NEW APPROACHES TO PROBLEMS OF BEARING CAPACITY AND SETTLEMENT OF PILES

NOUVEAUX ACCES AUX PROBLEMES DE LA PORTANCE ET DU TASSEMENT DES PIEUX

НОВЫЙ ПОДХОД К ПРОБЛЕМАМ НЕСУЩЕЙ СПОСОБНОСТИ И ОСАДКИ СВАЙ

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SYNOPSIS. Five authors who have been dealing with the problems of behaviour of piles present in this paper their reports about some aspects of their research. B. Černák informs about the tests with the filtercake and the consolidated material of suspension at piling and points out the decisive effect of the filtration time of suspension on the values of the skin friction of piles. A. Dvořák deals with the advantages of dynamic tests of piles, compares them with the static ones and emphasizes their significance for the estimation of the quality and the bearing capacity of piles. J. Hlaváček and J. Petrášek present the data of a long-term measurement of settlements of buildings founded on piles and draw attention to the mutual interaction between the pile foundation and the constructive qualities of the respective superstructure and to the reflexion of this interaction in the measured values. K. Klein summarizes the results of shear tests with specimens and piles of various roughnesses of the surface. He suggests a design of analysis that determines the skin friction resistance of piles with respect to this phenomenon.

EFFECT OF SUSPENSION ON SKIN FRICTION IN SANDS /B. ČERNÁK/

A series of field and laboratory tests, carried out in the last twelve years, implied that the excavating of wholes and concreting of piles in sands with the use of suspension manifest themselves, in comparison with the the use of a casing, by a minor loosening of sands and on the other hand by changes in the skin friction effected by the filtercake. The exploitation of these tests results in different hydrogeological and technological conditions requires often a detailed evaluation of effects of the filtration time and of the pressure of the suspension.

Therefore tests were made to state mechanical properties of the filtercake and of the concrete-filtercake-sand interface. A suspension of activated bentonite with the strenght of 85 mp/cm^2/1 min and with the filterability of 17 ml/30 min/1 kp/cm^2 was used. As a filter served a 2 mm dawn sand /I_D = 0,70, k = 1,1.10^{-7}cm/sec./

FILTERCAKE

The effect of filtration time /t = 1-256 h/ and of suspension pressure /p=0,02-1,0kp/cm^2/ was investigated on a circular filter Ø20cm. The filtercake was taken off in layers parallel to the surface of the filter. The distance between each layer and the filter and the average water content were established by a calculation. A linear course of water content in the filtercake was found in all cases /Fig. 1. - left/. The correlation between the water content and the undrained strenght of the suspension material, prepared in oedometers by different consolidating stresses, was established in order to state a basis for the evaluation of the strenght of the filtercake determined by its water content. The shear strenght of the consolidated suspension was specified by a laboratory vane test. The course of the strenght of the filtercake /Fig. 1. - right/ indicates that the filter cake changes its properties according to the distance from the filter from properties of a plastic clay to properties of a suspension. The strenght of the

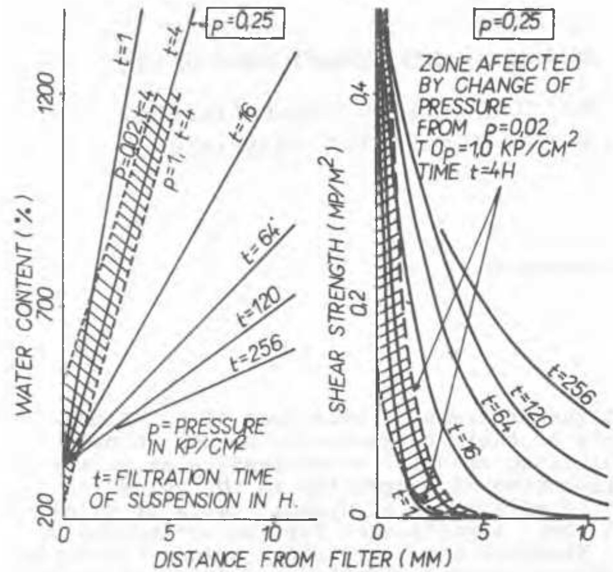

FIG. 1. WATER CONTENT AND SHEAR STRENGHT OF FILTERCAKE

filtercake at the filter decreases expressively with decreasing pressure of the suspension.

At concreting of piles a part of the filtercake is pressed together with the suspension by the rising concrete mix from the bottom to the surface. Thus the thickness of the filtercake between the sand and the pile corresponds to the distance between the movement boundary of certain strenght and the filter. The test showed that this distance is proportional to the square root of the filtration time /for p = const./. With the increasing thickness of the filtercake increase its average water content and compressability and decreases its average strenght.

SHEAR TESTS OF SPECIMENS

By means of an arrangement that allowed to make specimens of concrete-sand interface and concrete-filtercake-sand interface under conditions similar to the field ones comparative shear tests were carried out. The contact area had a dimension 15 x 44 cm. The specimens with the filtercake were made under the pressure of 0,25 kp/cm^2. After a consolidation under normal load the shear load was gradated until failure occured. The maximum skin friction of specimens with concrete--sand interface /t = 0/ and also concrete-filtercake-sand interface /t = 18/ increased proportionally with the normal load and were placed along the line /a/ /Fig. 2./. In these cases an expressive effect of the filtercake on the intensity of friction was not observed. But in the case of specimen t=168 a decrease of the angle of friction was stated. It decreases from $\delta = 33^o$ to $\delta = 14^o$.

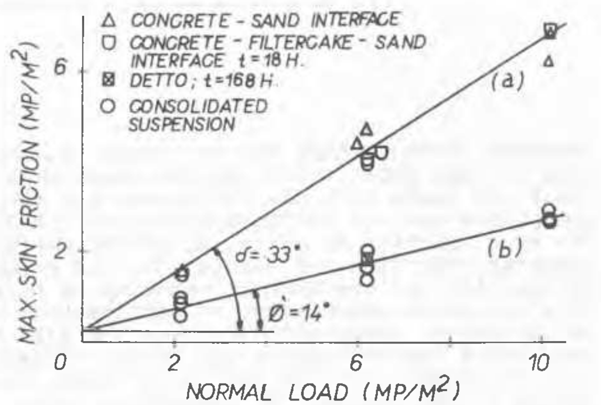

FIG. 2. MAXIMUM SKIN FRICTION OF SPECIMENS AND STRENGHT OF NORMALLY CONSOLIDATED MATERIAL OF SUSPENSION VS. NORMAL LOAD

Tests of normally consolidated suspension material were made in a direct shear box machine. The established line of strenght /b/ with an angle of 14^o verified the presumption that the maximum skin friction of the specimen t = 168 is given by the strenght of the consolidated filtercake. Then the high values of max. skin friction at the specimen t = 18 are explainable only by an unevenness of the concrete-sand interface. A strenghtening of the filtercake by the cement milk /Weiss 1965/ was not observed; probably in consequence of higher pressure of the suspension /0,25 in contr. to approx. 0,02 kp/cm^2/.

The suspension influences also the rate of the mobilisation of the skin friction i.e. the rate of the increase of the unit skin friction with the increase of displacements /Fig. 3./. In the areas of minor displacements /to about 0,5 mm/ the skin friction increases more quickly at specimens effected by a suspension / t = 1, t = 18/. In the areas of more substantial displacements the skin friction increases more quickly at the specimens with a direct concrete-sand contact /t = 0/. This fact is in agreement with the results of field tests / TER-GALUSTOV et al 1961/ as well as with the results of model pile tests /FARMER et al 1970/. It is explained by an additional cohesion of the

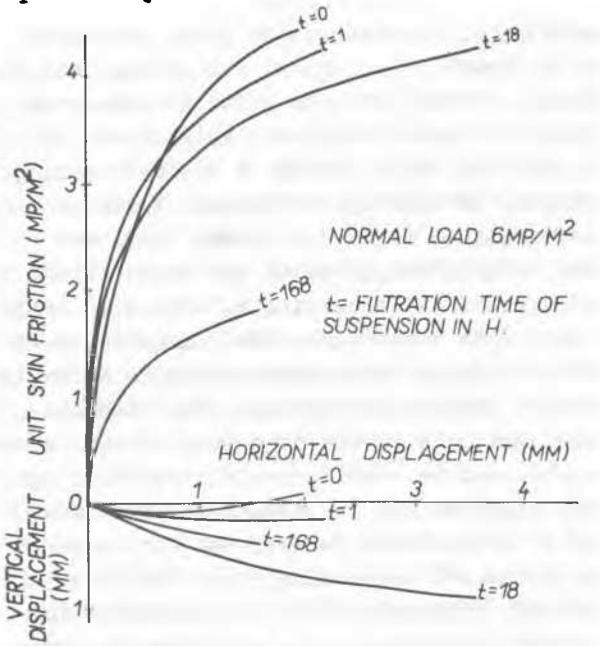

FIG. 3. SHEAR TESTS OF SPECIMEN OF CONCRETE -SAND INTERFACE AND SPECIMENS OF CONCRETE -FILTERCAKE-SAND INTERFACE

sand in the close surrounding of the pile surface. However the results of shear tests /Fig. 3./indicate that both the rate of the mobilisation of the skin friction and the maximum values of the skin friction decrease in consequence of increasing filtration time of the suspension.

APPLICATIONS OF RESULTS

During the consolidation there occurred a vertical displacement from 0,15 mm at the specimen t = 0 to 10,23 mm at the specimen t = 168./Fig. 3./ At the specimen t = 0, strained by shear, an increase of volume occurred, while the specimen with a filtercake showed a contractance. The more expressive decrease of the volume at the specimen t=18 in contrast to the specimen t = 168 was caused by the consolidation of the filtercake between the unevennesses of the concrete at the horizontal displacement of the specimen t = 18. Both the consolidation of the filtercake and the contractance at the straining by shear result in the decrease of normal stresses on the pile surface. Therefore at field piling there can be expected a more expressive decrease of the skin friction and of the rate of the mobilisation of the skin friction with an increasing filtration time, as the tests results of specimens at normal constant load showed. Thus one of the fundamantal requirements at piling by the use of the suspension must be to reduce the filtration time to the utmost in such positions of sands that require a high level of load transfer.

DYNAMIC TESTS OF PILES /A.DVOŘÁK/

Dynamic test is a non-destructive method within the range of elasticity. The tested pile is set into vibrations by means of a small hammer. The induced vibrations are recorded by a vibrograph. In the record two kinds of vibrations can be observed: /a/ vibrations of the pile as a rigid body, embedded into the foundation soil and /b/ vibrations inside the pile as in the slim, confined body /rod/. Vibrations of the first group have mostly greater displacement amplitudes, lower frequencies and appear in the vibrogram as basic waves, whereas the vibrations inside the pile with smaller displacements and higher frequencies show the character of secondary oscillations. As a rule a small displacement amplitude and a high frequency of vibrations indicate an undisturbed pile with a stiff embedment. Large amplitude and low frequency are the mark of a soft embedment of the pile or of its substancial necking or even interruption. An unfavourable indication can also be obtained in cases when concrete of cast-in-place pile has a low strenght. In order to determine the influence of the strenght of the concrete it is advisable to examine its quality by another non-destructive method e. g. using the SCHMIDT - hammer.

RESULTS OF DYNAMIC TESTS

The dynamic test was developed by the author some years ago owing to the necessity to quickly investigate a greater number of cast-in-place concrete piles as at the time only method available was the expensive and slow static loading test. The dynamic test distincly displays heavier faults of a pile. On the other hand a small necking e. g. from Ø 55 to Ø 45/50 cm cannot be determined but such a decrease of the section is not dangerous. It is obvious that a dynamic test enables a comparison of piles and relative evaluation of their quality as is also shown in Fig. 1. and 2. The results were verified by excavations of some piles after dynamic tests.

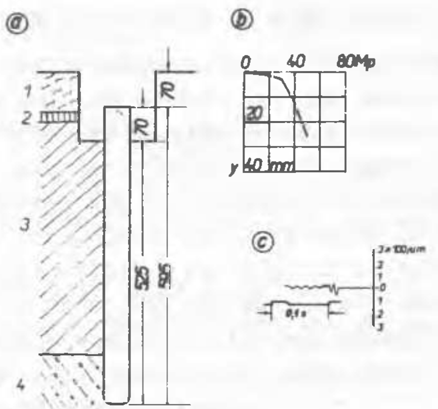

FIG. 1. a - an undisturbed pile with geological section. 1 - fill. 2 - organic loam. 3 - loess-loam. 4 - gravel with sandy loam. Dimensions in cm. b - load P vs displacement y graph of the static test.

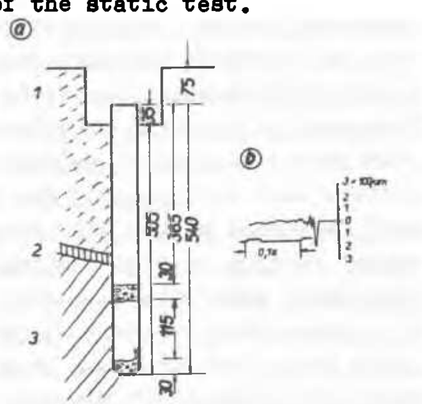

FIG. 2. a - a pile with discontinuities G /ungrouted gravel/. b - vibrogram of the dynamic test. Geology and dimensions as in Fig. 1.

CORRELATION BETWEEN STATIC AND DYNAMIC TESTS

This relation is of essential importance for the appreciation of the quality of piles. For this purpose a lot of parallel static and dynamic tests was performed. The dynamic test must precede the static one as at static loading up to the bearing capacity the soil is compressed and the stiffness of the embedment is increased. At piles, produced in conformable geological conditions, the relation of both tests is quite satisfactory. Piles with more favourable indications at dynamic test also present a greater bearing capacity /DVOŘÁK 1969/. Dynamic tests of piles, examined also by a static load, are used as calibration tests and other piles are appreciated according to this one. It is possible to investigate the foundation system on a large scale and usually 15 % of piles are dynamically checked. The displacement amplitude or the frequency of vibrations can be used as a criterion. According to present experiencies an exponential relation can be established between the displacement amplitude and the bearing capacity of a pile. Since at a dynamic test only elastic deformations take place it is necessary to compare only piles that are manufactured under similar geological conditions and by an identical method. An instructive figure can be obtained if the displacement amplitudes of the particular piles are compiled graphically as a spectrum of their resp. frequencies. Such an illustration is given in Fig. 3.

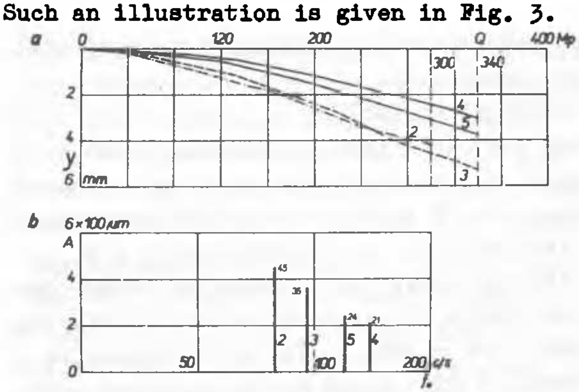

FIG. 3. PARALLEL STATIC AND DYNAMIC TESTS
a - load P vs displacement y graphs of the static tests. b - displacement amplitudes A as a spectrum of frequencies f_o.

The piles, manufactured by CALWELD machine, had a lenght from 11 to 13 m and were embedded 6 - 7 m into sandy marls with sandstone at the base. The upper layer consisted of loess, sand and sandy gravel. The diameter of piles 2 and 3 was 82 cm, of 4 and 5 it was 102 cm. The graph of static loading tests and the spectrum of displacement amplitudes of dynamic tests present a fair correlation. Pile 4 is of the best quality, 2 of the lowest.

FURTHER DEVELOPMENT OF THE DYNAMIC METHOD

A great number of parallel static and dynamic tests of piles and observations of settlement had recently been performed. The results enable a direct estimation of the bearing capacity of a pile from the dynamic test. This fact is very advantageous at large-diameter piles /e. g. BENOTO, CALWELD, POCLAIN/ where the static loading tests are rather expensive.

In many cases results of dynamic tests enabled to discover unexpected damage of piles e. g. disturbance of hammered piles or interruption of cast-in-place piles manufactured by Prépact method /DVOŘÁK 1963, 1969/. Satisfactory results were also obtained by testing thermically strenghtened bodies in loess /DVOŘÁK 1970/, further with piles stressed by tension and underground walls.

THE SETTLEMENT OF PANEL BUILDINGS ON PILES / J. HLAVÁČEK, J. PETRÁŠEK/

A great attention is payed in recent years to the nonuniform settlement of large precast concrete panel buildings. With this problem are very closely connected the questions of the stiffnes of a construction, of the stiffness of foundations and the questions of a mutual interaction between foundations and the respective superstructure. A certain answer to these questions can be given by the measurement of actual settlements.

That is why we measured during the years 1968 - 1971 the settlements of some high - rise appartment buildings in three localities with various geological conditions in the subground. The results of the measurements of all investigated structures in addition with a description of their construction and respective subground are presented in the table.

The piles at Petržalka and Košice were embedded into a sandy gravel, the piles at Dúbravka had charakteristics of friction piles. The building of the type T 06 had load bearing cross walls that were layd on a monolithic footing distributing the load to the piles. Some investigated structures formed single dilatable units /Petržalka, Košice D2/ the other ones consisted of two or more dilatable units. The physical and mechanical properties of soils were determined by geological investigations of remoulded samples, taken during the boring of piles. In two localities pressiometric tests according to MENARDE were made in soils above the tips of piles /Petržalka: p_1 = 5,0 - 8,0 kp/cm^2, E_p = 22 - 51,0 kp/cm^2; Dúbravka: p_1 = 4,0 - 6,5 kp/cm^2, E_p = 12,0 - 40,0 kp/cm^2. The resistance on the penetrative tip MAIHAK had a value 15 - 20 kp/cm^2 /Petržalka/. Loading tests of single piles were made in a close distance of investigated structures. The presented values were measured after the finishing of the buildings. The inclination and angular deformation, the mutual influnce of dilatable units and the rate of settlement were ascertained in addition to a current geodetic evaluation. Then the modulus of settlement /BABITCHEV, JUSHIN 1970/ was calculated in Mp/cm /i. e. the average load in a single pile that is necessary in order to press the pile foundation in a depth of 1cm/ and the settlement ratio too /i. e. the ratio between a settlement of a pile under the structure and a settlement of a single test pile/. The settlement was calculated according to the czechoslovak standards and according to various authors /BOWLES 1968, BARTOLOMEJ 1970/. The lower settlement at Košice was caused by the minor thickness of the loamy sandy gravel layer.

According to the measured settlements we can make following conclusions:

1. The average settlement of investigated structures reached from 3,3 to 19,2 % of the limited values of average settlement given

TECHNICAL DATA AND SETTLEMENTS OF PANEL BUILDINGS FOUNDED ON VIBRODRILLED PILES OF VÚIS SYSTEM Ø 37 CM

Data	Structure	Petržalka	Košice D 2	Košice T 8	Dúbravka S	Dúbravka N	Dúbravka 01C	Dúbravka 01A
Number of Storeys	1	12	14	8	4	4	9	9
Lenght of Piles	m	6,0 - 6,5	6,5 - 7,0	5,5 - 6,0	5,5 - 6,0	4,2 - 5,5	4,5 - 5,5	5,0 - 6,0
Number of Piles	1	152	132	165	94	94	275	275
Load in 1 Pile	Mp	44,2	38,6	41,0	28,6	28,6	27,8	27,8
Soil Description		Sandy Loam, Gravel, Sand with Boulders	Loamy Sand, Loamy Gravel, Neocene Clay	Loamy Sand, Loamy Sandy Gravel	Black Sand, Granitic Sandy Clay with Fragments Ø 6cm, Granitic Conglomerate		Loam, Granitic Sandy Clay with Fragments, Granitic Conglomerate with Fragm.	
s	P/cm^3	2,71	2,73	2,24	2,69	2,73	2,69	2,69
w	%	20,66	16,18	22,45	13,92	14,65	11,62	18,43
I_p	%	14,70	13,36	15,85	15,99	21,26	16,73	17,15
I_c	1	0,947	0,781	0,991	0,641	0,611	0,459	0,494
D 10	mm	0,656	0,138	-	0,056	0,011	0,018	0,018
Measured Settlement	cm	0,538	1,731	0,392	0,413	0,393	0,455	0,768
Predicted Settlement	cm	0,58	0,53	0,40	0,91	0,91	0,94	0,99
Inclination of Longitudinal Walls	$w/L.10^{-4}$	0,16 - 0,43	0,18 - 0,36	0,0 - 0,06	0,04	0,08 - 0,16	0,19 - 0,42	0,31 - 1,0
Cross Walls		0,12 - 0,25	0,76 - 1,86	0,0 - 0,24	0,80	0,26	0,67 - 1,67	0,17 - 2,76
Max. Angular Deformation of Longitudinal Walls	$w/L.10^{-4}$	0,70 - 0,84	0,50 - 1,71	0,50 - 1,0	-	0,17	0,29 - 0,57	0,33 - 1,23
Cross Walls		0,19 - 2,36	-	0,50	-	3,98	0,50 - 1,83	0,50 - 2,33
Settlement Modulus	Mp/cm	66,3	18,2	75,2	65,6	69,2	51,8	30,7
Settlement Ratie	1	1,92	13,62	5,02	3,25	2,89	4,50	7,60

by the czechoslovak standards.

2. The maximum nonuniform settlement of both longitudinal and cross walls reached in the first case from 3,2 to 45,7 % of limited values and in the latter one from 13,3 to 75,5%. The nonuniform settlement of panel buildings is considered as decisive for their dimensioning.

3. The cross footings amount usually greater inclinations and relative deflection than the longitudinal ones.

4. The consolidation of the subground is given by the rate of the settlement of the building after its beeing inhabited. The consolidation at Petržalka and Košice /T 8/ was minimal, at Dúbravka and Košice /D 2/ it reached greater values /0,19 - 0,40 mm monthly during a period of 11 months/.

THE EFFECT OF SURFACE ROUGHNESS OF PILES ON THEIR BEARING CAPACITY IN COHESIONLESS SOILS /K. KLEIN/

The bearing capacity of a pile in cohesionless soils depends chiefly on the density of the soil and on its construction method. The loading of a pile mobilizes by displacements the shear strenght in the adjacent soil while the voluminal changes result in it. Already JOHN 1960, FEDA 1963 and BROMS, SILBERMAN 1964 refered to the significance of these voluminal changes. This paper presents an investigation of the effect of a surface roughness of a pile on the values of voluminal changes of the soil in the surrounding of a pile and by that on its bearing capacity.

EXPERIMENTAL MEASUREMENT

Field tests were made in a saturated medium sand /I_D = 0,55 - 0,65/ on piles with different surface roughness. The results of these tests showed that by a machanical roughing of 25 - 50 % of the pile surface increased the bearing capacity of the precast piles three times at loading by a vertical or oblique tensile load. In the case of vibro piles /driven and cast-in-place displacement piles, 5 m long/ increased the bearing capacity five times in contrast to precast piles with a smooth concrete surface, made in a new steel soffit. The measurement of displacements of the sand in the surrounding of the pile during the loading test showed that the areas of the same vertical displacements /measured in the adjacent soil to the distance of 3 m/ were along the total lenght practically parallel with the pile surface and the displacements decreased hyperbolically in the direction from the centre of the pile. The tests with model piles /80 cm long and 3,6 cm in diameter/ with a smooth steel surface and a rough one /pasted sand/ showed that the ratio of the skin friction resistance amounts 2,3 - 3,5 /I_D = 0,35 - 0,60/ at piles forced into the sand and then loaded by a tensile or compressive load and 8,1 - 13,0 /I_D = 0,6 - 0,72/ at piles showered by sand.

In a direct shear box machine tests were made with constant loading /N = const./ and with practically constant volume of the sand sample /V = const./. Specimens with different surfaces were put in the lower jaw of the shear machine. At the test N = const. the ratio of tg φ'/ tg δ for the total extent of I_D was 1,49 - 1,70 for the sand and the smooth concrete, 1,9 - 2,35 for the smooth steel and 0,94 - 1,03 for the steel with pasted sand. At the test V = const. the ratio of the skin friction resistance amounted 4,5 for I_D = 0,39 and 9 for I_D = 0,72 for steel with pasted sand and smooth concrete.

DISKUSSION OF TESTS RESULTS

The mechanism of the deformation and the disturbance of the soil surrounding the pile loaded by a tensile load allows with a certain approximation to narrow the problem of the load transfer from the pile surface to the soil to a question of original normal stress σ /upright to the surface/ and its change $\Delta\sigma$ that results during the loading of the pile in consequence of the voluminal change at the contact pile-soil and in the surrounding soil. These changes can be approximately studied by a direct shear test, where the shear area is parallel with the pile surface.

A significant difference between the bearing capacities of piles with a smooth surface and the rough one results in consequence of the ability to transfer such a shear stress at the contact rough surface - soil that develops an increase of the soil volume in a close pile surrounding /Fig. 1./

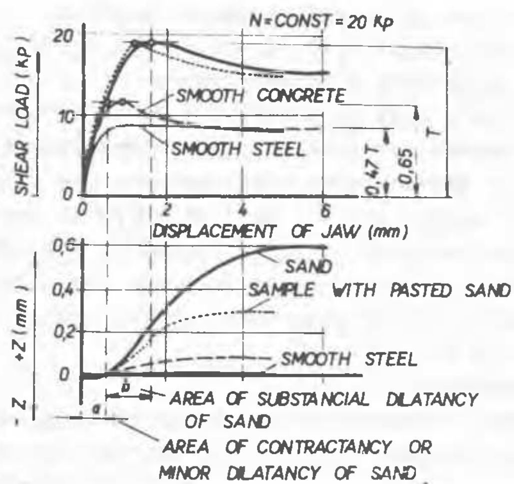

FIG. 1. RESULTS OF DIRECT SHEAR BOX TESTS

As the increase of soil volume is limited by the presence of adjacent soil, the original at the pile surface increases and by that also its bearing capacity. The area of dilatancy in the surrounding of the pile is limited by the axial symetry of this phenomenon. In the case of a smooth surface the contact pile-soil is able to transfer only such a shear stress that does not mobilize, in the moment of its maximum value, the increase of adjacent soil volume as a rule. /Fig. 1. - in our case 65%τ_f of the surrounding sand./ The fact that the continuity of the medium conserves itself causes that the original on the pile surface remains approximately the same or that it decreases. The difference between the bearing capacities of piles with a smooth surface and a rough one, experimentally stated, was therefore considerably greater than the difference established on the commonly used presumption that it is given only by the change of tg δ at the preserving of the original constant σ on the pile surface.

DESIGN OF ANALYSIS

We suggest to analyse the skin friction resistance of driven and cast-in-place displacement piles in sands of a lenght to approx. 6 m by means of this formula:

$$\tau_f = K \cdot \gamma \cdot h \cdot tg\,\delta$$

where for piles with a smooth surface

$K = 0,5 - 1,0$; $I_D = 0,33 - 1,0$; $\delta = 0,7\,\phi'$;

for piles with a rough surface

$K = 1,0 - 2,0$; $I_D = 0,33 - 1,0$; $\delta = 0,75\,\phi'$;

for driven and cast-in-place displacement piles or driven piles with contemporary injection $K = 0,7 + 0,9 \cdot tg^2(45^o + \phi'/2$; $\delta = \phi'$.

At the analysis of piles loaded by a tensile load it is necessary to decrease the calculated values of skin friction resistance by 15 - 30 %.

CONCLUSIONS

1. The intensity of the change of original normal stress on the pile surface and the bearing capacity connected with it depends on the roughness of the pile surface that influences the voluminal changes of the soil in the surrounding of piles.

2. The designed analysis of skin friction resistance takes into account the changes of original during the loading of the pile and it is in agreement with the results of field tests.

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