THE NÄSLIDEN PROJECT - STRESSES IN THE HYDRAULIC BACKFILL FROM ANALYTICAL CALCULATIONS AND IN SITU MEASUREMENTS

by

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When calculating the stresses within hydraulic backfill it is apparent that two different loading mechanisms exist. The first is derived from the weight of the backfill alone while the other originates from the convergence between the hanging-wall and the foot-wall contacts.

The first contribution can be calculated by means of silo theory. The second is dependent upon the compressibility and void ratio in the backfill. Stress-strain relationships have been established in the laboratory by means of one dimensional oedometer tests. These tests have been carried out for different void ratios, in "Rowe-oedometer" with a stepwise loading procedure.

It is shown in the paper, that stresses calculated in this way fairly well agree with those measured in situ in the Näsliden mine.

It is also shown, that in the mine the stress component caused by the weight of the backfill represents on average about 70-80 percent of the total stress. This means that the con-

vergence between hanging-wall and foot-wall contributes about 20-30 percent of the total stress in the backfill.

INTRODUCTION

When using the cut-and-fill mining technique, the free space obtained by excavation is usually filled with granular material which is applied in a slurry-like condition. After drainage, the surface of the backfill serves as a working platform when the subsequent slice is excavated. The ore body is thus successively replaced by a sediment which completely fills up the excavated space. This suggests a stress interaction between rock and backfill as will be discussed in this paper.

Primarily, the paper presents an analytical calculation method for the stresses in the backfill for non-failure conditions, i.e. when moderate rock strain prevails. Stresses calculated by this method are compared to those measured by the Boliden Company in the Näsliden mine, Fig.1.

THEORY

The stresses in the hydraulic backfill can be separated into two parts:

1. Stresses caused by the dead weight of the backfill.
2. Stresses induced by the convergence of the hanging-wall and the foot-wall.

The actual stress, in any given direction, will be the sum of these two parts.

The stresses caused by the dead weight of the backfill can be calculated without reference to the convergence. However, the stresses which are due to convergence depend strongly on the stress level and must therefore be calculated on the basis of the stresses caused by the dead weight of the fill.

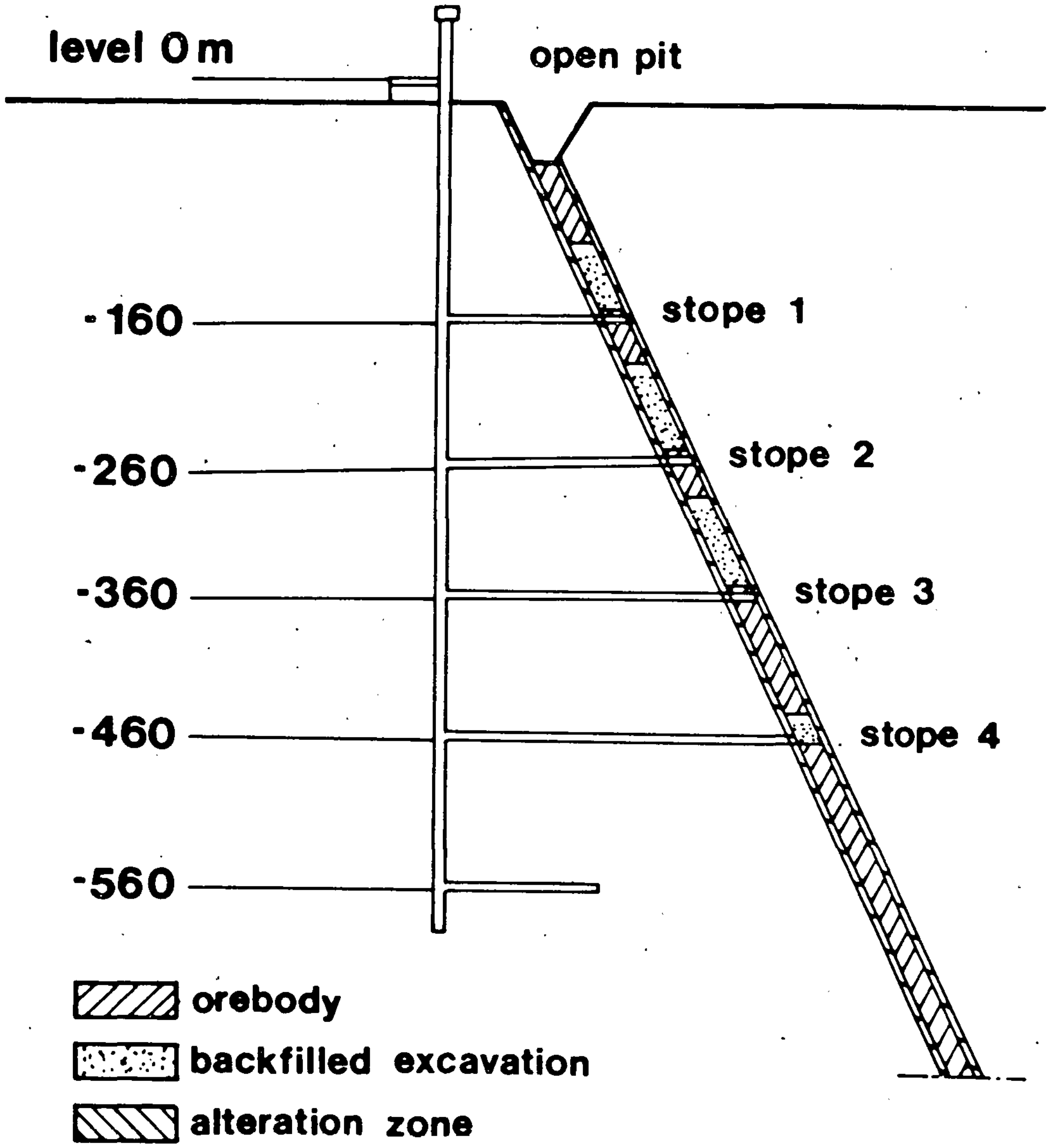


Fig. 1. Schematic drawing of the Näsliden mine.

Stresses caused by the dead weight of the backfill

The stress distribution in the hydraulic backfill depends on the friction between the fill and the confining rock walls because of the large height/width relation in the excavated room. In order to calculate the stresses perpendicular to the rock, the classical silo theory can therefore be applied. However, this theory is not valid if the silo has an inclination to the vertical. According to Jahns and Brauner[1] the deviation from the classical theory will be small, i.e. less than 10%, if the inclination to the verical is less than 30°. This is shown in Fig.2, where the ratio of the ultimate stress according to the classical theory to that of Jahns and Brauner[1] is given as a function of the inclination.

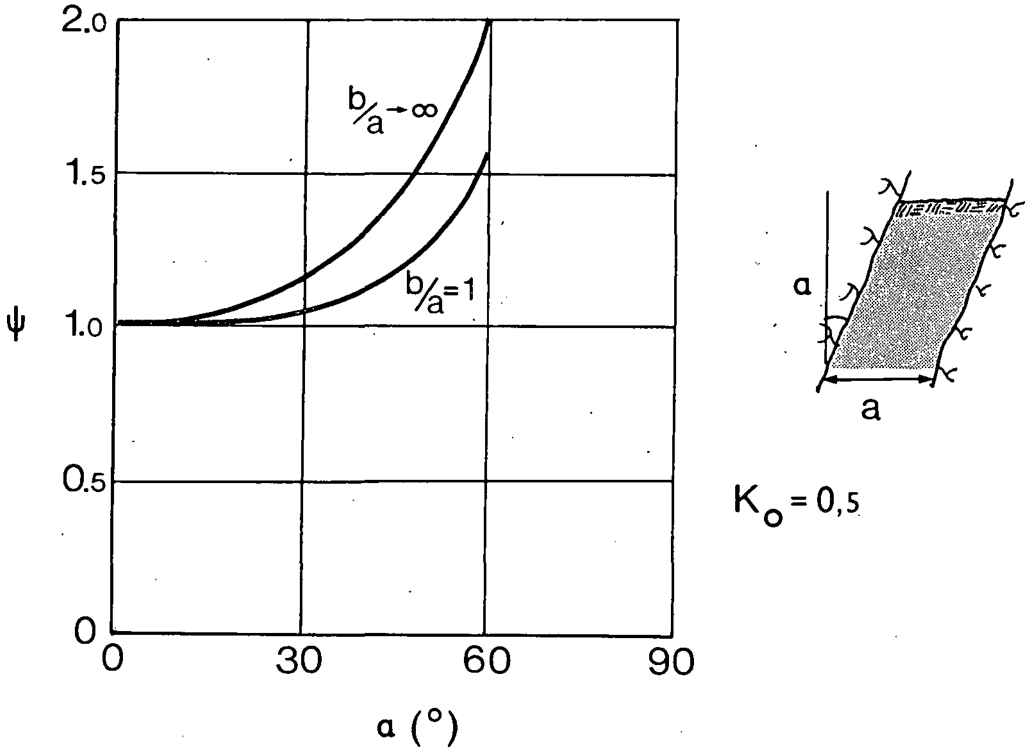


Fig.2. The ratio (ψ) of the ultimate pressure from the classical silo theory (vertical silo) to that of a silo with a varying inclination (α). Two curves are shown, one for a quadratic silo ($^b/a$ = 1) and one for a silo with infinite length ($\frac{b}{a} \rightarrow \infty$).

The classical theory states that the stress perpendicular to the rock wall can be calculated from Eq.(1) if the silo has a rectangular shape. This is true for most cases in cut-and-fill mining.

$$p_s = \frac{g\ \rho}{\tan\ \delta}\ A \cdot \left[1 - e^{-zK_o \tan\ \delta\ A}\right] \qquad (1)$$

$A = \frac{a}{4}$ (pressure against the short side of the silo)

$A = \frac{2ab-a^2}{4b}$ (pressure against the long side of the silo)

where δ = angle of friction between the rock wall and the hydraulic backfill

z = depth below the ground surface of the backfill (m)

K_o = relation between the horizontal and vertical stresses

ρ = bulk density ($^t/m^3$)

a = short side of the silo (m)

b = long side of the silo (m)

The factor K_o in Eq.(1), expresses the relation between the horizontal and vertical stress. Since the horizontal stress depends on the shear stress mobilized during consolidation, K_o becomes small when the angle of internal friction (ϕ') is high, and increases when this angle decreases. K_o of granual material is usually calculated by applying the relationship $K_o = 1 - \sin\phi'$.

At large depths below the ground surface of the backfill the stresses perpendicular to the rock walls approaches a maximum value. Here, additional surface loads will be carried practically completely by the friction between the backfill and the rock.

Stresses induced by the convergence between the hanging-wall and the foot-wall

Convergence produces increased stresses in the backfill. The stress increase depends on the compression, void ratio, and stress level. If the void ratio is low or the stress level is high the stress increase will be high.

In this paper plain strain conditions are assumed. Thus, the stress increase in the backfill can be calculated by means of classical soil mechanics.

The compressibility modulus (M) for one-dimensional compression is a function of the stress level according to Eq.(2) (cf. Andréasson[2])

$$M = \frac{\partial \sigma'}{\partial \varepsilon} = m \cdot \sigma_j' \left(\frac{\sigma'}{\sigma_j'} \right)^{1-\beta} \qquad (2)$$

where M = modulus of compressibility

m = modulus number

σ_j' = relative stress (usually = 100 kPa)

σ' = applied effective stress

β = stress exponent

ε = compression

Thus, the stress increment which produces a certain compression $\Delta\varepsilon$ can be calculated if the initial stress level (σ_o') is known:

$$\sigma' = 100 \left[\Delta\varepsilon \, m \, \beta + \left(\frac{\sigma_o'}{100}\right)^{\beta} \right]^{\frac{1}{\beta}} \qquad (3)$$

The parameters m och β are determined by compressometer tests. Since the compressibility of the backfill is strongly dependent on the void ratio, the parameters m and β are functions of this (cf. Andréasson[2]). Besides the void ratio the uniformity coefficient (C_u) and for low values of the void ratio (e<0.6) the mean particle diameter (d_{50}) have some influence on the compressibility.

HYDRAULIC BACKFILL

The hydraulic backfill used in the Näsliden mine is a mixture of silty sand from a natural deposit and silty sand from the concentrating plant. The grain size distribution of the backfill is shown in Fig.3, which is the result of 13 tests performed by Eriksson[3]. The samples were collected in various parts of the mine, but showed no significant variation in grain size. The uniformity coefficient (C_u) expressed as d_{60}/d_{10} was found to be 2.8 and the mean particle size d_{50} was 0.07 mm.

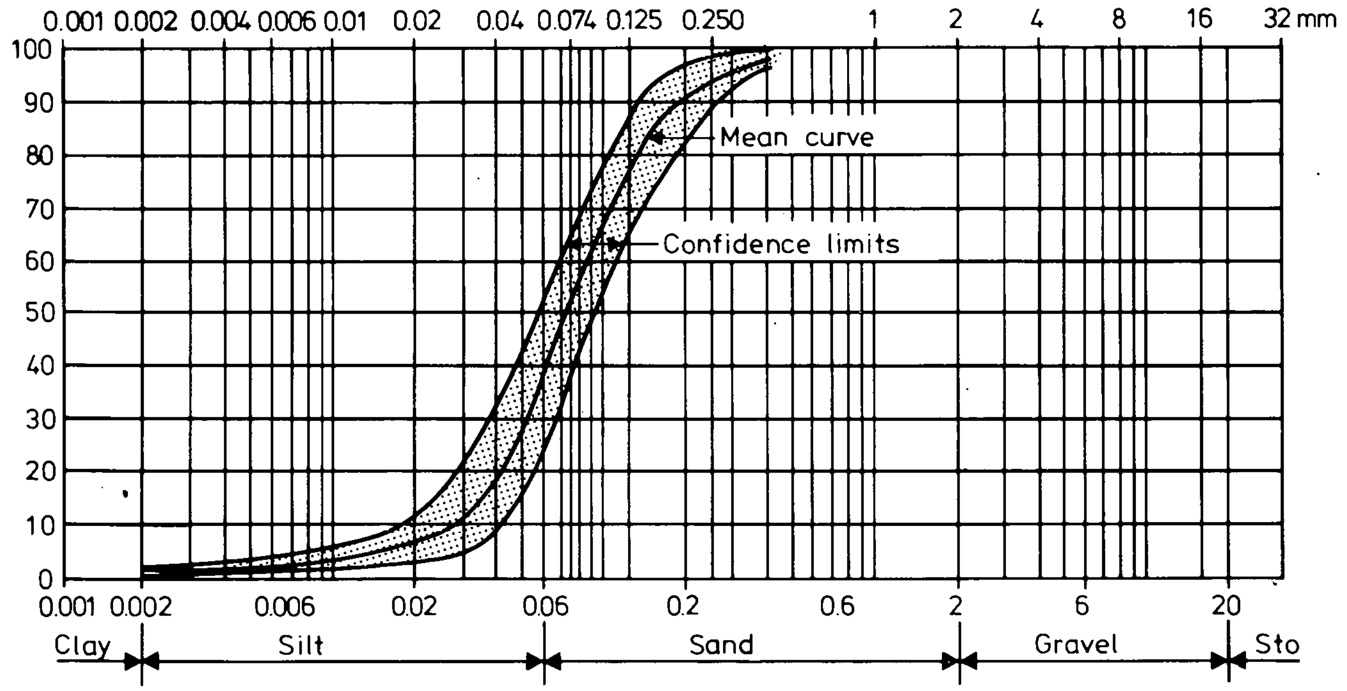
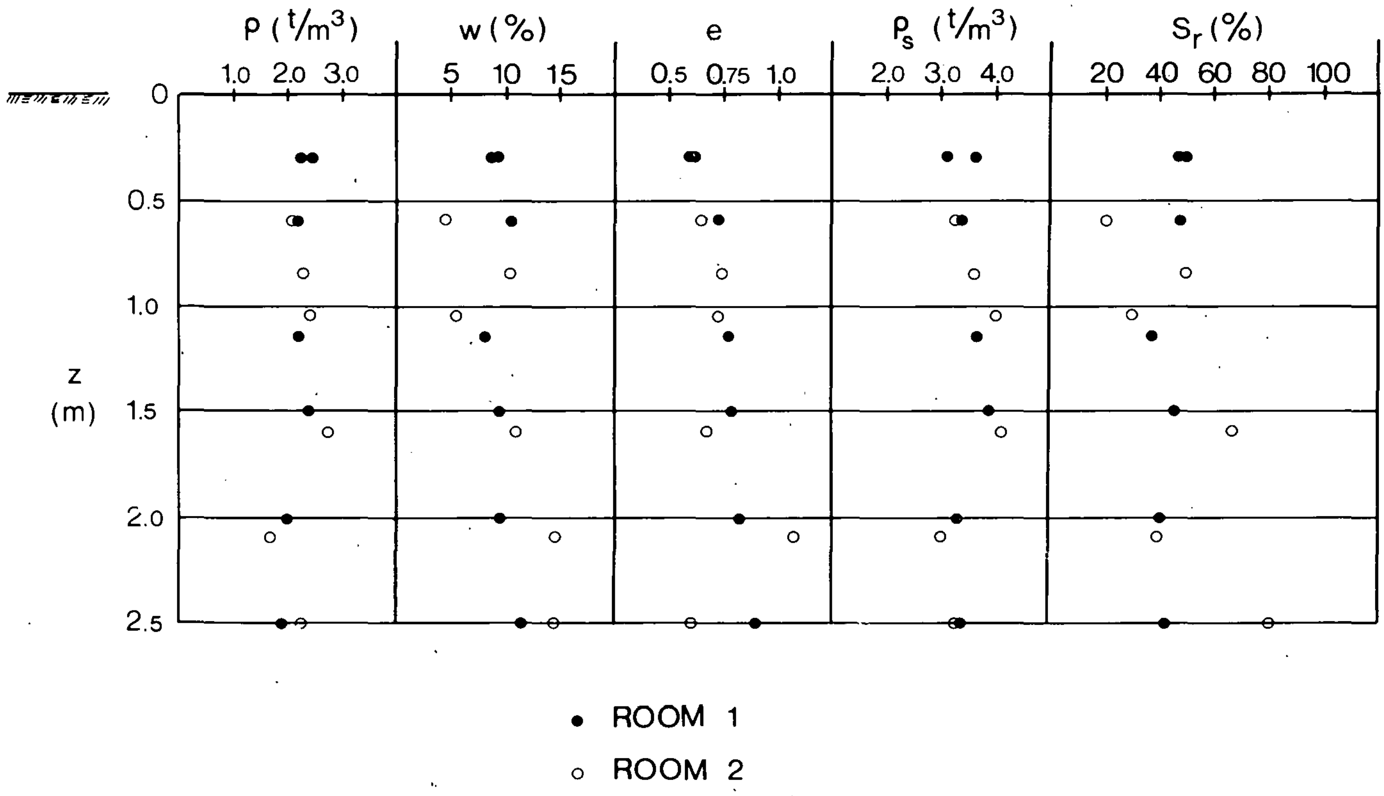


Fig. 3. The grain size distribution of the hydraulic backfill.
The dashed area represents the scattering.

Fig. 4 shows the main geotechnical data of the backfill from room 1 and 2. The bulk density and void ratio show no variation with the depth and the average values are 2.2 t/m^3 and 0.75 respectively. The backfill has a water content of about 10%, which corresponds to a degree of water saturation of 50%.



LEGEND: z = depth below the surface
ρ = bulk density
w = water content (by dry weight)
e = void ratio
ρ_s = grain density
S_r = degree of water saturation

Fig.4. The main geotechnical data of the backfill in the Näsliden mine.

EXPERIMENTAL

Test Program

The compressometer technique was applied for the determination of the compressibility of the hydraulic backfill. The compressometer was of the "Rowe-type", which is suitable for the testing of non-cohesive soils, Fig.5.

The samples (254 mm diameter and 75-85 mm height) were compacted in layers in a steel cylinder which allowed no lateral deformation. The uniaxial deformation was obtained by applying an air pressure at the top of the sample. The maximum pressure that could be applied was 500 kPa.

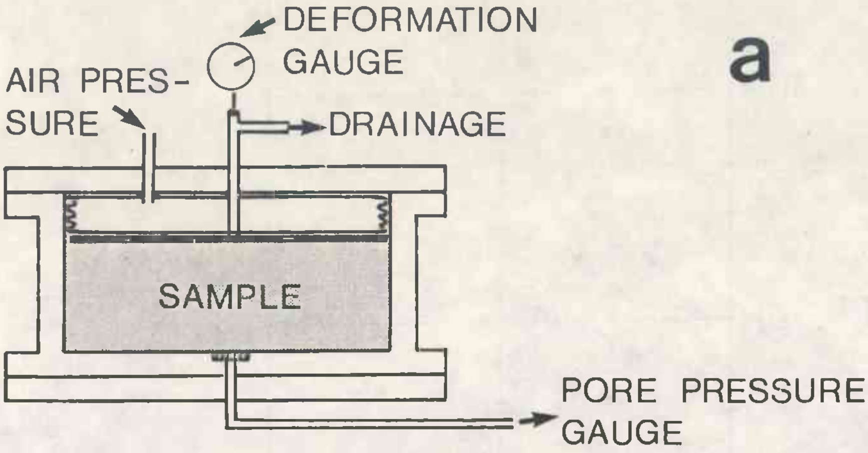
The pressure was increased stepwise to 10, 20, 40, 80, 160, 300, 400 and 500 kPa. The load was kept constant until the creep was less than 0.013% in 10 minutes, after which the load was increased to the subsequent level.

10 tests of air-dry backfill from room 3 of the mine were performed. The void ratio was different in all the tests, and this being achieved by changing the compaction work when the material was filled in the compressometer.

Test Results

The parameters m and β have been determined from the compressometer tests. The results are shown in Fig.6 och 7 where the parameters are presented as functions of the initial void ratio. Fig.6 shows that m decreases when the void ratio increases, which is in agreement with the behavior of natural soils.

Fig.7 illustrates the corresponding function for the parameter β. It is obvious that β decreases with increasing initial void ratio.



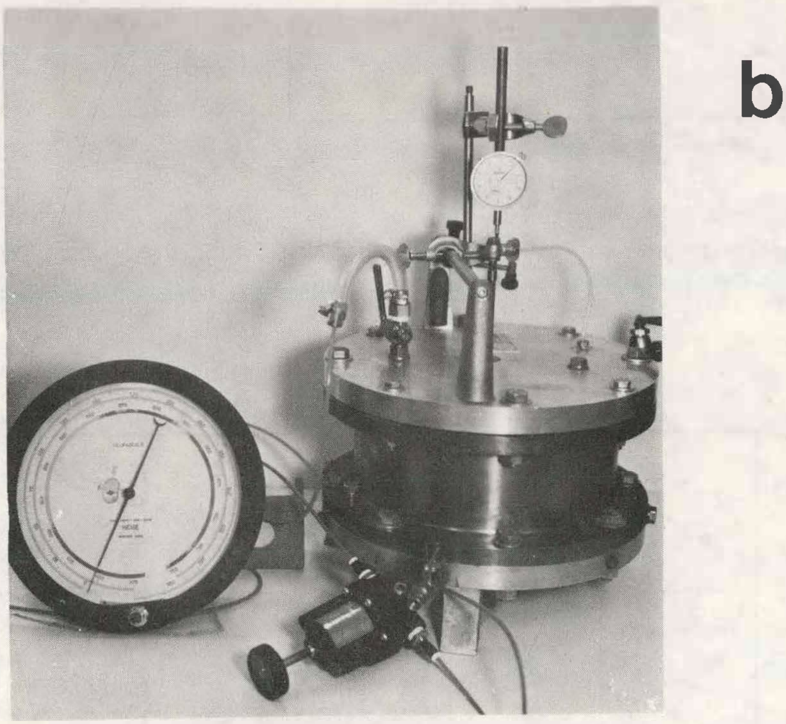


Fig. 5. a) Schematic drawing of the compressometer.

b) The compressometer in operation

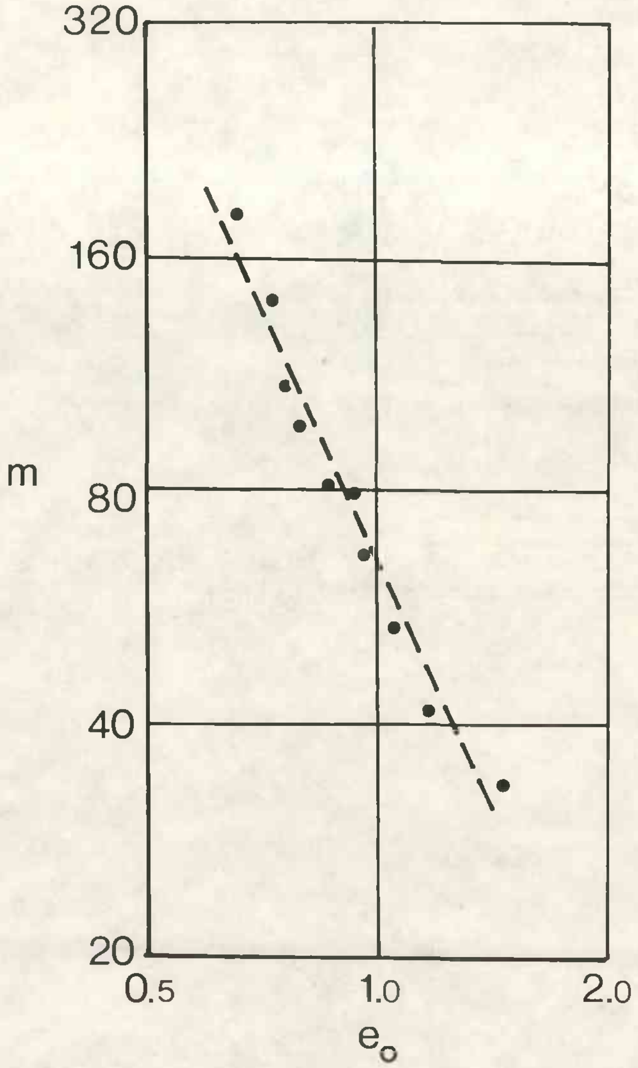


Fig. 6. The parameter m as a function of the initial void ratio, e_o.

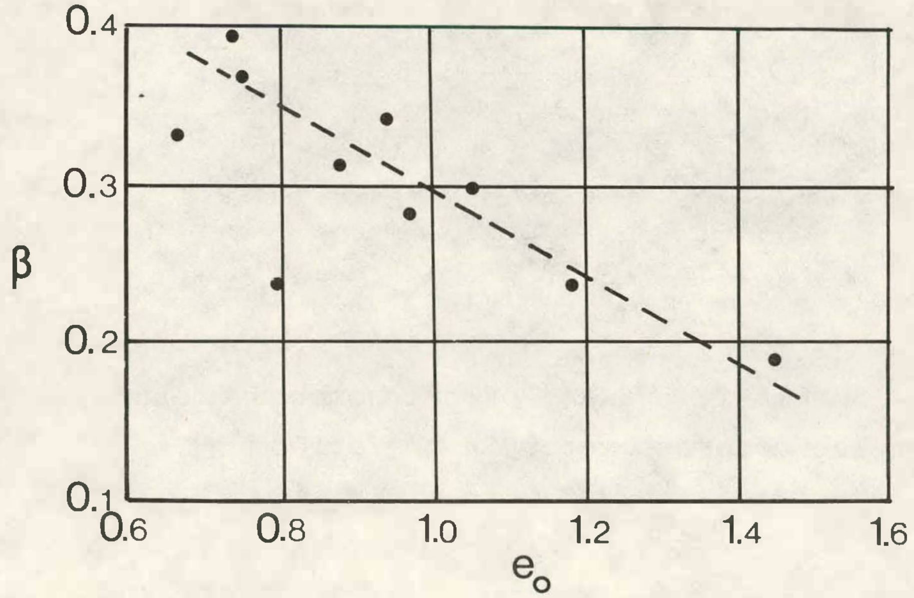


Fig.7. The parameter β as a function of the initial void ratio, e_o.

The stress increase caused by the convergence can be obtained by applying Eq.3 and the diagrams in Figs.6 and 7. It is given as a function of the void ratio in Fig.8.

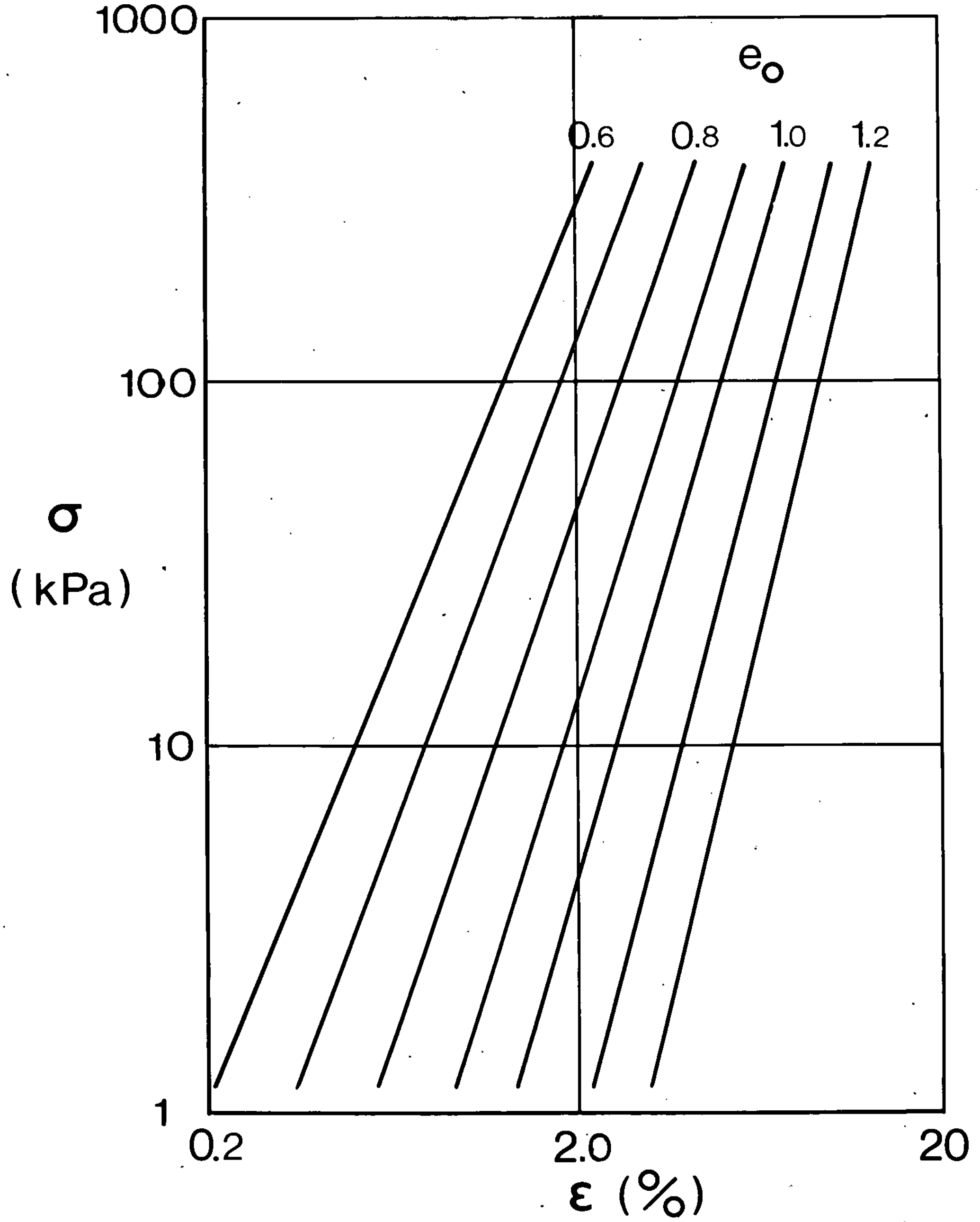


Fig.8. The stress increase (σ) caused by the convergence (ε). Each curve represents a specific value of the initial void ratio (e_o).

COMPARISON OF CALCULATED STRESSES WITH IN-SITU MEASUREMENTS

The Boliden Company has performed in-situ stress and convergence measurements in the Näsliden mine for several years. In all sections the stress component perpendicular to the hanging-wall has been determined. Some measurements of the vertical stress component have been made as well.

The calculation of the stress component caused by the dead weight of the backfill was made by using Eq.(1), since the inclination of the ore body was moderate (23^{o} to the vertical). The maximum error due to this assumption is less than 6%. The angle of internal friction, as well as the angle of friction between the rock wall and the backfill was taken as 36^{o}, which is the mean value of the angle of internal friction at failure, 39^{o} and that at the critical density, 33^{o}, as described by Börgesson[4].

As shown in Fig.4 the bulk density and the void ratio in-situ are $2{,}2\,^{t}/m^{3}$ and 0,75 respectively.

The values of the length (b) and width (a) of each room are given in Table 1.

Tabel 1. Room geometry

Room number	Length (m) b	Width (m) a
1	200	17
2	160	14
3	150	15

The additional stress due to the convergence was calculated by means of the in-situ convergence measurements made by the Boliden Company cf. Krauland and Nilsson[5].

Point 1FA5 (Room no.1)

The calculated stresses are in close agreement with those measured in the mine. The convergence is 0.8 mm which corresponds to a compression of $7 \cdot 10^{-5}$. This is a very small value meaning that the stresses due to convergence is small.

Point 1FB3 (Room no.1)

The calculated stresses are higher than those measured in-situ. This is mainly due to the complex geometry of the excavation, which yields a larger friction between the backfill and the rock than expected from the application of the silo theory. The stress caused by the convergence is very small, because of the very small compression of the backfill.

Point 1FC5 (Room no.1)

A very good agreement between calculated and measured stresses is obtained.

Point 1FG4 (Room no.1)

The stresses measured in-situ are higher than those calculated. This is explained by the fact that the section is very close to the ascent. The density of the backfill may have been largely increased here by heavy traffic by which the modulus of compressibility is also increased.

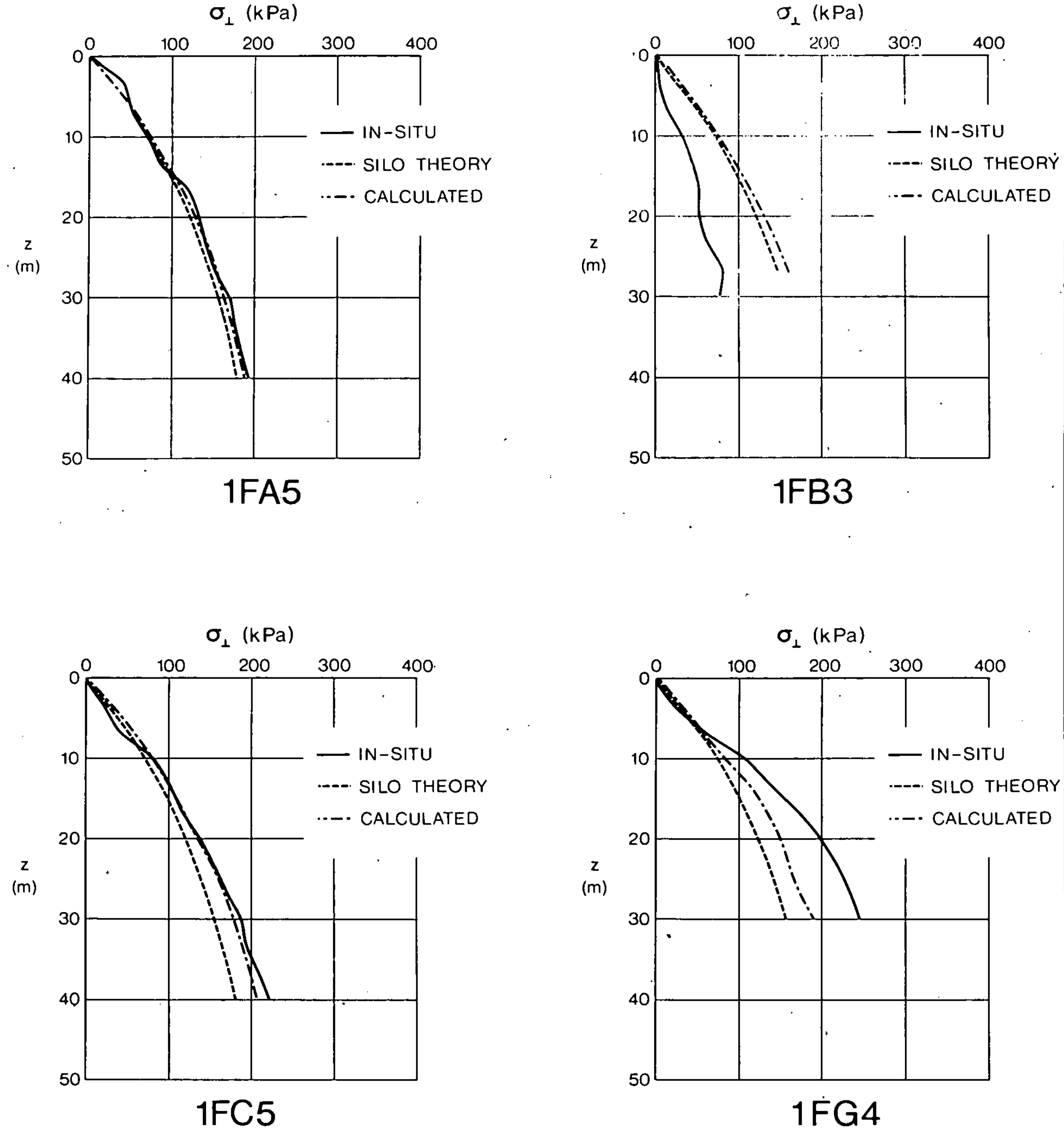


Fig.9. Measured and calculated stresses in the hydraulic backfill.
$\sigma_{\perp}$ stands for stresses perpendicular to the side walls.

Point 2FA7 (Room no.2)

A good agreement is obtained between measured and calculated stresses to about 20 m below the surface of the backfill. Below this depth the measured stresses are lower than the calculated, which may be explained by a higher friction between the rock and the backfill than assumed in the calculations. This assumption is supported by the decreasing in-situ stresses at 30 to 50 m below the ground surface.

Point 2FA7 Vertical stress component (Room no.2)

At this point the vertical stress as well as the stress acting perpendicularly to the rock wall were measured. Good agreement is obtained by using the expression

$\sigma_v = \sigma_{\perp}/K_o$.

Point 2FB4 (Room no.2)

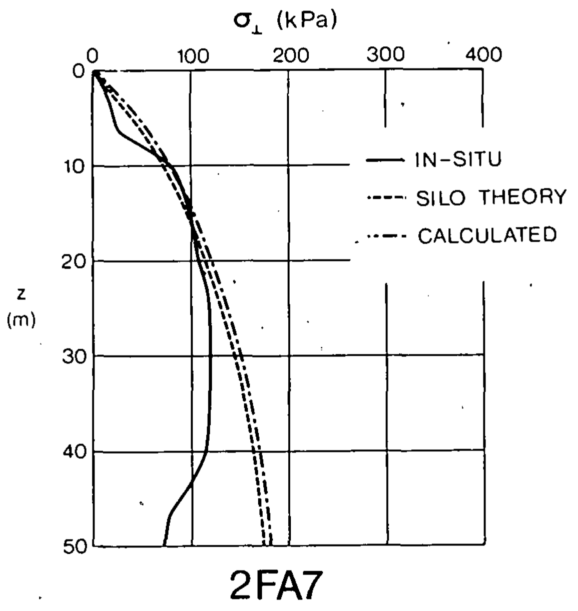
The measured stresses are higher than those calculated throughout the whole profile. This is explained by the narrow room (9 m), which may have caused a pre-stressing effect in the fill when the first slice was excavated after the installation of the pressure gauge. This assumption is supported by the observed high stress level at shallow depth.

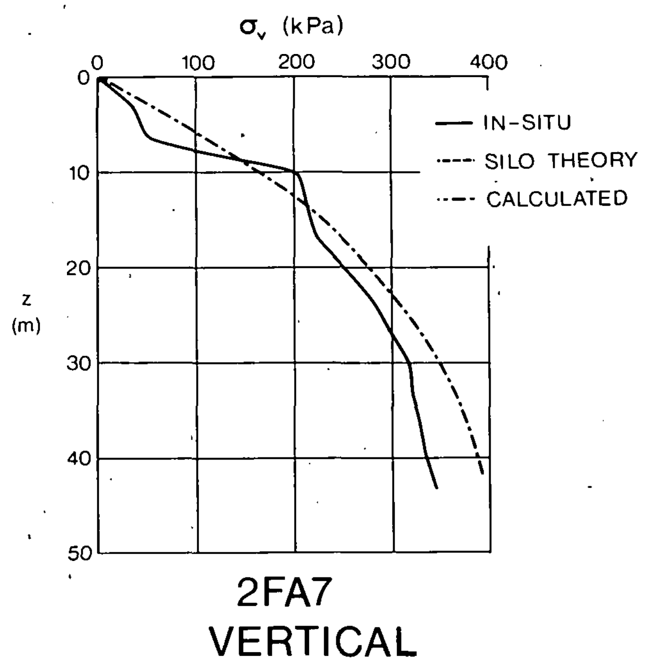
Point 2FD7 (Room no.2)

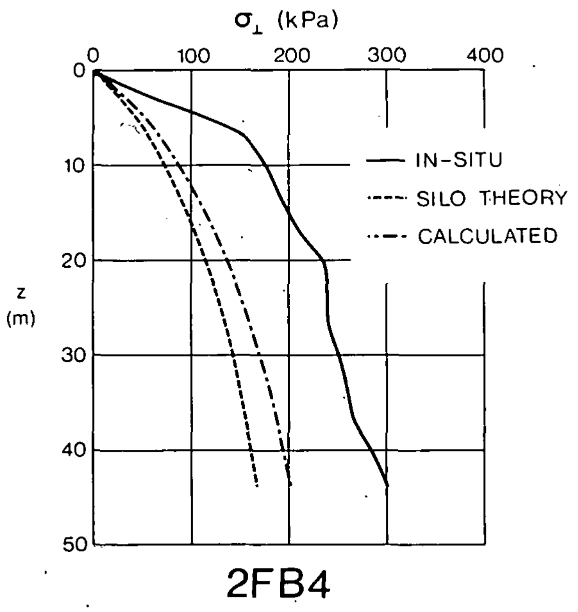
Good agreement is obtained between measured and calculated stresses.

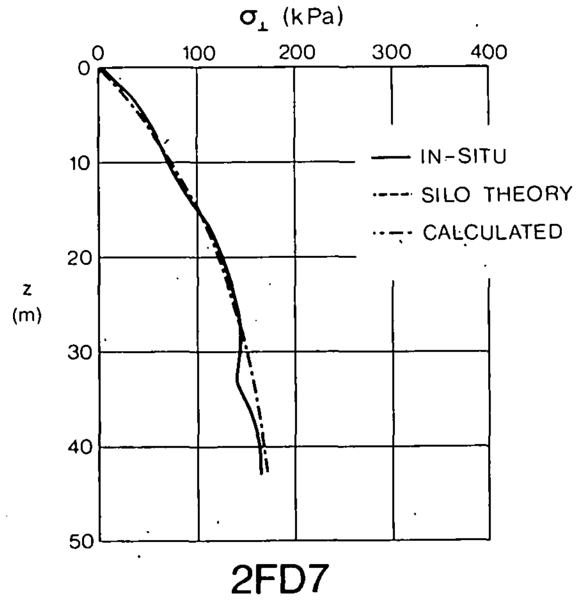
Point 2FE4 (Room no.2)

A fairly good agreement is obtained between measured and calculated stresses. Below 12 m depth the calculated stresses are higher than the measured. Since no information









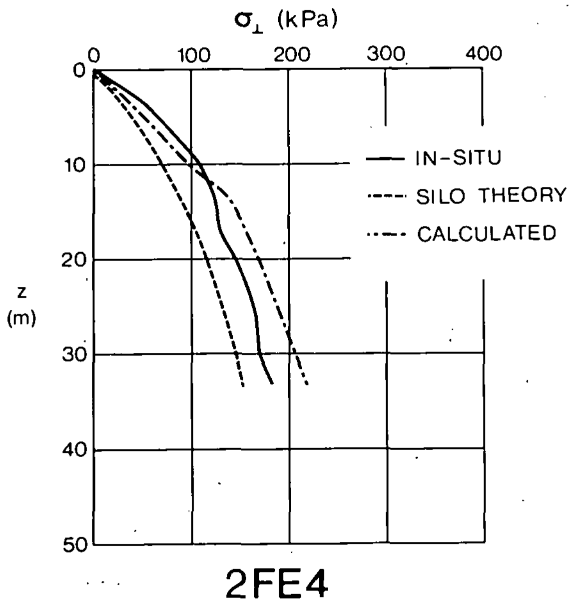


Fig.9. Measured and calculated stresses in the hydraulic backfill.

of the geometry of this room is available, the deviation cannot be explained.

Point 3FC4 (Room no.3)

Good agreement is obtained between measured and calculated stresses. The large additional stress due to convergence should be noticed.

Point 3FD3 (Room no.3)

Same comments as for point 3FC4 but the agreement is not so good; the calculated stresses being lower.

Point 3FF4 (Room no.3)

Same comments as for point 3FD3. The calculated stresses are somewhat higher than the measured.

Point 3FH4 (Room no.3)

Same comments as for 3FD3.

Point 3FK4 (Room no.3)

Good agreement is obtained above 12 m depth. Below this depth the measured values are lower than the calculated.

Point 3FM4 (Room no.3)

Above 10-12 m depth there is a fairly good agreement between measured and calculated stresses. Below this depth the calculated stresses are higher than the measured.

Point 3F04 (Room no.3)

Good agreement is obtained between measured and calculated stresses.

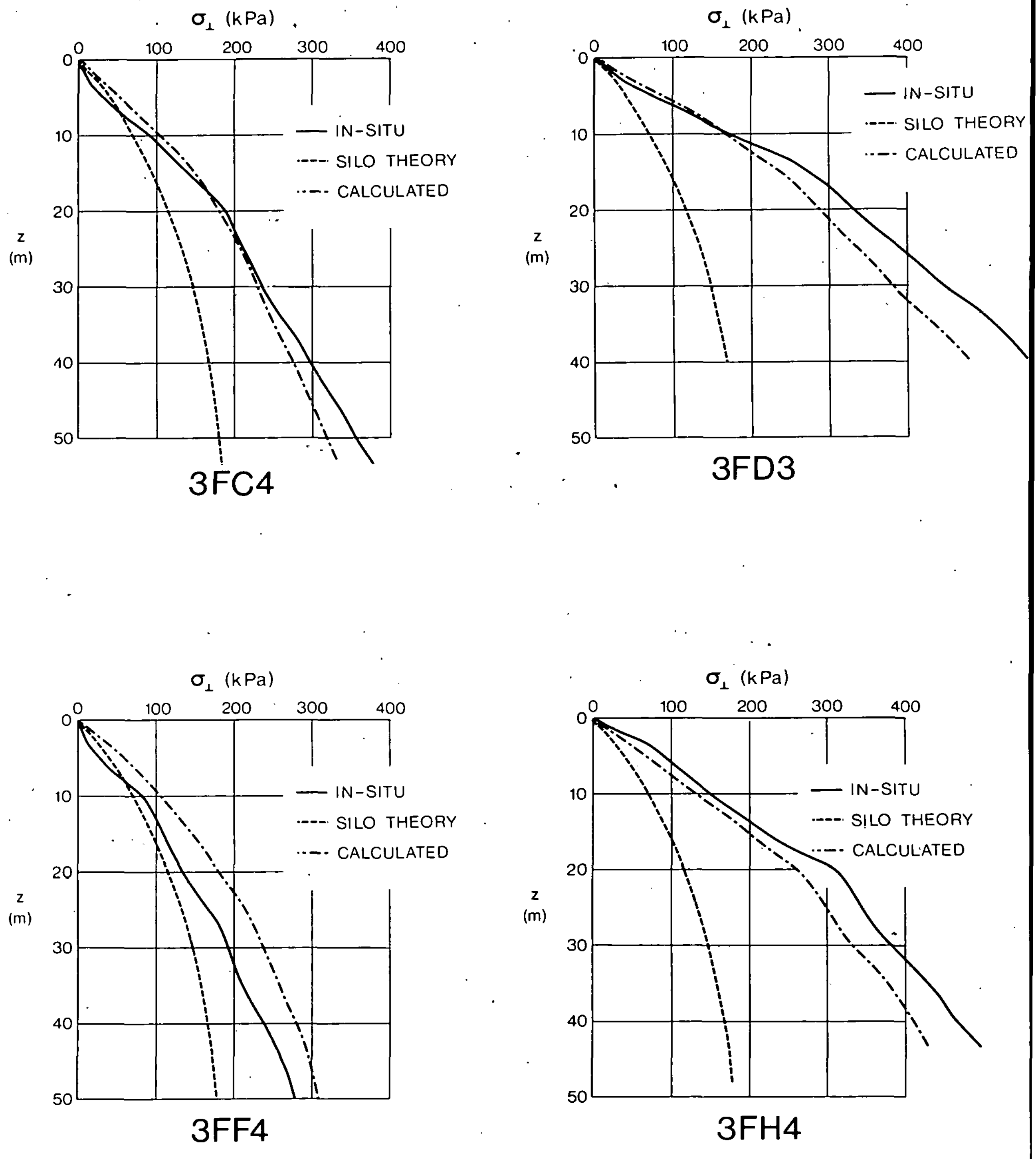


Fig.9. Measured and calculated stresses in the hydraulic backfill.

$\sigma_{\perp}$ stands for stresses perpendicular to the side walls.

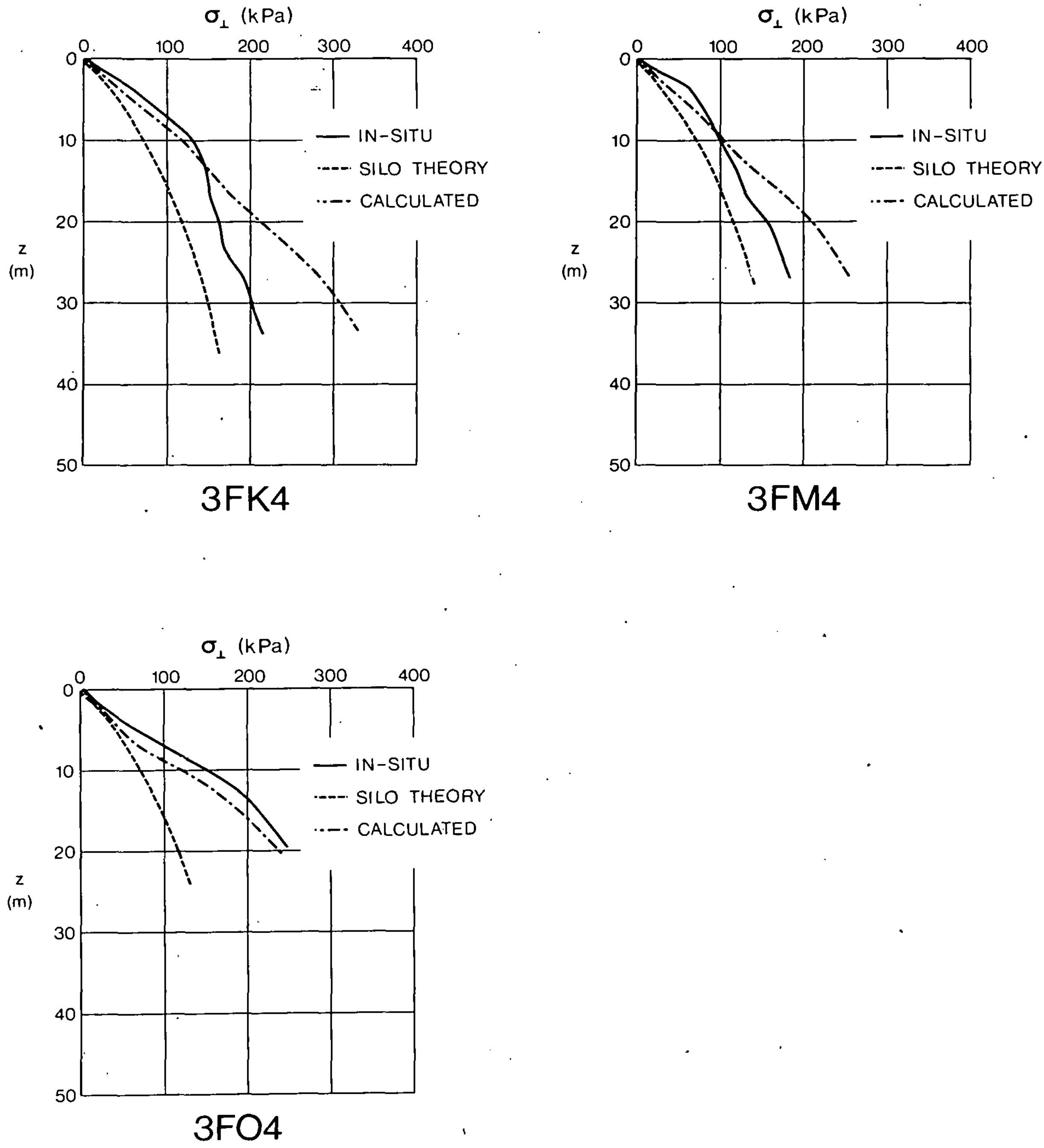


Fig.9. Measured and calculated stresses in the hydraulic backfill.
$\sigma_{\perp}$ stands for stresses perpendicular to the side walls.

It is concluded that, as an average, the stress due to convergence is responsible for 20-30% of the total stress in the backfill acting perpendicularly to the side-walls. Consequently, 70-80% of the total stress is caused by the dead weight of the backfill. It should be noticed, however, that the variations are considerable and that, locally, the convergence may cause the major part of the total stress.

CONCLUSIONS

The comparison of the calculated stresses with those measured in the Näsliden mine shows that the stresses in the hydraulic backfill can be calculated by the method proposed. The observed variation of the stress level in different points in the backfill is due to a varying void ratio and compression of the backfill, as well as to different shapes of the excavated rooms.

The stress component caused by the dead weight of the backfill is responsible for 70-80% of the total stress as an average. Consequently, the stress component caused by the convergence is responsible for 20-30% of the total stress. This rather small contribution indicates that the influence of the backfill on the stress situation in the confining rock is practically negligible.

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