Group Action of Laterally Loaded Bored Piles

Groupes de Pieux Moulés sous Charges Horizontales

H.G. SCHMIDT Bilfinger + Berger Bauaktiengesellschaft, Mannheim, F.R.G.

SYNOPSIS Groups of vertical bored piles for piers or abutments must be designed to withstand lateral loads. Some results of lateral load tests run on large diameter bored piles are described, and the pile-soil interaction is discussed. A testing equipment for investigating 2-pile groups is presented.

INTRODUCTION

Piers and abutments of modern bridges that span rivers or estuaries are often founded on groups of large diameter bored piles, which transfer lateral loads to the subsoil by horizontal contact pressures (fig. 1); knowledge on the interference of closely spaced piles is small, however.
The group action of laterally loaded piles has been investigated mainly by theoretical analyses and by model tests, whereas large-scale tests are scarce. These investigations were sometimes triggered by specific problems, or they are based on definite assumptions,

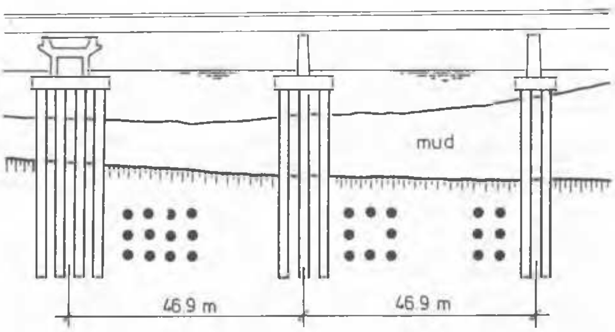

Fig. 1 Typical pier foundations of Shatt-al-Arab Bridge, Iraq

and for this reason they are related to driven or bored piles, to the elastic semi-space or to the failure state, to static, cyclic, or alternate loads; to pile groups consisting of both vertical and battered piles - and often the behaviour of single piles with unrestrained heads is directly compared with that of pile groups, where the pile heads are fixed in a rigid pile cap. Hence, general conclusions on the pile-soil interaction can hardly be derived from these investigations.

If a group of vertical, large diameter bored piles is to be designed for the support of lateral loads, the following questions arise:
(1) Pile-soil interaction of a single pile;
(2) load bearing behaviour of each individual pile within the group, related to that of a corresponding single pile.

The pile-soil interaction of vertical piles under lateral working loads is generally described by a modulus of horizontal subgrade reaction, which - for single piles - may be derived from lateral load tests or be estimated by experience (Schmidt 1979 a). The comparison of any individual pile of a group with a single pile should start from equal horizontal displacements at the soil surface and may be approached in three successive steps:
(1) investigate the group efficiency E_{gr}, i. e. the load of the pile group divided by the number of piles and related to the corresponding load of the single pile;
(2) find out the load distribution on the individual piles of the group H_i, related to the mean pile load;
(3) calculate the efficiency of each individual pile

$$E_{pi} = E_{gr} \times H_i \qquad (1)$$

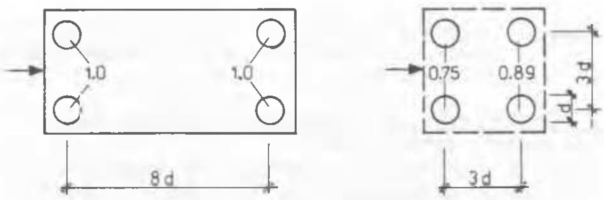

Fig. 2 Efficiency of piles in a laterally loaded group (Prakash, 1962)

Figure 2 shows a result evaluated by this procedure, using part of Prakash's detailed investigations on model piles, diameter 1.27 cm, embedded in sand (Prakash, 1962). Test no. 19 was run on a single pile as well as on a 4-pile group with hinged heads, allowing a direct comparison. Figure 83 yields the group efficiency, table 15 the load distribution. Hence, the efficiency of the individual piles was calculated.

TEST RESULTS

It is felt that the group action should be investigated by large-scale tests with view to the effects of pile installation, and that the basic problems may be investigated on groups consisting of two piles, which are aligned in the direction of the applied load. Two limiting conditions can be imagined concerning the pile-soil interaction (figure 3):

(1) Long piles penetrating through a very soft top layer into very hard rock. The pile tips are rigidly fixed in the rock, the contact pressures are far below the strength of this material; load transfer in the top layer is negligible. In this case, any individual pile of the group will behave like a single pile.
(2) Short piles that rotate rather than deflect under horizontal loads, embedded in an uniform soil. Interference will be greatest in this case and is likely to depend on the pile length, on the pile spacing, on the type and the strength of the subsoil, and on the amount of lateral loading.

The following measurement results from lateral load tests run on large diameter bored piles may provide a first glimpse into the pile-soil interaction.

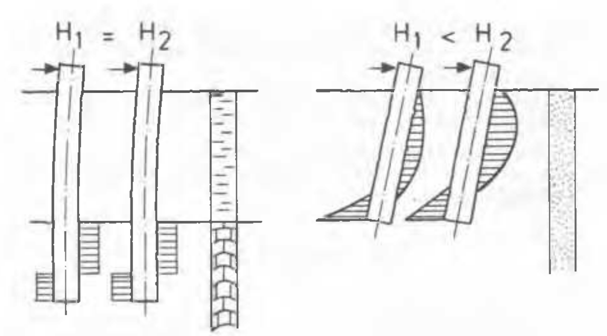

Fig. 3 Potential patterns for the interaction of laterally loaded, neighbouring piles

Displacements and stresses in front of a laterally loaded pile

General patterns are plotted in figure 4, and the displacements of the soil in front

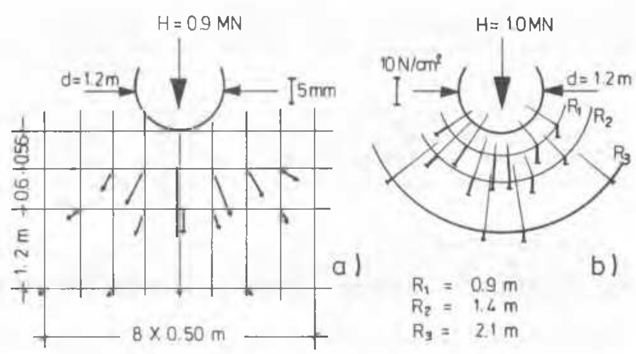

Fig. 4 Patterns of a) displacements (Schmidt 1979 b) and b) stresses (Stamm, 1973) in front of laterally loaded piles

of two piles in the direction of the applied loads in figure 5, showing a distinct effect both of the amount of loading and of the distance to the pile surface. The same applies to figure 6, showing the stresses within the soil at various depths in front of a laterally loaded pile. The clear distance between neighbouring piles generally will amount to at least one pile diameter, marked by a dotted line in the figures. From these diagrams may be seen that the interference of neighbouring piles is negligible for very small loads only. For increasing loads, the influence of the neighbouring pile is governed by the areas:

$$\int_{a=d}^{a=\infty} \sigma \cdot da \quad \text{or} \quad \int_{a=d}^{a=\infty} \varepsilon \cdot da \qquad (2)$$

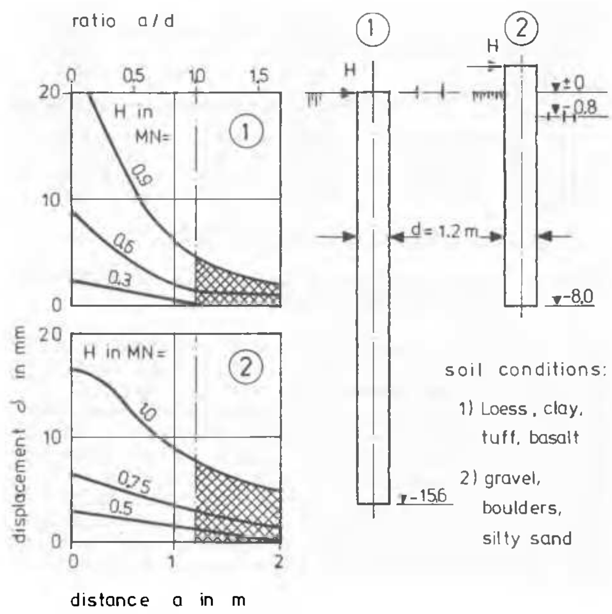

Fig. 5 Horizontal displacements in front of two laterally loaded piles

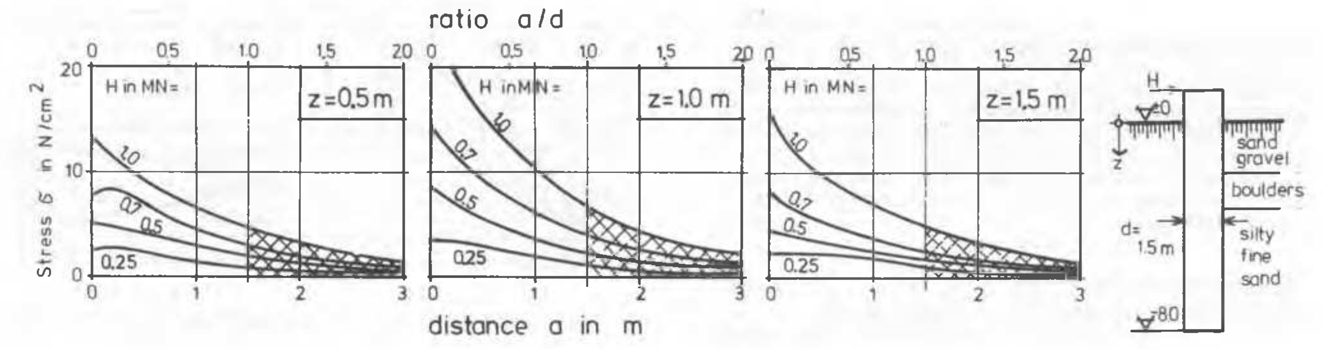

Fig. 6 Horizontal stresses at various depths in front of a laterally loaded pile (Stamm 1973)

which are cut off by the dotted line. Whilst the ratios of these portions to the total areas are constant, the interference of the neighbouring piles will be independent of the amount of loading.

Interaction of two neighbouring piles

If the second pile aligned in the direction of loading is not loaded itself, it improves the resistance of the soil due to the much higher stiffness of the pile material and to the flexural rigidity of the pile shaft. In this case, the soil in between the two piles acts like a spring, transfering part of the forces from the loaded to the unloaded pile. In any case, this spring will not be very effective: if the soil is soft, the load that can be transfered is small; and if the soil is strong, the effect of the additional pile will be dispensable.

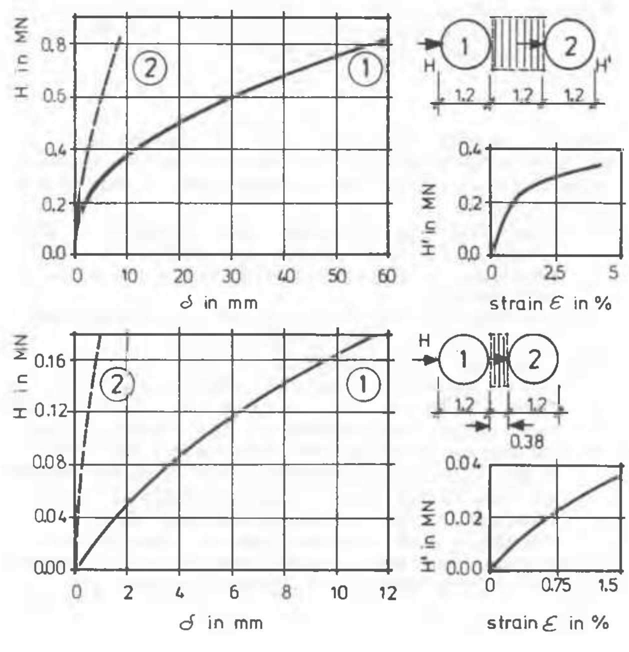

Fig. 7 Influence of laterally loaded pile on neighbouring unloaded pile

Two examples are plotted in figure 7, showing in either case the displacements of the loaded pile as well as of the unloaded neighbouring pile. An attempt was made to estimate the induced loads from the displacements of the front piles, and to relate them to the strains of the soil between the piles, which were calculated from the differences between the load-deflection curves and the minimum interspaces between the piles. The efficiencies of the soil "cushions" between the piles differ, which is in good agreement with the soil mechanical characteristics of the respective top layers. It appears for test no. 1 that the soil behaves more or less like an elastic spring under small loads, whereas plastic deformations are likely to govern the load transfer under heavy loads.

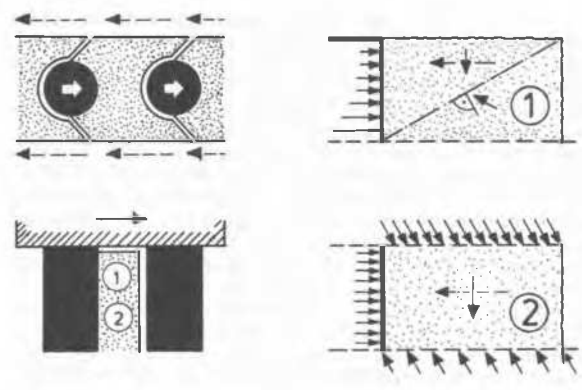

Fig. 8 Potential limits for the stress pattern in a soil bloc between laterally loaded piles

On the other hand, if both piles are loaded simultaneously, the deflection of the front pile decreases the soil resistance for the rear pile. Generally, the interspace between the pile heads remains constant under loading due to the pile cap. As the soil bloc between the piles is compressed by the stresses induced by the rear pile, fissures will open between the soil and the front pile, thus limiting the contact pressures of the rear pile to the possible shearing forces acting in horizontal planes of the soil bloc, and to the passive earth pressure, respectively, in the topmost layer. Hence, the rear pile is not very likely to affect the bearing capacity of the front pile, see figure 8. In figure 9, two load-deflection curves are plotted for the pile no. 14, the difference being caused by simultaneous loading of the front pile. The influence on the load bearing capacity of the rear pile grows with increasing lateral loads.

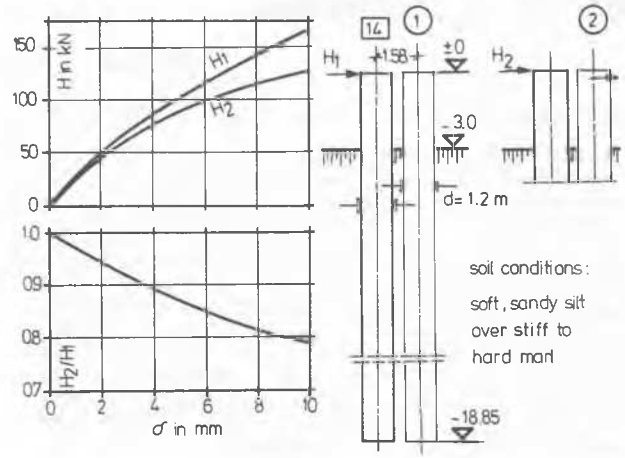

Fig. 9 Effect of loading the neighbouring pile on the resistance of pile no. 14 to lateral loads

Two-pile groups

The results of two test loadings run on pile groups are plotted in figures 10 + 11. Hydraulic jacks were placed in the interspaces between the pile heads, allowing to measure the loads that were transfered by these connections, and to correct the distances between the pile heads if necessary. The load-displacement diagrams of the groups, of the individual piles, and of corresponding single piles are plotted in the figures, as well as the group efficiencies and the load distributions on the individual piles of the group. From these results, the pile efficiencies related to those of the single piles may be calculated. In spite of small interspaces between the piles, the group efficiency is about 0.8 and apparently nearly independent of the amount of loading in either case. The group efficiency seems to be dominated by the loss of bearing capacity of the rear piles. In both tests, piles were long and penetrated into hard soil layers, i. e. they approach the characteristics of type (1) mentioned above (see fig. 3).

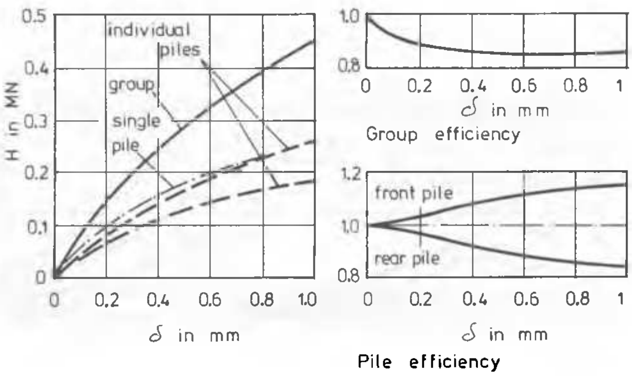

Fig. 10 Efficiency of two 1.2 m diameter, 28 m long piles in totally weathered gneiss, clear distance 1.7 m

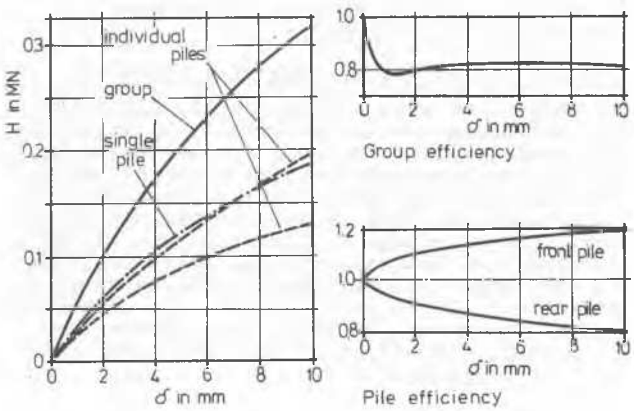

Fig. 11 Efficiency of two 1.2 m diameter, 16 m long piles in silt and marl, clear distance 0.4 m

TEST PROGRAMME

A series of tests on large diameter bored piles is intended for the next years, using the test equipment plotted in figure 12. It allows to apply lateral loads to two piles either individually, or successively, or simultaneously. The test programme is designed as follows:

(1) Simultaneous loading, unloading, and reloading of both piles, yielding the behaviour of the group and the load distribution;
(2) loading of the front pile, yielding the behaviour of the single pile;
(3) loading and unloading of the rear pile, yielding the effect of displacing the front pile on the bearing capacity of the rear pile; unloading of the front pile;
(4) repeated loading and unloading of the rear pile and measuring the displacements of the front pile; this procedure is thought to be a simple measure for checking the interaction of the piles.

It is expected that these results will improve the understanding of group action.

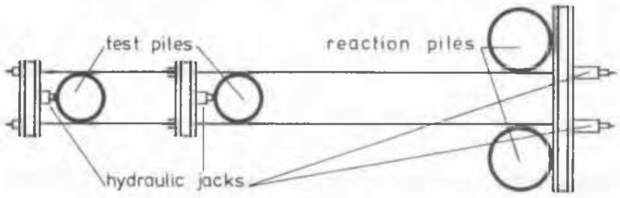

Fig. 12 Setup for laterally load tests on 2-pile groups

CONCLUSION

Meanwhile, the group efficiency of laterally loaded piles must be estimated based on the individual conditions, such as soil conditions, spacing and lengths of the piles, amount of loading. The test results reported yield that in many cases the effect of group action is likely to be less drastic than it is often supposed.

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