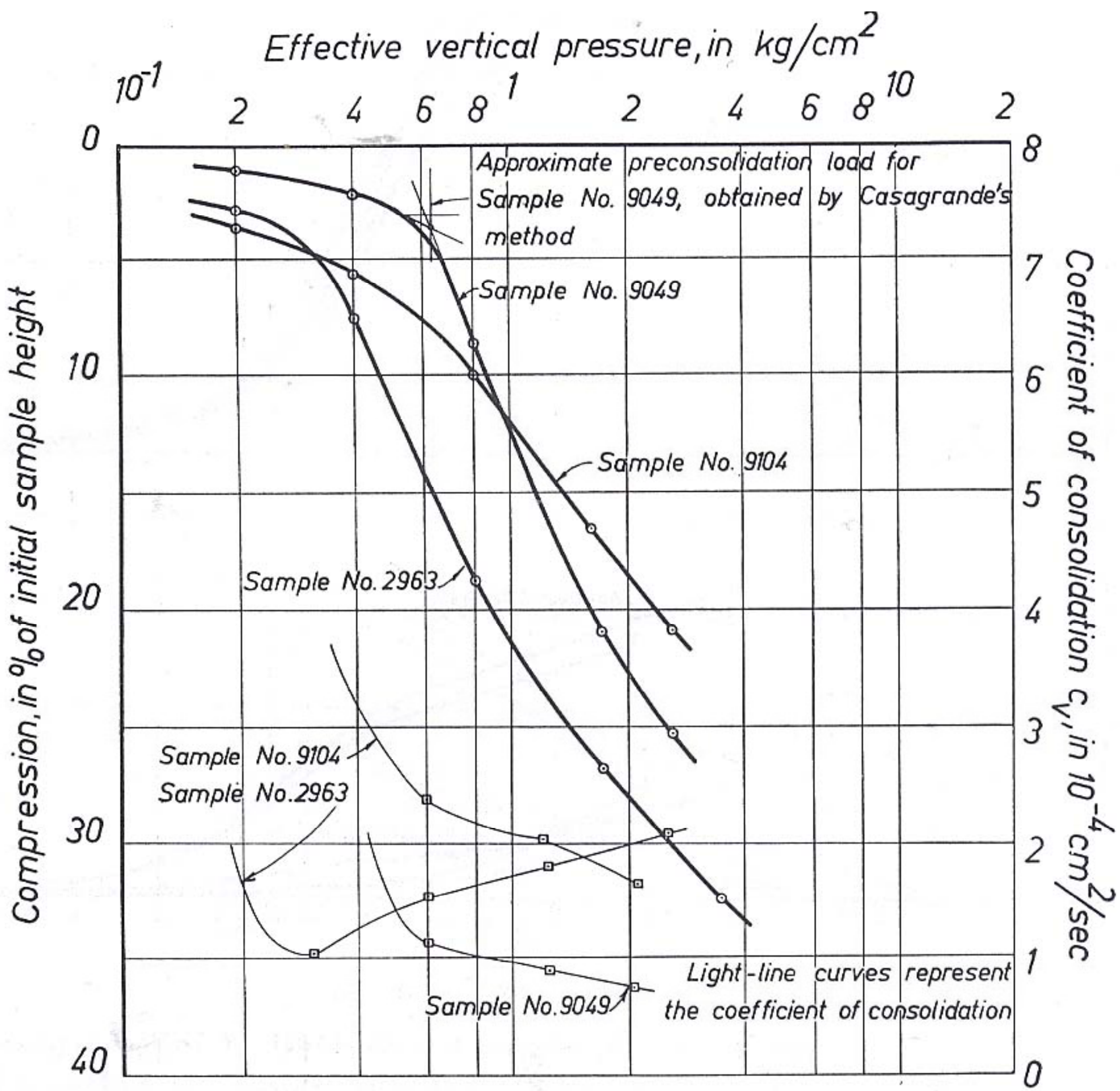
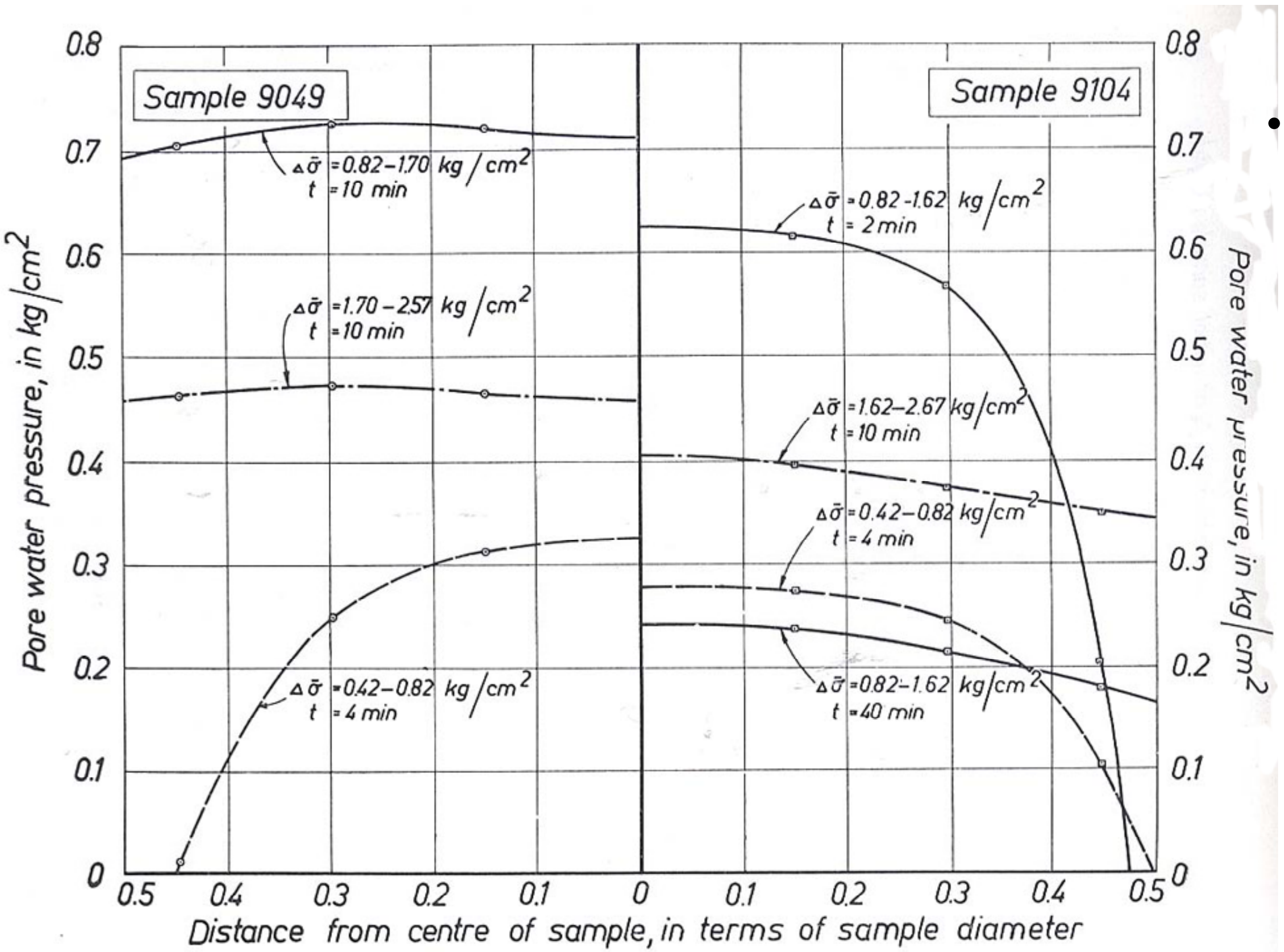
# Oedometer tests



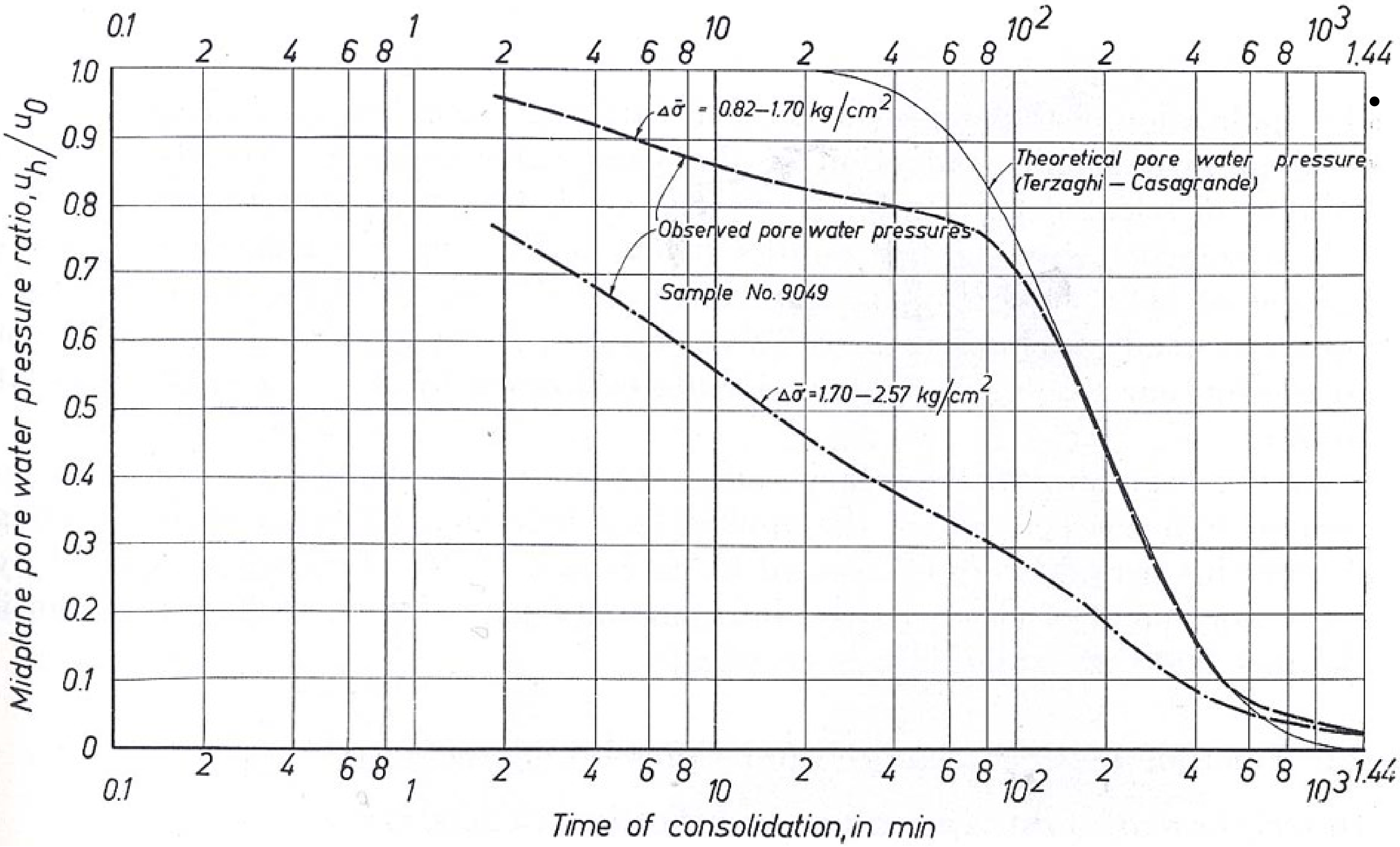

Consolidation characteristics of samples used in pore water pressure investigations. Sample 9104 disturbed (no sign of preconsolidation pressure).

# Oeometer tests




- Distribution of pore water pressure over impermeable base of the clay specimen at various times after beginning of the consolidation process. Sample 9049 undisturbed while sample 9104 disturbed

# Oedometer tests

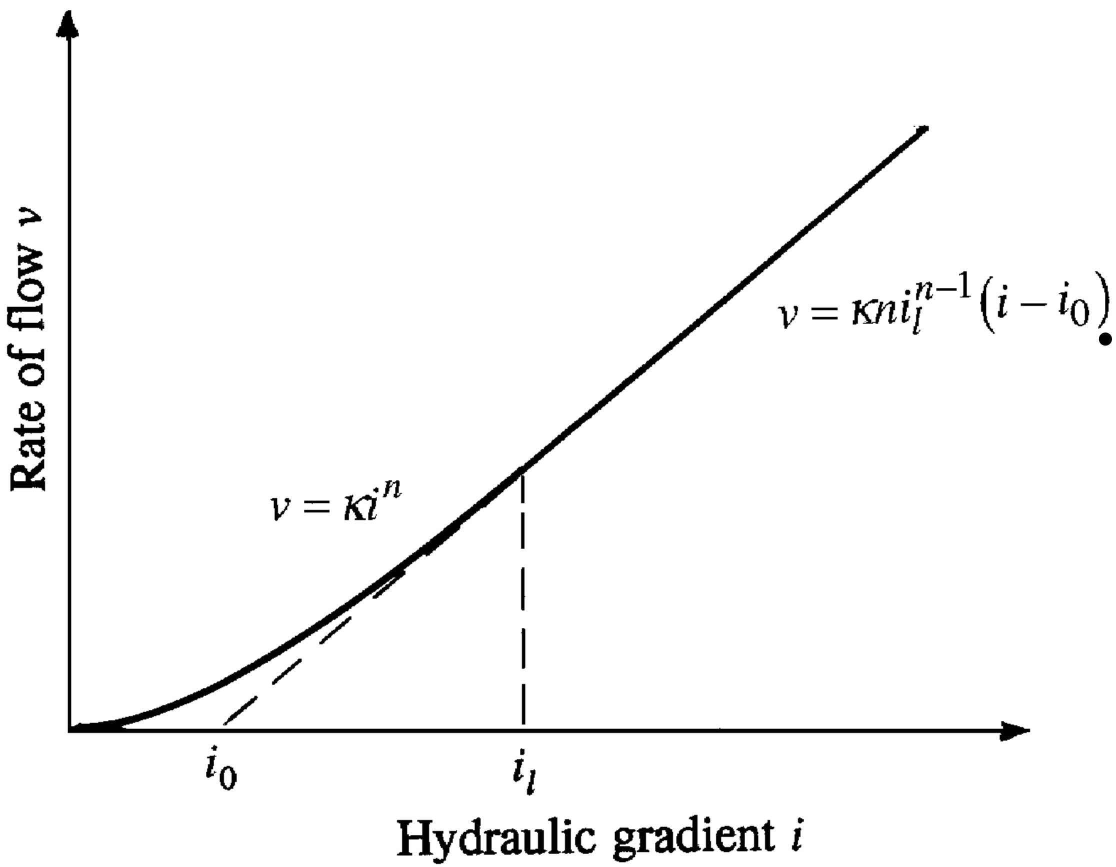



- Observed pore water pressure dissipation compared with that determined from Terzaghi's consolidation theory

# Flow conditions

- **Darcian flow**
- $v = ki$
- **Non-Darcian flow**
- $v = \kappa i^n$ when $i \leq i_l$ and $v = \kappa n i_l^{n-1}(i - i_0)$ when $i > i_l$, where $i_0 = i_l(n - 1)$,

# FLOW CONDITIONS




- Non-Darcian flow. Assumed correlation between rate of flow $v$ and hydraulic gradient $i$.

# Onedimensional consolidation

**Darcian flow:**

$$\frac{\partial u}{\partial t} = M \frac{\partial}{\partial z}\left(\frac{k}{\gamma_w}\frac{\partial u}{\partial z}\right)$$

**where $k$ is the permeability, $M$ is the oedometer modulus and $\gamma_w$ is the unit weight of water.**

Assuming that $\kappa M/\gamma_w$ is independent of $u$, we have: $\frac{\partial u}{\partial t} = \frac{kM}{\gamma_w}\frac{\partial^2 u}{\partial z^2} = c_v \frac{\partial^2 u}{\partial z^2}$

# Onedimensional consolidation

**Non-Darcian flow**

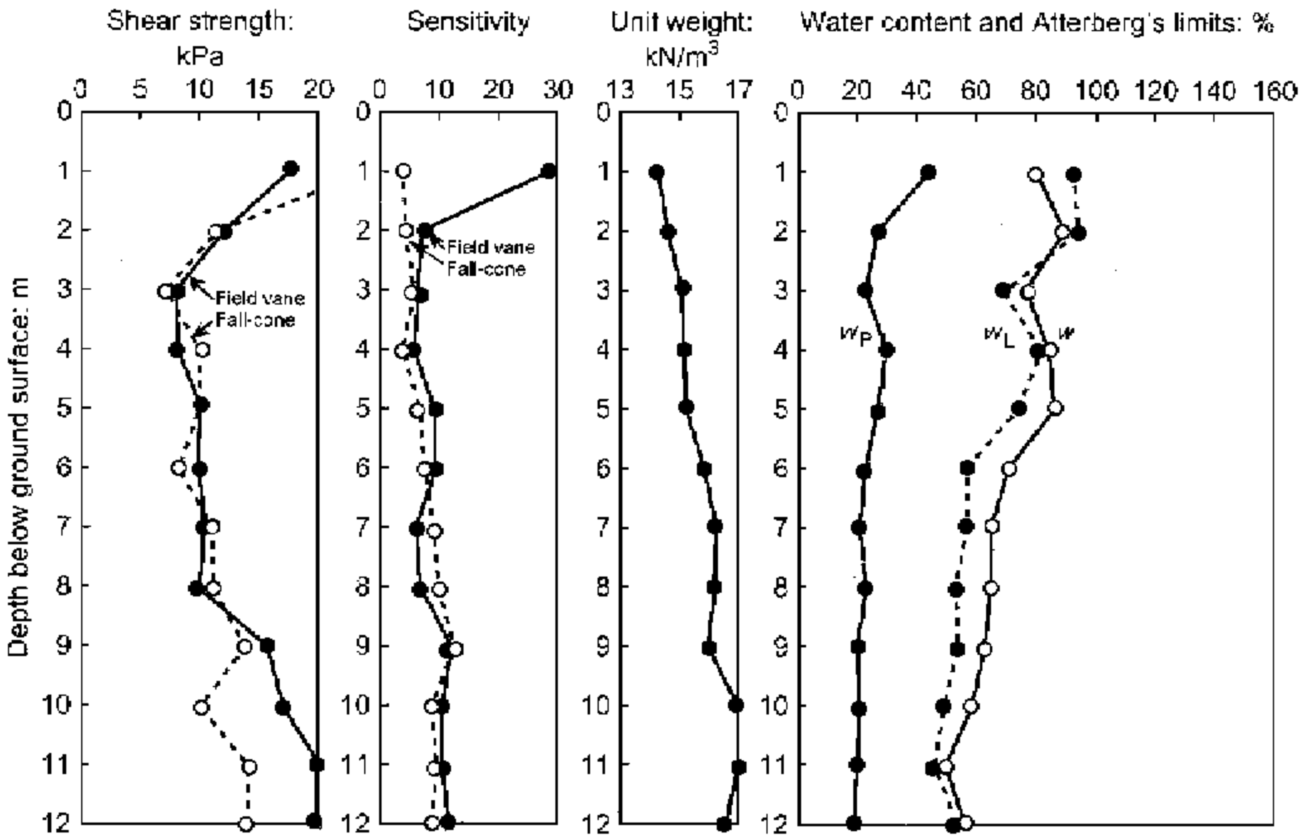
When ($i \leq i_l$), we have $v = \kappa i^n = \kappa \left( \frac{1}{\gamma_w} \frac{\partial u}{\partial z} \right)^n$ and $\frac{\partial v}{\partial z} = \frac{1}{M} \frac{\partial u}{\partial t}$.

Assuming that $\kappa M / \gamma_w$ is independent of $u$, we have: $\frac{\partial u}{\partial t} = \frac{\kappa M n}{(\gamma_w)^n} \left( \frac{\partial u}{\partial z} \right)^{n-1} \frac{\partial^2 u}{\partial z^2}$

When $i > i_l$, $v = \kappa n i_l^{n-1} \left( \frac{1}{\gamma_w} \frac{\partial u}{\partial z} - i_0 \right)$ and $\frac{\partial v}{\partial z} = \frac{1}{M} \frac{\partial u}{\partial t}$, which yields: $\frac{\partial u}{\partial t} = \frac{\kappa M n}{\gamma_w} i_l^{n-1} \frac{\partial^2 u}{\partial z^2}$

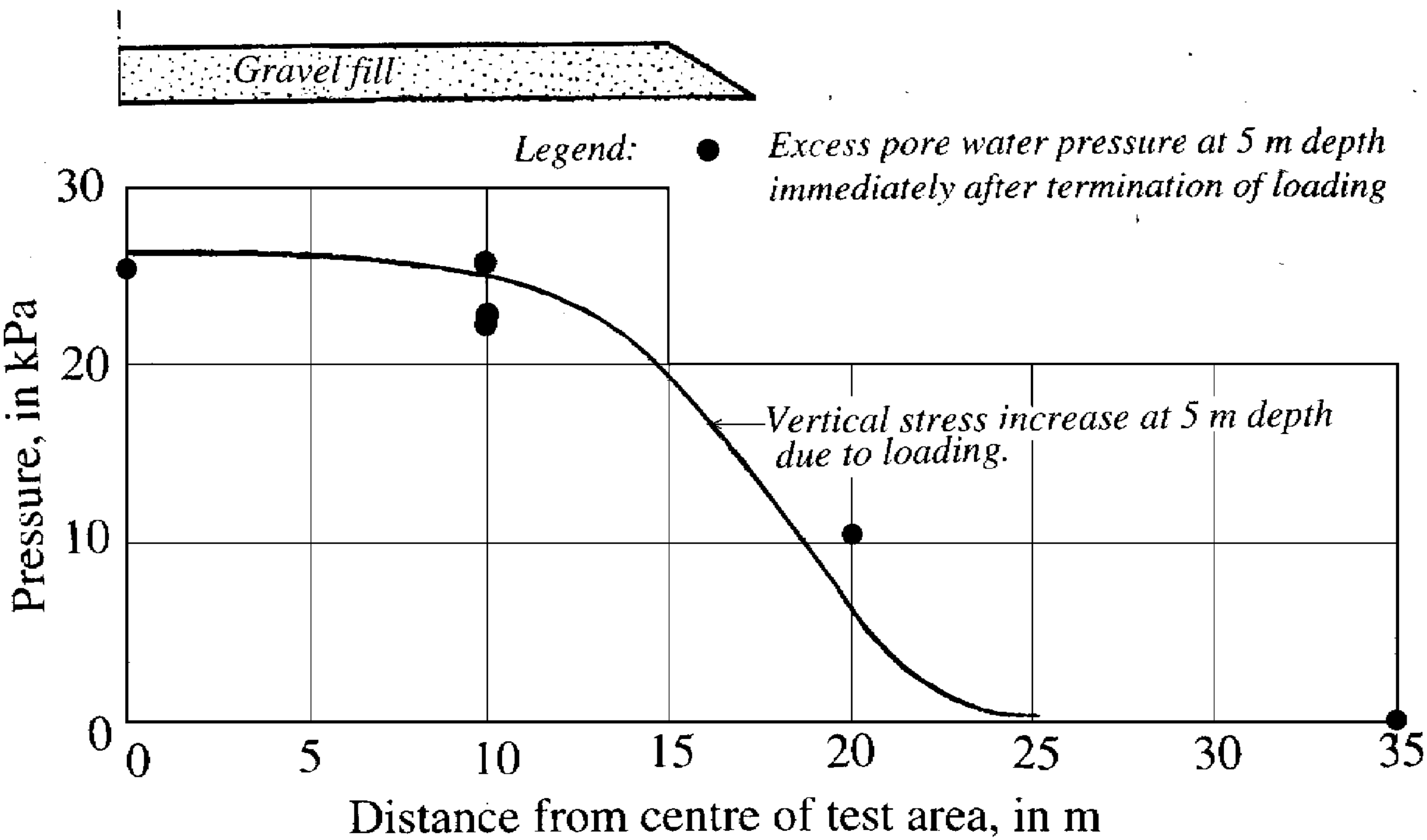
# THEORY VS. REALITY IN ONE-DIMENSIONAL CONSOLIDATION

**Test area at SkŒEdeby, 3 5 m in diameter, overload 27 kN/m$^2$**




**Geotechnical properties of the clay subsoil in Test Area IV (Hansbo, 1960)**

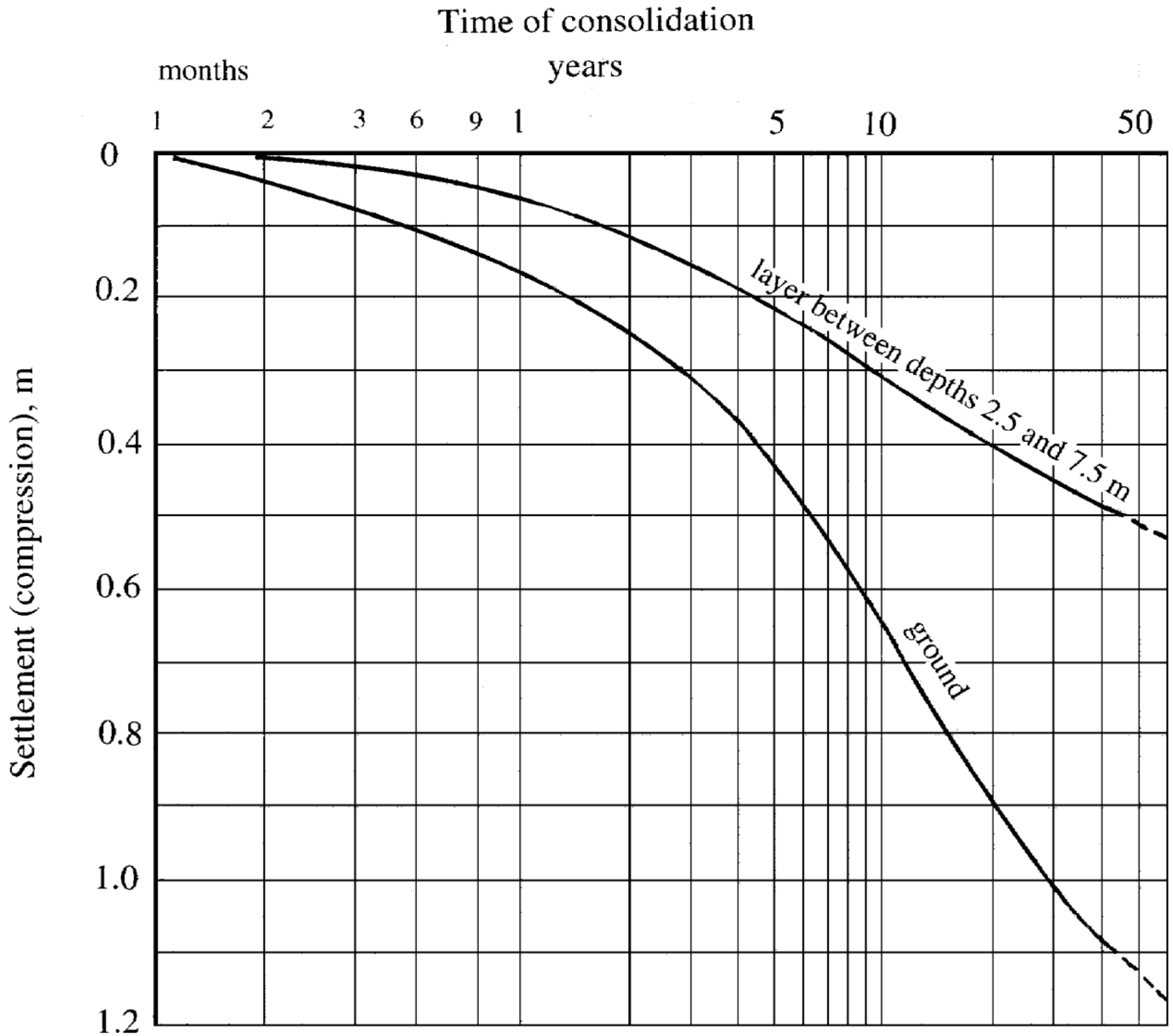
# Observed excess pore pressure distribution in Test area IV at 5 m depth, immediately after placement of the gravel fill.



## Observed excess pore pressure distribution in Test area IV at 5 m depth, immediately after placement of the gravel fill.

- This can be used in determining the parameters *A* and *B* in Skempton's pore pressure equation $u = B[\sigma_3 + A(\sigma_1 - \sigma_3)]$ where $\sigma_\square$ and $\sigma_\square$ are the major and minor principle stresses induced by loading (Skempton, 1954). As we are dealing with water saturated clay, $B = 1$. According to the solution presented by Love (1929) $\sigma_1 = 0.98q$ and $\sigma_3 = 0.60q$ below the centre, $\sigma_1 = 0.95q$ and $\sigma_3 = 0.49q$ 10 m from the centre, and $\sigma_1 = 0.50q$ and $\sigma_3 = 0.06q$ 20 m from the centre. Inserting $q = 27$ kN/m$^2$ and considering the observations made this yields $A \approx 0.85$.

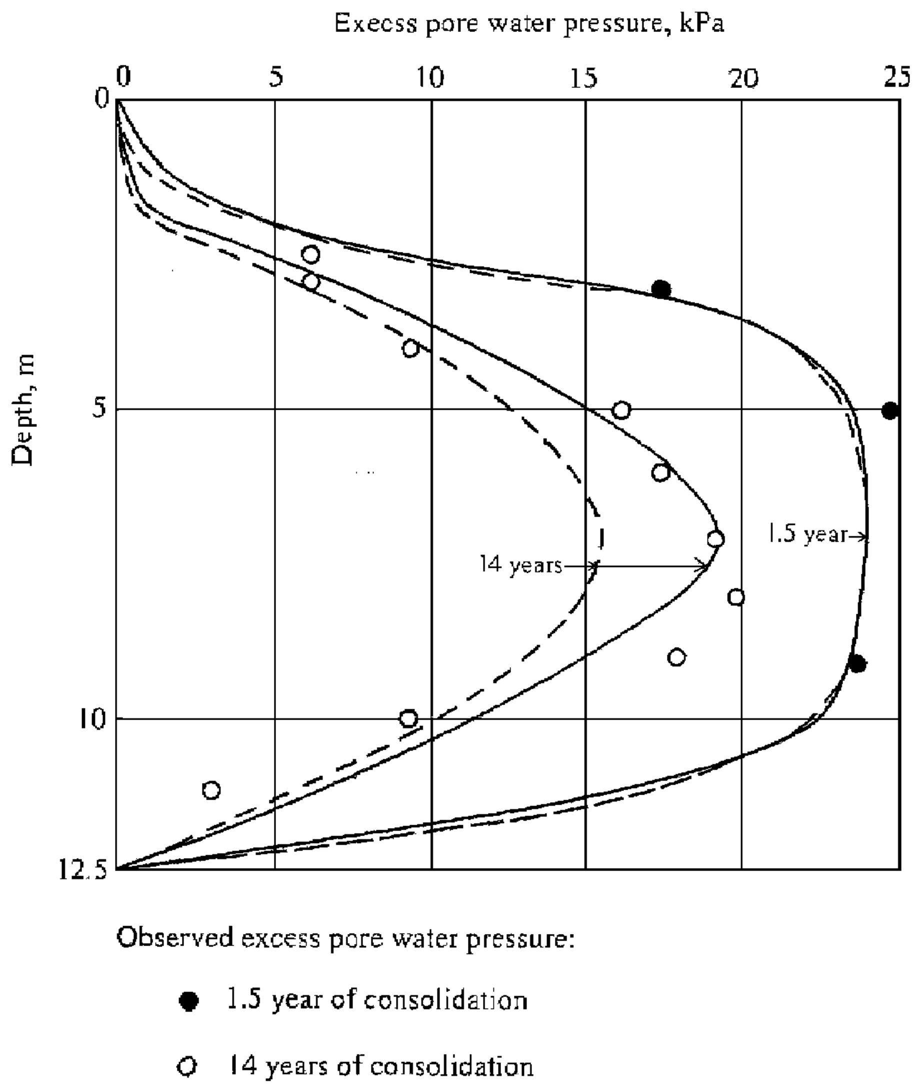
# Consolidation settlement of ground surface and compression of clay layer between 2.5 and 7.5 m of depth observed in Test Area IV.



# Consolidation settlement of ground surface and compression of clay layer between 2.5 and 7.5 m of depth observed in Test Area IV.

- According to Asaoka (1978), the total primary consolidation settlement $s_p$ can be estimated from the relation $s_i = 0.300 + 0.761 s_{i\text{-}1}$, which yields $s_p$ = 1.26 m ($s_{i\text{-}1} = s_i$) and the compression $\Delta s_p$ of the clay layer between 2.5 and 7.5 m of depth from the relation $\Delta s_i = 0.119 + 0.815 \Delta s_{i\text{-}1}$, which yields $\Delta s_p$ = 0.64 m.

**Comparison between observed excess pore pressure years dissipation in Test Area IV, Skå-Edeby, and analytical dissipation according to Darcian flow (broken lines) and non-Darcian flow (unbroken lines) after 1.5 and 14 years**

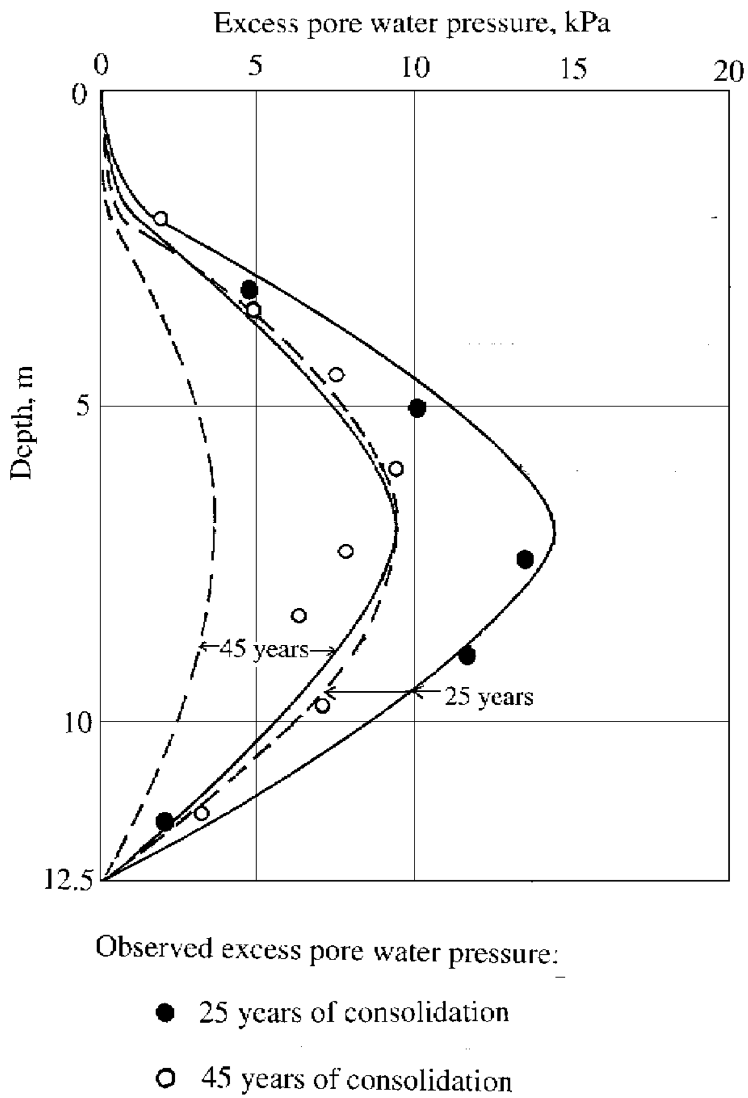


# Test Area IV, Skå-Edeby

**Parameters used in the consolidation analysis**

| Depth, m | 0–1.0 | 1.0–1.5 | 1.5–3 | 3–5 | 5–7 | 7–9 | 9–11 | 11–12.5 |
|---|---|---|---|---|---|---|---|---|
| $\Delta\sigma_v$ kPa | 27 | 27 | 27 | 26.5 | 26.5 | 26 | 26 | 25 |
| $\sigma_c'$ kPa | OC | 25 | 23 | 28 | 39 | 51 | 64 | 75 |
| $M$ kPa | 10000 | 400 | 250 | 240 | 250 | 300 | 400 | 500 |
| $\Delta s$, m | 0.01 | 0.03 | 0.16 | 0.24 | 0.24 | 0.23 | 0.22 | 0.15 |
| $k$ m/year | 0.031 | 0.031 | 0.025 | 0.022 | 0.018 | 0.018 | 0.017 | 0.016 |
| $\kappa$ m/year | 0.020 | 0.020 | 0.016 | 0.014 | 0.0115 | 0.0115 | 0.011 | 0.0095 |

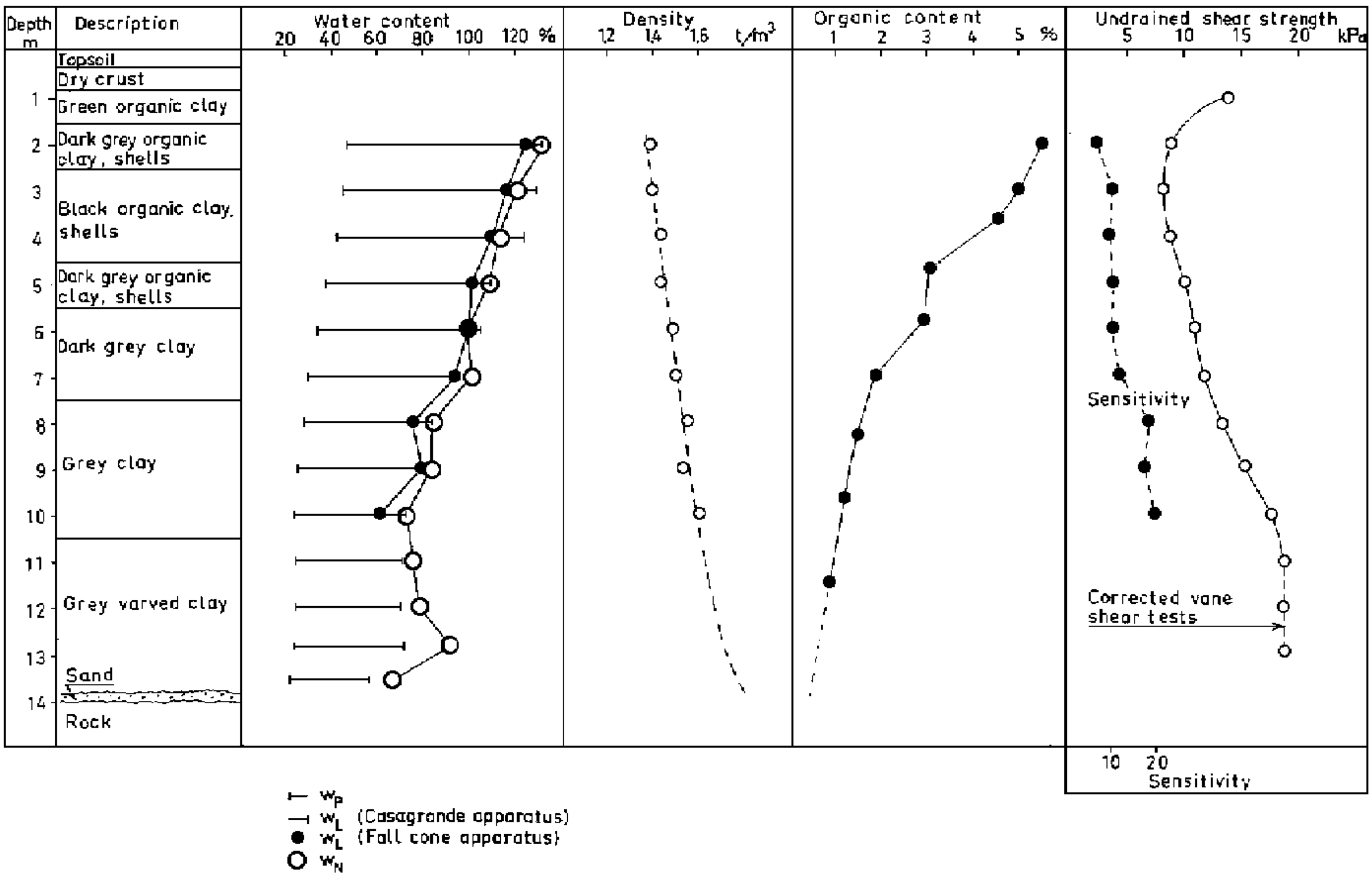
## Test Area IV, Skå-Edeby




- Looking at the remaining excess pore water pressure after 25 and 45 years of consolidation, we find the average degree of consolidation equal to, respectively, 69% and 79%. This leads in both cases to a total consolidation settlement of 1.39 m, about 10% larger than the estimated primary consolidation settlement. For the layer between the depths 2.5 m and 7.5 m, the average degree of consolidation after 25 and 45 years of consolidation becomes, respectively, 62% and 73%, which in both cases would lead to a primary compression of 0.69 m, about 8% larger than the estimated compression according to Asaoka.

# The Lilla Mellösa test area

**Soil characteristics at the Lilla Mellösa test site**

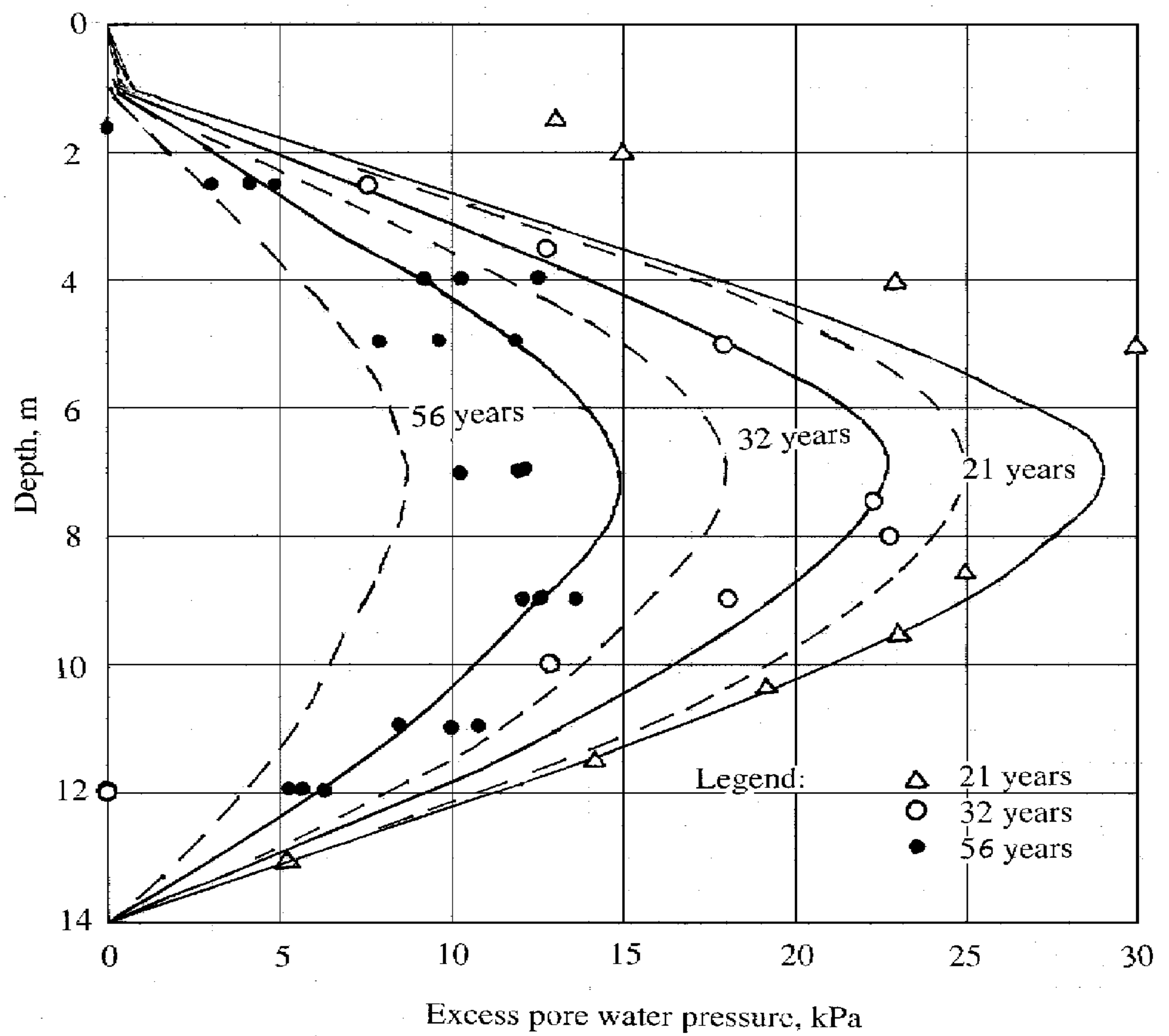


# Lilla Mellösa test site

- The test area is square with a base width of 30 m. It was filled up with 2.5 m of gravel, corresponding to an overload of 45 $kN/m^2$. The top width of the fill is 22.5 m.

- We do not know the magnitude of the pore pressure coefficient $A$ in Skempton's pore pressure equation. As in the case of the Skå-Edeby test area, we are dealing with water saturated clay, and thus $B = 1$. In our case, $A$ is also assumed equal to 1. In consequence, the initial excess pore water pressure has been considered equal to the vertical stress increase caused by the load, decreasing almost linearly with depth from 42 kPa at the ground surface to 32 kPa at the bottom of the clay layer.

## Comparison between observed excess pore pressure dissipation in the undrained test area at Lilla Mellösa

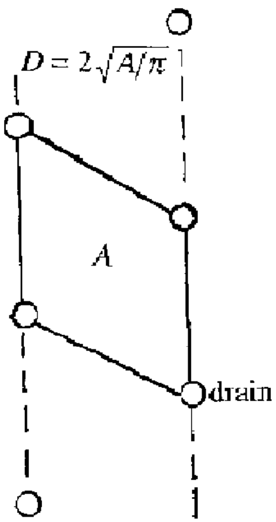


# The Lilla mellösa test site

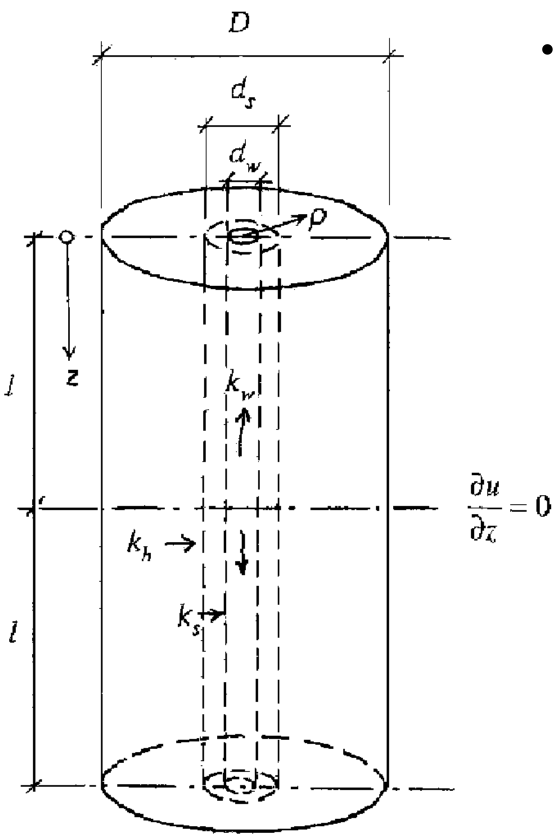
**Parameters used in the consolidation analysis**

| Depth: m | 0 Ğ 1.0 | 1.0 Ğ 1.5 | 1.5 - 3 | 3 - 5 | 5 - 7 | 7 - 9 | 9 - 11 | 11 - 14 |
|---|---|---|---|---|---|---|---|---|
| $M$ kPa | 9000 | 200 | 200 | 190 | 160 | 240 | 280 | 200 |
| $\Delta \sigma_v$ kPa | 42 | 42 | 41 | 41 | 40 | 39 | 38 | 33 |
| Æs m | 0.01 | 0.10 | 0.31 | 0.43 | 0.50 | 0.32 | 0.27 | 0.50 |
| $k$ m/year | 0.020 | 0.020 | 0.025 | 0.018 | 0.015 | 0.022 | 0.03 | 0.03 |
| $\kappa$ m/year | 0.013 | 0.013 | 0.017 | 0.012 | 0.010 | 0.015 | 0.02 | 0.02 |

# Vertical drainage




Plan




Perspective

- **Terms used in the analysis of vertical drains: $D$ = diameter of soil cylinder dewatered by a drain; $d_w$ = drain diameter; $d_s$ = diameter of zone of smear; $l$ = length of drain when closed at bottom ($2l$ = length of drain when open at bottom); $z$ = depth coordinate; $k_w$ = permeability in the longitudinal direction of the drain; $k_h$ = permeability (in the horizontal direction) of soil; $k_s$ = permeability (in the horizontal direction) of zone of smear; $\rho$ = radius vector.**

# Darcian flow

**Average degree of consolidation**

The solution to the consolidation problem is greatly simplified if one assumes that horizontal sections due to arching remain horizontal throughout the consolidation process Ñ the so-called *equal strain theory* (Barron, 1944, 1947)

The solution based on Darcian flow can be expressed by the relation (Hansbo, 1981):

$$\overline{U}_h = 1 - \exp\left(-\frac{8c_h t}{\mu D^2}\right)$$

$$\mu = \frac{D^2}{D^2 - d_w^2}\left[\ln\left(\frac{D}{d_s}\right) + \frac{k_h}{k_s}\ln\left(\frac{d_s}{d_w}\right) - \frac{3}{4}\right] + \frac{d_s^2}{D^2 - d_w^2}\left(1 - \frac{d_s^2}{4D^2}\right) +$$

$$+ \frac{k_h d_w^2}{k_s\left(D^2 - d_w^2\right)}\left(\frac{d_s^4 - d_w^4}{4D^2 d_w^2} - \frac{d_s^2}{d_w^2} + 1\right) + \frac{k_h}{q_w}\pi z(2l - z)\left(1 - \frac{d_w^2}{D^2}\right)$$

$$c_h = k_h M / \gamma_w$$

This gives results that are in good agreement with those obtained by advanced analytical and numerical solutions (e.g. Yoshikuni & Nakanado, 1974; Onoue, 1988; Zeng & Xie, 1989; Lo, 1991)

# Darcian flow

***Excess pore pressure variation.*** Replacing the initial excess pore water pressure $\bar{u}_0$ with $\gamma_w \Delta \bar{h}_0$, where $\Delta \bar{h}_0$ is the initial average hydraulic head increase, the variation of the hydraulic head increase Æh outside the zone of smear $(D/2 \geq \rho \geq d_s/2)$, based on validity of DarcyÕs law, becomes:

$$\Delta h = \frac{\Delta \bar{h}_0}{\mu D^2}\left(1 - \bar{U}_h\right)\left[\begin{array}{l} D^2 \ln \frac{2\rho}{d_s} - \frac{4\rho^2 - d_s^2}{2} + \frac{k_h}{k_s}\left(D^2 \ln \frac{d_s}{d_w} - \frac{d_s^2 - d_w^2}{2}\right) + \\ + \frac{k_h}{q_w} \pi z (2l - z)\left(D^2 - d_w^2\right) \end{array}\right]$$

Inside the zone of smear $(d_s/2 \geq \rho \geq d_w/2)$ we have:

$$\Delta h = \frac{\Delta \bar{h}_0}{\mu D^2}\left(1 - \bar{U}_h\right)\left[\frac{k_h}{k_s}\left(D^2 \ln \frac{2\rho}{d_s} - \frac{4\rho^2 - d_s^2}{2}\right) + \frac{k_h}{q_w} \pi z (2l - z)\left(D^2 - d_w^2\right)\right]$$

# Darcian flow

***Hydraulic gradient.*** The hydraulic gradient in Darcian flow outside the zone of smear ($D/2 \geq \rho \geq d_s/2$) becomes:

$$i = \frac{\Delta \bar{h}_0}{D}\left(1 - \bar{U}_h\right)\frac{1}{\mu}\left(\frac{D}{\rho} - \frac{4\rho}{D}\right)$$

and inside the zone of smear ($d_s/2 \geq \rho \geq d_w/2$):

$$i = \frac{\Delta \bar{h}_0}{D}\left(1 - \bar{U}_h\right)\frac{k_h/k_s}{\mu}\left(\frac{D}{\rho} - \frac{4\rho}{D}\right)$$

# Exponential flow. Average degree of consolidation

**Average degree of considation**

Assuming an exponential correlation between hydraulic gradient and flow velocity, $v = \kappa i^n$, the consolidation equation becomes (Hansbo, 1997a-b):

$$\overline{U}_h = 1 - \left[1 + \frac{\lambda t}{\alpha D^2}\left(\frac{\Delta \overline{h}_0}{D}\right)^{n-1}\right]^{\frac{1}{1-n}}$$

where $\Delta \overline{h}_0 = \overline{u}_0 / \gamma_w$ ($\overline{u}_0$ = initial excess pore water pressure, equally distributed), $\lambda = \kappa_h M / \gamma_w$, $t$ = time of consolidation, $M$ = compression modulus determined by oedometer tests (= $1/m_v$, where $m_v$ is the volume compressibility), $\gamma_w$ = unit weight of water, $\alpha = n^{2n}\beta^n / \left[4(n-1)^{n+1}\right]$

# Exponential flow, $\beta$

$$\beta = \frac{1}{3n-1} - \frac{n-1}{n(3n-1)(5n-1)} - \frac{(n-1)^2}{2n^2(5n-1)(7n-1)} +$$

$$+\frac{1}{2n}\left[\left(\frac{\kappa_h}{\kappa_s}-1\right)\left(\frac{D}{d_s}\right)^{(1/n-1)} - \frac{\kappa_h}{\kappa_s}\left(\left(\frac{D}{d_w}\right)^{(1/n-1)}\right)\right] -$$

$$-\left(\frac{1}{2n}-\frac{1}{3n-1}\right)\left[\left(\frac{\kappa_h}{\kappa_s}-1\right)\left(\frac{D}{d_s}\right)^{(1/n-3)} - \frac{\kappa_h}{\kappa_s}\left(\frac{D}{d_w}\right)^{(1/n-3)}\right] +$$

$$+\frac{\kappa_h}{2q_w}\pi z(2l-z)\left(1-\frac{1}{n}\right)\left(\frac{D}{d_w}\right)^{(1/n-1)}\left(1-\frac{d_w^2}{D^2}\right)^{1/n}$$

# Exponential flow

***Excess pore pressure variation.*** Replacing the initial excess pore water pressure $\bar{u}_0$ with $\gamma_w \Delta \bar{h}_0$, where $\Delta \bar{h}_0$ is the initial average hydraulic head increase, the variation of the hydraulic head increase Æh outside the zone of smear $\left(D/2 \geq \rho \geq d_s/2\right)$, based on non-validity of DarcyÕs law, becomes:

The variation of hydraulic head increase outside the zone of smear in exponential flow ($D/2 \geq \rho \geq d_s/2$), assuming that $i \leq i_l$, becomes:

$$\Delta h = \frac{\Delta \bar{h}_0}{2^n \beta n^2}\left(1 - \bar{U}_h\right)\left\{\begin{array}{l} F\left(\dfrac{2\rho}{D}\right) - F\left(\dfrac{d_s}{D}\right) + \dfrac{\kappa_h}{\kappa_s}\left[F\left(\dfrac{d_s}{D}\right) - F\left(\dfrac{d_w}{D}\right)\right] + \\ + \dfrac{\kappa_h}{q_w}\pi z(2l - z)\left(1 - \dfrac{1}{n}\right)\left(1 - \dfrac{d_w^2}{D^2}\right)^{1/n}\left(\dfrac{d_w}{D}\right)^{(1-1/n)} \end{array}\right\}$$

where

$$F(x) = x^{1-1/n}\left[1 - \frac{1-1/n}{3n-1}x^2 - \frac{(1-1/n)^2}{2(5n-1)}x^4 - \frac{(1-1/n)^2(2n-1)}{6n(7n-1)}x^6 - \cdots\right],$$

in which the variable $x$ represents $2\rho/D$, $d_s/D$ and $d_w/D$.

# Exponential flow

Inside the zone of smear ($d_s/2 \geq \rho \geq d_w/2$) we have:

$$\Delta h = \frac{\Delta \bar{h}_0}{2^n \beta n^2}\left(1 - \bar{U}_h\right)\left\{\begin{array}{l} \dfrac{\kappa_h}{\kappa_s}\left[F\left(\dfrac{2\rho}{D}\right) - F\left(\dfrac{d_w}{D}\right)\right] + \\ + \dfrac{\kappa_h}{q_w}\pi z(2l - z)\left(1 - \dfrac{1}{n}\right)\left(1 - \dfrac{d_w^2}{D^2}\right)^{1/n}\left(\dfrac{d_w}{D}\right)^{(1-1/n)} \end{array}\right\}$$

**Hydraulic gradient.** The hydraulic gradient outside the zone of smear ( $D/2 \geq \rho \geq d_s/2$ ) in exponential flow, i.e. assuming that $i \leq i_l$, becomes:

$$i = \frac{\Delta \bar{h}_0}{D}\left(1 - \bar{U}_h\right)\left[\frac{1}{4\alpha(n-1)}\left(\frac{D}{2\rho} - \frac{2\rho}{D}\right)\right]^{1/n}$$

while inside the zone of smear ($d_s/2 \geq \rho \geq d_w/2$):

# Correlations

**Correlation between $\lambda$ and $c_h$**

An approximate correlation between $c_h$ and $\lambda$ can be found by equalising the areas created below the flow vs. hydraulic gradient curves in the two cases non-Darcian and Darcian flow. This yields the correlation:

$$\lambda / c_h = \frac{n+1}{2 i_l^{n-1}} \quad \text{when } i \leq i_l$$

and

$$\lambda / c_h \approx \frac{i^2}{2} \left[ \frac{i_l^{n+1}}{n+1} + n i_l^{n-1} (i - i_l) \left( \frac{i - i_l}{2} + \frac{i_l}{n} \right) \right]^{-1} \quad \text{when } i \geq i_l$$

The maximum hydraulic gradient is obtained for $\overline{U}_h = 0$ and $\rho = d_s/2$. Assuming, for example, that the maximum gradients reached during the consolidation process are, respectively, 2, 5, 15, 25 and 75 and that the exponent $n = 1.5$ and the limiting gradient $i_l = 8$, we find in due order $\lambda / c_h = \kappa_h / k_h$ Å 0.88, 0.56, 0.34, 0.29 and 0.25.

Assuming $n = 1.5$ and $i_{\max} \leq 1.5 i_l$, the ratio of $\lambda$ to $c_h$ can be obtained by the relation:

$$\lambda / c_h = 1.25 / \sqrt{i_{\max}}$$

where $i_{\max} = \dfrac{\Delta \bar{h}_0}{D} \left[ \dfrac{1}{2\alpha} \left( \dfrac{D}{d_s} - \dfrac{d_s}{D} \right) \right]^{2/3}$

# **Contribution of**
# one-dimensional consolidation

**Contribution of $\bar{U}_v$**

According to CarilloÕs relation $\overline{U}_{\text{tot}} = \overline{U}_v + \overline{U}_h - \overline{U}_v \overline{U}_h$, the total average consolidation, including the effect of vertical drainage (horizontal pore water flow) and one-dimensional consolidation (vertical pore water flow) can be expressed by the relation:

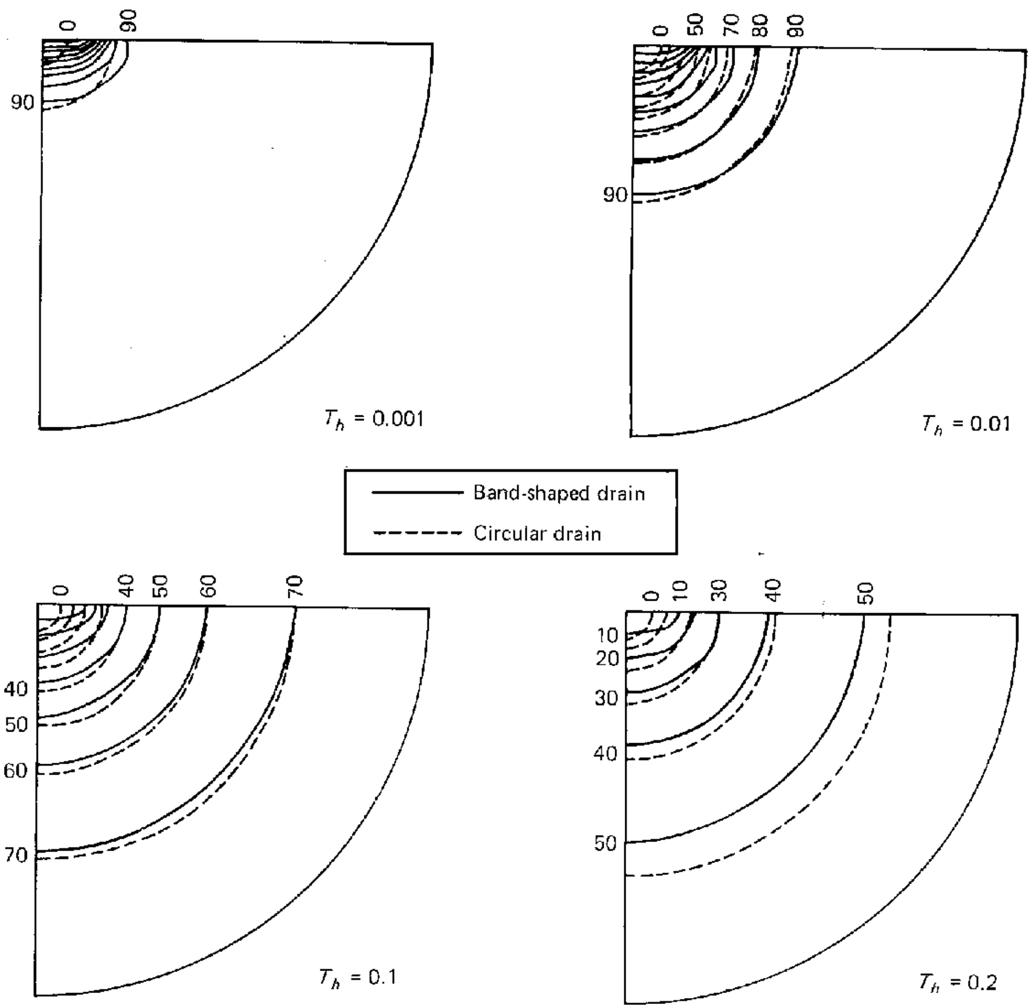
$$\overline{U}_{\text{tot}} = 1 - \left(1 - \frac{2}{l}\sqrt{\frac{c_v t}{\pi}}\right)\exp\left(-\frac{8 c_h t}{\mu_{\text{av}} D^2}\right)$$

in Darcian flow, and

$$\overline{U}_{\text{tot}} = 1 - \left(1 - \frac{2}{l}\sqrt{\frac{c_v t}{\pi}}\right)\left[1 + \frac{\lambda t}{\alpha_{\text{av}} D^2}\left(\frac{\bar{u}_0}{D\gamma_w}\right)^{n-1}\right]^{1/(1-n)}$$

in exponential flow.

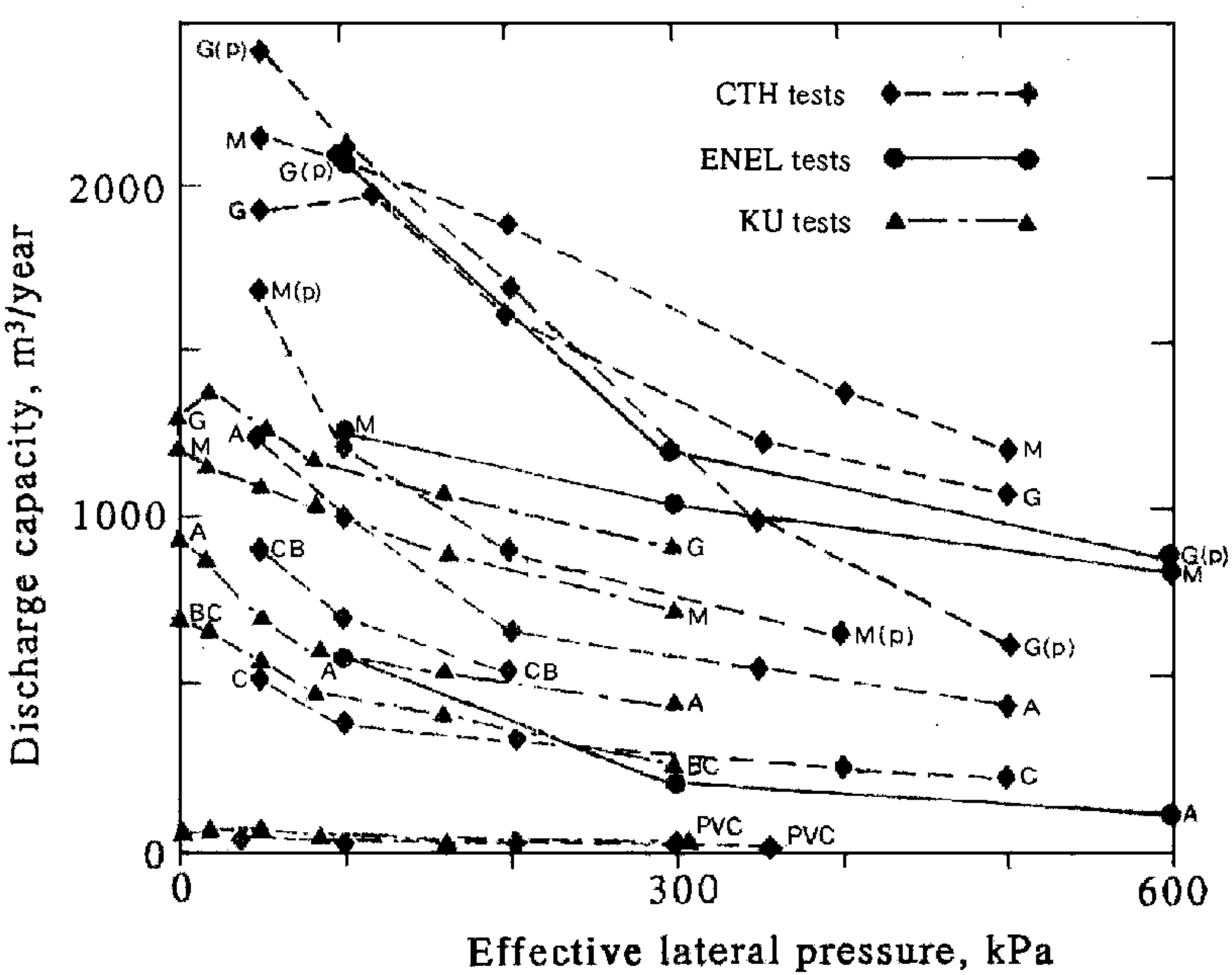
# Comparison band drain circular drain




- **Comparison of consolidation effects (remaining excess pore water pressure *u* in % of initial excess pore water pressure $u_0$) caused by a band drain (100 mm in width and 4 mm in thickness) and a circular drain with the same circumference ($d_w$ = 66 mm). *D* = 1 m. $T_h = c_h t/D^2$. No effect of smear or well resistance. (Hansbo, 1979)**

# Discharge capacity tests

**A = Alidrain, BC = Bando Chemical, CB = Castle Board, C = Colbond, G =Geodrain. (p) indicates filter sleeve of paper●**

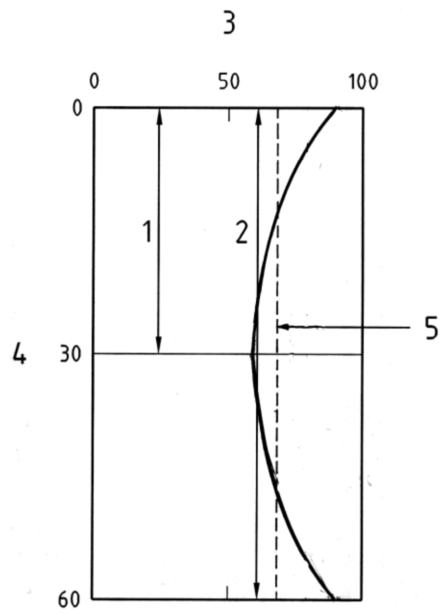


# Buckling

- Buckling and kinking of drain due to very large relative compression of peat

# Discharge capacity

Consolidation parameters: $q_w$ = 100 $m^3$/year (Å3,2 $cm^3$/s),
$c_h$ = 1,0 $m^2$/year (Å3,2 × $10^{-8}$ $m^2$/s ),
$k_s$= $k_h$ = 0,1 m/year (Å3,2 × $10^{-9}$ m/s),
time of consolidation $t$ = 0,5 year.
Drain spacing 0,9 m (equilateral triangular pattern;
$D$ = 0,945 m), drain diameter $d_w$ = 0,065 m.




Key

1 Partially penetrating drain ($l$ = 30 m)

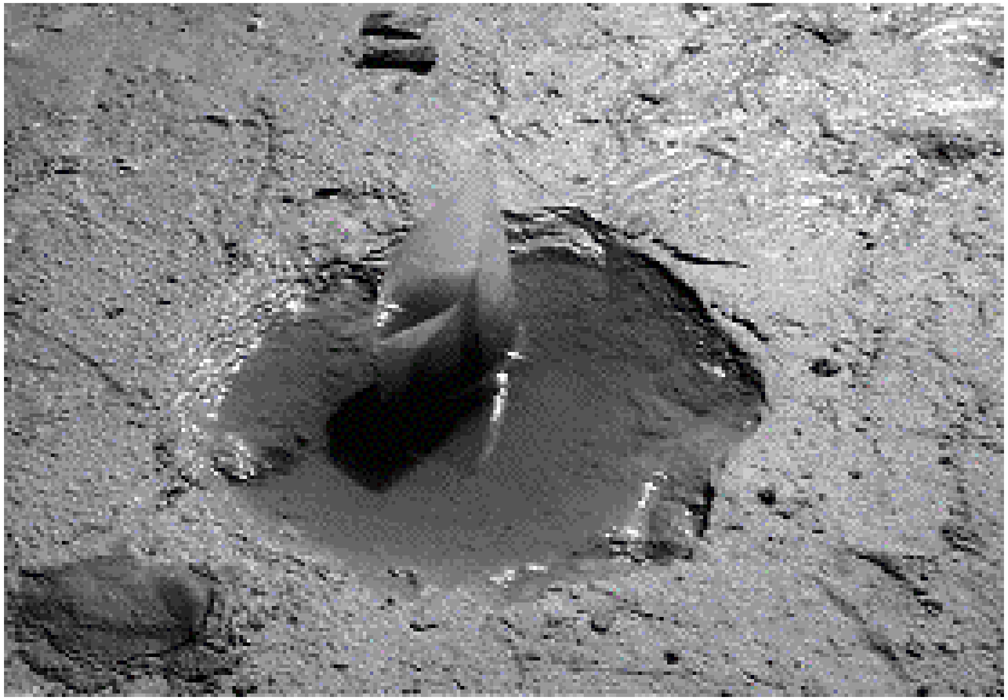
2 Penetrating drain (2$l$ = 60 m)

3 Degree of consolidation $\overline{U}_h$ %

4 Depth of drain installation, m

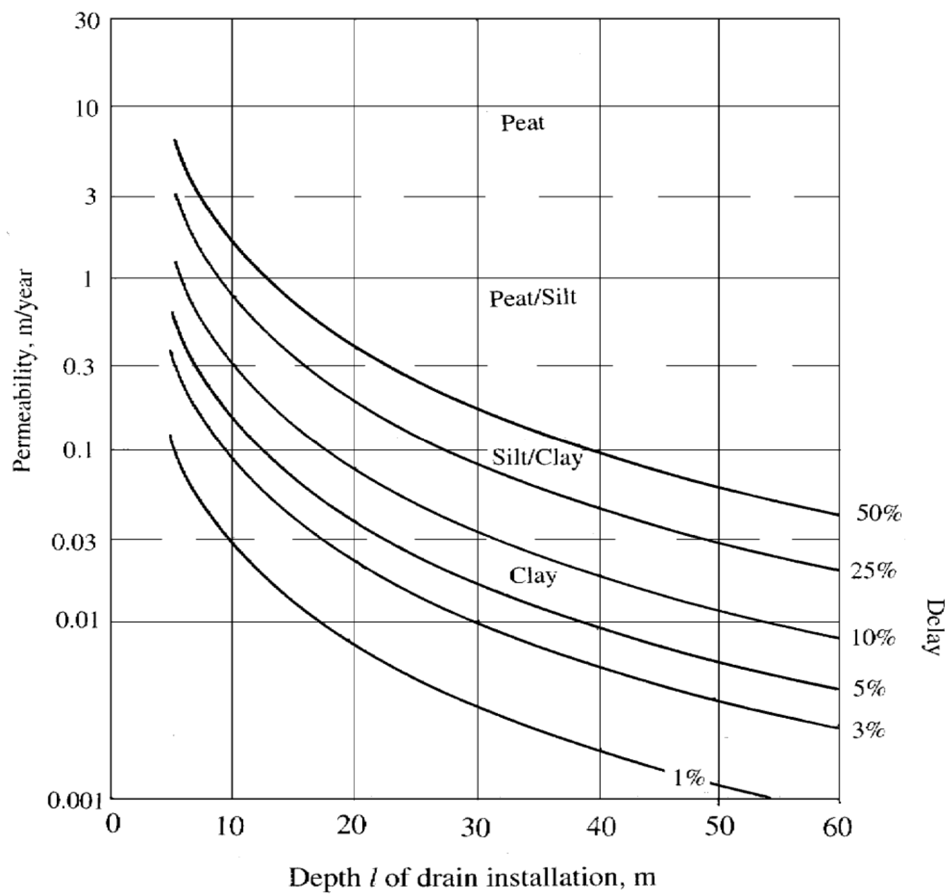
5 $\overline{U}_{h,\text{average}}$

# Drainage layer



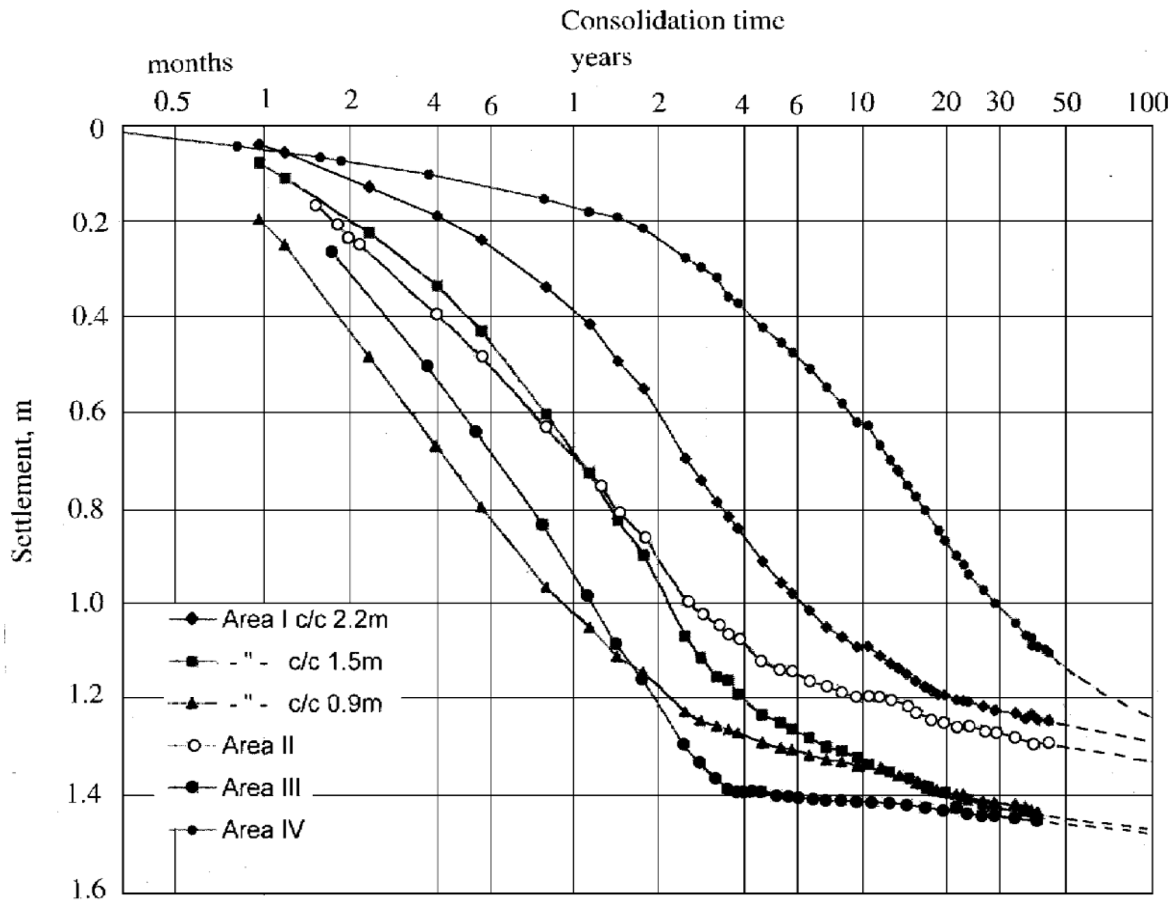
Example of drainage blanket of granular material with insufficient permeability, showing water trapped in the drainage blanket, implying backpressure in the drain

# Delay in time of consolidation




**Delay in time of consolidation at depth $l$ of drain installation for drains with a discharge capacity of 500 $m^3$/year (16 $cm^3$/s). Drain spacing 0.9 m (equilateral triangular pattern; $D = 0.945$ m), drain diameter $d_w = 0.065$ m.**

# Skå Edeby test areas



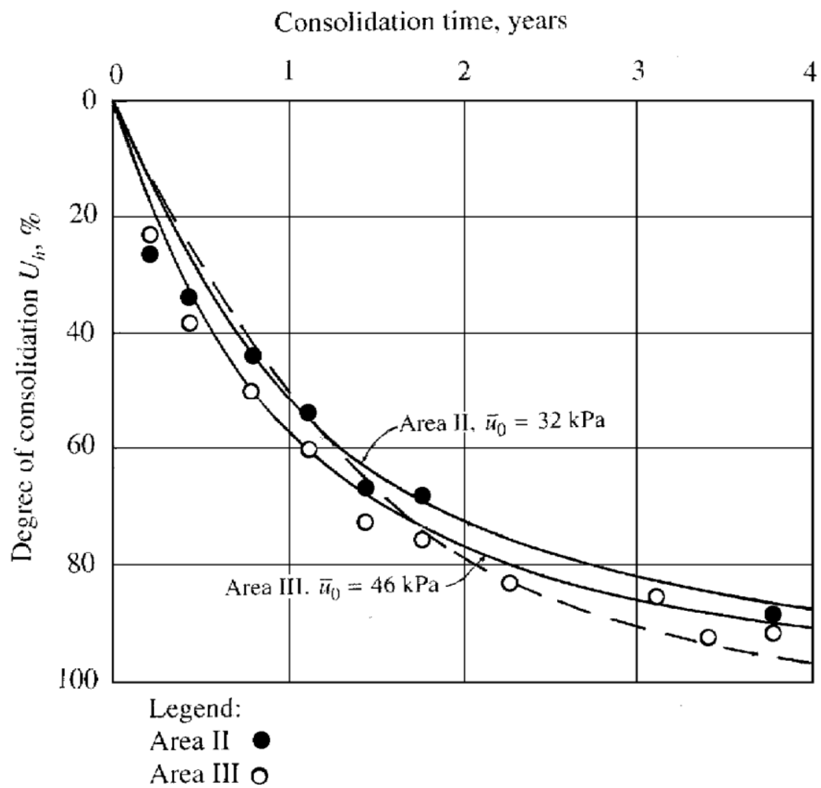

**Settlement *vs*. time of loading in the SkŒEdeby test areas, revised to represent a common depth of 12.2 m. After Larsson (1986). The broken lines represent an estimation of the continuation of the settlement process after the end of observations**

# Comparison analyses, Test Area I

Best fit of the $c_h$ and $\lambda$ values in Test Area I, based on settlement. (Load = 27 $kN/m^2$)

| Drain spacing | 0.9 m ($\bar{u}_0$ = 37 kPa) | | | 1.5 m ($\bar{u}_0$ = 31kPa) | | | 2.2 m ($\bar{u}_0$ = 27 kPa) | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, years | 1/6 | 1 | 2 | 1/2 | 1 | 4 | 1 | 4 | 9 |
| $\bar{U}_{tot}$, % | 34 | 82 | 94 | 35 | 52 | 92 | 33 | 71 | 89 |
| $\bar{U}_v$, % | 6 | 14 | 17 | 10 | 14 | 30 | 14 | 30 | 46 |
| $\bar{U}_h$, % | 30 | 79 | 93 | 28 | 44 | 88 | 22 | 59 | 79 |
| $c_h$, $m^2$/year | 0.88 | 0.49 | 0.42 | 0.70 | 0.62 | 0.57 | 0.61 | 0.58 | 0.46 |
| $\lambda$, $m^2$/year ($n$ =1.5) | 0.26 | 0.26 | 0.30 | 0.34 | 0.32 | 0.44 | 0.36 | 0.38 | 0.37 |
| $\bar{U}_h$, % ($\lambda_{av.}$ =0.34 $m^2$/year) | 37 | 85 | 94 | 28 | 46 | 83 | 21 | 55 | 78 |

# Test areas II and III, Skå Edeby



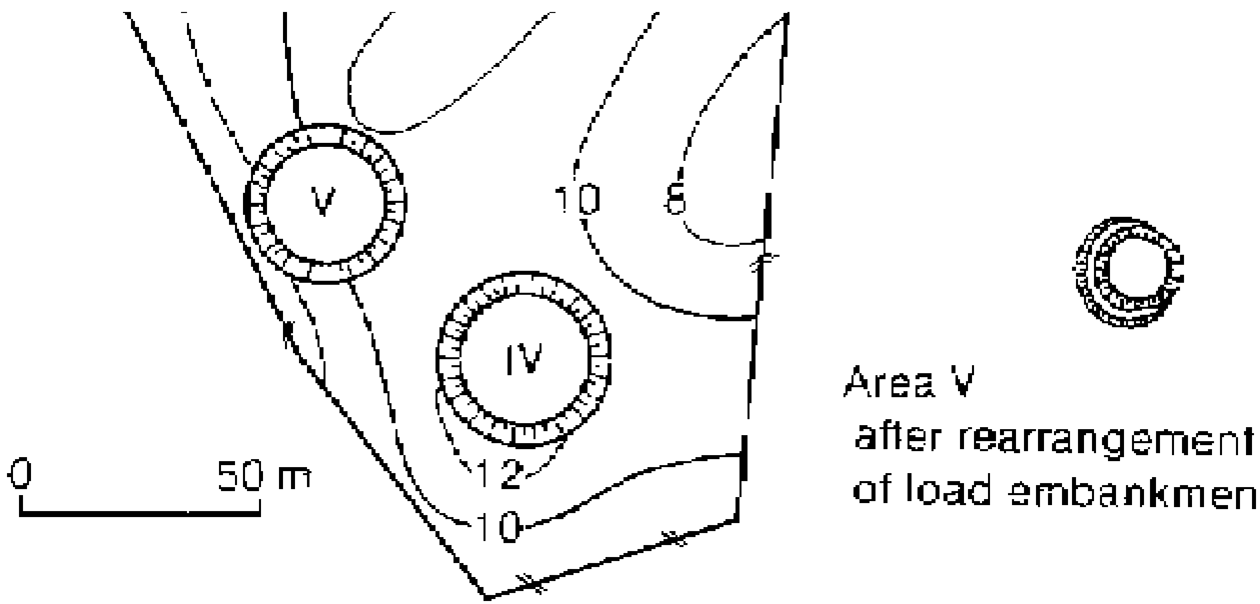

**Observed and calculated excess pore pressure dissipation at a depth of 5 m in the SkŒEdeby test areas II ($u_0$ = 32 kPa) and III ($u_0$ = 46 kPa). Unbroken lines represent exponential flow with $n$ = 1.5 and $\lambda$ = 0.43 $m^2$/year, broken line Darcian flow with $c_h$ = 0.8 $m^2$/year.**

# Comparison analyses test areas II and III

**Best fit of $c_h$ and $\lambda$ values in Test Areas II (load 27 kN/m$^2$) and III (load = 39 kN/m$^2$), based on total settlement.**

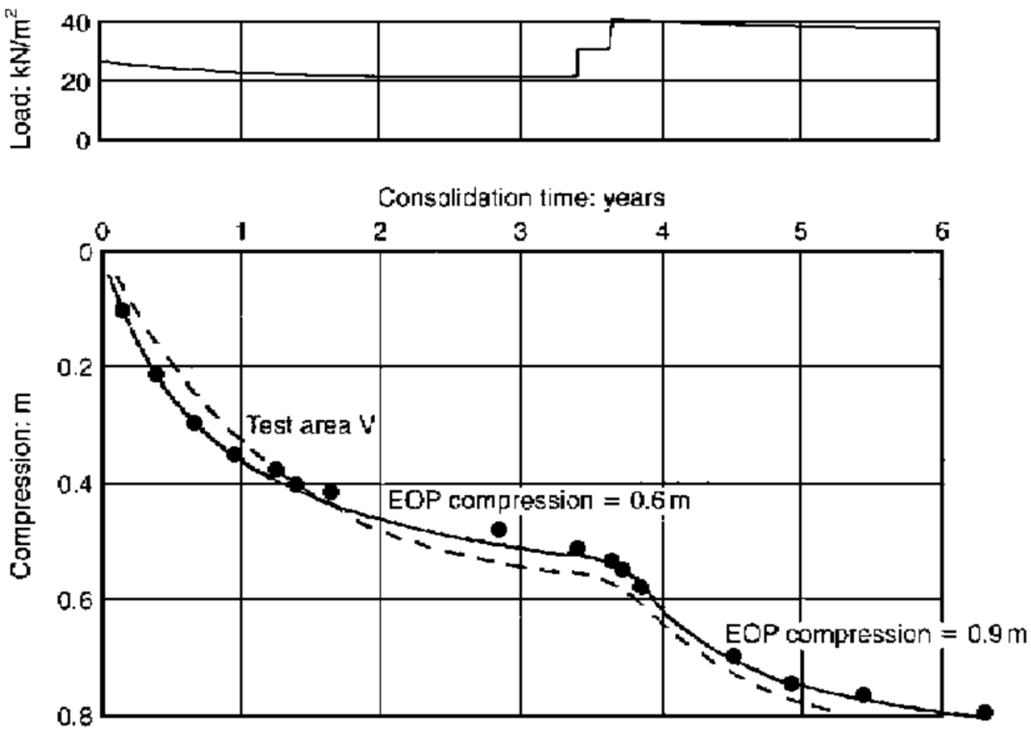
| Test Area | II ($\bar{u}_0$ = 32 kPa) | | | | | III ($\bar{u}_0$ = 46 kPa) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time, years | 1/6 | 1/2 | 2 | 4 | 9 | 1/6 | 1/2 | 2 | 4 |
| $\bar{U}_{tot}$, % | 20 | 42 | 75 | 90 | 98 | 20 | 45 | 80 | 94 |
| $\bar{U}_v$, % | 6 | 10 | 19 | 30 | 46 | 6 | 10 | 19 | 30 |
| $\bar{U}_h$, % | 15 | 36 | 69 | 86 | 96 | 15 | 39 | 77 | 91 |
| $c_h$, m$^2$/year | 1.04 | 0.95 | 0.63 | 0.52 | 0.39 | 1.05 | 1.05 | 0.78 | 0.65 |
| $\lambda$, m$^2$/year (n =1.5) | 0.47 | 0.46 | 0.37 | 0.39 | 0.42 | 0.40 | 0.44 | 0.42 | 0.46 |
| $\bar{U}_h$, % ($\lambda_{av.}$ = 0.43 m$^2$/year) | 14 | 34 | 73 | 88 | 96 | 16 | 38 | 77 | 90 |

# Test area V



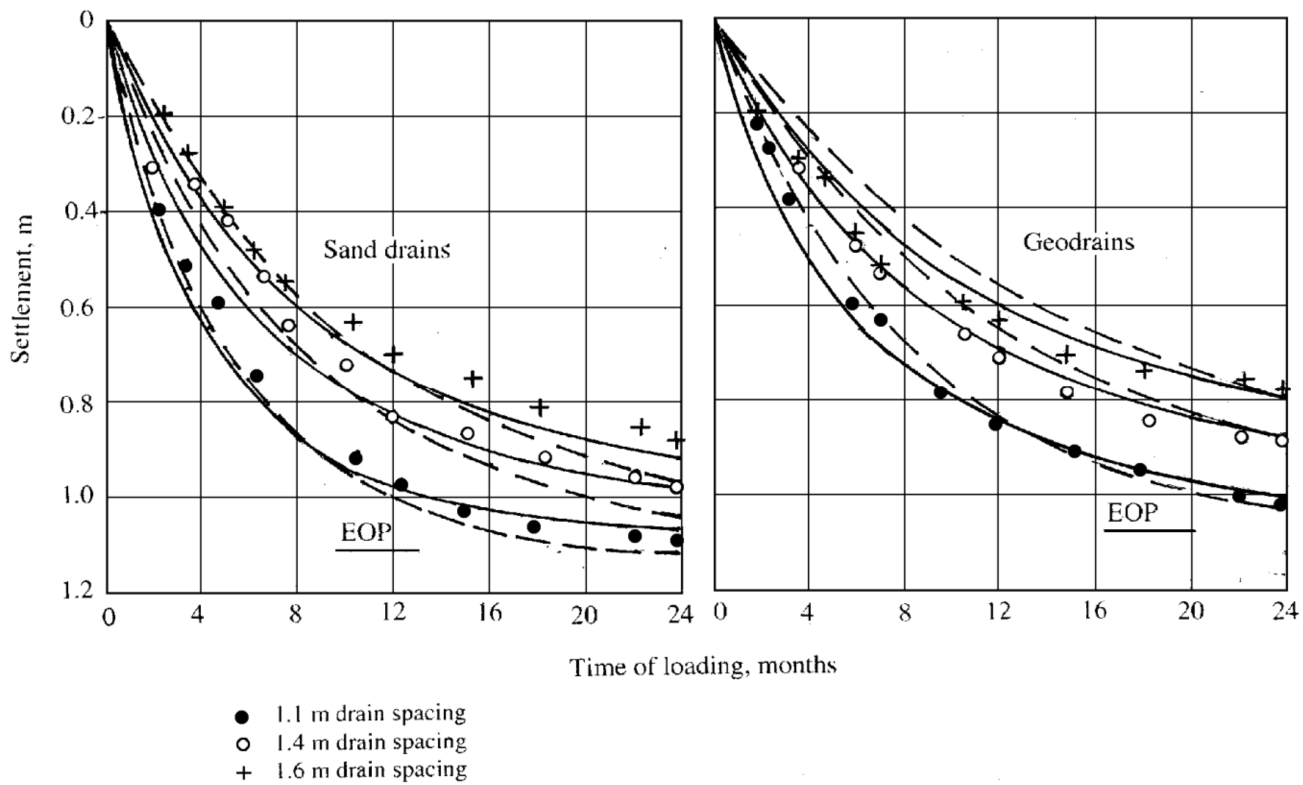

**The placement of test area V in relation to test area IV at SkŒ Edeby.**

# Test area V, follow-up




**Compression of the clay layer between 2.5 and 7.5 m of depths obtained at SkŒEdeby in Test Area V: 0.9 m drain spacing ($D$ = 0.95 m) Broken line: Darcian flowwith $c_h$ = 0.45 m$^2$/year; Unbroken line non-Darcian flow with $\lambda$ = 0.23 m$^2$/year and $n$ = 1.5.**

# The Örebro test areas



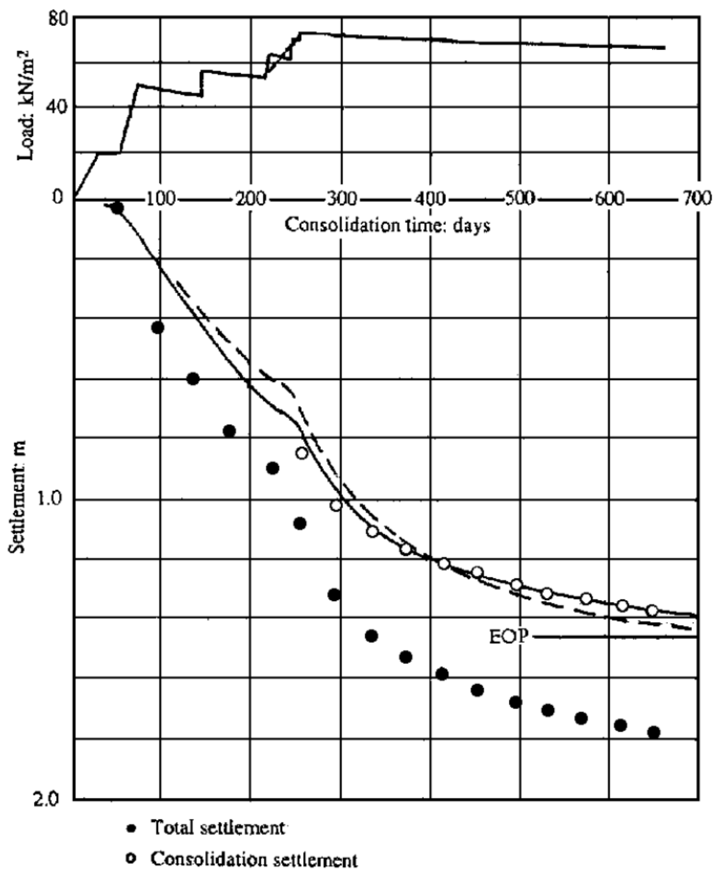

**Measured and calculated settlements in test field, ..rebro. Sand drains, 0.18 m in dameter, and band drains, type Geodrain. Load Æq = 40 kN/m². EOP means end of primary settlement. Unbroken lines represent exponential flow, equation (19) (λ = 0.58 m²/year; *n* = 1.5), broken lines Darcian flow, equation (18) ($c_h$ = 1.15 m²/year).**

# Comparison analyses

Best fit of $c_h$ and $\lambda$ values in the ..rebro test areas (load 40 kN/m$^2$).

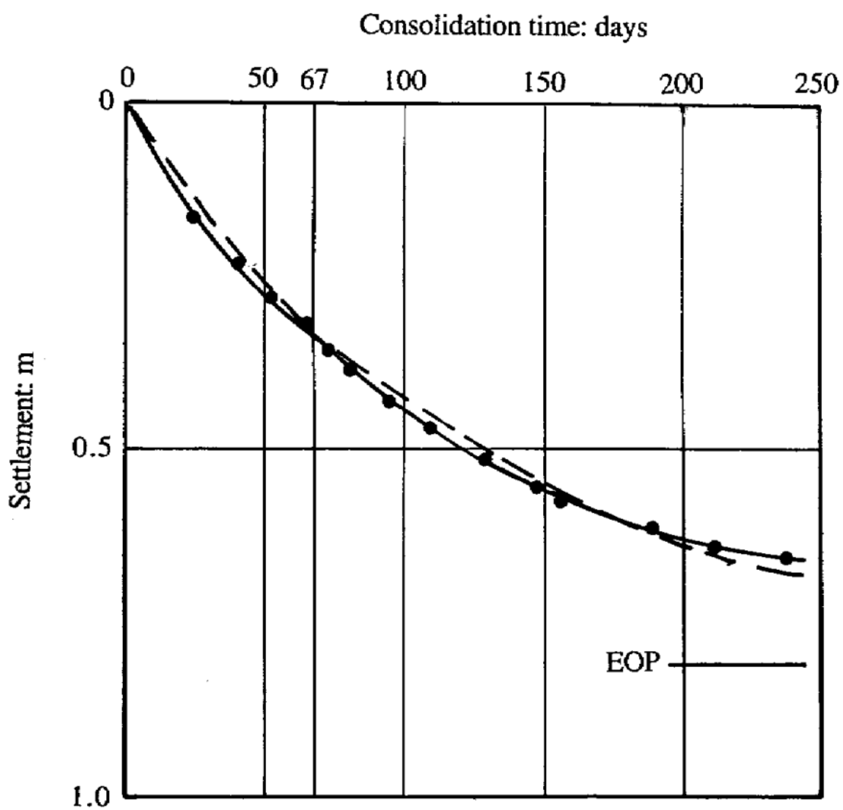
| | | | | | | |
|---|---|---|---|---|---|---|
| **Sand drains** | | | | | | |
| **$c_h$ m$^2$/year** | | | | | | |
| **Loading time** | **4 months** | **8 months** | **12 months** | **16 months** | **20 months** | **24 months** |
| **c/c 1.1 m** | **1.01** | **1.02** | **1.02** | **1.02** | **1.03** | **1.03** |
| **c/c 1.4 m** | **0,93** | **1.00** | **1.00** | **0.89** | **0.90** | **0.84** |
| **c/c 1.6 m** | **0.99** | **1.13** | **0.97** | **0.94** | **0.87** | **0.79** |
| **$\lambda$ m$^2$/year** | | | | | | |
| **c/c 1.1 m** | **0.42** | **0.50** | **0.62** | **0.75** | **0.93** | **1.15** |
| **c/c 1.4 m** | **0.38** | **0.46** | **0.53** | **0.48** | **0.53** | **0.52** |
| **c/c 1.6 m** | **0.42** | **0.52** | **0.47** | **0.48** | **0.47** | **0.48** |
| **Geodrains** | | | | | | |
| **$c_h$ m$^2$/year** | | | | | | |
| **Loading time** | **4 months** | **8 months** | **12 months** | **16 months** | **20 months** | **24 months** |
| **c/c 1.1 m** | **1.08** | **1.24** | **1.20** | **1.15** | **1.06** | **1.05** |
| **c/c 1.4 m** | **1.39** | **1.49** | **1.44** | **1.42** | **1.27** | **1.28** |
| **c/c 1.6 m** | **1.70** | **1.88** | **1.53** | **1.42** | **1.25** | **1.06** |
| **$\lambda$ m$^2$/year** | | | | | | |
| **c/c 1.1 m** | **0.36** | **0.50** | **0.57** | **0.64** | **0.60** | **0.67** |
| **c/c 1.4 m** | **0.66** | **0.74** | **0.67** | **0.65** | **0.59** | **0.52** |
| **c/c 1.6 m** | **0.57** | **0.57** | **0.62** | **0.69** | **0.61** | **0.67** |

# The Bangkok test area



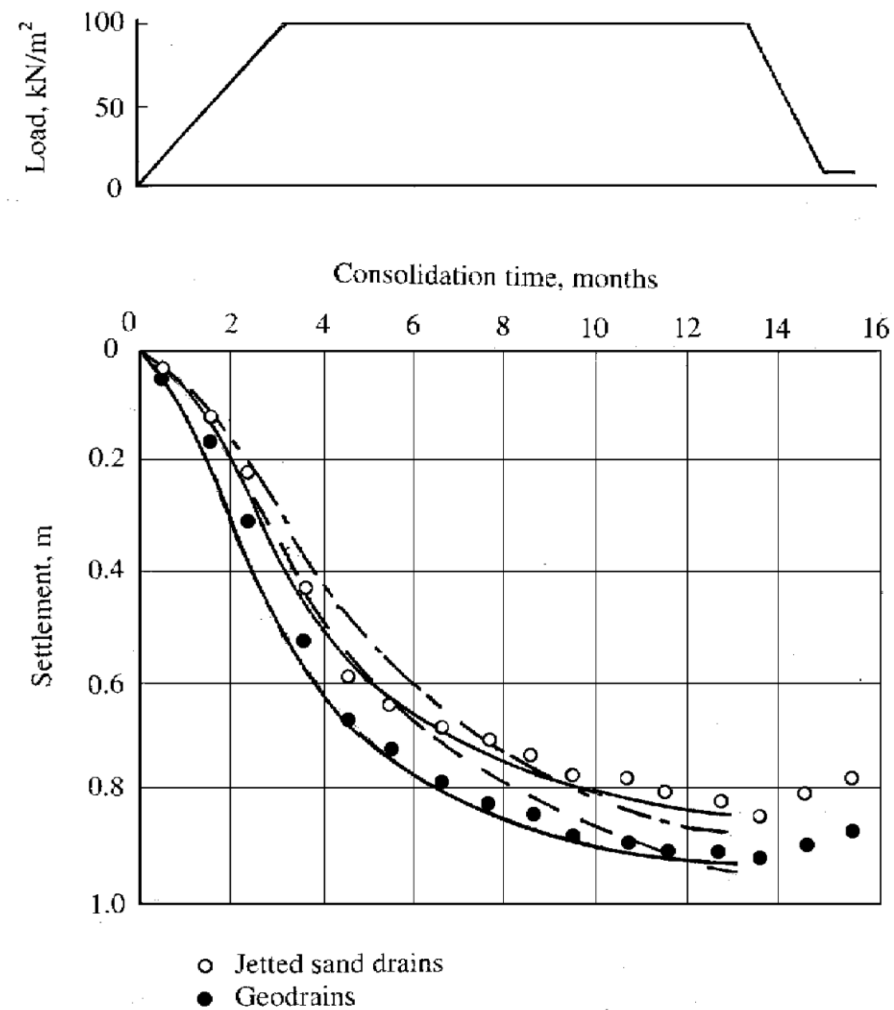

**Settlement of ground surface in the Bangkok test field, Thailand. Test area TS 3: 1.0 m drain spacing ($D$ = 1.13 m). Settlement corrected with regard to immediate and long-term horizontal displacements. EOP = end of primary consolidation settlement estimated according to Asaoka's method. Full lines: analytical results according to exponential flow with $\lambda = 0.37 m^2$/year and $n$ = 1.5. Broken lines: analytical results according to Darcian flow with $c_h = 0.93 m^2$/year.**

# The Vagnhärad vacuum test



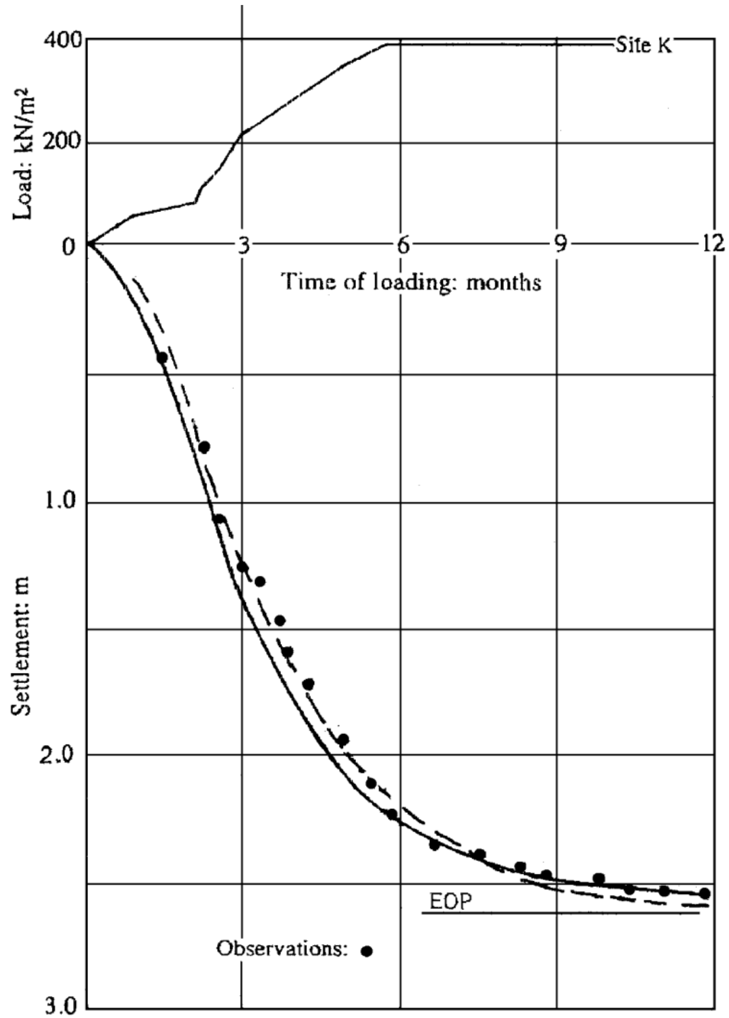

Results of settlement observations at VagnhŠrad, Sweden. Consolidation by vacuum. 1.0 m drain spacing ($D$ = 1.13 m). EOP = end of primary consolidation settlement estimated according to Asaoka's method. Full lines: analytical results according to non-Darcian flow, equation (19), with $\lambda = 0.95\ m^2/year$ and $n = 1.5$. Broken lines: analytical results according to Darcian flow, equation (18), with $c_h = 2.4\ m^2/year$

# The Porto-Tolle test site, Italy



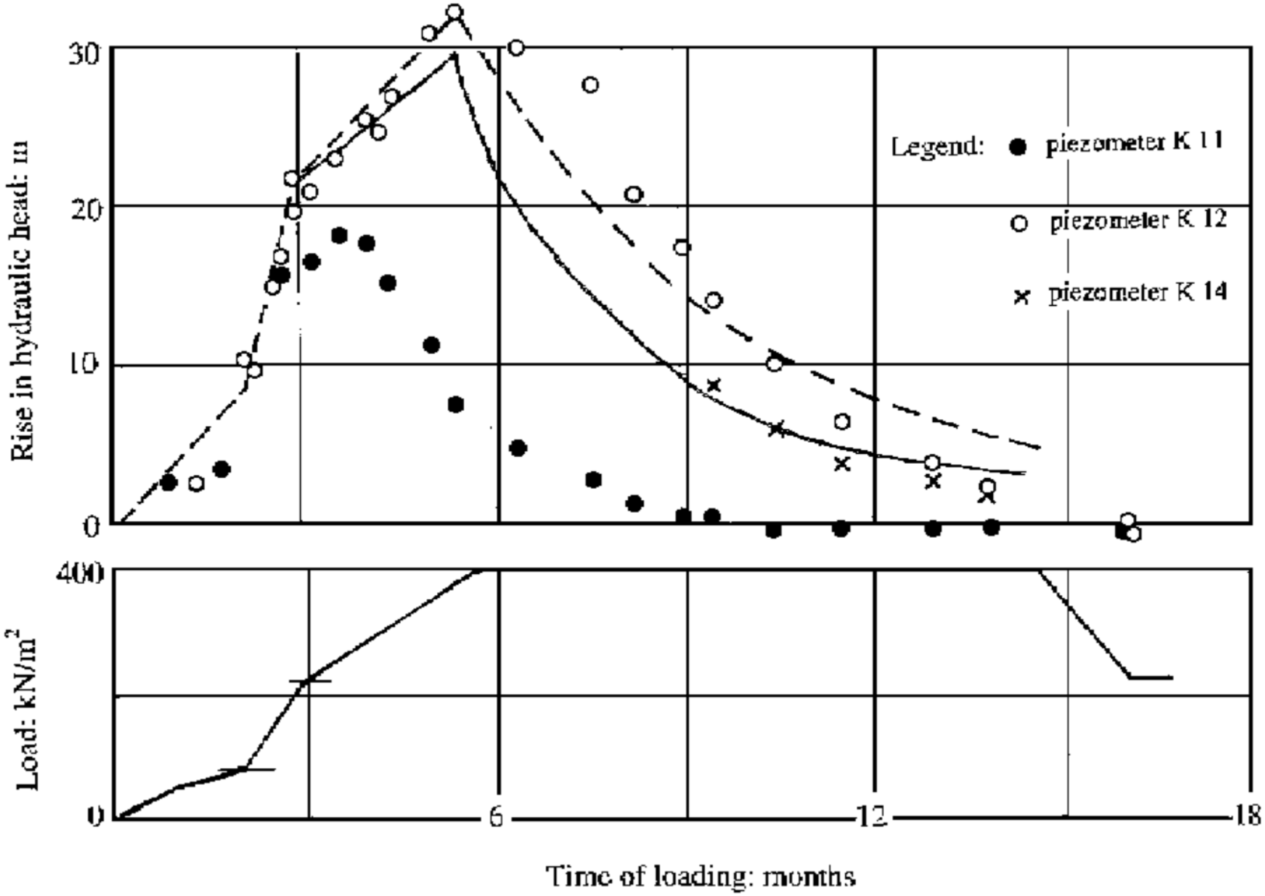

**Trial embankment at Porto Tolle, Italy. Measured and calculated settlements and loading conditions for test sections provided with band drains, type Geodrain and jetted sand drains. Broken line represents Geodrain, and the dash-dotted line jetted sand drains according to Darcian flow with $c_h$ = 24 $m^2$/year, and full lines exponential flow with $\lambda$ = 14 $m^2$/year and $n$ = 1.5.**

# The Stockholm-Arlanda project




**Comparison between calculated course of settlement and observations at Stockho lm Arlanda Airport. Broken line represents Darcian flow according to equation (18) with $c_h$ = 2.6 $m^2$/year, unbroken line non-Darcian flow according to equation (19) with $\lambda$ = 0.7 $m^2$/year and $n$ = 1.5.**

# The Stockholm-Arlanda project




**Comparison between theoretical and observed excess pore pressure dissipation at Stockholm Arlanda Airport. Piezometers placed at the following levels (level of original ground surface + 21.0): K 11 + 17.0; K 12 + 15.0; K 14 (after 10 months of loading) +14.3. Broken line represents Darcian flow with $c_h$ = 2.6 m$^2$/year, unbroken line non-Darcian flow with $\lambda$ = 0.7 m$^2$/year and $n$ = 1.5.**