

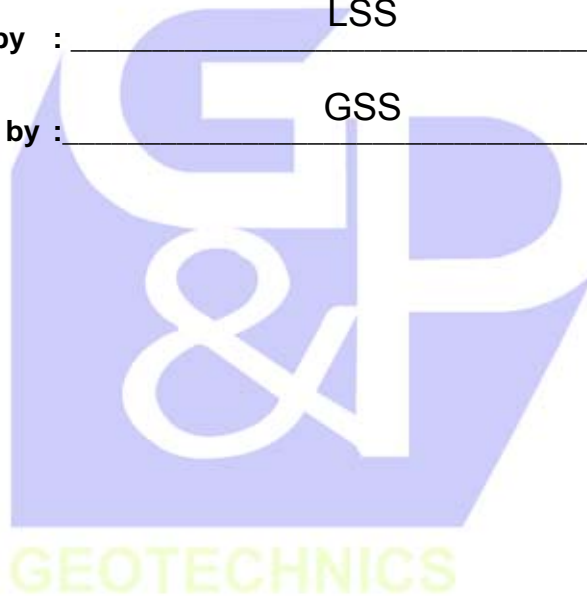


WORK INSTRUCTIONS FOR ENGINEERS

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OP-13. PROCEDURES FOR DESIGN OF EMBANKMENT

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13.0 PROCEDURES FOR DESIGN OF EMBANKMENT

13.1. OVERALL PROCEDURES

This section will briefly list down the overall procedures necessary for the design of the embankment over soft clay. The procedures are as follows :

- 1) Determine the Embankment Fill Height (EFH). (Section 13.2)
- 2) Settlement Analysis (Section 13.3)
- 3) Design of Surcharge Height (Section 13.4)
- 4) Stability Analysis of the Embankment (Section 13.5)

13.2. DETERMINATION OF THE EMBANKMENT FILL HEIGHT (EFH)

- 1) Determine the Net Fill Height (NFH) of the embankment. Net Fill Height (NFH) is the finished road level (FRL) minus the existing ground level (EGL).

$$NFH = FRL - EGL \text{ (m)}$$

- 2) First preliminary estimation of the Total Settlement (ρ_T). As a crude guide, the following percentage can be used :

<u>Subsoil Soft Clay Thickness</u>	<u>Total Settlement as Percentage of NFH (%)</u>
< 5m	15% - 20%
5m to 10m	20% - 30%
10m to 15m	25% - 35%
> 15m	30% - 40%

- 3) Estimation of the Embankment Fill Height (EFH) which is the total of Net Fill Height (NFH) and the Total Settlement (ρ_T).

$$EFH = NFH + \rho_T$$

- 4) Carry out Settlement Analysis (Section 29.3 for details) to obtain the representative total settlement which includes Immediate Settlement (ρ_i) + Primary Consolidation Settlement (ρ_c) + Secondary Consolidation Settlement (ρ_s). The embankment pressure shall be based on the Embankment Fill Height (EFH) times the bulk unit weight of the fill materials ($\gamma_{bulk(fill)}$).

$$\text{Embankment Pressure (kPa)} = EFH \times \gamma_{bulk(fill)}$$

$$\rho_T = \rho_i + \rho_c + \rho_s$$

Note : In most cases, the Secondary Consolidation Settlement (ρ_s) can be ignored in the calculation of the EFH. This is because ρ_s cannot be totally removed during construction.

- 5) After obtaining the Total Settlement from Steps 4 above, CORRECT the Embankment Fill Height as in Steps 3. Steps 3 to 5 shall be repeated until the error of Embankment Fill Height is less than 5%.

$$(EFH_{i+1} - EFH_i) < (5\% \text{ of } EFH_i)$$

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- 6) Obtain the correct Embankment Fill Height (EFH). It is important to calculate the EFH so that the stability analysis can take into consideration the loading from the fill to compensate settlement.

13.3. SETTLEMENT ANALYSIS

Settlement can be conveniently divided into three stages :-

- (A) Initial Settlement (also called immediate or undrained or shear settlement), ρ_i
- (B) Primary Consolidation Settlement, ρ_c
- (C) Secondary Compression, ρ_s

Total settlement (long term), (ρ_T) is the sum of **initial** + **primary** consolidation + **secondary** compression settlements.

$$\rho_T = \rho_i + \rho_c + \rho_s$$

For details of the equations to be used, please refer to Tan & Gue (2000) titled "Embankment over Soft Clay – Design and Construction Control".

13.3.1. Selection of Parameters

- 1) Plot all the boreholes results (subsoil cross-section).
- 2) Obtain correct existing groundwater level (install standpipes to monitor because water in borehole after drilling can be misleading).
- 3) Compile all consolidation parameters into following plots for all boreholes or in zones:-
 - $C_c/1+e_c$ vs Depth
 - $C_r/1+e_o$ vs Depth
 - $C_\alpha/1+e_p$ vs Depth
 - $\gamma_{bulk(fill)}$ vs Depth (so that correct initial effective overburden pressure, σ'_{vo} can be calculated)
 - OCR vs Depth
 - c_v vs Depth
 - m_v vs Depth
 - k_v vs Depth (as obtained from $m_v \cdot c_v \cdot \gamma_w$)
- 4) Select the design lines for Consolidation Parameters. (Need to be reviewed)
- 5) Obtain the Undrained Young's Modulus (E_u) of the subsoil to estimate immediate settlement based on :-
 - SPT'N' values Correlation,

$$E_u = 2000 \text{ to } 3000 \text{ SPT'N'} \quad (\text{kPa}) \quad (\text{crude guide})$$
 - Undrained Shear Strength Correlation,

$$E_u = 200s_u \text{ to } 600s_u \quad (\text{kPa}) \quad [\text{Can start with } 400s_u]$$
- 6) The correct E_u can be obtained from CIU tests.

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13.3.2. Immediate Settlement

Immediate settlement can be estimated using elastic displacement theory as :

$$\rho_i = \sum \frac{1}{E_u} (I \cdot q) dh$$

Where

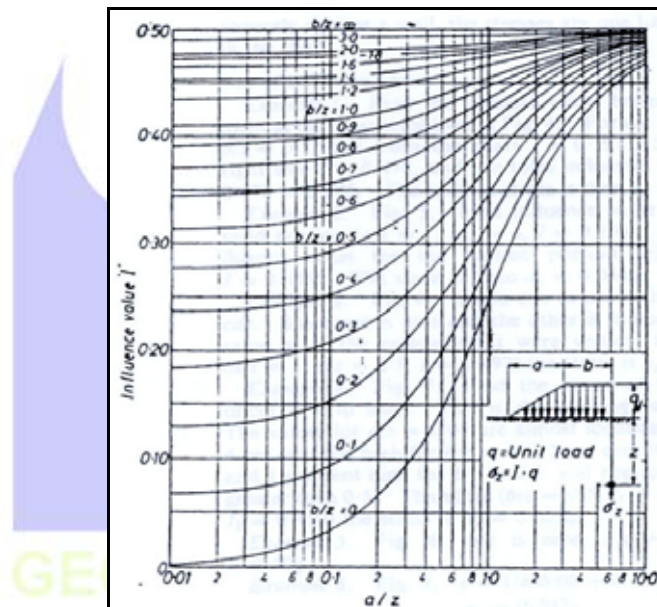
q = Applied Stress / Pressure on the subsoil (kPa).

dh = thickness of each layer (m).

E_u = Undrained Young's Modulus of the subsoil (kPa)

I = Influence factor

A useful chart is given by Osterberg (1957) and shown in Figure 1. The chart allows estimation of the initial settlement of the embankment. For embankment on very soft clay, it is advisable to include the immediate settlement of the soft clay in the calculation of the Embankment Fill Height (EFH).



13.3.3. Consolidation Settlement

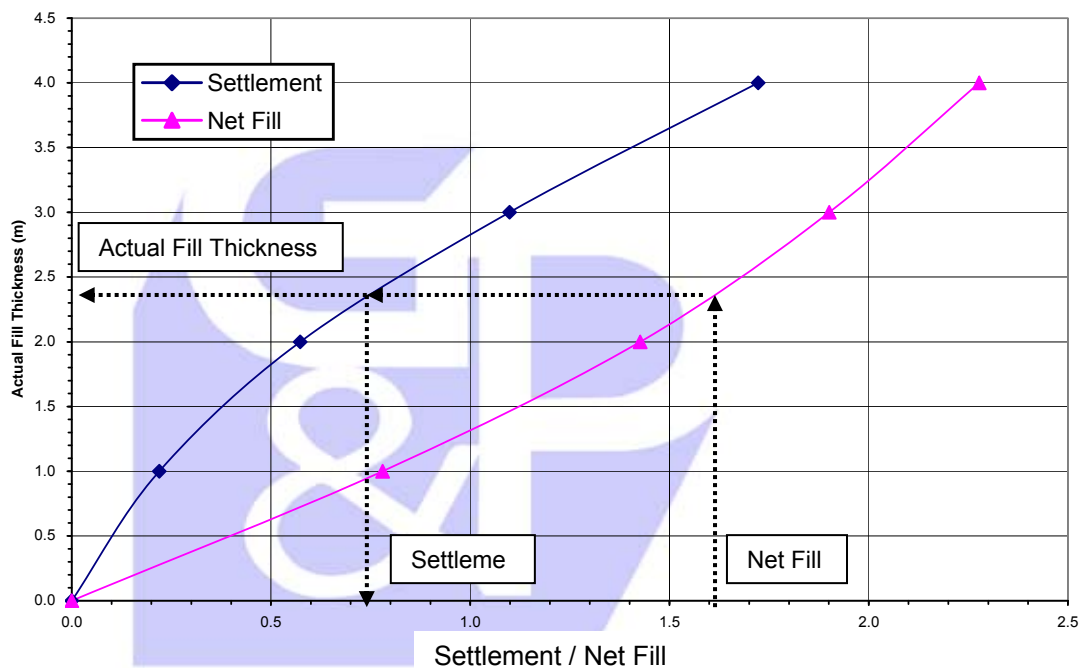
- 1) It is acceptable to use 1-D primary consolidation settlement for embankment.
- 2) The loading of the embankment shall be based on EFH (no surcharging) or GFH (with surcharging, see Section 29.4)
- 3) One dimensional primary consolidation settlement can be estimated using the expression :

$$\rho_c = \sum_{i=1}^n \left[\frac{C_r}{1+e_o} \log \frac{\sigma'_{vc}}{\sigma'_{vo}} + \frac{C_c}{1+e_o} \log \frac{\sigma'_{vf}}{\sigma'_{vc}} \right] H_i$$

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where

- ρ_c = Consolidation Settlement Magnitude (m)
- σ'_{vo} = Initial vertical effective stress
- σ'_{vf} = Final vertical effective stress
- $\sigma'_{vf} = \sigma'_{vo} + \Delta \sigma'_v \geq \sigma'_{vc}$
- σ'_{vc} = Preconsolidation Pressure / Yield Stress
- H_i = Initial thickness of incremental soil layer,
- e_o = Initial voids ratio
- C_C = Compression Index
- C_r = Recompression Index



- 4) The degree of consolidation, U_v is a function of the time factor, T_v where :

$$T_v = c_v t / H_D^2$$

Where

- c_v = Coefficient of consolidation ($m^2/year$)
- t = Time following application of loading (year)
- H_D = Drainage path length (m) (e.g. for soft clay of 20m, two way drainages [up and down], the H_D is 10m)

- 5) The average degree of consolidation as a function of time factor for Terzaghi's theory of consolidation by vertical flow can be expressed as :

$$U_v = \sqrt{\frac{4T_v}{\pi}}$$

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$$\text{for } T_v = c_v t / H_D^2 < 0.2$$

$$U_v = 1 - \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 T_v}{4}\right)$$

$$\text{for } T_v = c_v t / H_D^2 \geq 0.2$$

- 6) In order to calculate actual fill height properly (EFH or GFH), different pressure can be applied to obtain different settlement for each borehole or zone. The results are used to plot the Settlement/Net Fill vs Actual Fill Thickness. The total settlement in this plot shall include Immediate settlement + Consolidation settlement. From the plot, from the net fill, the total settlement and actual fill thickness can be obtained.

13.3.4. Secondary Compression

$$\rho_s = \sum_{i=1}^n \left[\frac{C_\alpha}{1 + e_p} \log(t) \right] H_i$$

where	ρ_s	=	Secondary Compression Magnitude (m)
	H_i	=	Initial thickness of incremental soil layer, i of n.
	e_p	=	Voids ratio at the end of primary consolidation
	C_α	=	Secondary Compression Index.
	t	=	Time for calculation.

13.4. DESIGN OF SURCHARGE

Surcharging is to subject the ground to higher pressure than that during the service life in order to achieve a higher initial rate of settlement thus reducing long term settlements. When designing surcharge, three major issues need to be addressed :

- Duration required for surcharging.
- Height of extra fill on top of the embankment required for surcharging.
- Bearing capacity check for the embankment at the edge with surcharged fill.

The gross thickness of the fill which include Embankment Fill Height (EFH) and Surcharge Fill (SF) is termed Gross Fill Height (GFH).

$$GFH = EFH + SF \text{ (m)}$$

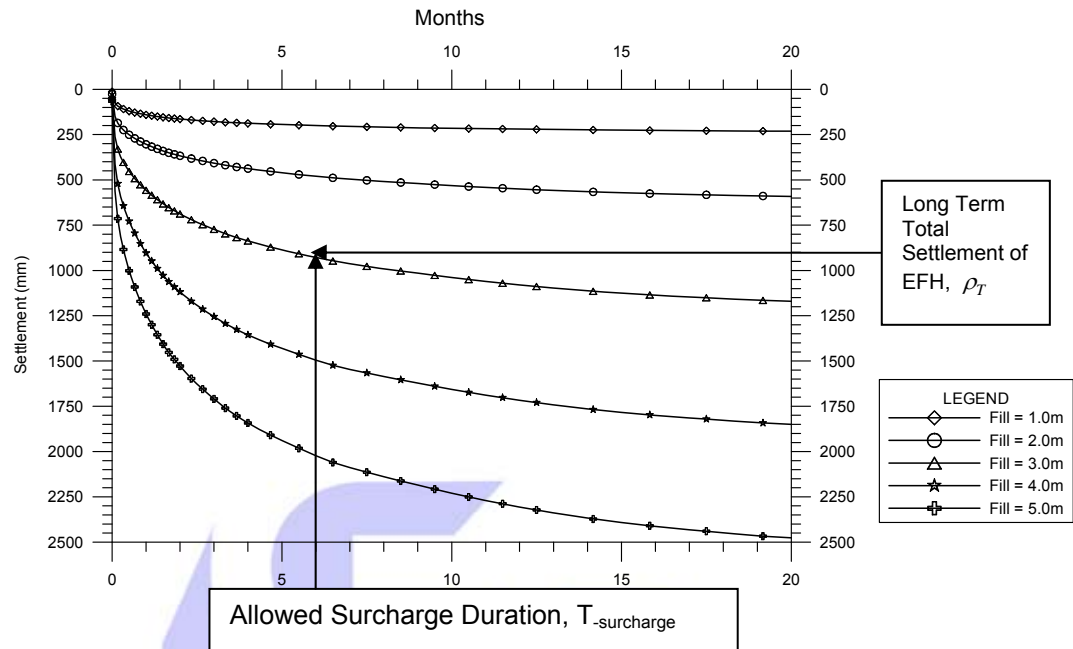
$$\text{Total Pressure Action, } PGFH = EFH \times \gamma_{bulk(fill)} + SF \times \gamma_{bulk(surcharge)}$$

The design process can be summarised as follows :

- 1) Determine the long term total settlement, (ρ_T) [Section 29.3] of the embankment under loading from Embankment Fill Height (EFH) [Section 29.2].
- 2) Determine the duration allowed ($T_{surcharge}$) for surcharging. This will depend on the project development schedule.
- 3) Obtain the total settlement vs time plot for different gross fill height (GFH) as follows:

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- 4) Based on the figure below, using the Total Settlement (ρ_T) from the EFH and the Allowed Surcharge Duration, $T_{\text{surcharge}}$, the Gross Fill Height (GFH) required to achieve the total settlement in the allowable time frame can be determined.
- 5) If vertical drains are used, this method can also be used with minor adjustment for vertical spacing, and more rapid rate of settlement.



13.5. STABILITY ANALYSIS

- 1) For stability analysis, at least two stages shall be checked :
 - (a) Short Term (Total Stress) using Undrained Shear Strength (s_u).
 - (b) Long Term (Effective Stress) using Drained Strength Parameters ($c'-\phi'$).
- 2) The required factor of safety (FOS) are as follows :
 - (a) Short Term, FOS = 1.2 to 1.3 (if confidence on strength, use 1.2)
 - (b) Long Term, FOS = 1.4 to 1.5 (1.4 can be used in Geoguide)
- 3) At least two types of potential failure plane shall be checked :
 - (a) Circular (Modified Bishop)
 - (b) Non-Circular or Wedge Method (Modified Janbu or Morgenstern & Price or Sarma)

Note : (1) Normally Wedge Method will produce lower FOS compared to Circular Method.

(2) Should select proper boundary (boxes) for the Wedge analysis, if possible should start with circular method first to determine potential failure zones.

- 4) In stability analysis the following dimension shall be used :
 - (a) The height of the embankment shall be :
 - Embankment Fill Height (EFH), if no surcharging. (Section 29.2)
 - Gross Fill Height (GFH), if surcharging. (Section 29.4)
 - (b) At least 10kPa surcharge loading (traffic, machineries, etc.) on top of the embankment (acting pressure)
 - (c) The magnitude of immediate settlement (both in the Soft Clay and Sand Layers) should be included in the Embankment Fill Height (EFH) to simulate settlement during

Note : (1) For embankment construction, normally surcharging with or without vertical drains are required.

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(2) The magnitude of immediate settlement (both in the Soft Clay and Sand Layers) should be included in the EFH or GFH to simulate settlement during construction so that the stability analysis do not under estimate the weight of the embankment.

- 5) General guidelines for the strength parameters of the well-compacted predominantly granular fill materials is $c' = 0$ to 5kPa, $\phi' = 28^\circ$ to 30° . It is recommended to carry out shear box test on the well-compacted fill materials to obtain representative parameters.

13.6. Selection of Ground Treatment for Stability of the Embankment

Preliminary selection of the ground treatment method to satisfy stability requirements for construction of the embankment listed in priority are as follows :

13.6.1. Priority 1 :

- 1) Counterweight Berms (should have sufficient ROW and fill materials are sufficient at site)
- 2) Partial Soft Soil Replacement (should be limited to not more than 4m deep if possible)
- 3) Combination of (a) and (b)

13.6.2. Priority 2 :

- 1) Staged Construction (With or Without Vertical Drains) (Note : need to validate gain in strength for each stage of filling)
- 2) Geosynthetics reinforcement (high strength geotextile).
- 3) Combination of Priority 1 with (d) or (e).

13.6.3. Priority 3 :

- 1) Piled Embankment using slab system (require transition piles between piled and unpiled embankment)
- 2) EPS
- 3) Stone Columns
- 4) Dynamic Replacement (only if soft clay is shallow)

Note : Refer to : Gue, S.S. and Tan, Y.C. (2001) "Geotechnical Solutions for High Speed Track Embankment – A Brief Overview" Technical Seminar – Permanent Way Institution Annual Convention 2001, Kuantan. 28-29 September 2001.