Behaviour of Combined Loaded Block Foundations

Tenue des Fondations Chargées Combinément

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SYNOPSIS Up to now separate proceeding was required to design vertically and horizontally loaded foundations for single columns in addition to further calculations of soil deformations. By using a new technique for manufactoring block foundations the possibility of utilizing the lateral support in the subsoil was offered. The problem was to develop another calculation method by means of previous statements. This method was to cover the load deformation behaviour of block foundations under simultaneous effect of vertical and horizontal loads as well as moments in case of working loads. Model tests were carried out in order to check the calculation model. Testing methods and results of importance are given in the present contribution. The model tests proved effects of main factors providing preliminaries to a series of in-situ tests at which the influence of main factors has to be studied at a full scale. Furthermore, the programme of the full scale tests is to give clear evidence to reciprocal effects of the main factors. The above programme aims at correcting the calculation method and to prove it in practice.

INTRODUCTION

In the GDR a new technique for manufactoring block foundations is being applied increasingly, which is used for founding of single columns, crane tracks, supported pipelines, etc.

According to J. Müller and M. Pilz (1975) this technique is characterized by placing concrete into vertically excavated foundation pits directly against solid soil. In this way the subsoil surrounding the foundations remains undisturbed helping to transfer loadings even above base of the footing.

Dimensions of the block foundations to be investigated range to the following extents: $0.66 \leq B/L \leq 1.5$ and $0.6 \leq B/D \leq 2$; being B - breadth, L - length and D - depth of foundation. Thus they are rigid showing negligible inherent deformations compared to soil deformations. Referring to A. Bolt, E. Dembicki and W. Odrobinski (1975) they are to attribute to the measuring range of $0.5 \leq B/D \leq 2$ in which both the soil reactions on the foundation flanks and base are appearing of importance.

Vertical and horizontal as well as moment loadings are to be taken from the building. At present for demonstrations of vertical load capacity the theory of the ultimate bearing capacity is used. Horizontal loads are to be taken up by base friction. The actual transfer of building loads, however, occurs within the entire range of embedding. A. Caquot and J. Kérisel (1967) have already pointed out a failure mechanism at the ultimate state. According B. Broms (1965) a linear proportionality between M (moment) and α (angle of distorsion) is acceptable up to 1/3 ... 1/2 of the ultimate moment.

For the combined bearing capacity of block foundation in case of working loads a calculation method has to be invented in order to improve utilization of existing bearing capacity. It is based on a factor of proportionality K between subsoil loading and deformations as already applied to this problem by G. Sulzberger (1928) as well as by V. Stötzner (1951), Z. Getzler (1968) and others.

In consequence of statements issued by N. Snitko (1963) another proportionality exists between shearing stress and amount of translation what will be taken into consideration. The model tests presented below already aimed at a qualitative confirmation of the calculation statements.

SPECIFICATIONS OF MODEL TESTS

Because of a great number of influencing variables seeming important at first sight a variation of subsoil properties was left out of consideration. The testing programme was arranged for investigations on the following factors:
- geometry of the foundation block (B,L,D)
- inclination of the resultant (H/N, where H - horizontal load, N - vertical load)
- eccentricity of vertical load (e = M/N)
- height of application of the horizontal load above surface
- proportion of vertical load applied to

ultimate load.

For the foundation models special steel boxes were prepared by rough spots on the surface situated within the embedded range. Vertical and horizontal (at four different levels) loads were applied by means of a column with cantilevers (Fig. 1).

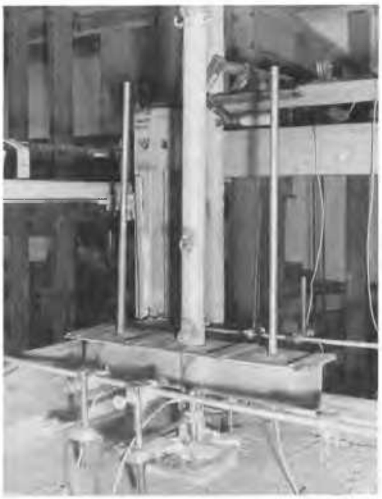

Fig. 1 Load apparatus for the model tests (without applying vertical loads)

The loading system selected and applying calibrated mass elements allowed the loading to be stabilised despite of movements of foundation. In a testing container (2 × 3 × 1.5 m) the loading of six of the footing models was executed. For foundation soil a fine to medium sand was used of unit dry density ρ_d = 1.699 ± 0.058 g/cm^3 and of uniformity coefficient $U = d_{60}/d_{10}$ = 4.8. The water content of w ≈ 3.5% showed greater variations filling by filling of the testing container. Sand applied in layers was compacted by means of a vibrator (attained density index $I_D \approx 0.9$). Simultaneously footing were placed in the upper sand layers.

Besides investigating the factors already mentioned simple vertical loadings were carried out comparatively. Each of the loads were applied in increments. For elevating the load increments the deformation speed of v = 0.01 mm/2 min proved to be a criterion in general. Movements of the solid body caused by horizontal and moment loadings were measured at four points by means of inductive displacement pick-ups (Fig. 2), thus indicating distinctly movement of the solid body in the plane of loading.

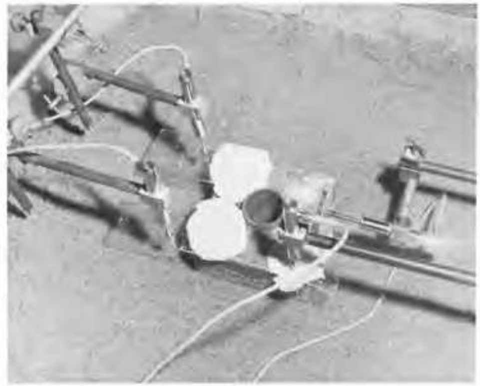

Fig. 2 Measuring apparatus for the model tests

The testing programme was designed for repeating some of the principle tests at various filling of the testing container. Additionally the influence of alternating loads was studied and special examples was selected for observations with regards to the state of failure in coloured subsoil layers.

RESULTS OF THE MODEL TESTS

The calculation method in case of working loads being opposed to the test results is based on statements of reaction forces due to subsoil as shown in Fig. 3, it reads as follows:

$$M/\alpha = K\ f(B,L,D,x_o,\ z_o) \qquad (1)$$

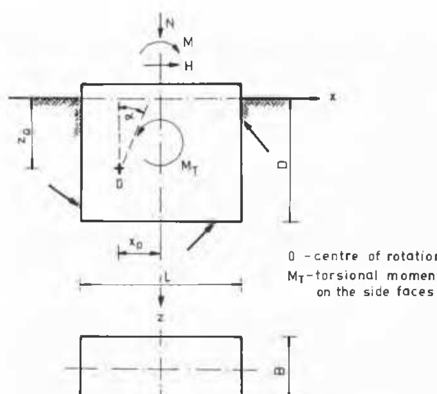

Fig. 3 Soil reactions

thus

z_o resp. $x_o = f(K,B,L,D,N,H,\alpha)$ (2)

are coordinates of the centre of rotation.

The following refers to results dependent on geometry of foundation blocks. M versus α-curves as shown in Fig. 4 are to be derived from measured values thus justifying a linear proportionality proved by B. Broms (1965).

For further investigations a direct proportionality was assumed ranging up to $M_{fail}/3$ according to formula (1). The attained results M/α are calculated correspondingly. As stated in Fig. 5 relations between M/α and the foundation geometry are derived from statistical investigations.

As to be expected a square law dependence appears in relation to L, thus illustrating its dependence on base resistance. Thus influence is superimposed by effects by the torsional moment at the side faces.

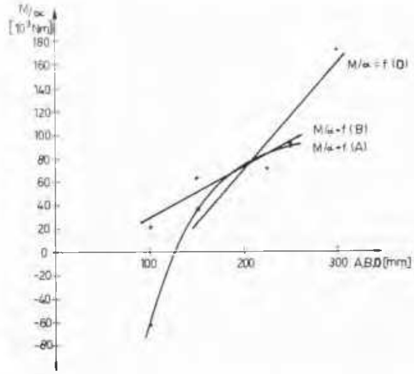

Fig. 5 Functional relation between M/α and the foundation geometry

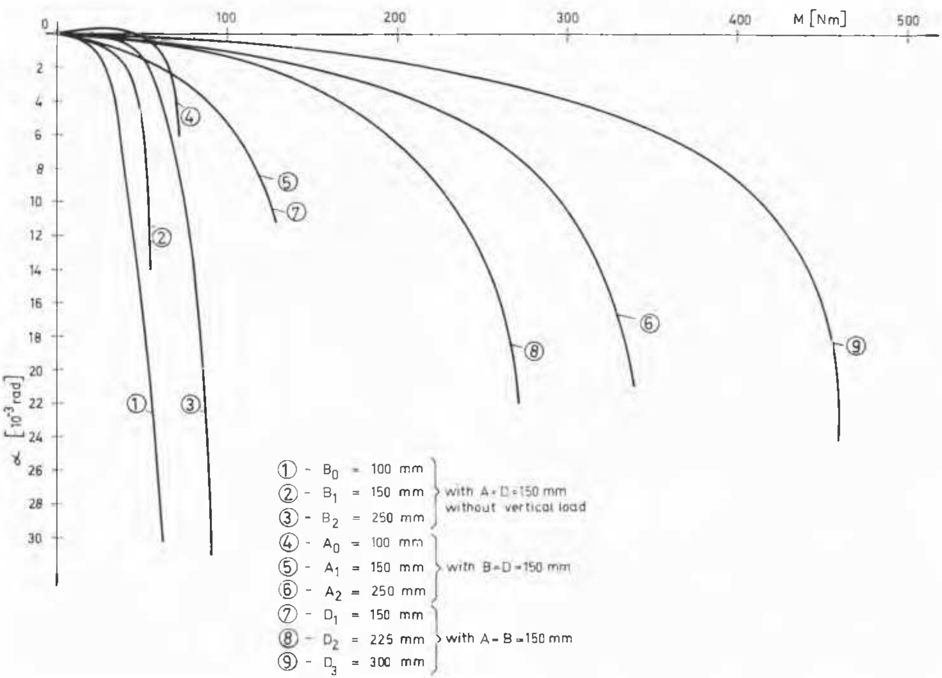

Fig. 4 M versus α-curves

Between the breadth of foundation B and M/α there is a mere linear functional connection which is based both on influencing of reactions at front faces and base closely linked to the load deformation model of the subsoil used.

The relationship between depth of embedment D and M/α is likewise statistically established to be a linear function. Some authors desist from the fact of dependence to the third power of depth, however, more than a linear function had to be expected. Two reasons are decisive for the test results attained: Variation in test values of approximately 20% do not qualify statistic reliability for possible superlinear function. Moreover, investigations on footings showed a higher influence of base reactions on the total behaviour than of fixating on the front faces. The immediate test values offer the possibility of superlinear functions (up to square).

CONCLUSIONS

In principle the model tests proved the applicability of the factor of proportionality.

The effenciency of influence due to geometry of foundation could be estimated in quality and being found principly in conformity with theoretical statements.

In consequence to investigations concerning influence of loading conditions on load-deformation-behaviour was stated that neither the inclination of resultant as well as eccentricity due to vertical loads nor the height of application of the horizontal load are playing a role in statistical reliability in case of working loads. The amount of vertical loads, however, is a decisive factor, for approximately 25% of the ultimate load shows a maximum value of moment, as pointed out by Ch. Ramelot and L.J. Vandeperre (1950). These important statements helped setting up a proper testing programme for in-situ tests.

The final calculation method has to be derived from basic results of full scale tests. Influences to be investigated were limited to the dimensions of foundation, to the vertical load and the differences in subsoil conditions. The increments in dimension was fixed to such an extent that results varied from each other obviously.

The choice of three stages is to make sure that square law dependence can be proved apparently as well as presumably. As a rule maximum and minimum values attained in these stages are likewise limits in the field of practical use, excluding extentively extrapolation on account of the calculation method. By recording the fixations of block foundations it is aimed at a more economic designing, simultaneously simplifying the calculations of load bearing capacity.

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