# Statistical Dimensioning of Slurry Trench Walls

## Dimensionnement des Fondations en Paroi Moulée par les Moyens de la Statistique

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SYNOPSIS The determination of the load bearing capacity of the slurry trench walls loaded by a vertical force and of the settlement belonging to it means a lot of problems for the designers, because the theories relating to this deliver significantly different results which leads generally to the overdimensioning of the foundation and by this to the wastage of material, energy and costs. The authors tried to determine the load bearing capacity-settlement in the empirical way so that with the mathematical-statistical processing of the data of 3oo load tests formulas were elaborated for the dimensioning of slurry trench wall foundations under different geotechnical conditions.

## INTRODUCTION

The slurry trench wall construction method is applied in Hungary since more than lo years not only for the enclosure and support of working pits, for the preparation of watertight curtain walls but for the foundation of different buildings and other projects too.

Its spreading was greatly promoted by the fact that the modern building structures to their great part are sensitive for settlement, i.e. they require such a foundation which can assure besides bad geotechnical conditions too the limited settlement difference of a small degree of the load bearing walls and pillars resp. of the building structure. The great advantage of the slurry trench wall foundation over the other deep foundation methods is that by the alteration of the geometrical dimensions - cross section and depth - of the foundation body the from the upper structure transmitted and often considerably changing loads can be followed easily and in a relatively simple way and so the problem of dimensioning for a nearly same settlement can be solved.

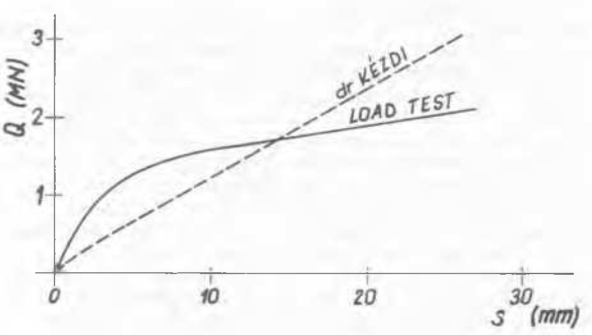
## LOAD BEARING CAPACITY OF SLURRY TRENCH WALL FOUNDATIONS

With slurry trench wall foundations loaded vertically the two main factors of the load bearing are the skin friction and the base resistance. Originating partially from the building technology and partially from the geometrical conditions the decisive role from among these is played by the skin friction. The excavation of the trench and its following concreting occurs namely under the protection of the bentonite suspension, therefore whatever technology is applied at the excavation the connection of the natural soil and of the trench outfilling concrete on the foundation level is always more or less uncertain, let it be because of the sedimentation of the contaminated slurry, because of the loosening effect of the bagger or of the drilling tool, or because of the technological faultiness with the introduction of the concrete. As a consequence of the above in the initial section of the loading - apart from rare exceptions - practically only the skin friction is functioning, the heterogeneous or loose layer at the base of the trench is acting as a soft spring and influences hardly or not at all the settlement because of the loading. This situation is the more true the deeper the slurry trench wall is and the ratio skin surface/ base surface the greater is. With the increase of the load and settlement the transitive layer on the base will be compressed and the base resistance will be involved gradually into the load bearing until finally - after the skin friction has reached its maximal value and afterwards diminishes to the value of the residual shear strength - gains a decisive role.

The excess of the critical load belonging to the total mobilization of the skin friction is going together usually with such a great settlement which can not be endured in the practice especially if we take into consideration that the dimensioning regulations of the different countries prescribe the determination of the limit load bearing capacity of the foundation body generally with the use of safety factors.

DIMENSIONING OF SLURRY TRENCH WALL FOUNDATIONS

With the theoretical determination of the load bearing capacity of the slurry trench wall-foundation body the designer has to take into consideration the absolute and relative settlement-settlement difference criteria which can be endured by the upper structure. From this follows directly that for the dimensioning only such a theory can be applied which renders the loadability of the foundation in function of the settlement.
In case of the use of those formulas which deliver the break load in their final result the settlement belonging to the given load must be calculated separately, what makes the whole dimensioning very uncertain / Caquot-Kerisel, Berezancev, Jamiolkowsky etc /. Therefore in Hungary the application of the theory of Kézdi became general which was adapted by one of the authors for the case of slurry trench walls because this corresponds to the above mentioned basic conditinn. But the practice has proved - in comparison with the data of the load tests made in series - that the value-pairs /Q,s/ do not describe punctually the load-settlement function; in the section preceding the critical load indicates a greater settlement in comparison with a certain load and in the section following the critical load a less settlement / Figure 1 /.




Fugure 1: Part samples of the soil type "C" between skin surface of K = 39 and 46 m²

The cause of this is partially that the theory - which was prepared for pile foundations and not for slurry trench wall foundations and so it could not take into consideration the specialities originating from this later technology - renders too great values for the base resistance and too little values for the skin friction; on the other hand the single soil physical characteristics'/mostly the angle of friction of the crossed and under the base lying soils/ determination,which characteristics we have in the formula is even with the present situation of science in the practical cases rather uncertain and the introduction of the constants - in lack of suitable experimental results - happens mostly by estimation.

EMPIRICAL DIMENSIONING METHOD

In the interest of the solution of the dimensioning - and of the neutralization of the previously mentioned difficulties - we have started in 1974 with the Institute for Geodesy and Geotechnics to collect the data of the load tests in connection with the slurry trench walls, and to process systematically the data assembly. Among these were such load tests too where we have built tension measuring cells into the loaded slurry trench wall foundation and by this it was possible to measure separately the skin friction and the base resistance in the process of the load test. The results of the measurements verified our previous suppositions; namely that in the range of the so called "standard load" - where the force transmitted effectively by the superstructure and satisfying the settlement criteria is acting - in the majority of the cases the skin friction plays the decisive role, the base resistance can be practically neglected to the benefit of the safety. In possession of the result of about 3oo specimens we endavoured to elaborate such a procedure which by the application of the means of the mathematical statistics can display a connection in the empirical way between the load bearing and the settlement of slurry trench wall foundations made under different geotechnical conditions and having different geometrical data.
In order to avoid the uncertainty originating from the determination of the soil physical characteristics and from the introduction of different constants we classified the possible soils in 3 main groups - granular, transient and bound - and made a further difference according to the fact, whether these soils are located in the crossed layer and under the base resp. This way we separated the slurry trench wall load tests into 9 soil type groups /Table 1/

Table 1

| soil class | majority of the crossed soils | soil under the base |
|---|---|---|
| A | granular | granular |
| B | transient | transient |
| C | bound | bound |
| D | granular | granularú |
| E | granular | granular |
| F | transient | transient |
| G | transient | transient |

granular soils: have no cohesion / sand, sandy gravel/
transient soils: soils having a little cohesion and having an index of consistency $I_p$ < lo / sand flour, silty sand flour/
bound soils: soils having a cohesion and an index of consistency $I_p$ > lo

In order to take the geometrical dimension differences into consideration we have distributed the load tests belonging to the single soil type groups into new subsections according to the magnitude of the skin surface of the loaded trench element. The so received analogous curve series became already suitable for the execution of the function analyse by taking a computer into account. Within single soil types we have produced by the distribution to $\underline{n}$ parts of the skin surface /$K_{min}$, $K_{max}$/ interval such ordinate part samples where there was a possibility to determine a common envelope, i.e. a Q/s,K/ function of two variables /Figure 2/. This work was executed by the Mathematical Professorate of the Building Engineering Faculty of the Technical University of Budapest.

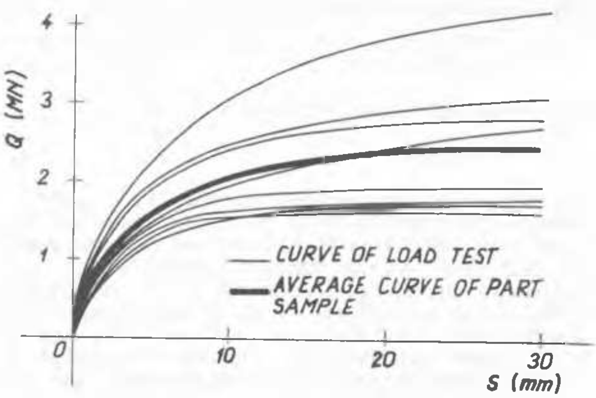



Figure 2: Depiction in space of the function Q/K,s/

COMPOSITION OF THE FUNCTION LOAD-SETTLEMENT

In the given soil type slurry trench walls number $\underline{n}$ were prepared. Data of the completed load tests are the following:
Exact datum is the skin surface $K_i$ /i=1,2,..n is the number of the slurry trench walls/
Measured data: /$Q_{ij}$,$s_j$/, where $\underline{j}$ is the number of measurements on a slurry trench wall.
With the assistance of the correlation calculation we have stated that among the measured data of the $\underline{n}$ slurry trench walls there is a tight correlation and so on the whole data assembly a function can be given, where the load $\underline{Q}$, the settlement $\underline{s}$ and the skin surface K are figurating as variables.
We determined the expectable value of the $Q_{i,j}$ values belonging to the $s_j$ of the slurry trench walls number $\underline{n}$. To the so received number series we have fitted a logarithmically quadratic function. The form of the function is the following:

$$\ln Q = A_0 + B \ln s + C \ln^2 s \qquad /1/$$

$$Q/s/ = A \cdot s^{B+C\ln s} \qquad /2/$$

In the formula /2/ the A,B and C values are concrete numbers but the skin surface does not figurate. In order to be able to realize the latter we have arranged the assembly of the data of the $\underline{n}$ slurry trench walls according to the magnitude of the skin surfaces and we have separated the whole sample to three part samples.
On basis of the calculation of the correlation it has followed that the expectable value-functions of the part samples are tightly connected too.
So

$$Q_1/s/ = A_1 s^{B_1} + C_1 \ln s \qquad 0 < K_i \leq K_I$$

$$Q_2/s/ = A_2 s^{B_2} + C_2 \ln s \qquad K_I \leq K_i \leq K_{II} \qquad /3/$$

$$Q_3/s/ = A_3 s^{B_3} + C_3 \ln s \qquad K_{II} \leq K_i \leq K_{III}$$

By help of these $A_j$ $B_j$ $C_j$ values a function connection can be found taking K into consideration. The form of these in case of the soil type "C" is the following:

$$A = a_0 K + a_1$$

$$B = b_0 \ln K + b_1$$

$$C = C_0 + C_1 \ln /C_2 \ln K + C_3/ \qquad /4/$$

$$s_0 = d_0 \ln K + d_1 ,$$

where the values $a_i$, $b_i$, $c_i$, $d_i$, are known numbers. The $s_0$ is that critical value, where the load-settlement curve follows in a straight line.
The final form of the searched function:

$$Q/s,K/=/a_0K+a_1/s^{b_0\ln K+b_1}+/C_0+C_1\ln/C_2\ln K+C_3//\ln s \qquad /5/$$

The values calculated from the received function approach with 1 % deviation the expectable values of the part samples.
With the help of the calculator HP 9825 A and the plotter HP 9862 A we have prepared the figure of function /5/
In case of other soil types the thought of the function construction is similar to that of the type "C".

The forms of the functions are more simple, the same time the usability intervals are less taking K into consideration,

The function received for soil type "A":

$$Q/s,K/=/AK^2+BK+C/s^{A_1K^2+B_1K+C_1} \qquad /6/$$

The function received for soil type "F"

$$Q/s,K/ = /AK+B/s^{A_1K+B_1} \qquad /7/$$

The form of the function received for the soil type "G" coincides with the function received for the soil type "F" with other parameters.

The applicability of functions /6/ and /7/ can be increased by further measurement data.

## APPLICATION OF NEW FUNCTIONS

The applicability control of the new calculation connections was accomplished by the computer type COMPUCORP 327. For the single functions we have prepared a program and determined the Q values belonging to the data /s,K/ of all load tests. Together with the meanwhile effected load tests we have controlled totally 3oo cases. In the course of the control we have stated that the empirical functions follow well the average curves but within the single soil types with the single curves present themselves deviations. With the detailed analysis of these we came to the point that the deviations can be brought into connection generally with the change of the soil condition. But because the running of the described function, as well as of the load test function coincides formally, so with the application of the transformation - depending from the soil condition - the function can be adjusted to the measured curve of the load test.

We have controlled the applicability of the functions with the comparison with the calculation relations used in the practice. With 36 load tests we have calculated the value pairs /Q, s/ with the theory of Caquot - Kerisel and Kézdi, as well as with the new formulas. In the interest of the comparison we stated the value of deviation $/P_{crit.meas.}/P_{crit.calc.}/$ according to soil types between the calculated critical load and the measured critical load and by summarizing we fixed the expectable value of the deviations /n/ and the empirical standard deviation / /.

Table 2

| Soil type | Caquot-Kerisel | | Kézdi | | New formula | |
|---|---|---|---|---|---|---|
| | n | | n | | n | |
| A | o,36 | 2,o8 | 1,6o | 1,48 | o,94 | o,21 |
| B | 1,3o | o,94 | 2,89 | 1,54 | 1,46 | o,56 |
| C | 1,o1 | 2,68 | 1,82 | 1,32 | 1,1o | o,22 |
| F | o,58 | 1,16 | 1,o6 | o,36 | 1,16 | o,16 |
| G | o,6o | o,98 | 3,31 | 1,83 | 1,16 | o,31 |
| for the controlled 36 data | o,63 | 1,72 | 2,3o | 1,66 | 1,16 | o,19 |

The data of the table show it clearly that the new functions render both concerning the deviation - i.e. the safety - and the empirical standard deviation essentially better values, as the previously used relations.

In the interest of the applicability we have written the formulas in such a form that they should be usable easily by help of nomograms too and they should be programable for computers of little capacity resp.

For example in case of the soil type "C" the function /5/ can be written in form

$$Q/s/ = \alpha A s^{B+C \ln s} \qquad /8/$$

where

$$A = 27{,}38\ K - 23o \qquad /9/$$
$$B = -o{,}184 \ln K + 1{,}12 \qquad /1o/$$
$$C = -o{,}o785 + o{,}o125 \ln/5{,}65 \ln K - 2{,}9/ \qquad /11/$$

Values of the modificating factor depending from the state of soil:

With soft clay soils / index of consistency $I_c < o{,}75$

$\alpha = o{,}67$

with rollable and hard clays / $o{,}75 < I_c < 1{,}5$/

$\alpha = 1{,}oo$

with very hard shaly clays / $I_c > 1{,}5$ /

$\alpha = 1{,}4o$

The empirical processing of the load tests brought favourable results, The described functions follow well the values determined by load test within the settlement range necessary in the practice. With the application of the new formulas it will be possible to make the dimensioning in a safe way and by far more economically of the foundation bodies having a near same settlement. The functions can be programmed on a simple computer, so their use is not complicated.

The number of the slurry trench wall load tests is increasing year by year, so the number of the appliable data is increasing too. The increase of the number of the samples will make it possible to punctuate further the functions later on.