. Central core dam on impervious foundation
c. Insilted core dam on impervious foundation
d. Homogeneous dam with internal drainage on pervious foundation
e. Central core dam on pervious foundation
f. Dam with upstream impervious zone on pervious foundation
Other Types of Dams

- Concrete
- Roller Compacted concrete
- Debris flows

Choice of Type Depends on

- Availability of materials
  - Trucking increases cost
- Homogeneous Earth Dam
  - Lots of low K material – Till
- Zoned
  - Limited core material
  - Rock available
- Upstream construction
  - Use mine tailings as a construction material
Foundation Requirements

1. **Strong foundation**
   - Minimal differential settlement
   - No bearing capacity shear failure
   - Sand/Gravel or rock

2. **Low hydraulic conductivity**
   - Silt and/or Clay, non-fractured rock

Since 1 and 2 are often incompatible we need to do foundation treatment

Foundation Treatment

- **Soil**
  - Cut-offs walls
  - Sheet pile walls
  - Slurry trench
  - Impervious upstream blanket
  - Removal and replacement
  - Densification
  - Zone grouting

- **Rock**
  - Removal and replacement of upper fractured rock
  - Grouting
  - Impervious upstream blanket
Hydraulic Efficiency

- Install upstream and down stream peizometers

\[ E_H = \frac{\text{Head loss across barrier}}{\text{Total head loss}} = \frac{\Delta h}{h} \]

- Efficiencies greater than 90% have been attained

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## Foundation Treatment (Mitchell)

<table>
<thead>
<tr>
<th>Cut-off Type</th>
<th>Nature Description</th>
<th>Subsequent Soil Type and Depth</th>
<th>Reinforcement and Compaction or Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>sheet piling</td>
<td>driven piles or set piles with optional cover or moderate cover</td>
<td>alluvium or lignite bedrock or consolidated pebbles</td>
<td>efficient and economical solution for softness 0 to 50% of soil. Also used in subsoil treatments in coastal areas. (1968)</td>
</tr>
</tbody>
</table>
Foundation Treatment (Mitchell)

Foundation Preparation

Want smooth transition to minimize negative skin friction and soil arching as that can lead to hydraulic fracturing as well as core cracking.
Foundation Preparation

\[ \varepsilon_L = \frac{2 \left( \frac{B}{2} \right)^2 + \theta_H^2}{B} + 1 = \frac{\Delta L_H}{L_H} \]

\[ \varepsilon_v = m \gamma H \]

Shear Strain (\( \tau \)) = \( \varepsilon_v - \varepsilon_H \) \( \leq 1\% \)

Foundation Distortion
Hydraulic Fracturing

Occurs when the porewater pressure is equal to the minimum embankment effective stress

\[ \sigma_h = K \sigma_v = K \gamma H - E_h \varepsilon_h > \mu = H \gamma_w \]

where

- K \sim 0.5 for compacted materials
- \( E_h \) is the tensile modulus obtained from a triaxial extension test
- \( \varepsilon_h \) = horizontal strain

Linear and Plastic Deformations

![Figure 3.5 Linear and Plastic Deformations](image-url)
Soil Arching

- Terzaghi 1943

![Diagram illustrating assumptions on which computations of pressures in sand between two vertical surfaces of sliding are based; (c) and (d) representations of the results of the computations.](image)

Note significant reduction is vertical stress
Soil Arching

- Terzaghi Trap Door

\[ \sigma_s = \gamma B \quad [6a] \]

\[ a = \frac{1}{K \tan \phi} (1 - e^{-K \tan \phi \cdot \sigma/B}) = \frac{1}{K \tan \phi} (1 - e^{-K \tan \phi \cdot \sigma/B}) \quad [6b] \]

For \( \varepsilon = \infty \) we obtain \( a = 1/K \tan \phi \) and

\[ \sigma_s = \sigma_{sa} = \frac{\gamma B}{K \tan \phi} \quad [7] \]

Fig. 18. (a) Diagram illustrating assumptions on which computation of pressures in sand between two vertical surfaces of sliding is based; (b) and (c) representations of the results of this computation.

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Soil Arching

![Graphs](image)

- Values of \( n = \pi/B \)

- \( \phi = 30^\circ, K=1 \)

- \( \phi = 40^\circ, K=1 \)

- \( \varepsilon = e^{-K \tan \phi} \) (b) and (c)
Approximation of Vertical Stress in DAMS

\[ \sigma_v = \frac{L \gamma}{2K \tan \phi} \left[ 1 - e^{-2K(\tan \phi)\frac{Z}{L}} \right] \]

Where \( L \) is the width of the valley
\( K = \text{constant} \sim 1 \)
\( Z \) is depth from dam crest

If \( H > L \) then \( z/L > 1 \) and \( K = 1 \)
Hydraulic Fracturing

if

\[ \mu \approx H \gamma_w \text { for full reservoir} \]

\[ \sigma_h \approx K \sigma_v \text { where } K \approx \tan \phi \]

\[ \sigma_h \approx \frac{L \gamma}{2} \]

then

\[ \sigma_h' = 0 \text { when } \frac{L \gamma}{2} = \gamma_w H \]

\[ \text {note } \frac{\gamma}{2} \approx \gamma_w \text { there } \sigma_h' \approx 0 \text { when } L = H \]

Note: hydraulic fracturing will occur when L is approximately equal to H

A few dams exists where average \( L < \) average H
Design of Cutoffs

- Must prevent hydraulic fracturing
  - $\sigma'_h > \text{porewater pressure}$
  
  Then $L_{\text{cutoff}} > H_{\text{cutoff}}$

![Diagram showing the relationship between $L_{\text{cutoff}}$ and $H_{\text{cutoff}}$]

Foundation Preparation

1. To prevent hydraulic fracturing must:
   - Have no vertical shear boundaries that can create differential settlement
   - Smooth profile along base of dam
   - Cord Length greater than the height of dam
   - Cutoffs with cord lengths greater than cutoff height
2. Hydraulic conductivity that will allow water to pond behind the dam
3. Strong enough to minimize distortional strains to less than 1 percent
Design of Zoned Dams

Rock fill will be much stiffer than core. As core settles arching will occur in the core.

![Diagram of Differential settlement between shells and core](image)

**Figure 3.9 Arching in Compressible Core**

Design of Zoned Dams

To prevent core arching and hydraulic fracturing we need:

1. wide enough core
2. need shear layer between core and shell to prevent internal core cracking
How wide of core do we need?

\[ \sigma_v = \frac{Z \gamma_{\text{core}}}{1 + \frac{GZ^2}{D_c tW}} \]

where:
- \( W \) is the width of core
- \( Z \) is depth below crest
- \( \gamma_{\text{core}} \) is unit weight of core
- \( G \) is the shear modulus of filter material
- \( t \) is width of filter material
- \( D_c \) is confined modulus of core = 1/\( m_v \)

Can Geotextiles Prevent Shear

Note \( t \) is very small for geotextiles this makes \( \frac{GZ^2}{D_c tW} \) very large

Resulting is significant arching in core...creating core cracking and hydraulic fracturing.

To prevent hydraulic fracturing need

\[ \frac{GZ^2}{D_c tW} < 0.35 \]
Methods to Prevent Core Cracking

- Wider cores
- Greater filter width
- Greater core compaction
- Benched cores to increase vertical stress

Transverse Core Cracking

- Develops when D/S shell material distorts to resist U/S water pressures transmitted by core
- Limit to less than 1% by having

\[ G < \frac{200H\gamma_w}{\cot \beta} \]

- Where G is modulus of shell material
- H is dam height
- \(\beta\) is down stream slope angle
Tranverse Cracking

- Often dams designed with u/s arch. This keep d/s in compression

Design Limits

<table>
<thead>
<tr>
<th>$\delta_{v}/H\cot\beta$</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001</td>
<td>No cracking</td>
</tr>
<tr>
<td>0.002</td>
<td>Thin reinforced concrete may crack</td>
</tr>
<tr>
<td>0.003</td>
<td>Longitudinal cracking in dry cores</td>
</tr>
<tr>
<td>0.005</td>
<td>Transverse cracks in cores and oblique core to shell cracks</td>
</tr>
<tr>
<td>0.01</td>
<td>Longitudinal cracks in wet cores &amp; jointed concrete facing</td>
</tr>
<tr>
<td>0.02</td>
<td>Danger of transverse cracks and piping failures</td>
</tr>
</tbody>
</table>