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Discussion by Michael D. Justason[5] and Bengt H. Fellenius,[6] Members, ASCE

The authors are complimented for undertaking the publishing of the 1990 field test data. However, the Statnamic method was invented in 1989, only one year before the field test. The authors present the approximate method of interpretation as applied in 1990. However, since that time, a method of analysis of the records has become available, as will be detailed in this discussion.

The Statnamic method uses a propellant to send a weight up in the air above a pile, in the process creating a downward force on the pile. The Statnamic measurements of the resulting event consist of force, movement, acceleration, and time. The process is described generically as a "rapid loading test," or "long-duration impulse test," suggesting that, while the dynamic effects of inertia and damping must be addressed, the method is different from the procedures employed for both static and dynamic loading tests. The most important display of the results consists of the Statnamic force-movement curve and the calculated load-movement curve (static response load), as illustrated in Fig. 21, presenting the Statnamic results for Piles 4 and 7 of the 1990 FHWA field test. The static curves are derived according to the "Unloading-Point Method" (Middendorp et al. 1992; Matsumoto and Nishimura 1996). The unloading point is where the pile movement changes from downward to upward—i.e., the pile rebounds.

Fig. 22 presents a schematic of the model employed in the process—a simple mass with a spring and a dashpot attached. The Statnamic force acting at the pile head, the pile inertia, the damping force (which is a function of the pile velocity), and the static resistance are in equilibrium, as described in Eq. (1):

$$F_{STN} - (ma + cv + ku) = 0 \qquad (1)$$

where F_{STN} = Statnamic force, measured; m = mass of pile, known; a = acceleration of pile, measured; c = damping factor, unknown; v = velocity of pile, known (from either a or u) k = pile/soil modulus, unknown; and u = pile movement, measured. Eq. (1) presents the general relation. For comparison, in a static loading test, both acceleration and velocity are essentially zero and force is simply equal to modulus times movement, i.e., the force is at all times equal to the static component of the pile/soil response.

The two unknowns in (1) are the damping factor, c, and the modulus, k. The other values are either known or measured. In the early days (late 1960s) of pile dynamic testing of driven piles, a method was used that assumed the pile capacity to be equal to the force measured in the pile when the velocity was zero, that is, when the pile just starts to rebound (Rausche et al. 1985). The method was not useful, however, because the velocity in a driven pile is never zero at the same time all through the pile. For the long-duration impulse of the Statnamic method, however, the pile moves essentially as a rigid body (Justason et al. 1998; Nishimura et al. 1998)—that is, zero velocity occurs simultaneously along the full length of the pile. This becomes less true as the pile length increases, but for piles shorter than 40 to 50 m, observations and research have shown the above statement to be valid (Middendorp et al. 1995; Nishimura et al. 1998).

At the time of zero velocity, the damping component of (1) is zero, because the velocity is zero. This determines the static resistance, ku, at the unloading point, as shown in Eq. (2):

$$ku = F_{STN} - ma \qquad (2)$$

In the measured Statnamic force-movement curve, the pile movement continues downward even after the measured force begins to decrease (Fig. 21). This continues until the unloading point is reached and the pile begins to rebound. In the range between the maximum Statnamic force and the unloading point, where the load is decreasing and the movement is still increasing, the value of the term "ku" *at the unloading point* is assumed to represent the static resistance of the pile. This is the primary assumption of the unloading-point method. Eq. (1) can be rearranged to Eq. (3), indicating the solution for "c" with the variable "ku" replaced with the constant "F_{STAT}" (which is the value of "ku" determined at the unloading point):

$$c = (F_{STN} - ma - F_{STAT})/v \qquad (3)$$

The value of the damping factor, c, in (3) is calculated for each instant in time between the maximum F_{STN} and the un-

[5]Sr. Engr., Berminghammer Foundation Equipment, Wellington St. Marine Terminal, Hamilton, ON, Canada L8L 4Z9.
[6]Prin., Urkkada Technology, Ltd., 1010 Polytek St., Unit 6, Ottawa, ON, Canada K1J 9H8.

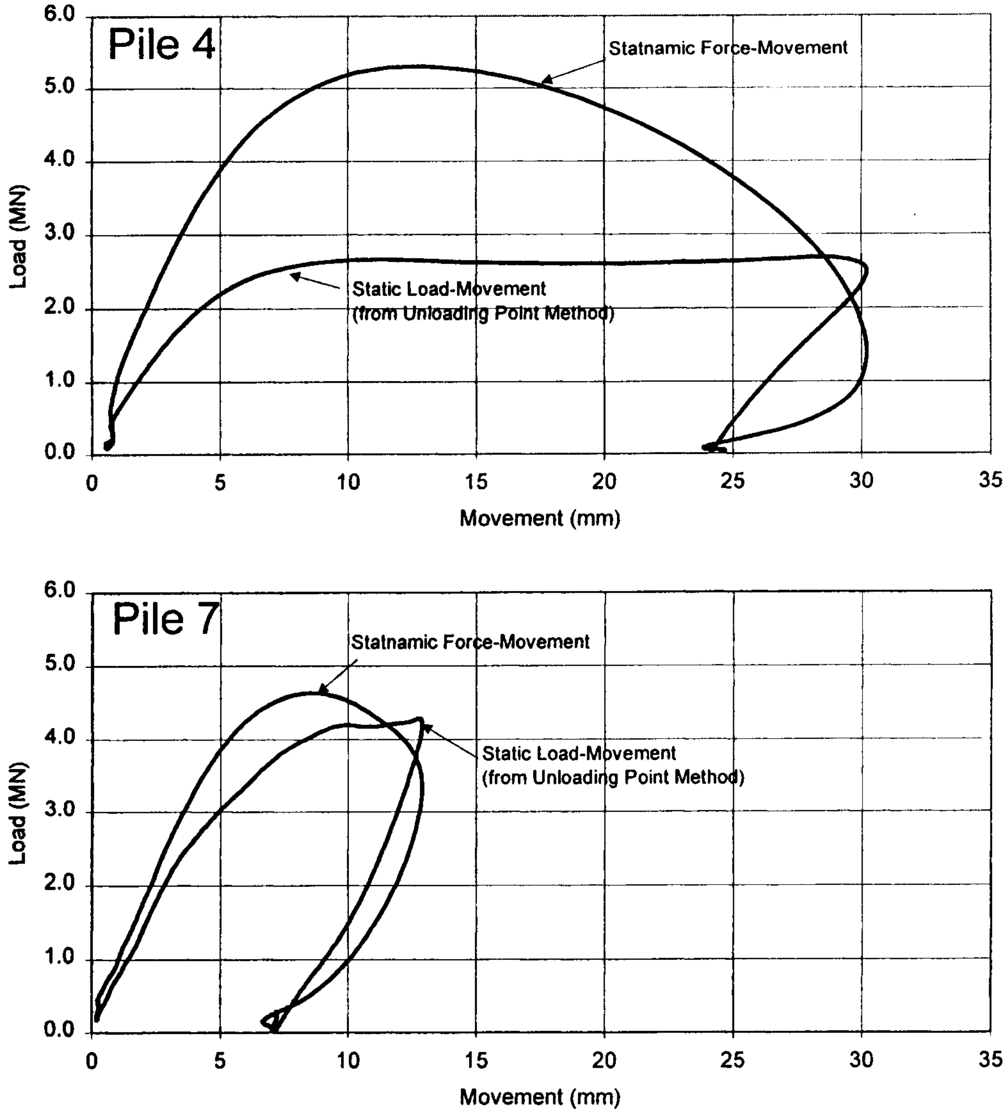

FIG. 21. Statnamic Force-Movement and Static Load-Movement Curves from Unloading Point Method for Piles 4 and 7

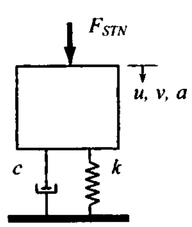

FIG. 22. Schematic Model for Analysis of Statnamic Results

loading point. (Typically, the number of data points collected in this range is 50 to 200 for which the factor can be calculated. The number of data points depends on the magnitude of movement of the pile after the maximum Statnamic force is reached). The c-values are averaged and input into Eq. (4) in a calculation of all collected data points, resulting in a static load-movement curve, as illustrated in Fig. 21. Fig. 21 shows plots of F_{STN} versus u (the measured Statnamic force-movement curve), and ku versus u (the derived static load-movement curve) for Piles 4 and 7. The difference in load between the Statnamic force at the Unloading point and the static load is the inertia of the pile at that point.

$$ku = F_{STN} - ma - c_{avg}v \tag{4}$$

The discussers recognize that the calculations involve approximations. However, the experience during the past decade from a total of several thousand Statnamic tests, for which many have had the analysis results correlated to the results of static loading tests, has shown the method of analysis to agree well with static pile capacities (Nishimura et al. 2000; Shibata et al. 2000).

Unfortunately, the Statnamic results of Pile 2 could not be analyzed using the unloading point method, since the maximum range of the optical movement transducer was exceeded before the unloading point was reached. (The current state of the art in Statnamic instrumentation includes an accelerometer as a backup to the optical transducer to prevent such loss of data).

When comparing the results of the static loading tests and the dynamic tests, just using the values of ultimate resistance are not meaningful. Instead, the full stress-history needs to be

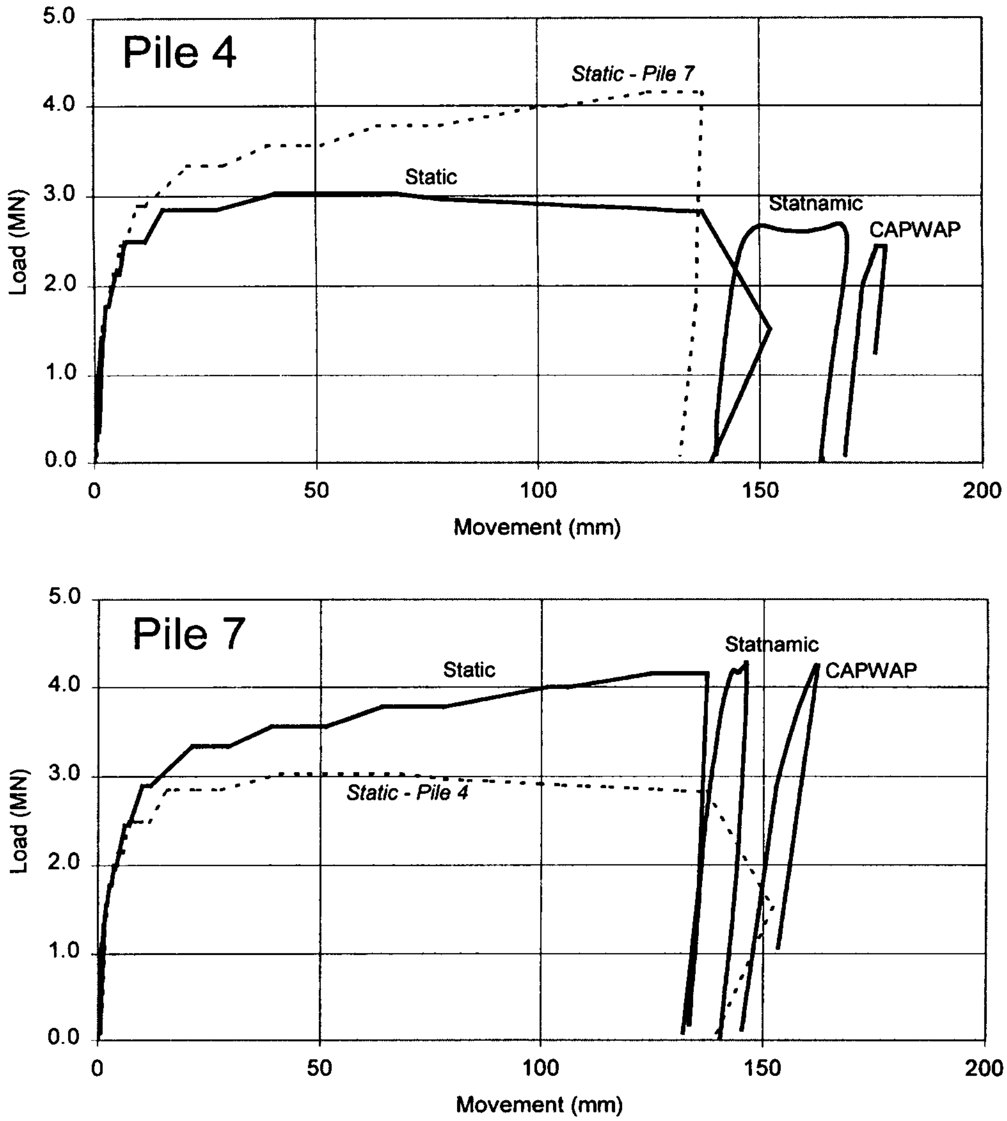

FIG. 23. Static Load-Movement Curves for Actual Sequence of Testing of Piles 4 and 7

presented. When the discussers compared the Statnamic records with the results of the static loading tests and the CAPWAP results, it became evident that, while the Statnamic and the CAPWAP results for Piles 4 and 7 agreed very well, there was poor agreement with the results of the static loading tests. The disagreement was so large and deviated so much from what is normally observed that it is questionable if the dynamic tests and the static tests were indeed made on the same pile. The situation becomes clear when the dynamic and Statnamic results from Piles 4 and 7 are plotted with the results of the static loading test on Piles 7 and 4, respectively. The discussers believe that the static loading tests on Piles 4 and 7, as presented in the paper, have exchanged numbers. (The computer field records of Statnamic and PDA test data verify that these tests were carried out on the same piles, as numbered here and in the discussion).

The results of all three types of test are presented in Fig. 23 per the actual stress history (sequence of testing). As seen, there is very good agreement between all three types of testing. (For comparison purposes, Fig. 23 also indicates the static load-movement curves of the "misnumbered" tests). A comparison between the load values obtained early in the static tests, be it at the Davisson Offset Limit load or at a percentage of the pile diameter, is not meaningful, as the dynamic tests are reloading tests. A reloading test will always depend on the effect of the loads locked in from the preceding test(s) and show a difference in capacity and stiffness response, as opposed to a test performed under virgin conditions.

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