Discussion

On the Interpretation of Bidirectional Loading Tests

Discussion by:
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The method presented by the author is an evolution from the usual procedure, which is commonly used to interpret the bidirectional test, since it also takes into account the elastic deformations of the pile. However, some considerations must be made.

The author uses, as his main case study to validate the method, a case in which two static load tests were performed in similar and closely spaced piles. The value of y_1, *i.e.* the pile displacement required to trigger non-linear response along the shaft-soil interface, is considered equal to 0,35 mm. This value was probably inferred by identifying, in the load-settlement curve obtained from the conventional test, the point at which the shaft resistance reaches maximum for the first section of the pile. In another section of the article, it is stated that usually y_1 is "of the order of a few millimeters". When the load-settlement curve from the conventional test is not available – which happens very often – it becomes very hard to determine this value. In two other cases to which the method was applied by the author, different values were assumed for y_1: in one, it is stated that "the value of y_1 was large", therefore the pile behaved like a rigid or short pile; in the other, "y_1 was assumed to be 3,8 mm".

The readers applied the method to a case study in Curitiba, PR, and found out that a variation of 2 mm in the value of y_1 could be the difference between classifying the pile as short/rigid or as long/compressible.

It is also of note that the O-cell is not always ideally placed along the pile shaft. In most cases – like the one the author based his proposed method on – there is a huge difference between the shaft and toe movements. When this happens, one of the curves must be extrapolated in order to build the equivalent load x settlement curve from the conventional test. This extrapolation may induce errors and misinterpretation of the pile behavior.

Finally, in Fig. 22 the author presents the download curves from both the conventional test and the equivalent curve from the bidirectional test obtained by the proposed method. He observes that both curves have a remarkable fit up until the full mobilization of the shaft resistance in pile E 46A, but its fictitious toe resistance is much lower than that of E 46 due to an "unknown reason". This suggests that, even if the method is successfully applied to a bidirectional test set of curves, the failure load obtained could be lower than the actual failure load of the pile, thus underestimating the pile capacity.

In conclusion, the method proposed by the author theoretically solves the problems inherent to interpreting the results of the bidirectional tests. Not only it introduces the elastic shortening of the pile shaft, but also corrects it by the ratio *c*/*c*' to simulate the top-down loading of the pile. Nevertheless, the aforementioned practical difficulties – determination of the value of y_1, extrapolation of almost linear curves – make it difficult for the method to be incorporated into foundation design routines.

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Closure by author

The author wishes to thank the readers for the comments and questions that surely will help in understanding the basis of the new procedure to find the equivalent curve of the conventional test through the bidirectional test on piles.

1) The new procedure is based on approximate formulas given by Eqs. (17) and (18) of the paper, applicable when one or more expansive interconnected cells are placed near the pile toe. Note that the term y_l of Fig. 4-a does not appear in these equations, that are an extension of the usual procedure to determine the equivalent curve. Modifications were introduced to take into account the elastic shortening of the shaft induced by the loads in the bidirectional test, just knowing pile elasticity modulus (E), its dimensions and the distribution of lateral load along depth, for example through the *SPT*. The magnitude of the elastic shortening determines pile compressibility: if large the pile is "long" otherwise it is "short". There is no need at all to know the term y_l.

2) The term y_l was used in the paper associated to the application of the mathematical model developed by the author based on Cambefort Relations (Fig. 4). This model was used both, to show that the coefficients *c* and *c'* play an important role to find the equivalent curve and to support and validate the application of the approximate formulas, as it was done, for instance, through Fig. 22 for the two CFA piles E 46 and E 46A. In this figure there are 4 curves, one related to the conventional test on pile E 46 (measured curve) and the 3 others to the bidirectional test on pile E 46A. The last 3 curves were obtained by:

a) the mathematical model (Cambefort) applied to pile E 46A;
b) the equivalent curve for pile E 46A, based on the new procedure using the approximate formulas, Eqs. (17) and (18), that again do not depend on y_l; details of the calculations are shown in Table 3; and
c) the usual procedure for pile E 46A, that ignores pile compressibility, as if it had an infinite stiffness.

The paper stressed that the fittings are remarkable up to the point of full mobilization of the shaft resistance except for the usual procedure, with much smaller settlements because it did not consider the large compressibility of pile E 46A. Fig. 22 shows moreover that the fictitious toe resistance of Pile E 46A is much smaller than the toe resistance of Pile E 46, submitted to the conventional test, due to an unknown reason. One may guess that some problem occurred during the O-Cell installation, supported by the result presented in Fig. 20-b relating toe loads and downward movements of the bidirectional test on pile E 46A.

3) Other models may be used in the above mentioned validation, like the software algorithm UniPile of Fellenius or the Coyle-Reese model, as the author mentioned throughout the paper and in its Appendix, where the Ratio Function (Fig. A2) was considered instead of the Cambefort Relation as the shaft transfer function. In the case histories validated by the mathematical model based on Cambefort Relations, the terms y_l, A_{lr} (total shaft load at failure) and *R.S* (toe stiffness) were estimated using the data measured in the bidirectional tests, in the upward and downward directions. This was the case in determining particularly the term y_l of the aforementioned pile E 46A, using Figs. 19 and 20, and not in the way speculated by the readers.

4) The readers mentioned difficulties in extrapolations when dealing with the upward and downward curves of the bidirectional tests. In fact this problem may happen and extrapolations are usually done by those who apply the usual procedure to find the equivalent curve. The two procedures, the usual and the new one proposed by the author, require good quality tests. The paper showed various case histories that accomplished this condition. In all of them the O-cells were placed near the pile toe, except for the two short (rigid) Omega Piles in São Paulo City. In all cases the results were very good, revealing the potential and simplicity of the new proposed procedure.

5) Finally, summing up and going to the main point of the readers' arguments, the new procedure does not require the knowledge of the term y_l. It suffices to compute the elastic shortening of the pile shaft in some way, as pointed out by the author in his paper.