Statnamic Load Testing Using Water as Reaction Mass

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ABSTRACT: The following paper describes experiments performed in Hamilton, Canada, using water as reaction mass for Statnamic testing. These trial tests represented the first such tests performed in the world. These tests were performed in Lake Ontario, on a 323 mm diameter pipe pile driven in 8 m of water. The tests were performed using a 0.6 MN Statnamic device and hydraulic catching mechanism with a specially designed hanging structure from which a submerged steel container was used to contain a mass of water. The goal of the testing was to investigate the potential for using water to replace concrete and steel for use as reaction mass for Statnamic tests. This paper also describes Statnamic test results from the first two Statnamic testing contracts for the Port of Lake Charles, Lake Charles, Louisiana, USA. These jobs were performed by Applied Foundation Testing, Inc. of Green Cove Springs, Florida, USA. These tests were performed on square concrete piles, with test loads ranging from 4.0 MN to 5.0 MN. This paper also summarizes the theoretical research conducted by Middendorp and Courage in 1995, which influenced the design of the actual water reaction mass assemblies for the experimental work of 1998.

1 INTRODUCTION

Statnamic load testing is frequently performed on foundations for bridge piers and port structures. Since these locations are over-water, a support structure is required for the Statnamic apparatus. The typical support structure consists of four temporary piles and a steel platform. Although this setup is not difficult, it does require extra time and cost to install.

Alternatively, it is possible to construct a platform supported only by the test pile using a collar or sleeve that slides over the test pile. This method has been popular in Japan and has some advantages and disadvantages compared to the four temporary support piles.

In both of the methods described above, the Statnamic reaction masses, base frame and gravel container must be mobilized to the jobsite, in addition to materials for the support structure.

The idea of using the water surrounding the foundation to replace the conventional use of concrete and/or steel as reaction mass has been discussed for several years. The advantages of this idea would be: mass would not need to be mobilized to the jobsite; a support frame would not be required; and the time for setup and tear-down could be decreased.

This paper describes the research and experiments performed in 1998 surrounding the use of water as reaction mass for Statnamic testing, as well as the preceding theoretical work. This paper also describes the test results for the first contract Statnamic tests performed using water as reaction mass in 1999.

2 RESEARCH

2.1 *Theory*

In a typical Statnamic test, a mass (usually concrete or steel) is used as reaction for an upward thrust produced by expanding gases within the Statnamic device. The masses are placed on top of the Statnamic device and are typically accelerated at about 20 times the acceleration of gravity in the upward direction. The result is a downward force on the foundation of 20 times the weight of the reaction masses. Although the applied force on the foundation cannot be sustained (force durations of 100ms are typical), the magnitude of the force is large in relation to the amount of mass needed.

Even though the amount of mass required to perform a Statnamic test is small in relation to the mass required for a static load test, there is still cost involved in the mobilization of this mass. It had been proposed in the early 1990's, that for foundations situated in a marine environment it should be possible to use the readily available quantity of water to provide the mass needed to perform a Statnamic test, thus eliminating the mobilization cost of the concrete or steel masses.

Middendorp and Courage of TNO Building and Construction Research performed one of the first theoretical studies of water as Statnamic reaction mass in 1995. In this analysis three configurations of the underwater container were examined.

The first mathematical model described a completely closed steel container, filled with water and submerged. The steel container was assumed to remain entirely below the water surface throughout the test. After the initial upward acceleration of the Statnamic test, it was calculated that the continued upward movement of the container would be very large due to the upward momentum of such a large volume of water. The deceleration force of gravity could only act on the mass of the steel container and not on the mass of water, which was weightless while submerged, and moving upward very quickly.

The main advantage of this first model was that a relatively small amount of mass would need to be 'caught' by whatever type of catching mechanism was to be devised. The disadvantage was that an unrealistically large jumping height of the mass would need to be accommodated.

The second mathematical model examined the simple case where the container described in the first model was allowed to rise above the surface of the water. In this case the deceleration force of gravity was able to act on the mass of water as well as the mass of the steel container. As expected, the jumping height of the mass was greatly reduced. Unfortunately, this configuration would place greater physical demands on the catching mechanism.

The third model presented the most attractive solution. In this model the top of the steel container was left open, and valves or 'trap-doors' were introduced to the bottom of the container. This configuration allowed for the same mass of water to be 'contained' as in the first two models, thus providing equal inertial reaction for the Statnamic loading event. During the upward acceleration of the Statnamic device the valves in the container bottom remained closed. During the deceleration phase of the event the contained moving mass of water was allowed to flow through the container rather than 'lift' the container along with it.

Modest jumping heights were observed in this container configuration, even when the container remaining completely submerged throughout the event. This was the most favorable model for the design of an over-water catching mechanism. A schematic of this third model is shown in Figure 1.

Additional theoretical work was performed by Baddour in 1998, just prior to the construction of the first prototype underwater reaction mass container. The main issues addressed were: the additional mobilized mass of water 'above' the container, drag forces above and below the container, and drag forces on the sides of the container. Calculations generally agreed with the previous work by Middendorp and Courage. However, the work by Baddour focused more on the forces that would govern the structural design of the steel containers.

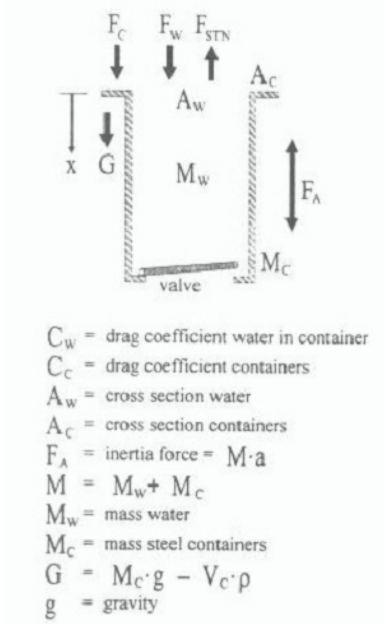

Figure 1 Force Diagram of Middendorp and Courage mathematical model of water reaction mass

Most of the remaining questions centered on the physical concerns of assembling such a test. The only remaining task was to undertake a physical experiment.

2.2 *Experiment*

In the spring of 1998, a series of 12 Statnamic load tests were performed in Hamilton, Canada. These tests were conducted using a 0.6 MN Statnamic device and a prototype submerged reaction mass container.

2.2.1 *Apparatus*

Testing was conducted using a 0.6 MN Statnamic device. A hydraulic catching mechanism was also used to facilitate repetitive testing. The testing apparatus, along with the fabricated reaction mass assembly is shown in Figure 2.

The test pile was located in a corner of the dock structure at the Berminghammer Facility, thus it was possible to span the corner with long beams to provide a temporary platform for the Statnamic apparatus. A view of the test setup can be seen in Figure 3.

The fabricated steel reaction mass assembly consisted of a 1.07 m diameter steel casing 2.13 m in length. On the inside of the casing, another steel pipe was used to centralize the assembly over the

323 mm diameter pipe pile that was used as the test pile. The top of the container was constructed with a flat top with six 250 mm holes. The container was fabricated with a flat bottom with six 250 mm holes. The purpose of the bottom holes was to allow the container to fill with water as it was lowered over the test pile. Each 250 mm bottom hole was also equipped with a hinged door that opened in the upward direction. These doors were designed to remain closed during the upward acceleration of the container to prevent the water from simply flowing through in the downward direction. The doors did allow water to flow through the container in the upward direction after the completion of a test, to prevent the creation of a low-pressure area at the bottom of the container due to the upward momentum of the contained water and to act as the valves proposed by the Middendorp and Courage model. A photo of the submerged reaction mass assembly is shown in Figure 4.

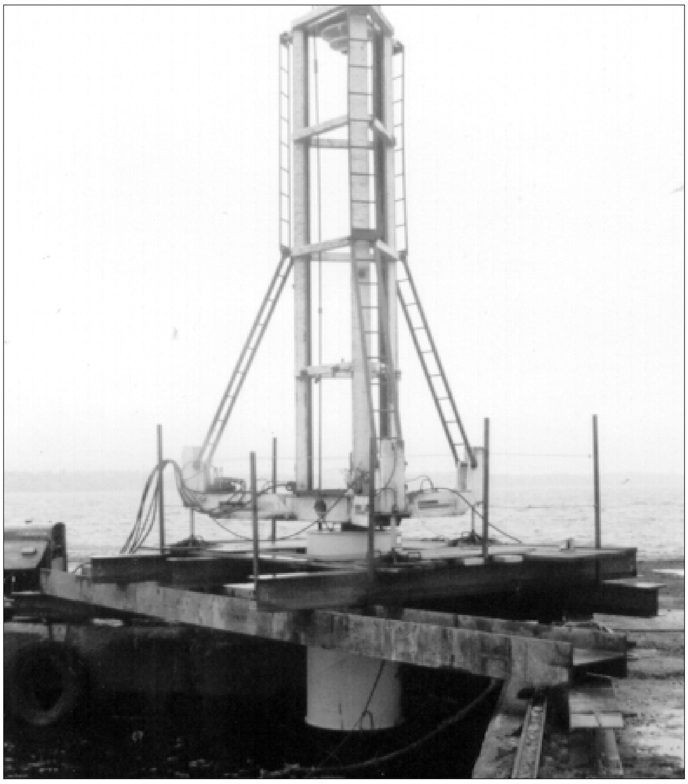

Figure 2 Test apparatus consisting of 0.6 MN Statnamic device, hydraulic catching mechanism, platform, and underwater reaction mass assembly (shown above water).

High tensile strength anchor rods provided the load transfer from the Statnamic device to the top and bottom of the reaction mass assembly. Two sets of three rods were used. The first set was 8 m long while the second set were 4 m long. The two sets were coupled together to provide the required length to perform one series of tests with the top of the reaction mass assembly 3.3 m below the water surface (masses stayed below the water surface during testing), and another set of tests with only 0.3 m of submergence (masses jumped out of the water during testing).

The test pile was a 20 m long closed end steel pipe pile 323 mm in diameter with a wall thickness of 8.0 mm. The pile was installed using an MKT V16 vibratory hammer with a peak driving force of 1.1 MN.

The soil at the test location consisted of 7.8 m of water, overlying soft marine silt sediments to a depth of 33 m. The purpose of the foundation was to provide a consistent elastic load deflection behavior for all tests with the loading capacity of the 0.6 MN Statnamic device.

Figure 3 View of test setup clearly showing the support platform spanning the corner of the dock.

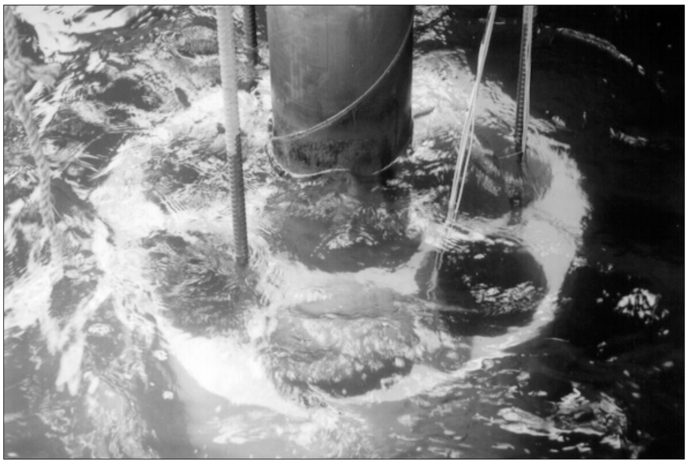

Figure 4 View of submerged reaction mass assembly

After the first seven load tests using the above reaction mass configuration, a 250 mm wide flange was welded to the outer edge of the water container. This flange (added to the bottom outer edge), essentially doubled the plan area of the reaction mass assembly. This was done to investigate the effects of drag on the behavior of the underwater reaction mass assembly.

The total reaction mass for this testing was 3350 kg, with 1490 kg (44%) provided by the Statnamic cylinder, silencer and reaction mass assembly. The remaining 1860 kg (56%) of the reaction mass was provided by the contained water.

2.2.2 *Instrumentation*

Accelerometers were placed on the reaction mass flange of the Statnamic device. These measurements were used to determine the acceleration of the under water reaction mass assembly. The jumping height of the Statnamic device was measured after each load cycle.

Pressure transducers were mounted in various locations, both inside and outside the water reaction mass assembly. These measurements were made to help investigate the behavior of the water both inside and outside the steel container.

In addition to the above special instrumentation, the typical Statnamic load cell, laser displacement sensor, and pile accelerometer was also used.

2.2.3 *Typical Results*

For all of the loading cycles performed in this experiment, the test pile was not displaced beyond its elastic range, providing an essentially rigid test foundation. Peak displacements of 7-8 mm were typical for the test pile, with net displacements of zero.

For discussion purposes, the results of three typical loading cycles will be discussed.

2.2.3.1 Series 1, Test 4 – Results

The first test to be discussed was performed during the first series of tests prior to the addition of the ‘drag flange’. The peak Statnamic load was 480 kN, with a measured upward acceleration of the reaction mass assembly of 10 g. Typical upward accelerations for the same test, performed with a typical amount of concrete reaction mass would have been approximately 15 g. The drag of the water provided a reduction in the upward acceleration of approximately 50%.

On land, with conventional reaction masses, the jumping height of the masses would have been approximately 2.3 m, while the measured jumping height of the water reaction masses was only 1.7 m – a reduction of 30%.

The pressure transducers mounted on the reaction mass assembly suggested peak drag forces on the underside of the reaction mass assembly of 35 kN. The peak drag force on the top of the assembly was 58 kN. These forces occurred at the same time as the peak Statnamic load. Together the drag forces accounted for 93 kN, or about 19% of the applied load. Significant changes in the lateral pressure on the container were not observed suggesting minimal drag along the sides of the reaction mass assembly.

2.2.3.2 Series 2, Test 10 – Results

This series of tests was performed with the additional drag flange welded to the bottom of the reaction mass assembly.

The peak Statnamic load for this test was 496 kN. The load was very near to the previously discussed test, however the 3% increase in the peak force was achieved without increasing the amount of Statnamic fuel. This was likely achieved by a combination of the increased mass of the drag flange (120 kg), as well as the increased drag at the peak load.

The peak upward acceleration of the reaction mass assembly was approximately 9 g rather than 10 g. And the jumping height of the masses was only 1.4 m, down from the previous 1.7 m, a reduction of 18%.

The pressure transducers indicated similar pressures to the previous testing, both on the top and bottom of the reaction mass assembly. The increased area on the bottom of the container translated into an estimated peak drag force of 85 kN.

The addition of the drag flange increased the total drag resistance to approximately 140 kN or 28% of the peak Statnamic load.

2.2.3.3 Series 2, Test 12 – Results

Test 12 provided data on one of the highest peak loads of all the tests performed. This test was also performed with the drag flange included on the reaction mass assembly.

The peak Statnamic load for this test was 573 kN, very close to the device capacity of 600 kN.

For an equivalent land test using the same mass of concrete or steel, the peak upward acceleration would have been approximately 17 g. The peak measured acceleration was 11.5 g, a reduction of 32%.

Pressure transducer measurements implied a peak drag force beneath the container of 115 kN and peak drag forces on top of the container of 40 kN. In this case the drag forces accounted for a total resistive force equal to 27% of the applied load.

Compared to Test 10, the drag forces provided a slightly lower percentage to the peak applied force, however the magnitude of the forces did increase with the increased applied load. This suggested that the drag forces provided additional resistance ‘for free’ under additional applied load. In other words, the total ‘effective’ reaction mass was increased without increasing the actual mass.

2.2.4 *Discussion*

From the data presented here, it was observed that the drag forces on the top and bottom of the reaction mass assembly both contributed to the overall resistance provided to the Statnamic loading event. More generally, it was observed that the combination of water mass and drag forces provided an effective reaction mass.

The valves proposed by Middendorp and Courage appeared to function as intended, although an additional series of tests were also performed with the valves welded shut. These tests showed only small increases to the jumping height of the masses. This was not readily explained by the theory. For tests with the valves open and with the valves shut, there was a visible plume of upwardly moving water that appeared at the water surface about 2 seconds after the Statnamic test (see Figure 5).

Tests were also performed in which the submerged reaction mass assembly was permitted to exit the water surface. In these tests, the reduction in the jumping height was significant and, although spectacular, the tests it did produce an increased strain on the catching mechanism.

Use of the hydraulic catching mechanism provided a convenient means of performing this research, however, the contribution of the hydraulic cylinders to the jumping height of the reaction mass was not quantified. One small test was performed without the use of the catching cylinders simply to observe the rate of decent of the masses after the test. This test was not repeated due to the rapid rate of decent that was observed and due to the possible risk of damage to the equipment. This highlighted the need for a catching device.

More detailed results and analysis of this series of tests are provided in Janes (1998).

Figure 5 Plume of water visible shortly after each loading event

3 FULL SCALE TESTING

Given the positive results of the small-scale testing in 1998, it was decided that the water reaction mass technology and theory was sound enough for use in the commercial sector. The American testing company, Applied Foundation Testing, Inc. in conjunction with Berminghammer Foundation Equipment of Canada collaborated on a project performed for the Lake Charles Harbor and Terminal District.

Two testing contracts were undertaken for the Harbor. The first contract was performed in May of 1999, and involved the testing of two 600 mm square concrete piles. The test load for these piles was 4.0 MN.

The second contract for the Harbor was performed in June of 1999 and involved the testing of three 750 mm square concrete piles and three 600 mm square concrete piles. The test load for these piles was 5.0 MN.

3.1 *Apparatus*

Figure 6 shows an elevation schematic of the apparatus used for testing in Lake Charles. For this project it was not possible to use a supporting platform as for the experiments performed in 1998. Without the supporting platform, it was necessary to devise a catching frame that was solely supported by the test-pile. The resulting design consisted of two 5 m steel truss towers, connected at the top and bottom, with enough space in between for the Statnamic device.

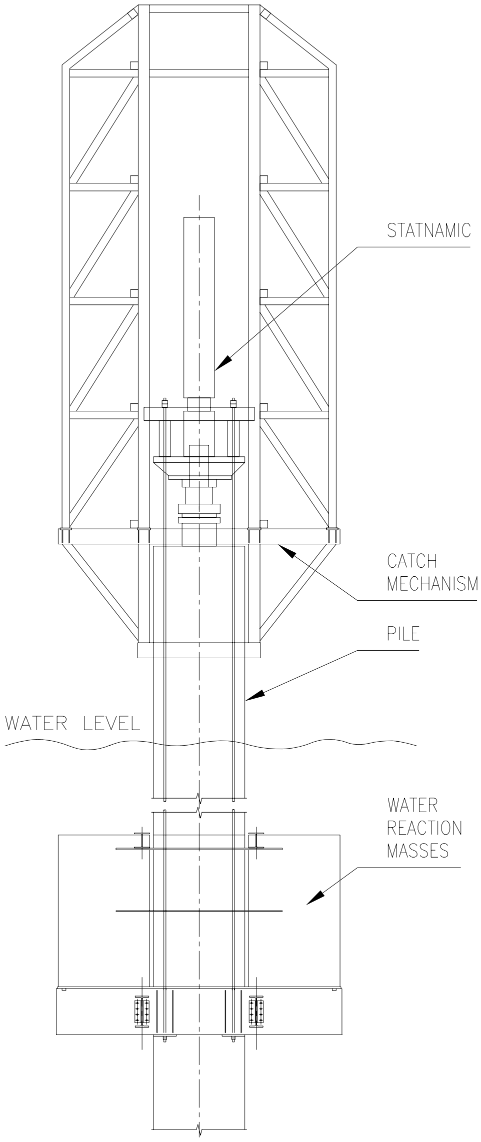

Figure 6 Elevation view of the Lake Charles testing apparatus

The catching mechanism was a mechanical latch system running on vertically mounted racks of ‘teeth’. Due to the reduced quantity of mass that was actually ‘caught’, it was believed that a simple mechanical system could provide the required catching capacity. This was in contrast to the hydraulic catching systems that are normally required for land based tests in which the entire reaction mass must be ‘caught’.

The water container consisted of six, 1.2 m diameter steel casings with closed bottoms. The length of the containers was 2.0 m. The structural support for the casings was provided by two, 1 m deep steel I-beams, mounted below the casings. The upward Statnamic force was transferred to the containers through high-tensile rods connecting the I-beams with the Statnamic device, similar to the 1998 experimental testing.

A photo of the system is shown in Figure 7, in which the entire reaction mass assembly is visible. Figure 7 also demonstrates the means by which the system was moved from one test pile to the next. The convenience of a large crane allowed the entire system to be moved from pile to pile without disassembly. On the second testing contract this allowed for as many as three piles to be tested in one day with the possibility for more.

Figure 7 Statnamic equipment being placed on a test pile

Unlike the prototype equipment of 1998, the reaction mass container was not equipped with ‘valves’ in the bottom of the steel casings. The trap-door type valves of the Middendorp/Courage model were replaced by two manually operated gate valves. The superior watertight sealing of these valves allowed the reaction mass containers to actually float for several hours while the above-water equipment was assembled on the test pile. Allowing the containers to float made the logistics of the test setup much more straightforward. The gate valves were opened just before the each test to allow the containers to fill with water and to sink to their starting elevation below the water. During testing the gate valves were left open. After the testing, the open gate valves allowed the water to drain from the containers as they were extracted from the water.

In comparison to the 1998 testing, the Lake Charles under-water equipment contained a larger percentage of actual contained water mass. The mass of water was 13,600 kg, while the mass of the containers and associated structures was only 9,400.

However, including the mass of the Statnamic silencer, high-tensile rods, and reaction beams mounted on the Statnamic device, the total non-water mass was very close to the 13,600 kg of the contained water. In general, the testing system was expected to behave much like the 1998 prototype.

Perhaps the largest uncertainty in this test program was the performance of the new ‘mechanical’ catching mechanism.

3.2 *Test Results*

Unlike the 1998 experimental testing, the main focus during the Lake Charles testing was the actual movement of the pile, rather than the movement of the reaction masses. Unfortunately, data was not collected on the upward acceleration of the reaction mass assembly. From the test data the force-time curves give the most information about the behavior of the testing apparatus. Jumping heights were recorded, but are not presented here.

Figure 8, shows the force-time curve for one of the first 4MN tests on the 600 mm piles. Figure 9, shows a typical force-time curve for a conventional Statnamic testing using concrete and steel masses. The similarity between the two graphs shows the effectiveness of the water reaction mass assembly.

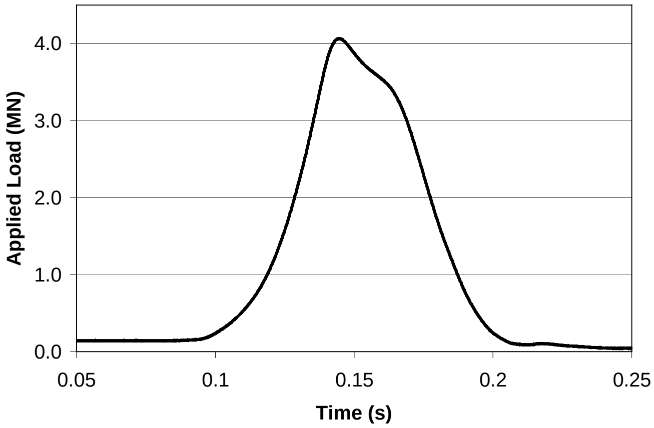

Figure 8

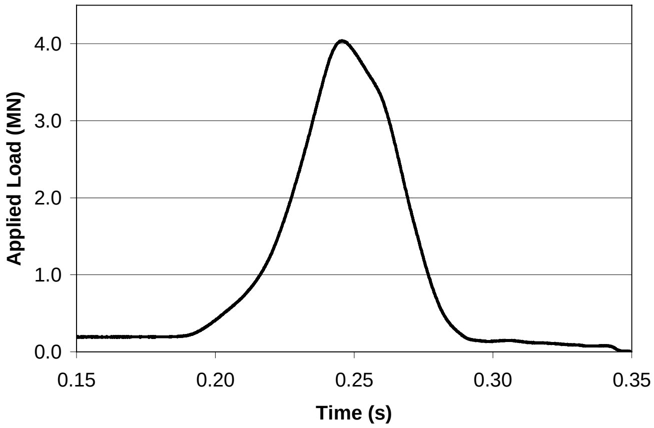

Figure 9

4 SUMMARY AND CONCLUSIONS

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