Design Criteria

- Prevent shear failure
  - STAGE CONSTRUCTION
- Account for settlement in design
- Ability to construct within required time frame
- Cost effective design
STABILITY
DURING CONSTRUCTION

METHOD OF ANALYSIS:

• SLICES (BISHOP, MORGENSTERN PRICE)
• TOTAL STRESS ANALYSIS IN CLAYS (SHANSEP)
• UNDRAINED SHEAR STRENGTH: $Su = f(p')$
• $Su/p' = f($LIQUIDITY INDEX$) = 0.1$ TO $0.3$
• NOTE: $p' = \sigma'_{0v}$ FOR N/C CLAYS

![Diagram of stability during construction](image)

How High can you Build?
Embankment Shear Failure

Shear Equation

\[ q_{\text{ultimate}} = CN_c + \gamma D_f N_q + 0.5BN_\gamma \]

For \( \phi = 0 \) \( N_c = 5.14, N_q=1, N_\gamma =0 \) \( c=\text{Cu} \)
For embankment sitting on ground surface \( D_f = 0 \)

\[ q_{\text{ultimate}} = 5Cu = N_c Cu \]
Typical Soft soil Stress-Strain Response

![Diagram of stress-strain response](image)

- $q_{allowable}$
- $q_{ult}$
- $\varepsilon_v = \text{vertical strain}$

$q_{allowable} = \frac{q_{ultimate}}{F}$

Total Stress Design Analysis

$$F = \frac{N_c Cu}{\gamma_e H_e}$$

**where:**
- $F = \text{factor of safety typically 1.2}$
- $Cu = \text{undrained strength of soil}$
- $\gamma_e = \text{embankment unit weight}$
- $H_e = \text{height of embankment}$
**Cu Design Considerations**

- Cu is the average undrained strength to a depth approximately equal to the height of the embankment.
- Soil will fail at the weakest point...
  - Use average Cu values in the soft zone.
- Cu are corrected values..see Mitchell notes.

**Nc Design Considerations**

\[ N_c = 5 + 4\left(\frac{d_1}{d_2} - 0.4\right) \]

Varies from 5 to 8.
Embankment with Berms

- Addition of Berm can be used to increase height of embankment

![Figure 1.17 Effects of Berms and Slope Angle](image)

Embankment with Berms

- Use of berms can reduce lateral spread
- More material efficient than flattening the slope angle

\[ F = \frac{N_c Cu}{\gamma_e (H_e - d)} \]

Dmax must satisfy

\[ F = \frac{N_c Cu}{\gamma_e d} \]
Other Embankment Design Options

- Use of light weight fill or geo-foam
- Stage construction
  - Allow for consolidation and increase in Cu

Note:
To increase Cu $\sigma'_v$ must be greater than the soil preconsolidation pressure

Stage Construction Process

1. Construct embankment to $H_1$
2. Allow 90% of the excess pwp to dissipate
   - Estimate using consolidation theory
   - Monitor peizometer installed in the soft zone
3. Determine increase in Cu due to increase in vertical effective stress
4. Determine the magnitude of settlement
5. Increase height to $H_2$
6. Repeat steps 2 to 5 to get to design height
Normally Consolidated Clay

Skempton 1957

\[ \frac{C_u}{\sigma'_v} = 0.11 + 0.37 \frac{PI(\%)}{100} \]

Embankment Height at any time

\[ H = \frac{N_c}{F} \left( \frac{C_u}{\sigma'_v} \right) \left( \frac{\sigma'_0}{\gamma} + UH_1 \right) \]

Where:

U is the average degree of consolidation over the potential failure zone
Degree of Consolidation

STABILITY
DURING CONSTRUCTION

PROBLEM ASSOCIATED WITH FAST CONSTRUCTION: FAST PORE PRESSURE GENERATION AND SLOW DISSIPATION IN FINE SOILS

BEFORE CONSTRUCTION: HYDROSTATIC PORE PRESSURES

DURING CONSTRUCTION: HYDROSTATIC PLUS EXCESS PORE PRESSURES
Time Rate of Consolidation

\[ t = \frac{T_v H^2}{C_v} \]

Figure 1.21 (a) Derivation of Eq. (1.60); (b) nature of variation of \( \Delta u \) with time
Figure 1.22 Drainage condition for consolidation: (a) two-way drainage; (b) one-way drainage; (c) plot of $\Delta u / \Delta u_0$ with $T_v$ and $H / H_c$

Figure 1.23 Range of $C_p$
(after U.S. Dept. of Navy)
Figure 1.24 Plot of time factor against average degree of consolidation ($\Delta u_0$ = constant)

Stress Under Embankment
Osterberg Chart

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Corner of triangular Load

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Fig. 8.23 Influence values for vertical stress under a very long embankment; length = ∞ (from U.S. Navy, 1971, after Osterberg, 1957).

Fig. 8.24 Influence values for vertical stress under the corners of a triangular load of limited length (after U.S. Navy, 1971).
Figure 1.25 One-dimensional consolidation due to single ramp loading
Figure 1.26 Olson’s ramp-loading solution: plot of $U$ vs. $T_v$ (Eqs. 1.69 and 1.70)