BEM Analysis of the Dynamic Response Experiments for Pile-Soil Systems

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This paper arises from some experimental tests carried out last summer at the University of Catania on three piles on line under dynamic horizontal loads. Figure 1 shows the lay-out of the tests, but further details may be found in the literature, [1], [2], [3].

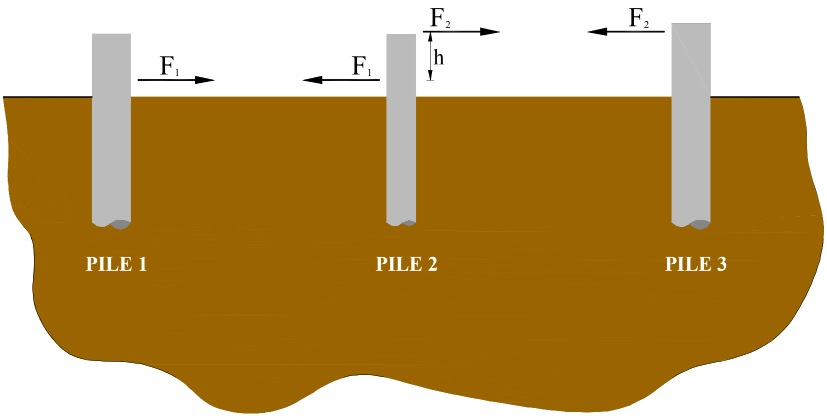

Figure 1. Schematic view of the load condition.

Piles 1 and 3 were subjected to horizontal forces applied at different heights at the pile head, while pile 2 should ideally have been subjected to a pure couple. However measurements showed that practice at times may be quite different from theory and pile 2 turned out to be subject to a couple plus a horizontal force at the pile head. The results of the tests will be reported in full elsewhere; here it suffices to say that tests where performed at three different nominal load levels, namely 50kN, 100kN and 150kN. At each load level tests were repeated several times. The nominal load was applied in a pseudo-static way and then was suddenly released to provide a dynamic response.

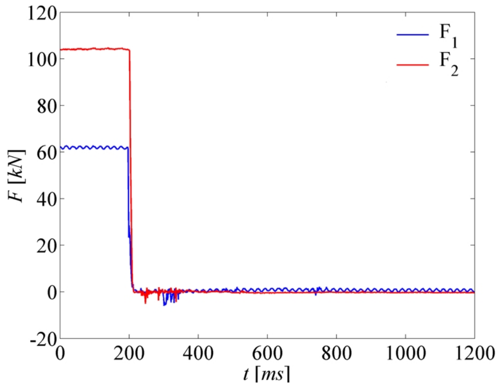

Figure 2. Load histories at nominal loading level of 50 kN.

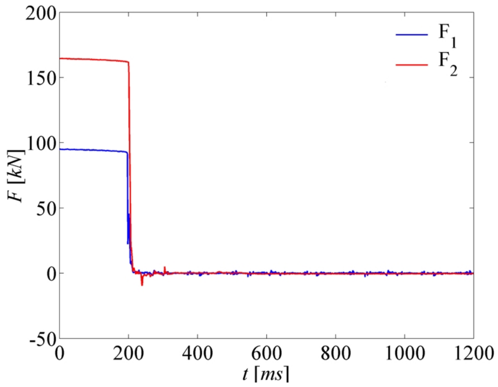

Figure 3. Load histories at nominal loading level of 100 kN.

The sudden load release will be shown during the presentation of the paper in a few tests at different nominal load levels. The loads applied at each pile were measured by dynamic load cells and two typical measurements at different load levels are shown in Figures 2 and 3. The measurements of Figure 2 refer to the nominal load level of 50kN. However Figure 2 shows that the nominal load was exceeded by about 20%

on pile 1, while the load was more than double on pile 3. This situation gives rise to the presence of a net horizontal force on pile 2, in addition to the expected couple. At the higher nominal load of 100kN, the nominal load is closely attained on pile 1, but again is exceeded by nearly 50% on pile 3.

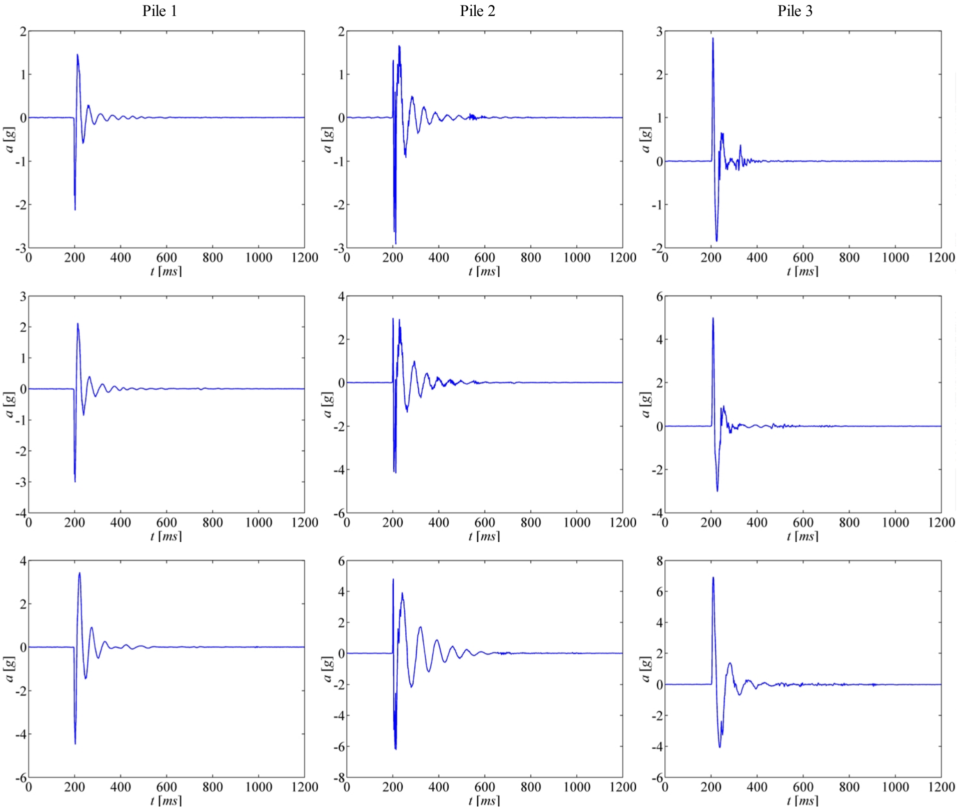

Figure 4. Horizontal acceleration at pile heads for load levels: 50 kN (top), 100 kN (middle) and 150 kN (bottom).

Typical results obtained in terms of the acceleration at the pile heads are shown in Figure 4 for the three nominal load levels. Textbook expectations are satisfied such as amplitude and period of the oscillation increasing with the load level, clearly indicating the influence of local non-linearities in the response. One more subtle effect has also been shown by the tests at higher nominal loads; the shortening of the oscillation period with time.

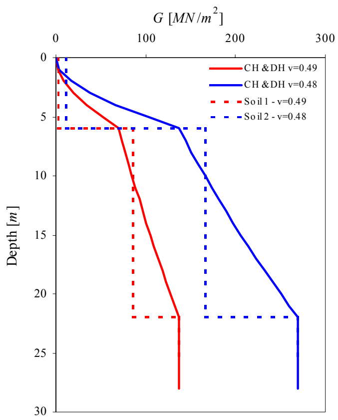

Figure 5. Two idealized soil profiles.

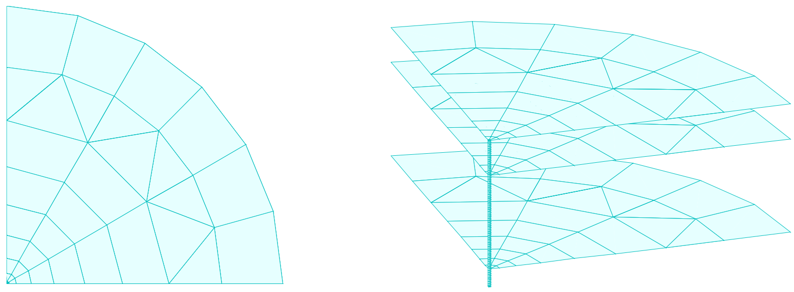

Figure 6. BEM discretization of the pile-soil system.

Numerical Modelling .The numerical modelling has posed several problems that are still under investigation at the moment. The variability of the soil properties with depth has been the first problem to be faced. From cross-hole and down-hole wave propagation tests, the two limit soil profiles shown by solid lines in Figure 5

were identified. These were replaced by piecewise constant profiles as shown by dotted lines in the same Figure 5. Preliminary studies showed that the distance between the test piles was large enough for the pile-soil-pile interaction to be considered as negligible, [3]. Therefore a 3D BEM model for the soil and the pile was constructed as shown in Figure 6. The problems that had to be solved to arrive at the optimal mesh are reported elsewhere in the literature [2], [3]. As may be easily gathered from Figure 6, the Kelvin-Stokes fundamental solution that requires the discretization of the free surface has been used in the BEM formulation. This gives rise to an undesirable and potentially lethal effect that should be properly addressed in the literature, the non symmetry of the stiffness matrix of the soil-pile system. This is not due to mesh problems, but to the use of the Kelvin-Stokes fundamental solution in an unbounded domain limited by an unbounded free surface; the reciprocity condition cannot be enforced whenever the discretization of the free surface must be truncated. The cross-terms of the dynamic stiffness matrix are not equal as they should be.
Another relevant problem arises when damping is considered. It is traditional to use the hysteretic or rate independent damping model when dealing with soil-structure interaction problems; however it has been amply demonstrated that the hysteretic model is non-causal, [4], and unpredictable and erratic results may come out of its use. An example of the application of the hysteretic damping model for the soil to the piles in the experimental tests described above is reported below. The load history has been specified by a ramp function followed by a constant function, to simulate pseudo-static behaviour, and then by a sudden drop to zero. By using the dynamic stiffness functions derived from the BEM model of Figure 6, the displacement response history shown in Figure 7 is found. Here the non-causal behaviour of the hysteretic model is clearly visible with the oscillating behaviour just before the load is released and with the unexpected behaviour after its release; the rest condition is approached from above and not with a normal decaying oscillatory behaviour of zero mean. In terms of acceleration the behaviour obtained is shown in Figure 8 against the experimental results.

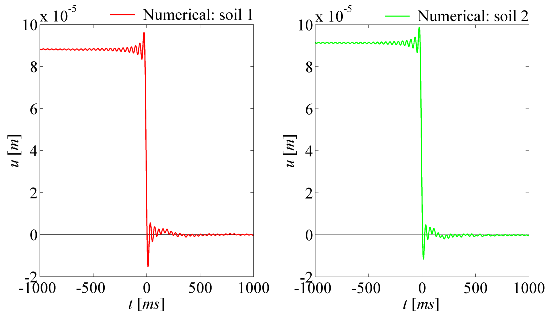

Figure 7. Displacement history.

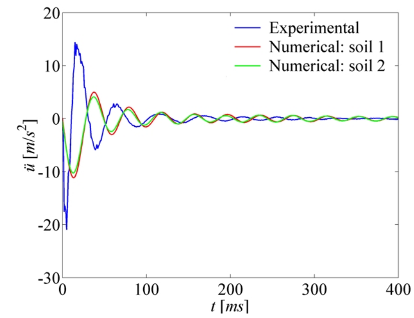

Figure 8. Numerical versus experimental acceleration history.

The smaller peak in the numerical result may be due to an excess of damping, tan $\delta = 0.10$ was used in the computation of the dynamic stiffness functions, but the unexpected result is the zero value of the acceleration when the force is suddenly released while one would expect maximum value instead.
Investigations are underway replacing hysteretic with equivalent viscous damping at the frequency of the experimental oscillation. Damping will also be adjusted to match the peak response as closely as possible. Although these are important points in this experimental-numerical investigation on pile-soil interaction, the really relevant points currently under investigation are how to tackle local non-linearities in the description of the actual structure-pile-foundation-soil system under earthquake excitation.

References

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