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Comparison of Test Pile Profiles with Simulated Low-Strain Integrity Test Data

Citation

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ABSTRACT

A total of eight precast concrete piles, six reinforced and two without reinforcement, were installed at the Experimental Campus of the Universidade Estadual de Campinas (UNICAMP) 100 km northwest of São Paulo, Brazil. The piles were installed horizontally on the ground to minimize the effect of soil friction and had reductions or increases in the cross-section area at distinct locations along the shaft. One pile had an abrupt cross-section area increase that tapered down to the nominal area at one of the extremities. The piles were submitted to low-strain integrity testing by placing an accelerometer on and hitting each extremity with a small hand-held hammer. The data were processed using equipment from two different manufacturers. The collected data were compared with computer simulations using the known pile geometry as input. The program used for the simulations generates graphs of the top velocity and applied force based on a discreet Smith-like model. In general, the simulated

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signals were very close to the real ones. In one case, however, the collected data did not clearly show a relatively small clay spherical intrusion. Possible reasons for this discrepancy are discussed.

Keywords

low strain, pile integrity test, foundation piles, precast concrete piles

Introduction

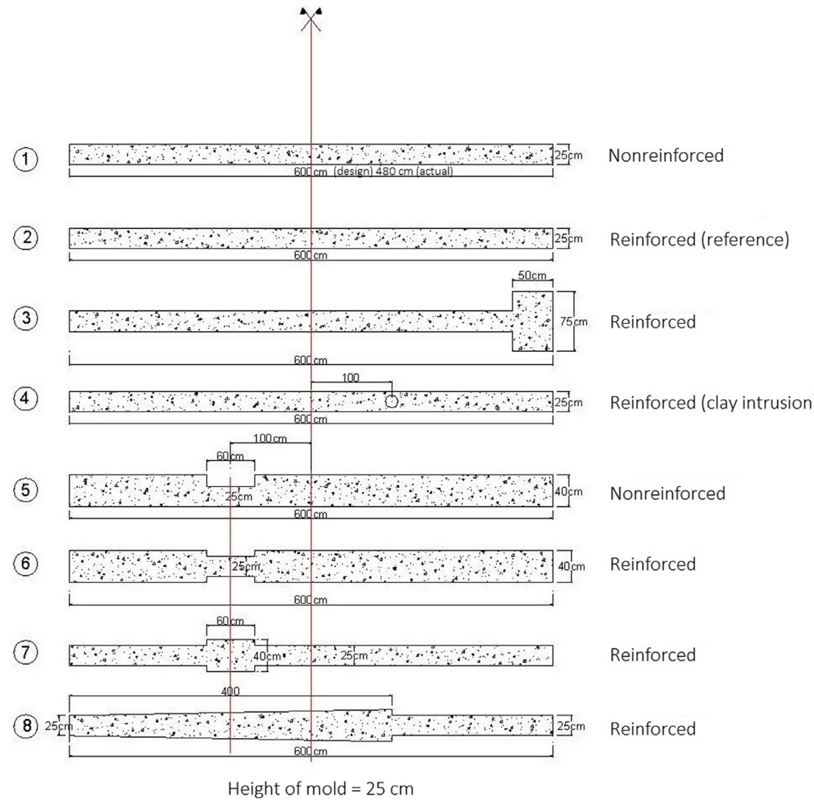
The evaluation of the integrity of concrete foundation piles by means of low-strain stress waves makes it possible to trace an overview of the quality of the foundation with regard to integrity in a fast and inexpensive way [1]. The interpretation of the collected data, however, can sometimes be challenging, especially in cases in which the data lack a clear toe reflection or in which there are defects close to the pile top or with tapered piles. Several tools are available to help the pile tester, such as programs that can simulate the test response to different pile shapes and soil configurations. These programs allow the comparison of actual field data with predictions based on assumed or predicted pile geometry and on the description of the soil. A question arises, however, as to how reliable these predictions are. The objective of this investigation was to compare the simulation of data for piles with known nonuniformities with the simulations from one such program and with the actual data collected with industry-standard equipment.

Description of the Test Program

The test program, carried out at the Experimental Campus of the Universidade Estadual de Campinas (UNICAMP) 100 km northwest of São Paulo, Brazil, consisted of installing a total of eight 4.8- to 6-m-long precast concrete piles with a square cross section. The piles were placed horizontally on the ground to minimize the effect of soil friction and were cast using concrete mixed on site at the Experimental Campus; two of the piles were uniform, one without reinforcement (Pile 1) and the other regularly reinforced (Pile 2), to serve as reference. Due to construction issues during casting, Pile 1 ended up having a length of only 4.8 m instead of 6 m as originally designed. The reinforced piles were not prestressed. The objective of using some nonreinforced piles was to study the effect of the steel reinforcement in the overall wave speed. The other six piles had nonuniformities, as shown in Fig. 1 and described as follows:

- Pile 3 had a 300 % cross-section increase over the last 0.5 m on one of the extremities.
- Pile 4 had an approximately spherical clay intrusion with a diameter of 0.15 m located 2 m from one of the extremities.
- Pile 5 had a 0.6-m-long notch starting 1.7 m from one of the extremities. The cross-section area at the notch was reduced by 37.5 % compared with the rest of the pile. This pile had no reinforcement.

FIG. 1 Sketch of the eight tested piles.



- Pile 6 had a 0.6-m-long necking starting 1.7 m from one of the extremities. The cross-section area at the necking was reduced by 37.5 % compared with the rest of the pile.
- Pile 7 had an enlargement starting 1.7 m from one of the extremities. The cross-section area at the enlargement was increased by 60 % compared with the rest of the pile.
- Pile 8 had an enlargement starting 2 m from one of the extremities that gradually returned to normal size at the other extremity. The cross-section area at the beginning of the tapered enlargement was increased by 60 % compared with the nominal cross section.

The reinforced piles had a light reinforcing cage that consisted of four 10-mm-diameter, 5.8-m-long longitudinal steel bars plus spiral loops made of steel bars 5 mm in diameter. The spiral loops were bent in a 20- by 20-cm square and were installed with a 20-cm pitch. As outlined previously, care was taken not to place any cross-area change at the middle of the pile to avoid the superposition of secondary reflections from the cross-section change with the reflection coming from the toe.

The test was conducted by hitting the piles on each extremity with a 900-g instrumented hammer after placing an accelerometer on the same extremity. The acceleration data were integrated to obtain the velocity, and the signals from several blows were averaged to reduce random noise. The applied force, determined from the acceleration of the hammer, was also recorded. The data were processed and recorded by two devices from different manufacturers. Because the results from both units were very similar, only those obtained from one unit will be presented.

The data were collected 3, 7, 14, and 28 days after the piles were cast. Only the results at 28 days will be presented. An analysis of the earlier data is beyond the scope of this work.

The program used to perform the simulations uses a discreet Smith-like approach [2]. The applied force is simulated as a half sine wave, and the pile and soil are divided into 0.125-m-long elements, plus one soil element for the toe. The inputs to the program are the cross-section area of each pile segment, and the resistance, quake, and damping factor of each soil segment. A single uniform loose non-cohesive soil layer was used to simulate the effect of the weight of the pile on the ground. The soil parameters used followed the values recommended by the program for this kind of soil: skin quake of 2.54 mm, toe quake equal to the equivalent toe diameter divided by 120, a unit skin friction of 24.5 kPa, and a Smith-viscous damping factor of 0.16 s/m in the skin and 0.5 s/m in the toe. The program output is the velocity response corresponding to the user-input pile and soil model.

Results

Figs. 2–17 show the signals obtained and the corresponding simulations. Piles 1–8 were hit from the left extremity as shown in Fig. 1, and Piles 1A–8A were the same ones hit from the right extremity. The gray rectangle at the bottom of the simulations

FIG. 2 Pile 1: (a) actual data and (b) simulated data.

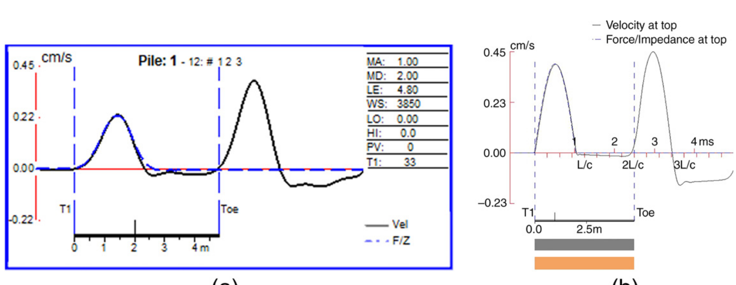


FIG. 3 Pile 1A: (a) actual data and (b) simulated data.

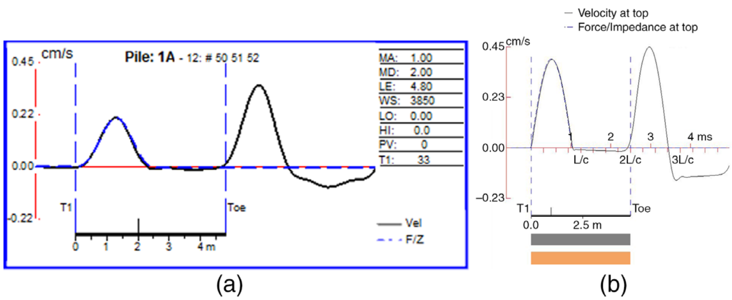


FIG. 4 Pile 2: (a) actual data and (b) simulated data.

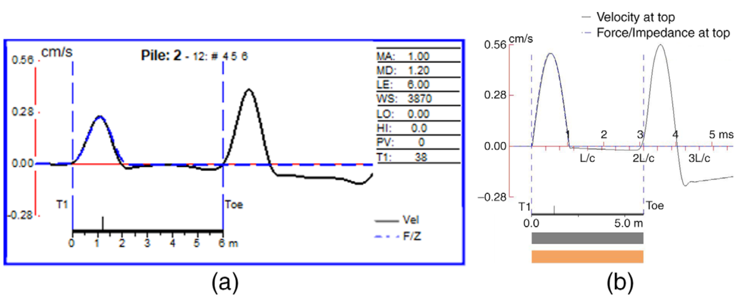


FIG. 5 Pile 2A: (a) actual data and (b) simulated data.

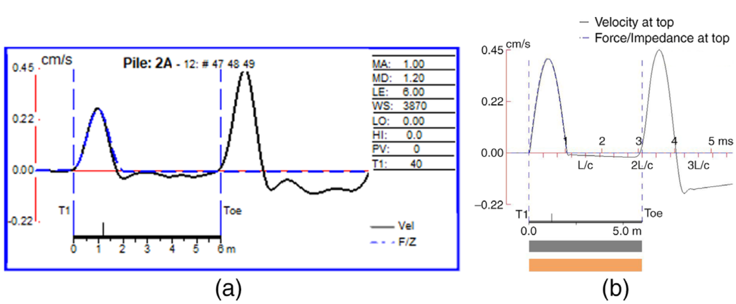


FIG. 6 Pile 3: (a) actual data and (b) simulated data.

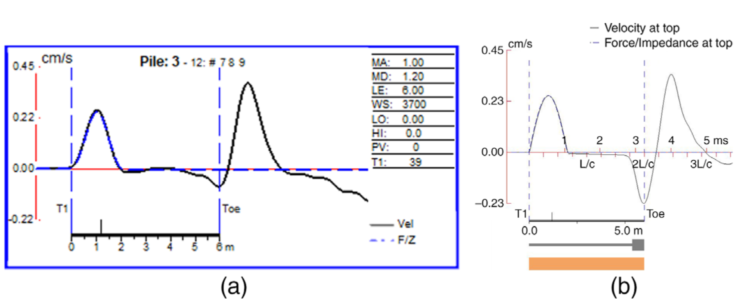


FIG. 7 Pile 3A: (a) actual data and (b) simulated data.

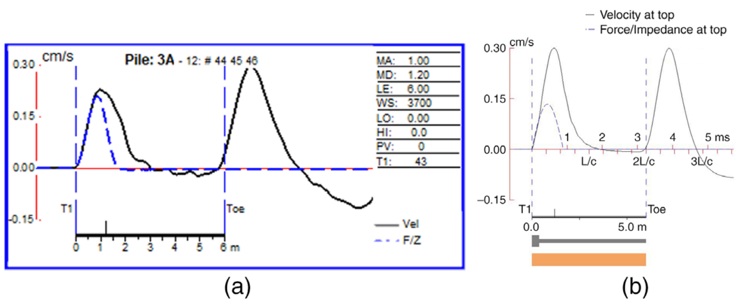


FIG. 8 Pile 4: (a) actual data and (b) simulated data.

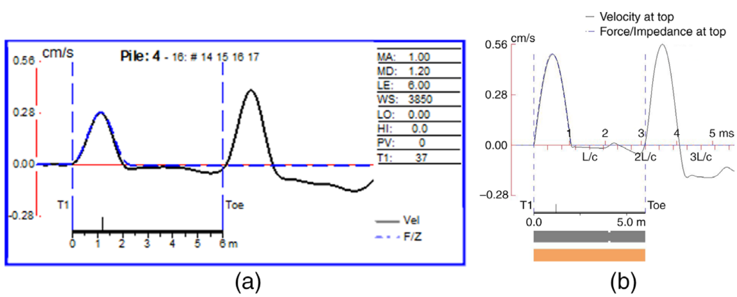


FIG. 9 Pile 4A: (a) actual data and (b) simulated data.

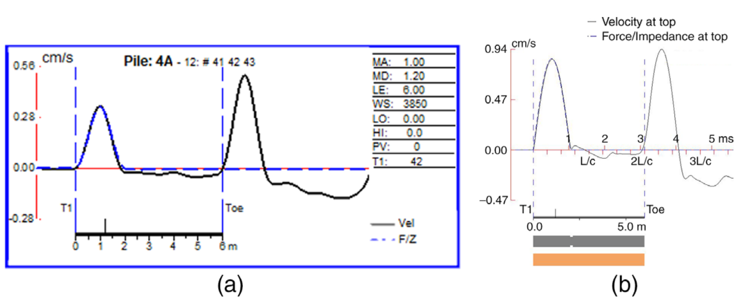


FIG. 10 Pile 5: (a) actual data and (b) simulated data.

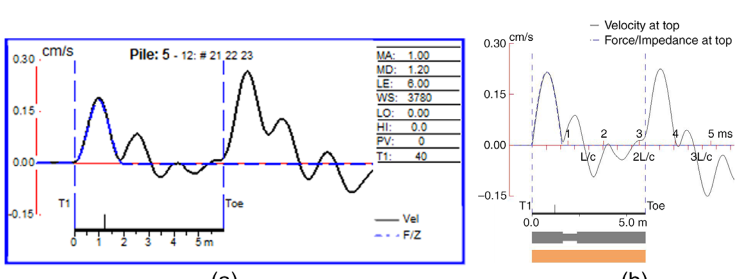


FIG. 11 Pile 5A: (a) actual data and (b) simulated data.

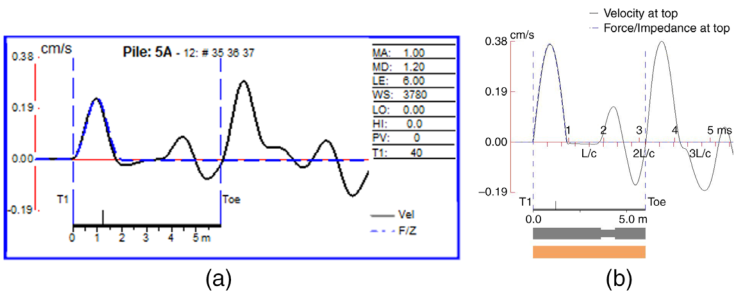


FIG. 12 Pile 6: (a) actual data and (b) simulated data.

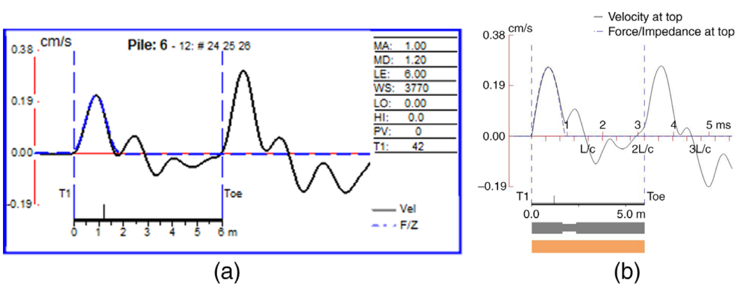


FIG. 13 Pile 6A: (a) actual data and (b) simulated data.

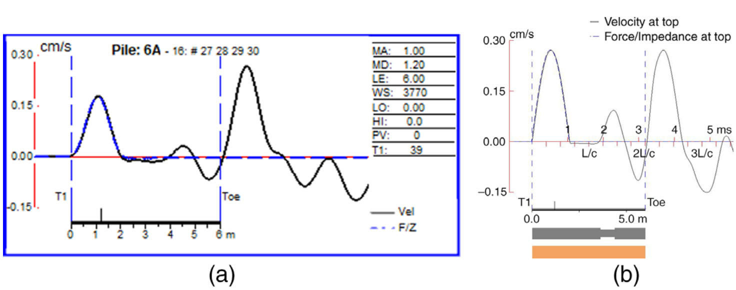


FIG. 14 Pile 7: (a) actual data and (b) simulated data.

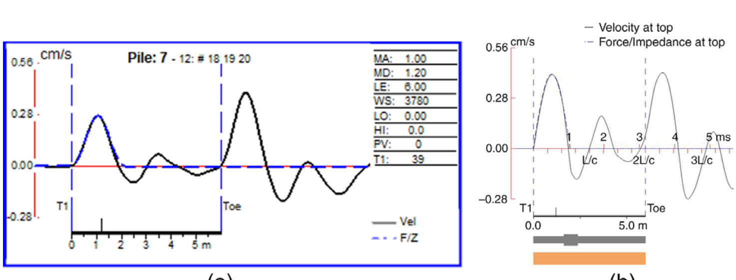


FIG. 15 Pile 7A: (a) actual data and (b) simulated data.

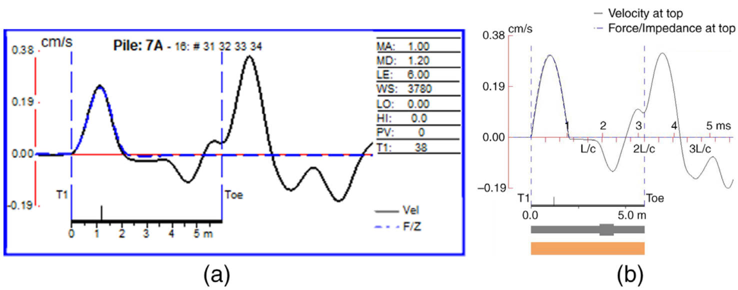


FIG. 16 Pile 8: (a) actual data and (b) simulated data.

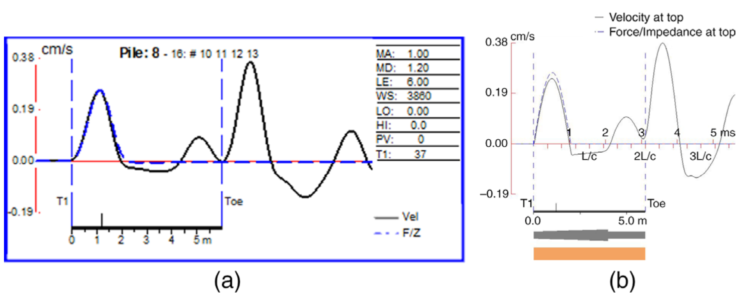
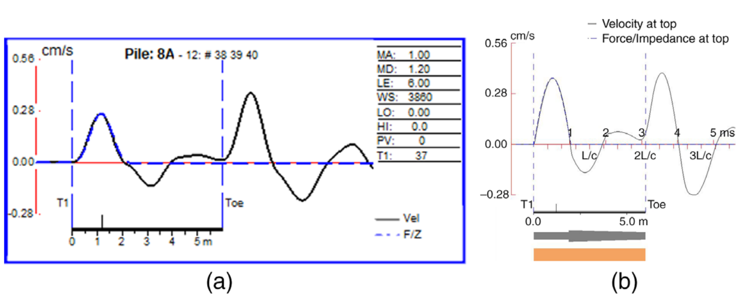


FIG. 17 Pile 8A: (a) actual data and (b) simulated data.



represents the pile profile, and the orange rectangle represents the soil profile. Table 1 shows a summary of the characteristics of the tested piles, including the wave propagation speeds determined from the time between impact and the arrival of the toe reflection in the actual field data.

Discussion

The similarity of the simulated and actual data was very good. There was, however, a noticeable difference between the shape of the actual input pulse and the half sine

TABLE 1 Characteristics and wave speeds determined for the tested piles.

Pile	Length (m)	Reinforced?	Wave speed (m/s)	Notes
1	4.8	No	3850	
2	6.0	Yes	3870	Reference pile
3	6.0	Yes	3700	
4	6.0	Yes	3850	Clay intrusion
5	6.0	No	3780	
6	6.0	Yes	3770	
7	6.0	Yes	3780	
8	6.0	Yes	3860	

wave used in the simulation. This accounts for some negligible differences between the actual and simulated shapes of the reflections caused by the cross-section changes.

The simulations for Pile 4, with a clay intrusion, already showed that the effect of the intrusion in the data would be very small. The actual data, however, showed even smaller reflections than predicted, and it is safe to say that in normal test practice such reductions would not be reported. Two factors contributed to the discrepancy between simulated and actual data:

- The intrusion was simulated as a total void in the concrete, when in fact a rather hard clay was used to fill the void, thus reducing the effective impedance decrease caused by the intrusion.
- Although the maximum cross-section area reduction caused by the intrusion was 28.27 %, it was only reached at the middle of the void. The effective reduction length was therefore very small, which made it more difficult to detect.

The wave propagation speeds for all piles varied in a narrow range between 3,700 and 3,860 m/s. The steel reinforcement cage caused no noticeable trend in the wave speed. One possible explanation is that, because the wave speed is directly proportional to the elastic modulus and inversely proportional to the specific weight, an equal change in both parameters would not cause an appreciable change in wave speed.

Conclusions

Eight square precast concrete piles were placed horizontally on the ground and submitted to low-strain integrity testing from both extremities. The piles had cross-section area changes made on purpose, and two of the piles did not have reinforcement cages. The test results were compared with computer-generated simulations. A summary of the findings is as follows:

- In general, the simulations were in very good agreement with the actual data. There was, however, a noticeable difference between the shape of the actual force pulse and the half sine wave used in the simulation. The effect of this difference in the effectiveness of the simulations was negligible.

- The good agreement between the simulations and the actual data encourages the use of the simulation program in a reverse-analysis mode, where the shape of the pile is interactively changed until the best possible match between the simulation and the actual measured velocity record is achieved.
- The simulations overestimated the effect of a small spherical clay intrusion in one of the piles. The intrusion, with a diameter of 0.15 m, was practically unnoticeable in the actual data. Possible reasons for this discrepancy between simulated and real data are (1) the effect of the hard clay used to fill the intrusion and (2) the very small effective length of the defect, also due to its spherical shape.
- There was no appreciable difference between the wave propagation speeds determined for piles with or without non-prestressed reinforcement or any detectable trend in those speeds that could be attributed to the absence of reinforcement.
- Although the piles tested had a square cross section, these conclusions apply to piles of any shape because the low-strain integrity test is sensitive only to variations in the value of the cross-section area.

The UNICAMP Experimental Campus is an ongoing project, and it is hoped that the results described herein will encourage other research projects, especially in the field of low-strain integrity testing.

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