Bearing capacity and settlement of individual foundations near slurry supported trench excavations

La capacité portante et le tassement de fondations isolées proches d'excavations à la boue

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SYNOPSIS: In order to study the behaviour of foundations adjacent to slurry supported trenches model tests were carried out. In a first test series the failure mechanism of individual foundations was identified and a calculation model was established. In the second test series the settlement of the foundation was observed.

1 PROBLEM

Diaphragm walls and water tight walls are often excavated close to existing individual footings or strip foundations. Because of this, the external stability of the trench has to be calculated by considering the development of failure planes in the ground due to the excavation of the trench.
In case of a strip foundation a soil arching effect helps to transfer the earth pressure due to the foundation loads to soil regions outside the trench. Furthermore, bending of the strip foundation and arching of ascending walls will aid to balance foundation loads.
Individual foundations on the other hand impose almost all of their load onto the trench unless the inherent stiffness of the building will consume at least some of it. Therefore the performance of individual footings close to slurry trenches is controlled by two aspects:

1. The ultimate bearing capacity of the foundation and
2. the allowable settlements of the foundation.

The paper presented is based on model tests (scale 1:10) in cohesionless, dense sand. The trench was supported by bentonite slurry with a bentonite content of 3.8 % and a shear strength $\tau_f = 10.0\ N/m^2$. Therefore the results of the tests are restricted to cohesionless soils.
Essential for the ultimate bearing capacity of foundations is the distance to the trench. If the distance between the foundation and the trench is large the regular bearing capacity formula is relevant. With decreasing distance the failure path caused by the foundation will tend to touch the trench, which creates an active earth pressure problem with spatial boundary conditions.

2 EXPERIMENTAL DEVICE FOR MODEL TESTING

2.1 Premoulded trenches

Pulsfort (1986) created a model trench of 30 cm length by means of an iron formwork behind which the sand was built in in layers (Fig. 1).After the trench was filled with slurry the formwork was removed, leaving a slurry trench of 1 meter depth. The settlements of the soil due to this procedure were neglegible (0,03 mm). After setting up the trench a rigid foundation block resting at a distance of x_F from the trench was loaded with a constant velocity of settlement until the bearing capacity was exceeded. The foundation was fixed by means of bearing rollers in order to maintain a vertical loading but allow horizontal and vertical movements of the foundation.

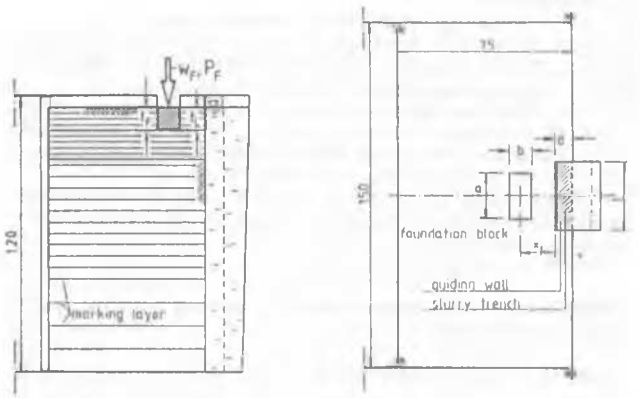


Fig. 1

2.2 Continously cutted trenches

The investigation of milled slurry trenches aimes towards the assessment of the settlement of the loaded foundation during the excavation of the trench. The constant loading of the foundation during the excavation of the trench was insured by means of a block-and-tackle and lever device. A possible distortion of the foundation was surpressed.
In order to excavate the trench a slurry trench milling cutter was developed (Fig.2). The mechanism of the cutter is based on the principle of a crawler bucket ladder. An endless chain with 10 cm long and 6 cm wide buckets attached to it is driven over a vertical frame. The bucket chain speed can be controlled in a range from 0 to 4 m/min. The frame with the bucket chain

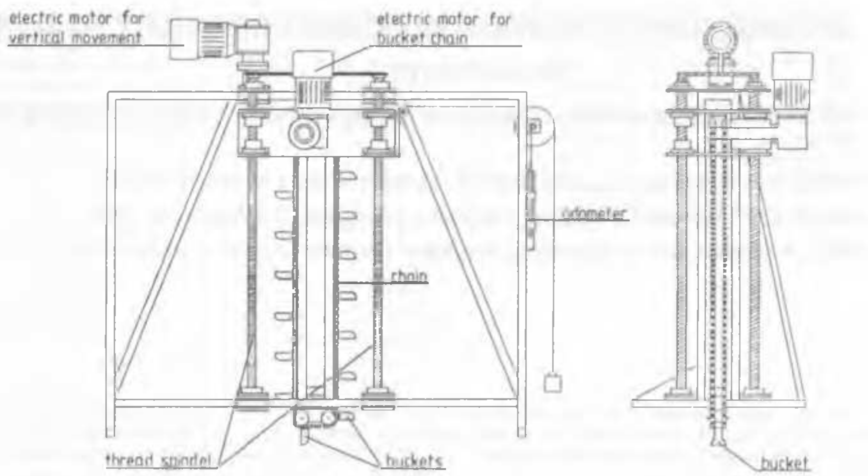


Fig. 2

is mounted on a horizontal platform which can be moved vertically with four thread spindles. The maximum vertical distance the cutter can travel is restricted to 100 cm. The descending speed can be regulated within a range of 0 to 30 cm/min. The buckets are emptied into a funnel by means of several rinsing jets. In order to avoid a dilution or changing consistence of the slurry suspension during the excavation of the trench the suspension itself is used as rinsing fluid. The rinsed sand is lead through a pipe into a deposit container.

3 RESULTS OF THE MODEL TESTS FOR THE ULTIMATE BEARING CAPACITY

3.1 Model tests with premoulded slurry trenchs

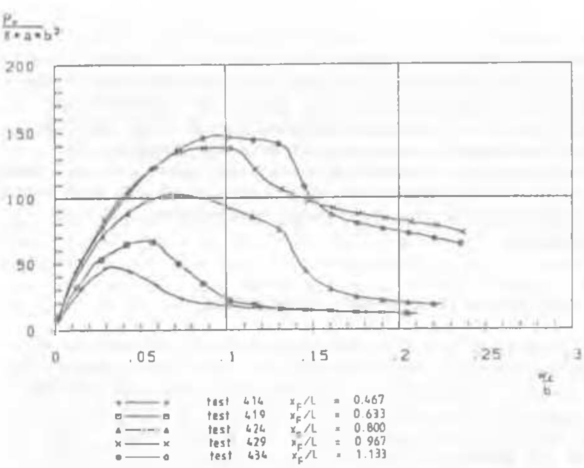


Fig. 3

Fig. 3 presents the dimensionless load deformation paths of a particulare test series. During this series the foundation block (a/b=20/10 cm), which was not embedded, was placed at five different distances x_F from the slurry trench. Figure 4 gives the bearing capacity of the foundation as a function of the ratio x_F/b, which refers to the distance from the trench, and the ratio t_F/b, i.e. the embedded depth.

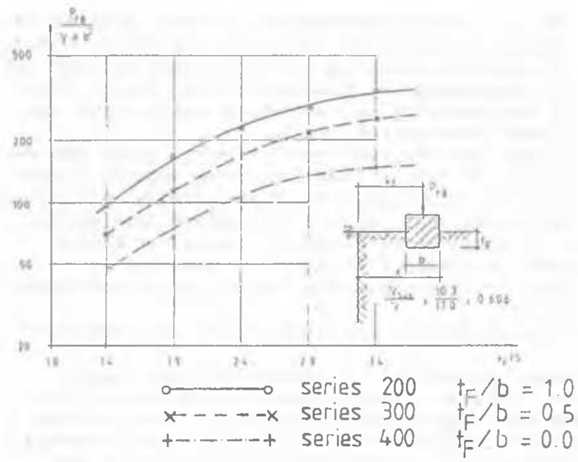


Fig. 4

It can be seen that there is no further increasing of the ultimate bearing capacity above a ratio x_F/b = 3,0 to 3,5, which means, that a regular bearing capacity problem is encountered. After the settlements of the foundation were increased, the sand was hardened by temporary floodding with water. Thereafter, the sand was cut perpendicular to the trench axis. Using photogrammetric measurment methods, the deformed marking layers, which were spread horizontally beforehand, and the three dimensional shape of the failure mechanism could be derived. In figure 5 the failure mechanisms are shown for various distances of the foundation from the trench. This graph also shows a tendency towards a regular foundation failure with increasing distance from the trench.

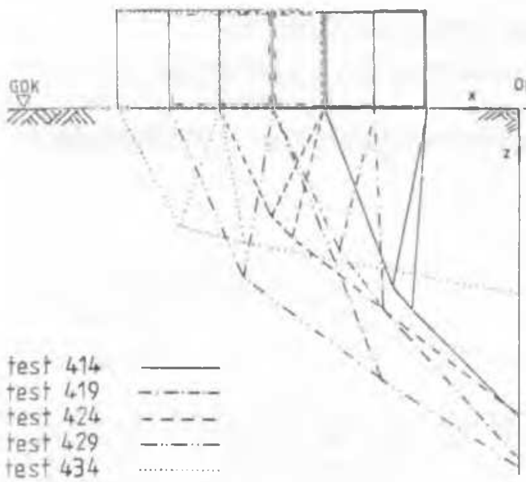
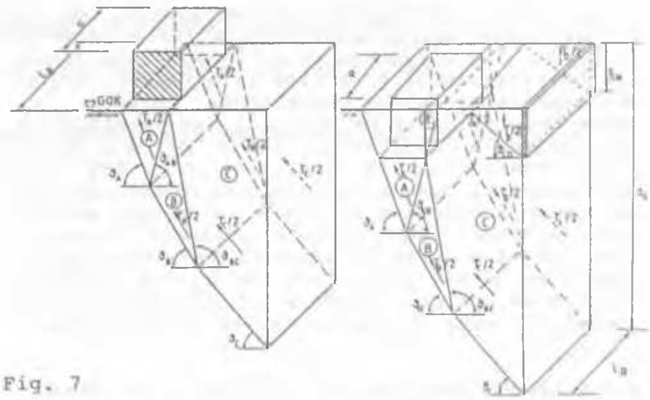


Fig. 5



shear stresses, which act within the face of three solids. This results in a pseudo-spatial calculation model. The lateral pressure distribution was applied in accordance with Terzaghi (1936):

$$\tau_\vartheta = \sigma_y(x,\ z)\ \cdot\ \tan\varphi$$
$$= k_y\ \cdot\ \sigma_z(x,\ z)\ \cdot\ \tan\varphi$$

with $\sigma_z(x,\ z) = RK_i\ .\ .(1-e^{-z/RK_i}) + P_0(z=o).e^{-z/RK_i}$
and
$$RK_i = \frac{L_R}{2\cdot k_y\cdot\tan\varphi\cdot\sin\vartheta}$$

Furthermore, an opening angle α was introduced, which extends from the face of the foundation to the face of the failure mechanism (of length L_R) considered. This angle, the foundation pressure P_0 will have no impact on $\sigma_z(x,\ z)$.
The integration of the stresses τ_ϑ for each face of the solid allows the formulation of the equilibrium equations for each part of the failing mechanism, yielding an equation for the bearing capacity of the foundation.

3.2 Model tests with milled slurry trenches

Because of the so called "swept out of memory effect" (Gudehus 1980), which states that there is no influence of the stress path on the ultimate bearing capacity, the sequence of setting up the model tests must not have any effect. Because of this it was possible to perform a slurry trench first and subsequently load the foundation. In the second test series the foundation was preloaded with a live load P_p, in a second step the trench was cut while the foundation load remained constant, and in a last step the foundation load was increased until the bearing capacity P_f was exceeded. Figure 6 shows a comparison of the ultimate bearing capacities achieved with the two methods.

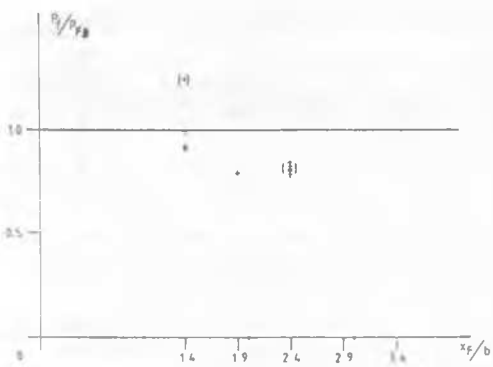


Fig. 6

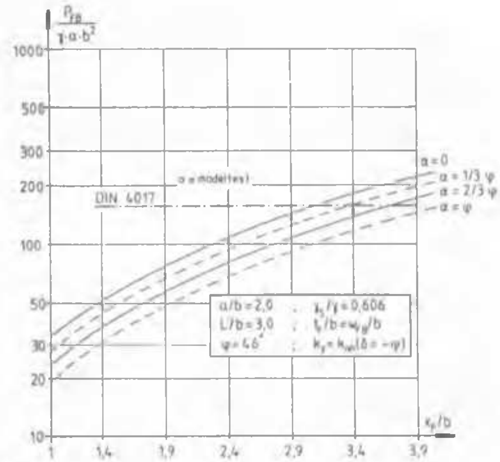


Fig. 8

3.3 Calculation model of a combined failure mechanism

Based on the results of the geometrical leveling of the model tests mentioned in chapter 3.1, a calculation method was developed, which considers an assemblage of three rigid solids (Fig.7) The three dimensional effect,given by the limited length of the trench is idealized with

This equation was solved iteratively by variation of all geometrical parameters, i.e. inclination ϑ of the sliding planes and the theoretical length L_R of the failing assemblage. Figure 8 compares theoretical and experimental results. The best approximation of the experimantal results can be accomplished by introducing the ratio of active earth pressure $k_v = k_{ah}(\delta = -\varphi)$ and $\alpha = \frac{2}{3}\varphi$. At x_F/b = 3,0 - 3,5 the transition to the regular bearing capacity problem is attained, which was expected from the experimental results. Using this calculation model it was possible to recalculate a large scale test of Mailand by Fasiani (1965) with a precision of 10 to 20%. For practical purpose a less complicated failure mechanism consisting of, only one single solid (Walz/Pulsfort 1983) will be adequate. In assumption of a forced sliding surface through the back edge of the foundation and $k_v = k_0$, bearing capacities are calculated which are secure in comparison with the mechanism of three solids.

4 SETTLEMENT BEHAVIOR OF THE FOUNDATION DURING TRENCH EXCAVATION

In order to study the performance of the foundation during excavation work, two model test series with different distances x_F were carried out. A trench of 30 cm length was cut adjacent to a rectangular foundation (a/b=20/10 cm, not embedded) subjected to various load conditions. The guiding wall of the trench was not embedded for these test series. In the course of the excavation the vertical and horizontal displacement of the foundation was measured with inductive odometers. Also the depth of the trench was noted. The test data were called up every 15 seconds by means of a multi-channel analyser and stored on a micro-computer for later processing. After the excavation of the trench, the foundation load was increased until the ultimate bearing capacity was exceeded. It appeared that the rate of loading during the excavation has no influence on the final bearing capacity after the excavation. In Figure 9 the settlement w_F/b caused by the trench excavation is plotted over the ratio P_p/P_f (constant preloading/failure load) using a half-log-scale.

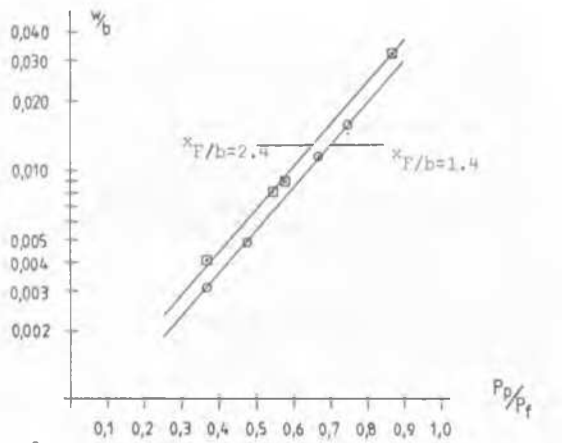


Fig. 9

The development of the settlements during the excavation is illustrated in figure 10. In the first instance the settlement increases with increasing excavation. With successive excavation the increase in settlement becomes smaller. After a particular reference depth is passed, the settlement approaches a constant final value. This reference depth coincides rather

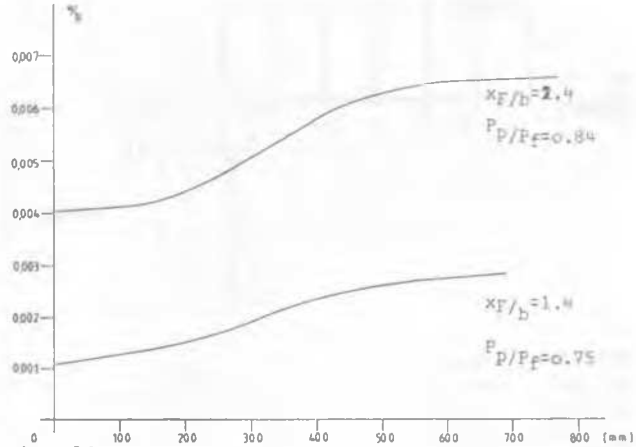


Fig. 10

good with the depth of the failure mechanisms investigated in Fig. 5.

5 CONCLUSION

On the basis of the model tests and findings of this study the following conclusions may be drawn:

1. With increasing distance between foundation and trench the influence of the trench diminishes and a regular bearing capacity problem is relevant.
2. The calculation model based on these tests appears to be applicable for practical purpose.
3. It was proved that the so called "swept out memory effect" corresponds with the real behaviour of cohesionless soil.
4. There is no effect of the preloading of a foundation close to the slurry trench on its ultimate bearing capacity.
5. The excavation of the trench beneath the soil region subjected to failing with increasing foundation load will cause only little settlement.

Further research will be directed towards the prediction of settlement of individual foundations adjacent to slurry supported trenches in cohensionless sand.

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