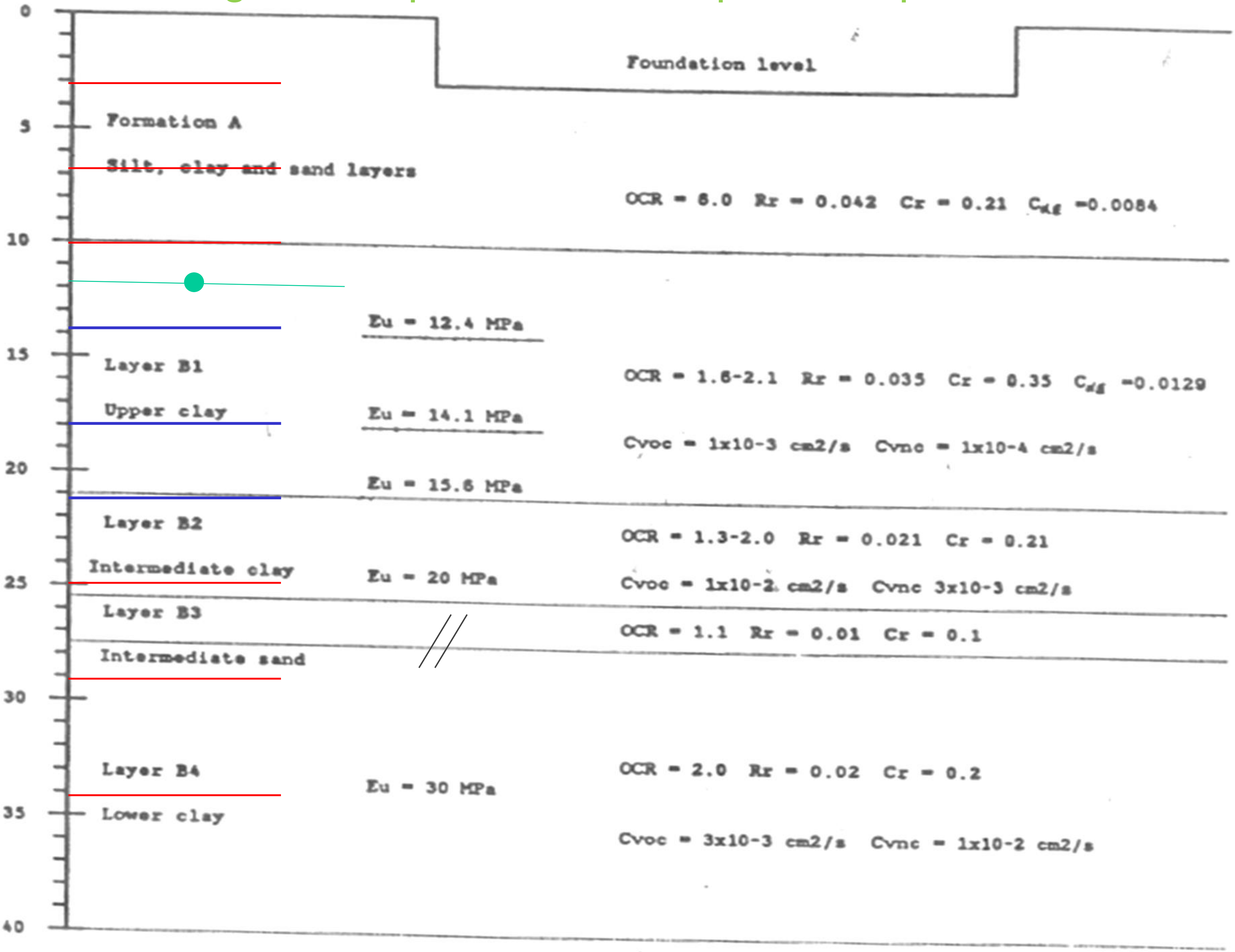
MSC IN ANALYSIS AND DESIGN OF EARTHQUAKE RESISTANT STRUCTURES (ADERS)

Course: **Geotechnical Engineering in the Design of Structures**

PROJECT: SETTLEMENT CALCULATIONS FOR THE LEANING TOWER OF PISA

The leaning Tower of Pisa was designed as a circular bell tower of 19.06m in diameter. The tilt of the Tower (before the period of strengthening 1990-2001) is shown in Fig. 1.
The first stage of construction took place in the period 1173-1178 and the load applied by three floors to the foundation was 92904kN. Settlement was introduced during this stage.
The second stage of construction took place in the period 1272-1278 and the total load applied to the foundation was 134534kN.
The third stage of construction in the period 1360-1370 resulted in total load of 141640kN.
Calculate the settlement of the Tower until 1990 when a multinational task force of engineers started work on its stabilization. The soil profile and the parameters required for settlement calculations are given in Figs 2,3 and 4.

Fig. 2 Soil profile and compression parameters



$$E_u = \frac{\Delta\sigma}{\varepsilon_z}$$

Immediate settlement, ρ_i

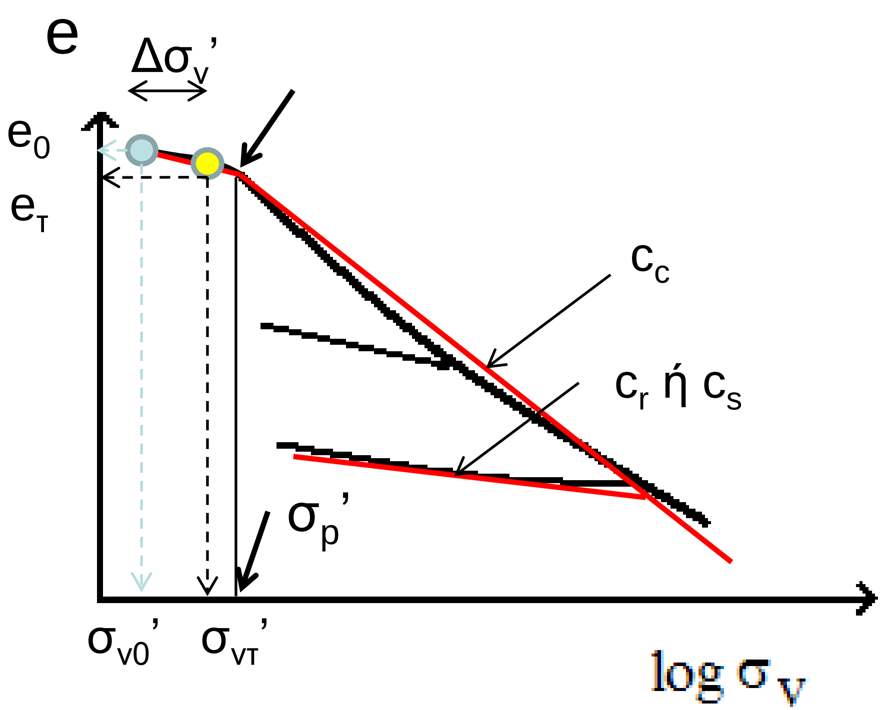
$$\rho = H \frac{c_r}{1+e_0} \log\left(\frac{\sigma_{v0}' + \Delta\sigma_v'}{\sigma_{v0}'}\right)$$

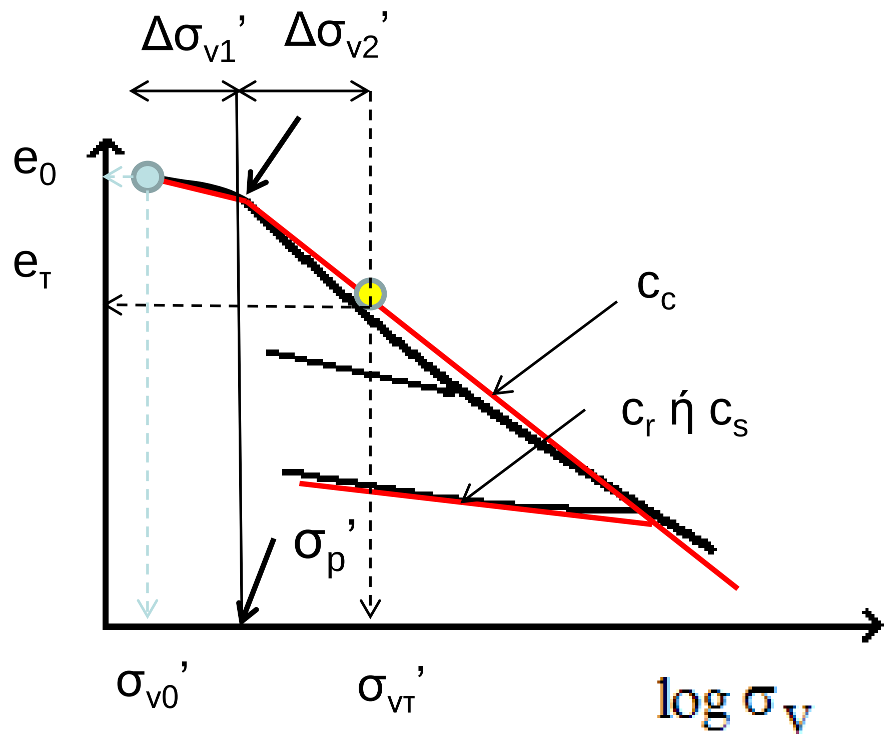
Consolidation settlement, ρ_c

$\delta_s = h_s C_{\alpha\varepsilon} \log_{10}(t/t_s)$ where t_s=time of completion of primary consolidation, h_s =depth of layer at the beginning of secondary consolidation

Secondary settlement, ρ_s

Consolidation settlement ρ_c





$$\rho = H\frac{c_r}{1+e_0}\log\left(\frac{\sigma_{v0}' + \Delta\sigma_v'}{\sigma_{v0}'}\right)$$

σ_p' = pre-consolidation stress

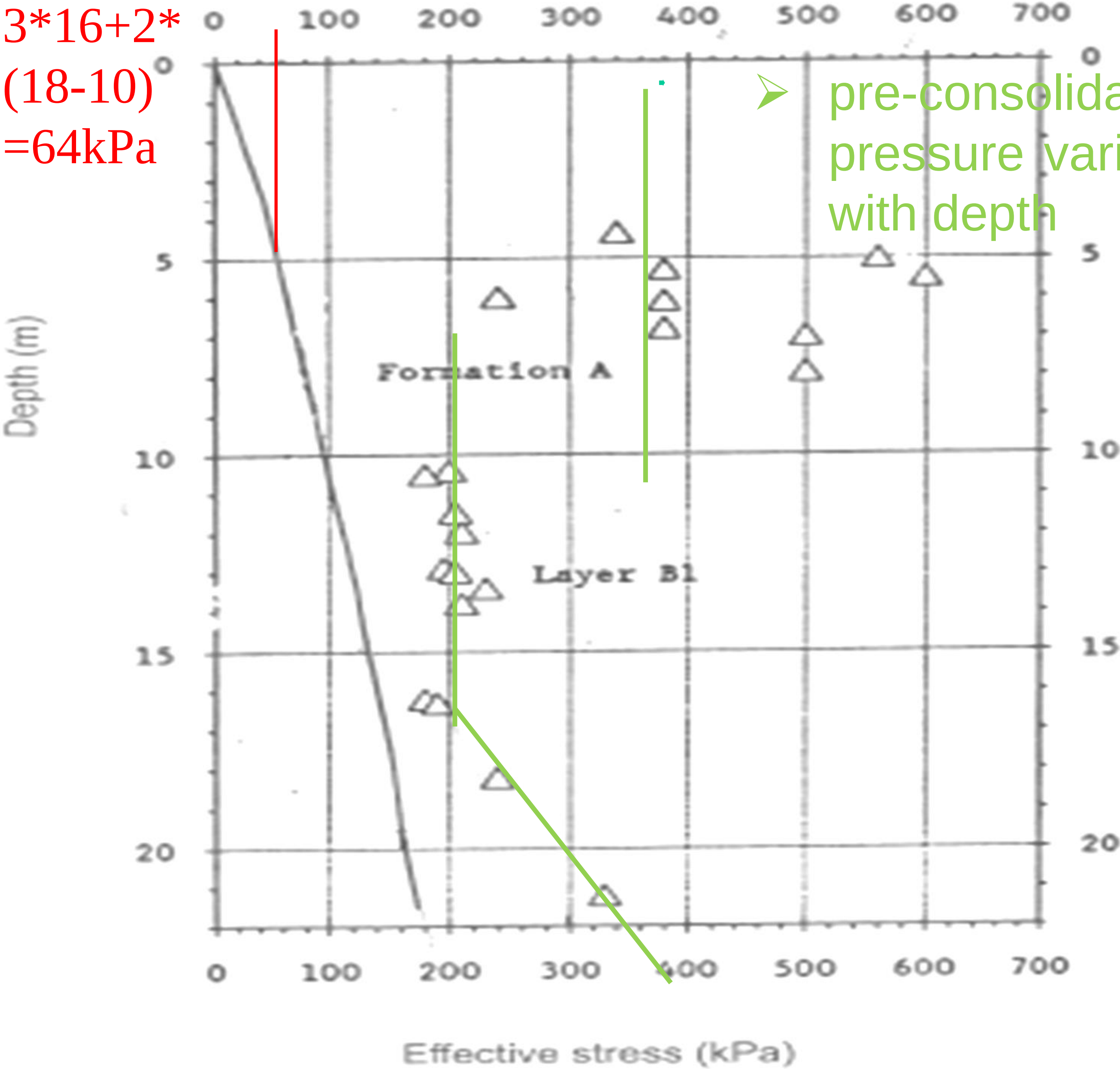
$\sigma_{v0}' < \sigma_p'$

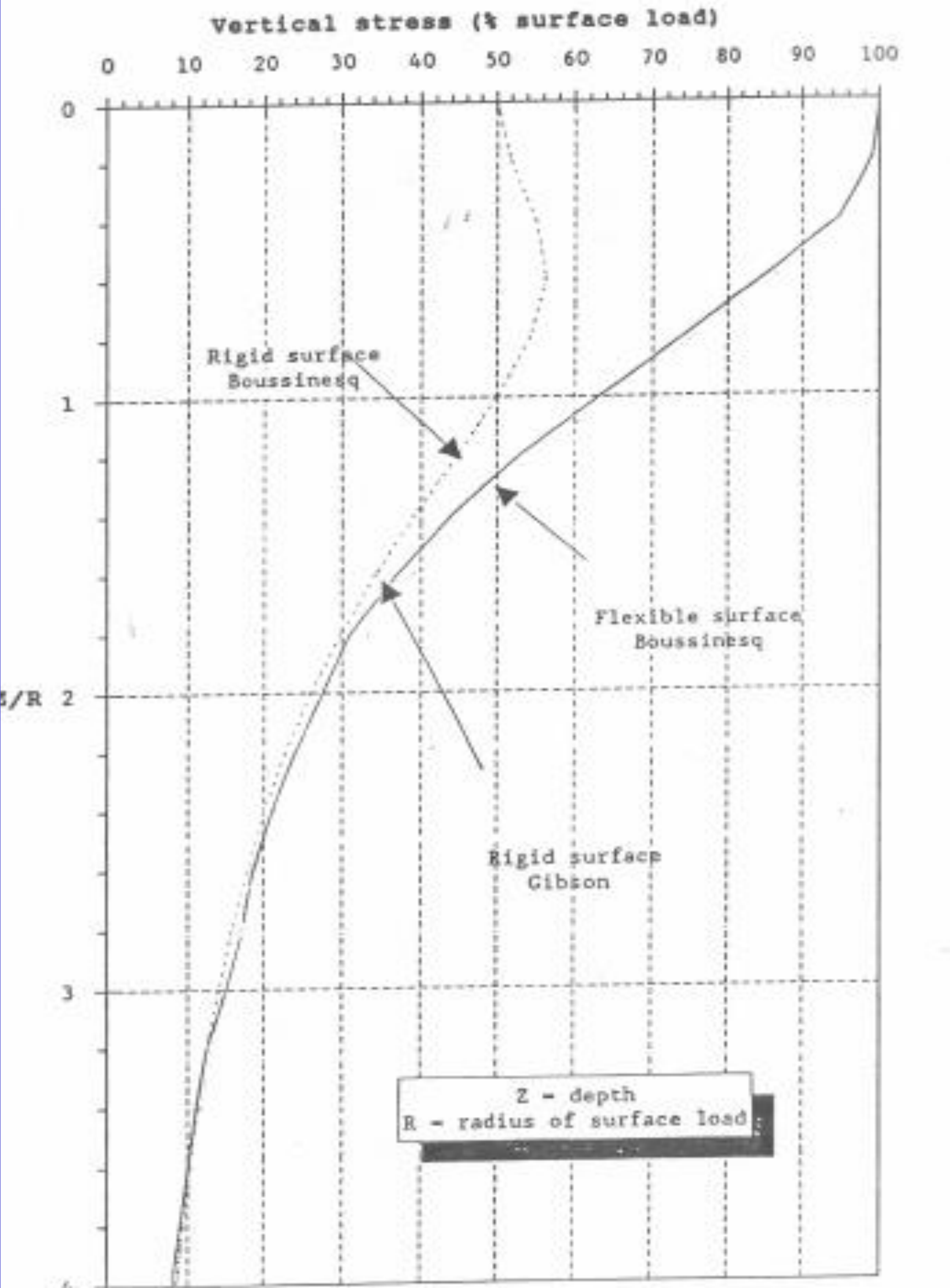
$$OCR = \frac{\sigma_p'}{\sigma_{v0}'}$$

$$\rho = H\frac{c_r}{1+e_0}\log\left(\frac{\sigma_{v0}' + \Delta\sigma_{v1}'}{\sigma_{v0}'}\right) + H\frac{c_c}{1+e_0}\log\left(\frac{\sigma_p' + \Delta\sigma_{v2}'}{\sigma_p'}\right)$$

3*16+2*(18-10)=64kPa

- pre-consolidation pressure variation with depth

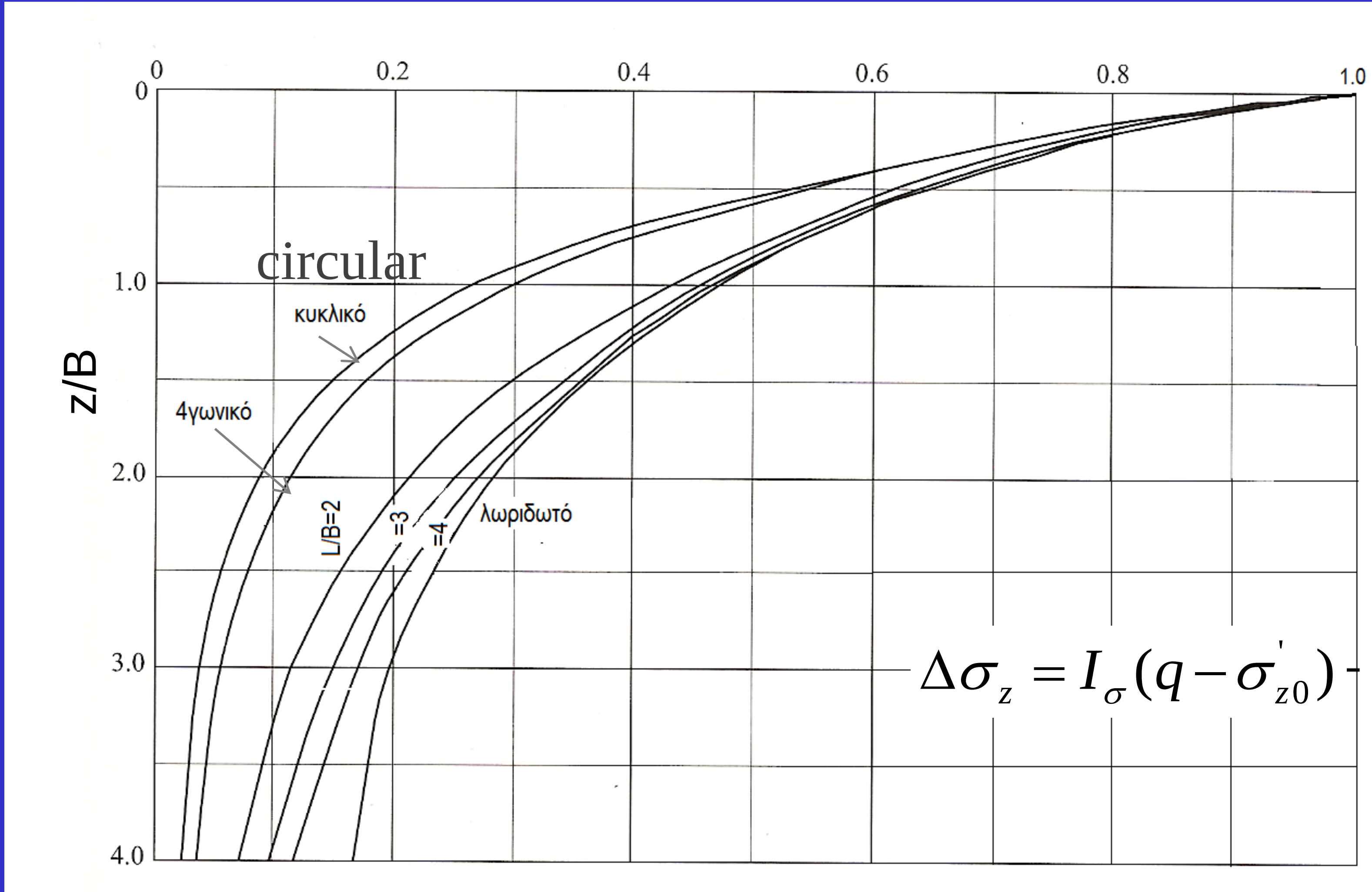




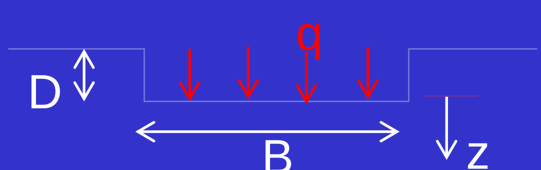
Vertical stress distribution with depth under circular foundation

$$\Delta\sigma_z = \left[1-\left(\frac{1}{1+\left(\frac{B}{2z}\right)^2}\right)^a\right](q-\sigma'_{z0})$$

Poulos & Davis 1974 used Boussinesq's equations to calculate stresses on the centre line under a circular footing (α=2.6, B=width of footing)



Stresses under the centre line of rigid footing (Butterfield & Banerjee 1971)



σ_{z0}'=normal effective stress at depth D