Settlement Analysis

STABILITY

DURING CONSTRUCTION

STAGED CONSTRUCTION:

TYPICALLY IN TWO TO THREE STAGES AND COMPLETED IN ONE OR TWO CONSTRUCTION SEASONS (REMEMBER THAT WE CANNOT INSTALL WICK DRAINS IF THE GROUND IS FROZEN AND WE USUALLY DO NOT PLACE FILL DURING THE WINTER)

STABILITY

DURING CONSTRUCTION

STAGED CONSTRUCTION:

TYPICAL STAGES IN CENTRAL AND NORTHERN ONTARIO:

- STAGE 1: 0 TO 8m, WAIT FOR 3 MONTHS
- STAGE 2: 8 TO 12m, WAIT FOR 3 MONTHS
- STAGE 3: 12 TO 14m, WAIT FOR 3 MONTHS BEFORE REMOVING SURCHARGE

Loaded Soil will Compress Due to:

1. Deformation of soil grains (elastic)

Degree water saturation <1

2. Compression of air and water in voids
3. Squeezing out of water and air out of voids
4. Plastic flow (creep)

Degree water saturation =1

5. Compression of water (very small)
6. Squeezing out of water out of voids
7. Plastic flow (creep)

For Load Problems Need to Answer

- How much settlement will occur due to an applied load?
  - Magnitude of consolidations
- How long will it take for settlement to occur?
  - Time rate of consolidation

EMBANKMENT SETTLEMENT

IMMEDIATE (“ELASTIC”)

PRIMARY CONSOLIDATION (ASSOCIATED WITH DISSIPATION OF EXCESS PORE PRESSURES)

SECONDARY CONSOLIDATION (ASSOCIATED WITH REARRANGEMENT OF PARTICLES)

CREEP (ASSOCIATED WITH SHEAR STRESS-STRAIN)

EMBANKMENT SETTLEMENT

IT IS IMPORTANT TO RECOGNIZE THE IMPACT OF DIFFERENT TYPES OF SETTLEMENTS ON THE PROJECT:

SETTLEMENTS THAT OCCUR DURING CONSTRUCTION (PRIOR TO DRIVING PILES AT THE BRIDGE ABUTMENTS AND PRIOR TO CONSTRUCTION OF THE BRIDGE)

POST CONSTRUCTION SETTLEMENTS (HAVE SERIOUS COST IMPLICATIONS: BRIDGE AND PAVEMENT PERFORMANCE)

EMBANKMENT SETTLEMENT

WE *USUALLY* DESIGN THE EMBANKMENT SO THAT:

IMMEDIATE SETTLEMENTS AND SETTLEMENTS DUE TO PRIMARY CONSOLIDATION OCCUR DURING CONSTRUCTION

AND SETTLEMENTS DUE TO SECONDARY CONSOLIDATION AND CREEP OCCUR AFTER THE END OF CONSTRUCTION

EMBANKMENT SETTLEMENT

IMMEDIATE SETTLEMENTS

USUALLY NOT A KEY ISSUE:

USE CLOSED FORM SOLUTIONS BASED ON THE THEORY OF ELASTICITY WITH CONSERVATIVE UNDRAINED SOILS PROPERTIES

ALTERNATIVELY, CARRY OUT NUMERICAL SIMULATION USING TOTAL STRESS ANALYSIS WITH UNDRAINED SOIL PROPERTIES

EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

TERZAGHI'S 1D THEORY OF CONSOLIDATION

KEY ASSUMPTIONS:

- CONSTANT VERTICAL TOTAL STRESS AND ELASTIC PROPERTIES DURING CONSOLIDATION
- VERTICAL DRAINAGE ONLY
- NO LATERAL STRAINING OF THE SOIL (OEDOMETER TESTING)

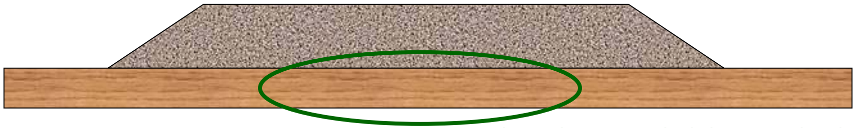
EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

THE THEORY IS COMMONLY USED BECAUSE:

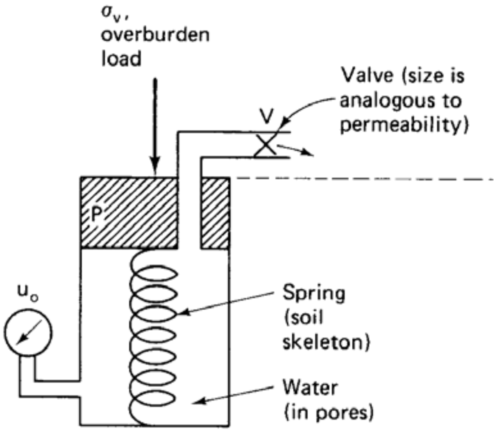
•IT IS SIMPLE (IT CAN EASILY BE INCORPORATED IN A FINITE DIFFERENCE FORMULATION)

•IT PROVIDES REASONABLE PREDICION OF SETTLEMENT OF WIDE EMBANKMENTS FOUNDED ON RELATIVELY THIN CLAY LAYER



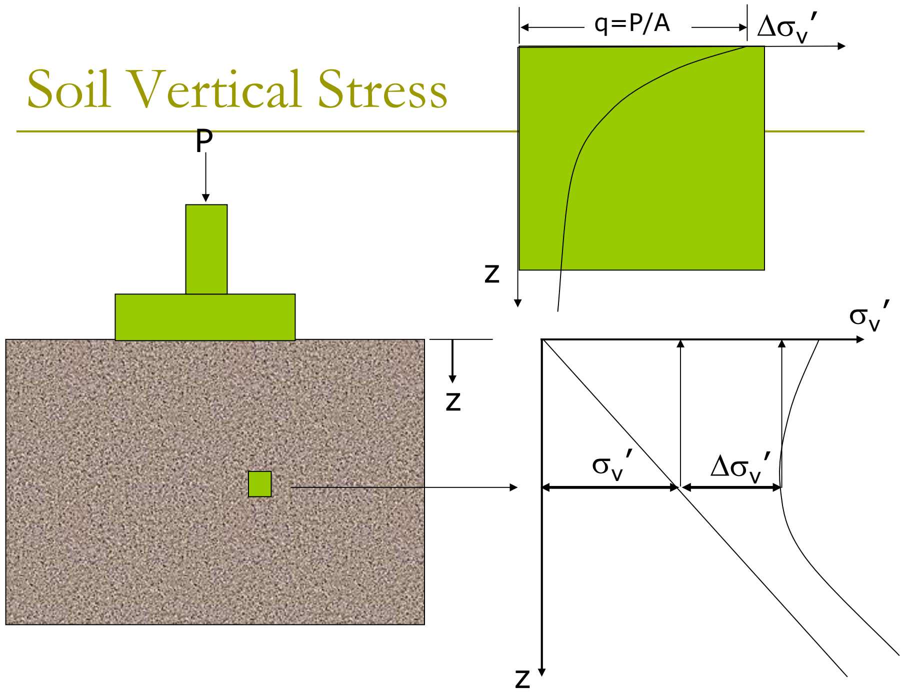
OEDOMETRIC CONDITIONS

Spring Analogy to Soil Consolidation

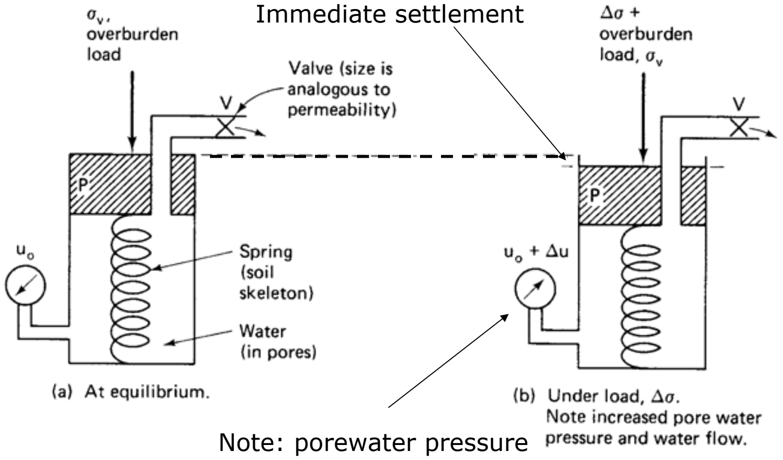


(a) At equilibrium.

Soil Vertical Stress



Spring Analogy to Soil Consolidation



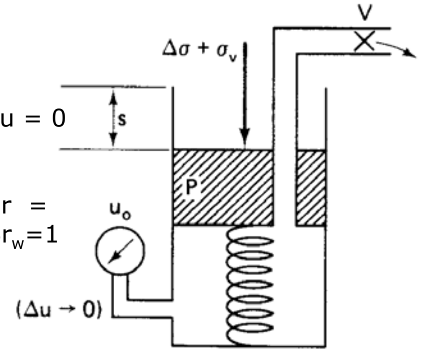
Immediate settlement

Note: porewater pressure increased by $\Delta u = u_e$

Spring Analogy

S_{max} occurs when $\Delta u = 0$

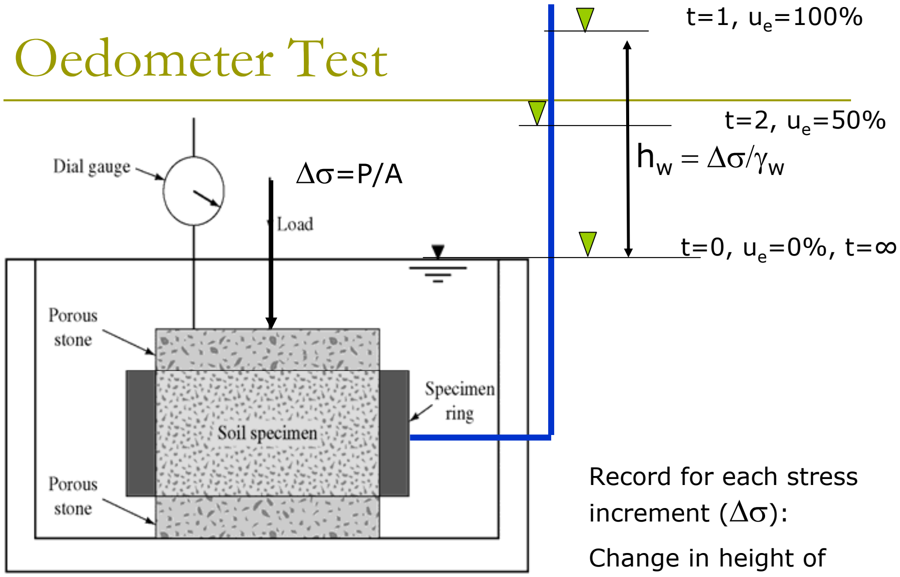
Change in volume in container = volume of water removed if $Sr_w=1$



(c) At equilibrium under $\sigma_v + \Delta\sigma$. Note settlement s.

Fig. 8.2 Spring analogy as applied to consolidation.

Oedometer Test



$\Delta\sigma = P/A$

t=1, u_e=100%

t=2, u_e=50%

$h_w = \Delta\sigma/\gamma_w$

t=0, u_e=0%, t=∞

Figure 7.2 Consolidometer

Record for each stress increment ($\Delta\sigma$):

Change in height of specimen with time

Typical Stress Increment Test Data

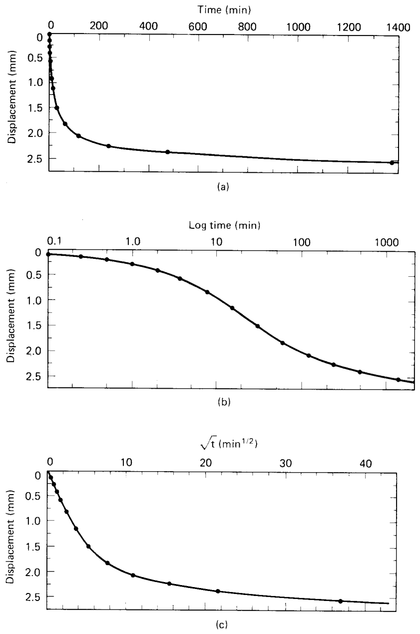
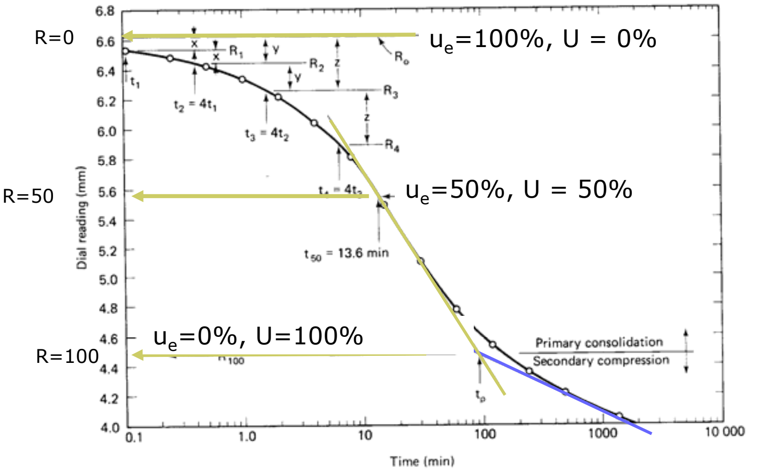


Fig. 9.6 Deformation-time curves for data from Table 9-2: (a) arithmetic scale; (b) log time scale; (c) square root of time scale.

Casagrande Log Time Method

U = degree of pore water pressure dissipated



R=0

u_e=100%, U = 0%

R=50

u_e=50%, U = 50%

R=100

u_e=0%, U=100%

Fig. 9.7 Determination of t_{50} by the Casagrande method; data from Table 9-2.

Casagrande Log Time Method

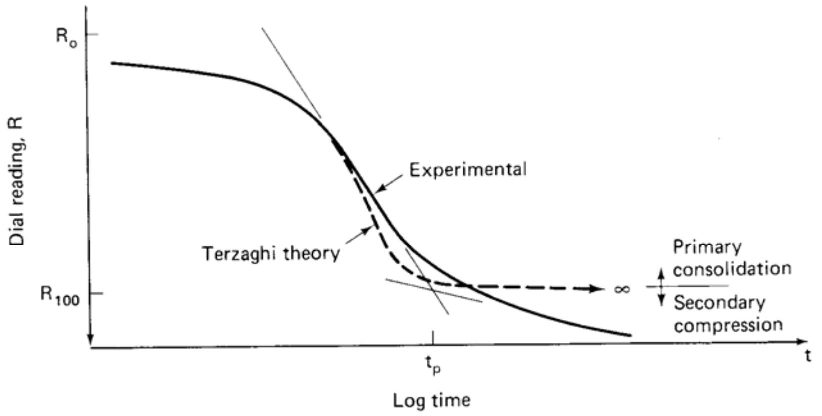


Fig. 9.8 Terzaghi consolidation theory and a typical experimental curve used to define t_p.

Root Time Method

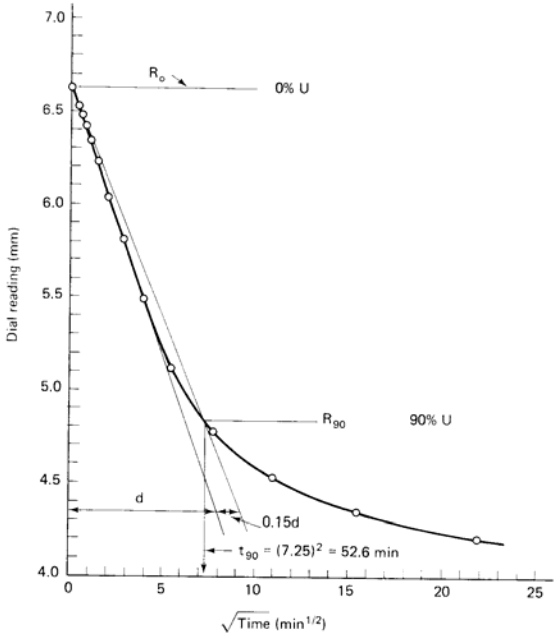
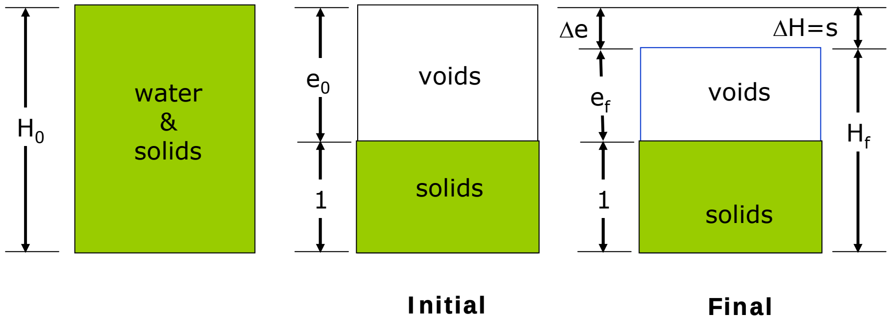


Fig. 9.9 Determination of c_v, using Taylor's square root of time method; data from Table 9-2.

Settlement Calculations



Consolidation Settlement Calculations

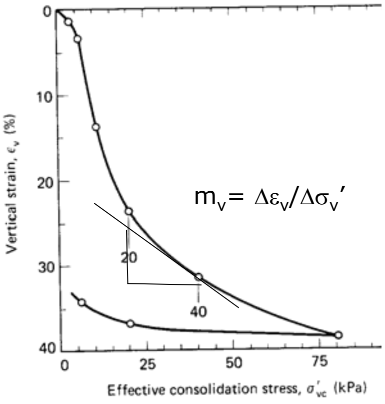
$$\varepsilon_v = \Delta H/H_0 = s/H_0 = \Delta e/1+e_0$$

$$s = \varepsilon_v H_0 = (\Delta e/1+e_0)\, H_0$$

Note: Want settlement @ U=100%

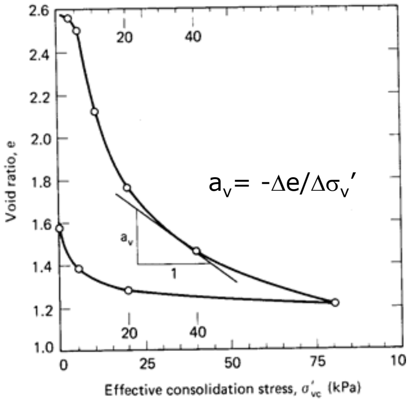
100% dissipation of excess porewater pressure

U_{100} Data for Stress Increments



(a)

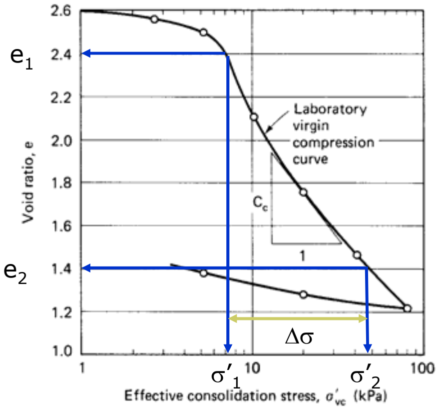
Coef. Volume change (m_v)



(b)

Coef. Of compressibility (a_v)

U_{100} Data for Stress Increments



(b)

Compression Index (C_c)

$c_c = \Delta e/(\log\sigma_2' - \log\sigma_1')$

$c_c = (e_1 - e_2)/\log(\sigma_2'/\sigma_1')$

If $\sigma_2' = \sigma_1' + \Delta\sigma$

$c_c = \Delta e/\log[(\sigma_1'+\Delta\sigma)/\sigma_1']$

e$_1$ =2.4, **e**$_2$=1.4 Δe = 1.0

σ'_1=7.1, σ'_2=49

c_c = 1.0/(log49-log7.1) = 1.19

Settlement Equation in Terms of m_v

$$S = \varepsilon_v H_o$$

$$m_v = \frac{\Delta\varepsilon_v}{\Delta\sigma'} \qquad (1/\mathrm{kPa} = \mathrm{m}^2/\mathrm{kN})$$

$$\mathrm{S} = \int_0^{\mathrm{H}} \mathrm{m_v} \Delta\sigma' dz$$

if $\mathrm{m_v}$ and $\Delta\sigma'$ are assumed constant with depth then

$$\mathrm{S} = \mathrm{m_v} \Delta\sigma' H$$

Settlement Equation in Terms of a_v

$$S = \varepsilon_v H_o = \frac{\Delta \mathrm{e}}{1+\mathrm{e_o}} H$$

$$a_v = \frac{\Delta e}{\Delta\sigma'} \qquad (1/\mathrm{kPa} = \mathrm{m}^2/\mathrm{kN})$$

$$\mathrm{S} = \int_0^{\mathrm{H}} \frac{\mathrm{a_v}}{1+\mathrm{e_o}} \Delta\sigma' dz$$

if $\mathrm{a_v}$ and $\Delta\sigma'$ are assumed constant w ith depth then

$$\mathrm{S} = \frac{\mathrm{a_v}}{1+\mathrm{e_o}} \Delta\sigma' H = \mathrm{m_v} \Delta\sigma' H$$

therefore $\mathrm{m_v} = \dfrac{\mathrm{a_v}}{1+\mathrm{e_o}}$

Settlement Equation in Terms of c_c

$$S = \varepsilon_v H_o = \frac{\Delta \mathrm{e}}{1+\mathrm{e}_\mathrm{o}} H$$

$$c_c = \frac{\Delta e}{\log \frac{\sigma_2'}{\sigma_1'}}$$

Note: c_c = 0.009(LL-10)

$$\mathrm{S} = \frac{c_c}{1+\mathrm{e}_\mathrm{o}} H \log \frac{\sigma_2'}{\sigma_1'} = \frac{c_c}{1+\mathrm{e}_\mathrm{o}} H \log\left(\frac{\sigma_1' + \Delta\sigma}{\sigma_1'}\right)$$

Settlement due to Δσ

$$S_{total} = S_r + S_c$$

$$S_r = S_{rebound} = \frac{C_r}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_2}{\sigma'_1}) = \frac{C_r}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_\mathrm{c}}{\sigma'_1})$$

$$\text{note: for this case } \sigma'_1 = 0$$

$$\mathrm{S}_\mathrm{c} = \frac{C_c}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_2}{\sigma'_1}) = \frac{C_c}{1+e_0} \mathrm{H}_0 \log(\frac{\sigma'_\mathrm{c} + \Delta\sigma}{\sigma'_c})$$

Over Consolidation Ratio (OCR)

$$OCR = \frac{\sigma'_c}{\sigma'}$$

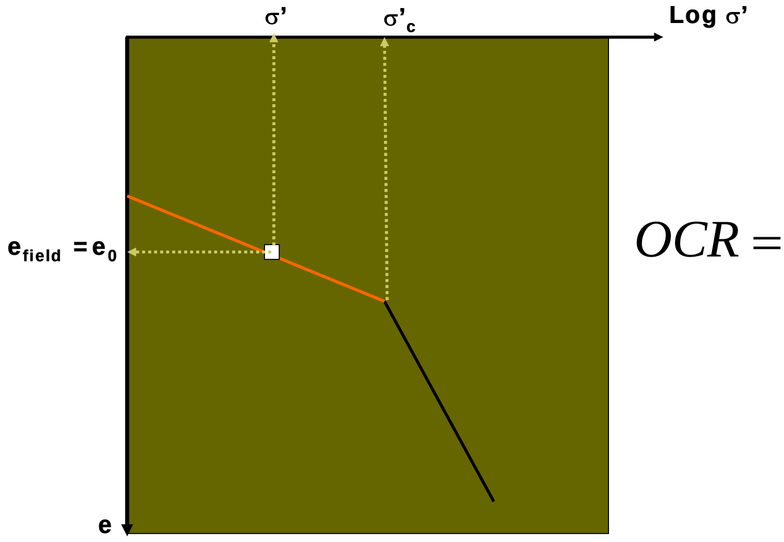
where :

OCR = Over Consolidation Ratio

σ'_c = preconsolidation pressure of a specimen

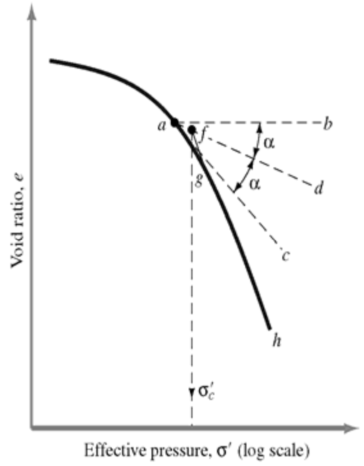
σ' = present (field) effective overburben pressure

Over Consolidation Ratio (OCR)



$$OCR = \frac{\sigma'_c}{\sigma'}$$

Determination of σ_c’



See Das for procedure

Note σ_c’ is not a distinct point

Figure 7.8
Graphic procedure for determining preconsolidation pressure

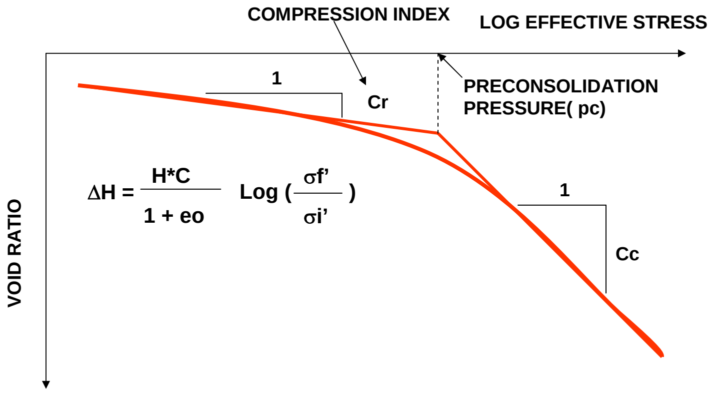
Over Consolidation Ratio (OCR)

- If OCR ≤ 1.2 $\sigma'_c \sim \sigma'$ then soil is normally consolidated
- If OCR ≥ 1.2 then soil over consolidated

EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

1D THEORY OF CONSOLIDATION TIME-INDEPENDENT ANALYSIS

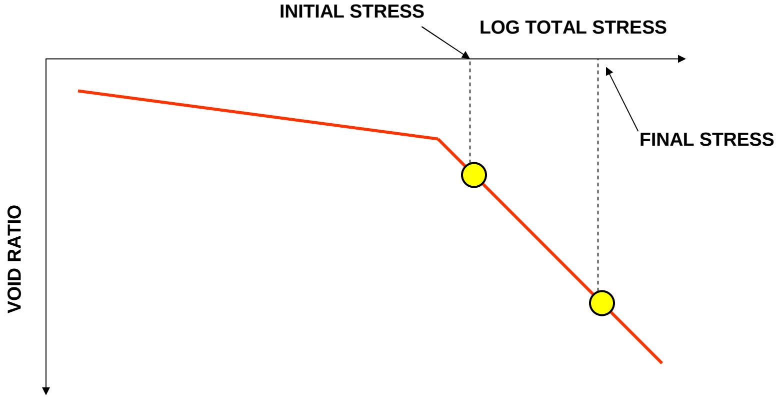


$$\Delta H = \frac{H*C}{1 + eo} \text{Log} \left(\frac{\sigma f'}{\sigma i'} \right)$$

EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

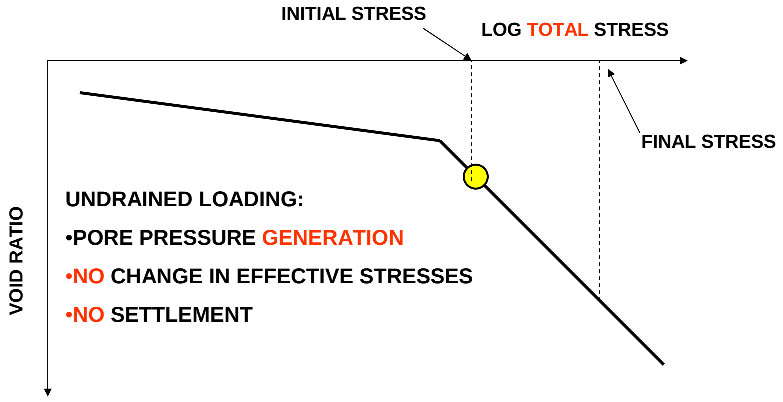
1D THEORY OF CONSOLIDATION TIME-INDEPENDENT ANALYSIS



EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

1D THEORY OF CONSOLIDATION TIME-DEPENDENT ANALYSIS



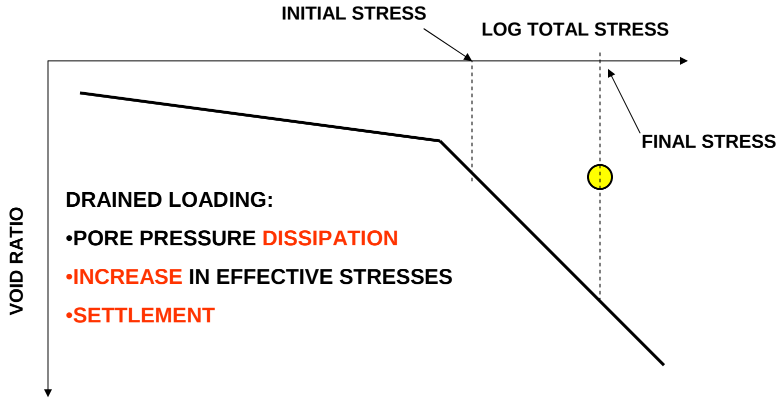
UNDRAINED LOADING:

- PORE PRESSURE GENERATION
- NO CHANGE IN EFFECTIVE STRESSES
- NO SETTLEMENT

EMBANKMENT SETTLEMENT

PRIMARY CONSOLIDATION

1D THEORY OF CONSOLIDATION TIME-DEPENDENT ANALYSIS



DRAINED LOADING:

- PORE PRESSURE DISSIPATION
- INCREASE IN EFFECTIVE STRESSES
- SETTLEMENT