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# DISCUSSIONS AND CLOSURES

## Discussion of "Axial Load Tests on Bored Piles and Pile Groups in Cemented Sands" by Nabil F. Ismael

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The writer reported results of static loading tests in tension and compression on two small-scale, single, bored piles in compact, dry to moist, slightly cemented sand. The tension test was performed on a pile with a diameter of 200 mm and an embedment length of 2.65 m and the compression test was performed on a pile with a diameter of 100 mm and an embedment length of 2.25 m. The load–movement response in the tension test was that of a gradual rise rather than a plunging failure (Fig. 7 of the original article). The writer defined the capacity of the tension pile to the maximum load applied in the tension test—157 kN at a pile head movement of 20 mm. The maximum movement in the compression test was 12 mm and no plunging failure occurred (Fig. 8 of the original article). By applying "the slope tangent method" to the shape of this load–movement curve, the writer determined the capacity of the compression pile to be 90 kN. The compression-pile head movement at this load was 7 mm.

For the tension test, the writer calculated the 157 kN capacity to correspond to an average unit shaft resistance of 91.5 kPa. The writer then applied this average value to the 90 kN capacity of the compression tested pile, establishing a 66 kN total shaft resistance for this pile. The balance of the capacity, 24 kN, was assigned as pile toe resistance.

The writer based his analysis on a simple total stress analysis, applying constant unit shaft resistance along the piles. The discusser believes that an effective stress analysis is better suited to the analysis of the test results. In contrast to the total stress method, the effective stress analysis accounts for the difference in embedment depth of the piles; the embedded length of the compression pile is 85% of that of the tension pile. Accordingly, for the unit shaft resistance in an effective stress analysis to be equal for the two piles, the *average* shaft resistance of the compression pile must also be 85% of that of the tension pile.

Moreover, the writer's values of shaft resistance in the two tests were determined at different pile head movements. Considering the load–movement dependency, in the discusser's opinion, correlation of the shaft resistance measured for the tension pile to the shaft resistance measured for the compression pile should be made at equal pile movements. In the tension test at a pile head movement equal to the movement at the 90 kN compression test capacity, 7 mm, the tension load was 125 kN, as opposed to 157 kN for the maximum movement. Combining the aspects of both length and movement results in an average unit shaft resistance of 61.8 kPa for the compression test as opposed to the 91.5 kPa value calculated by writer, resulting in a total shaft resistance for the compression pile of 45 kN as opposed to 66 kN reported by the writer. The toe resistance balance, therefore, is 45 kN as opposed to the writer's value of 24 kN.

The effective stress values correspond to a ratio (beta coefficient) between shaft resistance and effective vertical stress of about 3, which may seem to be a rather large value. However, the value is consistent with the cemented nature of the sand and, more so, by the test being made at shallow depth in an overconsolidated sand. As indicated by Altaee and Fellenius (1994), the dilation of the sand occurring at low confining stress (shallow depth) increases the lateral soil stress against the pile and results in a beta coefficient that is larger than that developing deeper down where the confining stress is much larger.

The writer also reported the results of the strain-gage-determined distribution of resistance (load transfer) for the compression pile: The load value indicated by the strain gage closest to the pile toe was very similar to the 24 kN toe resistance value calculated by the writer's method of applying the results from the tension test. The writer suggested that this confirmed the assumption of the analysis that the shaft resistance was independent of the direction of movement (equal in tension and compression). In contrast, the measured toe resistance appears to disagree with the 45 kN toe resistance determined from the effective stress analysis. Moreover, also the effective stress analysis assumes that shaft resistance is independent of the direction of movement and the disagreement, therefore, would seem to indicate that the assumption is wrong.

The discusser believes that the disagreement between the strain-gage-determined toe resistance and the value determined in the effective stress analysis is false. The explanation lies in that the pile was considered to be under zero load at the outset of the test. (The writer did not report anything about the "zero reading" of the gage.) Even for a bored pile, such as the test pile, some

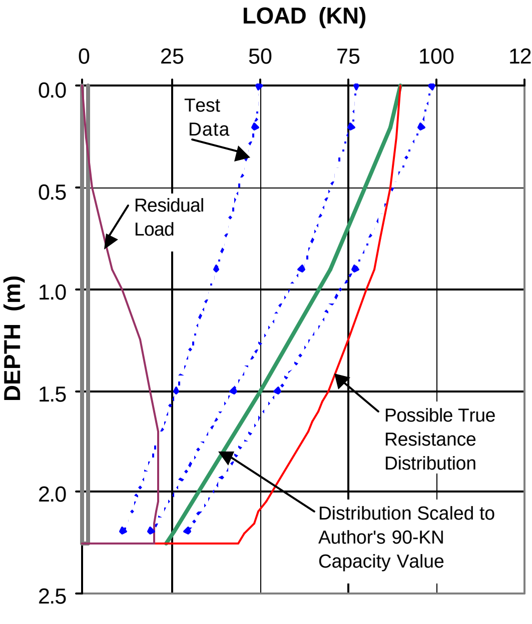

**Fig. 1.** Distributions of measured loads, resistance, and residual load for pile 6 (single pile, length 2.25 m, and diameter 100 mm)

compression—residual load—will have been introduced in the pile as a result of the recovery of the soil after the construction and the curing of the concrete. Excluding the residual load from the analysis results in underestimation of the toe resistance. The discusser considers it possible, indeed plausible, that the compression pile was subjected to a residual toe load of about 20 kN, the value of which must be added to the strain-gage-determined toe resistance. This eliminates the disagreement, i.e., when the residual load is considered, the effective stress analysis does show the shaft resistances in compression and tension to be equal. It also transfers the conflict between calculated and measured toe resistance values to the results of the writer's analysis.

The effect is illustrated in Fig. 1 of this discussion, showing the writer's test data and a load distribution scaled to the writer's 90 kN capacity value. The discusser has also added a possible resistance distribution called "true" determined in the effective stress analysis. The difference between the resistance distribution and the 90 kN measured load distribution is the distribution of the residual load in the pile at the start of the test.

It is wrought with uncertainty to apply results from one pile to a neighboring pile already when the piles are identical. When they are of different lengths and diameters, any agreement or disagreement may well be coincidental. Therefore, in order for the conclusions to be of acceptable numerical credibility, those of the writer as well as of the discusser, the tension and compression tests would have had to be carried out on the same pile. Moreover, the results of model tests cannot be directly transferred to full-scale behavior without consideration of the limits inherent with physical modeling.

The writer also presents results of static loading tests in compression on two small pile groups of five piles having the same size and embedment depth as the compression pile. The center-to-center spacings of the piles were 2 and 3 diameter respectively. Each group was encased in a pile cap cast on the ground surface. One cap had a width of 0.40 m and a length of 0.56 m, and one had a width of 0.51 m and a length of 0.73 m. The corresponding footprints are 0.22 and 0.37 $m^2$. The writer states that the influence of the pile cap was "judged to be very small and was ignored".

Both groups were subjected to a static loading test until a pile cap movement of 20 mm. The load movement curves (Figs. 10 and 11 of the original article) show no indication of ultimate resistance (failure). Applying the "the slope tangent method" to the shape of the load–movement curves, the writer determined the values of 57 and 90 kN as the single-pile capacities of the two pile groups, occurring at pile cap movements of 4 and 8 mm, respectively. Again, the discusser would suggest that an "apple-to-apple" comparison is not obtained unless the comparison is made at equal shaft movement. At the 7 mm reference movement selected for the compression test, the applied loads for the two pile groups were 620 and 810 kN, respectively. These values imply an efficiency of the five-pile group of 1.4 and 1.8. That is, only marginally different from those of the writer's values, 1.2 and 1.9.

However, the discusser disagrees with the writer's approach that the influence of the pile cap can be ignored. It is simple to show that footings of the pile-cap sizes cast on the ground and loaded until movement of 7 mm would require loads of about 150 to 400± kN, respectively, in sand with E-moduli representative for compact sand. When these load values are subtracted from the 7 mm values of the test (620 and 810 kN), the efficiency values become close to unity, refuting that the piles in the group would be more efficient than the single piles. The discusser finds that the test results have a value for similar size pile-enhanced footing foundations at the site, but finds it difficult to accept the writer's generalized conclusions.

## Reference

Altaee, A., and Fellenius, B. H. (1994). "Physical modeling in sand." *Can. Geotech. J.* 31(3), 420–431.