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But, Surely, Dynamic Measurements are Only for Special Projects, Eh?

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"Having dynamic monitoring to test for pile capacity, hammer performance, and/or integrity is great; whenever I realize that I have a problem with pile capacity, hammer performance, and/or integrity, I will order the measurements".

The foregoing statement includes the same difficulty as "when I am caught out in a rainstorm I will ensure that I have my umbrella along". Clearly, the statement does not 'hold water' unless one 'ensures' that the umbrella is there at all times or, at least, whenever there is a chance for rain.

Most piling projects go well. When the construction is over, the capacities are satisfactory, the hammers worked well, and there is no lingering question of integrity; all are satisfied and no litigation casts a shadow over the future. After all, most people do not have an accident when driving to work. So, would it not be good if we only needed bother about having a paid-up, valid car and life insurance on the very few days we have an accident? The perfect world is a low-cost, very predictable place. Just like Utopia.

In the real world, difficulties during pile installation work are unpredictable and costly. They are also frequent. Very wisely, therefore, the new Public Works Canada master construction specifications for piling indicates that dynamic monitoring should be included in the specifications for all piling projects. For most projects, only a limited verification testing would be necessary - at a cost of $2,000 to $3,000, much less than the cost of a static loading test, which the dynamic monitoring in almost all projects would show to be redundant. For the many projects where problems arise, by means of dynamic measurements, the magnitude of a problem is minimized, the solution is obtained at a minimum of costs, time is saved, and, above all, the trauma of an unresolved dispute going to litigation is avoided. This is especially true when dynamic measurements are also taken before a problem appears.

The following brief case histories from recent piling projects illustrate the benefits of including dynamic measurements in routine projects. For each case, routine dynamic measurements were included in the contract specifications and, therefore, the particular problem was discovered very early and its solution was simple. Without the measurements, each case would have suffered delays, and costly special testing. Most likely, they would have lead to a contract dispute.

Case 1. H-piles, Size 310 x 110, were driven for the foundations of a highway bridge across a stream where the soils consisted of about 14 m of loose to compact layers of clay and silt sublayered by a variable deposit of very dense sand with lenses of gravel, silt, some clay - probably a reworked ablation till. The Standard Penetration Test N-values in the sand ranged from a low of 80 through a high of 110. The boreholes were terminated at a depth of about 36 m. Routine dynamic measurements were taken on piles and the testing included a static loading test on a 20 m deep pile. The driving of the test pile was easy at first. The penetration resistance increased upon reaching and driving into the first few metres of the very dense sand fetching up over the last 3 m of penetration to a final value of 20 blows/25 mm. The results of a static test - the pile did not fail at the maximum applied load of 2,700 KN - agreed well with a wave equation analysis, and with the results of the dynamic measurements. At a penetration resistance of about 10 blows/25 mm, the calculated capacity was about 2,500 KN. Capacity calculated for "refusal" driving was about 3,000 KN. The hammer performed well.

When the construction moved across the stream, the driving behavior was markedly different: the resistance in the sand did not fetch up: at a depth of 35 m, it was a mere 250 blows/m (6 blows/25 mm) and the dynamic measurements indicated a capacity of only 1,700 KN. No increase was gained by driving deeper - at 41 m depth (5 m deeper than the borehole), the resistance was 7 blows/25 mm and the capacity was unchanged. Values at continued driving and at restriking were the same indicating complete lack of gain in capacity due to set-up.

The dynamic measurements could exonerate the pile driving hammer and pile damage, leading the engineers to look to the soil for the answers. It became evident that the low capacity and the absence of gain from driving deeper were due to artesian pore pressure conditions (upward gradient) and that no benefit would be obtained from placing the abutment on long piles. A decision was made to use shorter piles with a corresponding increase of the number of piles of a downgraded individual pile capacity. The technical and economical pile lengths and number of piles was arrived at quickly from analysis using the results of the dynamic measurements.

Had the initial routine dynamic measurements not been available, the solution would not have been as readily reached. One can speculate to what extent additional investigation would have been necessary for static loading tests, driving test piles, and making new soil borings. And the delays, the delays! The cost of those, of the engineering efforts, and of the testing would have been considerable. Furthermore, it is very probable that the contractor would have had cause for hefty claims.

Case 2. High yield steel pipe piles, Size 178 x 10 mm, were installed by means of a drop hammer at a site where the soil consisted of about 4 m of sand fill followed by about 5 m of silt deposited on a shale and limestone bedrock, a very common rock formation found at a depth of about 9 m. On the face of it, a very simple and assured project and one often not even considered to require more than a minimum of quality control and inspection.

The piles were driven to bedrock to penetration resistance of up to 25 blows/25 mm and restruck after a waiting period of a day of two. In restriking the piles, however, the piles did not behave as expected, but penetrated as much as an inch in two blows! Needless to say, this reduced blow count created a considerable concern for the foundation. Had the contractor's hammer worked properly during the initial driving? If the reason was to be found with the rock response, what should be done to solve the problem?

The routine dynamic measurements showed that the hammer was functioning properly - the transferred driving energy was adequate and the impact stress was about 200 MPa. Furthermore, analysis of the measurement data showed that the pile capacity at beginning of restrike was about 700 KN to 800 KN instead of the desired value of about at least 1,000 KN which was determined from measurements taken at the termination of the initial driving. This phenomenon is known as "relaxation".

Relaxation is an irregularly occurring phenomenon in this rock formation and thought to be the effect of negative pore pressures created when the pile toe enters the bedrock. The negative pore pressures are caused when the pile displaces the broken rock pieces and water is prevented by the impervious soils above the rock from filling the voids between the rock pieces. The result is an apparent, or temporary capacity, and a falsely high penetration resistance. When the pore pressures have dissipated and the pile is restruck, the rock pieces can more freely be displaced and, in restriking, the pile encounters a smaller, "the true", static resistance.

The steel yield was 345 MPa and the dynamic measurements showed that there was an ample margin for increasing the driving stress in the piles. Therefore, the problem was easily solved by raising the hammer height-of-fall to increase the impact stress and transferred driving energy during initial driving, thus obtaining a larger initial capacity. Then, after the relaxation had occurred, the final capacity determined in restriking was adequate.

Obviously, had not the routine dynamic measurements been available, delays would have been unavoidable due to time spent in discussing the cause of the problem, deciding on special investigations, test driving, and, possibly even static loading tests. Instead, the measurements immediately identified the problem, the solution was obvious, its success was proven with no delays to the project and at minimal costs, and there was no dispute with the contractor.

Case 3. High yield steel pipe piles, Size 178 x 14 mm, were installed by means of a diesel hammer at a site where the soil consisted of about 7 m of clay followed by about 1 m of clayey silt deposited on a weathered shale bedrock found at a depth of about 16 m. The piles were intended for an allowable load larger than about 1,200 KN. Although the piles are heavier and the intended capacities larger, this case is, on the face of it, as simple as that of the second case history.

The bedrock formation is not the same as for Case 2. Otherwise, the observations are almost identical. Piles driven to a penetration resistance at end-of-initial-driving close to "practical refusal" exhibited a penetration resistance at first blow of restrike equivalent to values as low as 2 blows/25 mm. The obvious solution was the same. In this case, though, the diesel hammer was already working at its maximum level. To achieve the higher capacity at end-of-initial-driving, a drop hammer was brought in for restriking the piles after the initial driving. The dynamic analysis indicated and subsequent dynamic measurements confirmed the suitable hammer weight, height-of-fall, and termination criterion (penetration resistance) required to achieve a surplus capacity at the end of the initial driving that gave an adequate margin for relaxation to develop. Dynamic testing in restriking confirmed the solution. Again, without the measurements, any other approach to the problem would have been very costly, difficult, and time consuming.

Final Comments. The three brief case histories are just a few of many encountered in routine practice. Because the engineers for these projects were prudent enough to follow the guidelines of the new Public Works Canada master specs and had foresight to include the routine dynamic measurements with the contract, the problems were readily resolved and the projects were characterized as easy and good. As good as the about two to three times as common projects when the dynamic measurements and other observations of the pile driving did not indicate any problem. In contrast, the many projects, where the dynamic measurements were not included in the contract as a matter of routine and where problems arose, can surely not be characterized as easy and their solution is hardly "effortless".

Perhaps, even more important and worthy of a thought or two - might even be the cause and topic of a bad dream - are the projects where no dynamic measurements were used <u>and</u> no one noticed the problem of too low capacity, damaged piles, and other undesirable by-products of an haphazard approach to or wishful thinking in the design of a piling project.

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