Statnamic Test on Piles

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ABSTRACT
The statnamic pile load test combines the advantages of both static and dynamic load tests. It is performed to test a pile's capacity and uses a rapid compressive loading method. The applied load, acceleration, and displacements are measured using load cells, accelerometers, and displacement transducers with a stationary laser reference. The statnamic device consists of a large mass, combustion chamber, and a catch system of some sort. The force applied to the pile is produced by accelerating a mass upward. This is done by firing a rapid-burning propellant fuel within the combustion chamber, which applies equal force to the mass and to the pile. After the fuel is burned the gas port is opened, this allows the duration of the load pulse to be long enough to keep the pile in compression throughout the test (maintains rigid body). During the loading cycle, which is only a fraction of a second, over 2000 readings are taken of the load and displacement and the data are stored in a data-acquisition unit. The mass is caught as it falls by a gravel catch or mechanical tooth catch before it impacts the pile. The load–displacement curves generated are used to determine the equivalent static force from the measured statnamic force using the unloading point method.

Keywords
Static load test, Statnamic load test, Dynamic load test, Rapid load test.

1. INTRODUCTION
Statnamic Test on Piles is a new method of testing piles. Statnamic load testing has been used extensively all over the world on bridges, high rise structures, office towers, military facilities, Corps of Engineers, flood control structures, water and wastewater facilities and various other commercial structures. Statnamic is a combination of 2 words "static & dynamic", which is a new way to test pile capacity of deep foundations with loading period of around 200 milliseconds.

2. LOAD TESTS
2.1 Static Load Test
Static compressive load testing involves the placement of a large, stationary load on top of a foundation element. It is then left for a specified length of time and settlement is recorded. The Static load test is administered following ASTM D1143-81, and these guidelines inherently create restrictions on the testable size and capacity. One major limitation of the static test is the proximity restrictions of reaction piles or anchors which is determined by the diameter of the test pile. According to the test standard, the reaction anchors should be placed no closer than five diameters of the test pile to minimize the interference in zones of influence. As a result, larger shafts would require very long clear span reaction beams. For example, a 6´ diameter drilled shaft would require a 60´ reaction beam (five diameters away on either side). Further, the reaction beam would need to resist even larger loads. A 1500 ton static load is a practical upper limit with extreme cases of up to 3500 tons. Supplying and placing such a beam and load combination increases the cost of the test. Such tests would require weeks of preparation, which further increases the cost.

2.2 Dynamic Load Test
Dynamic testing is usually associated with driving piles (ASTM D4945-00). When it is applied to drilled shafts, it is termed a drop hammer test. Therein, a steel mass is dropped from a prescribed distance in order to impart a sufficient force. The impact induces tensile stresses that are not well tolerated by drilled shafts constructed of reinforced concrete. This type of test is best when applied to driven piles made of steel, wood, or prestressed concrete. Concrete piles have not always used prestressed concrete, however, the reinforced concrete counterparts were heavily reinforced (2% steel), far exceeding the reinforcement of typical drilled shafts (1% steel). A dynamic load test has a very short duration, lasting as little as 5 milliseconds as defined by ASTM. In order to use the results, there must be a visible return of the stress wave to the surface in the recorded data (Middendorp and Van Foeken 2000).

2.3 Rapid Load Test
Rapid load tests do not induce tensile stresses and have minimal to no wave effects due to the duration of the load test. However, rapid tests do induce an acceleration to the entire foundation mass, which in turn requires proper evaluation techniques. The statnamic load test is a type of rapid load test based on its duration, usually lasting 100-250 milliseconds (Lewis, 1999). The ASTM standard for this test is still in the drafting process; it will be similar to the test standard proposed by the Japanese Geotechnical Society. It is developed jointly by Birmingham Foundation Solutions of Canada and TNO Building and Construction Research of the Netherlands in 1989.

3. STATNAMIC TEST METHOD
3.1 The Principle of Statnamic Method
The main principle of statnamic load testing is based on launching reaction masses from top of pile. It is accelerated upward by combustion of fast burning solid fuel (Rock fuel). As force of burning fuel accelerates the reaction mass (at 20 times the acceleration of gravity), an equal & opposite force (m x a of reaction mass) pushes test pile downward. Using Newton´s II law of acceleration, the reaction masses are accelerated upward at 20g where a force acts downward onto the pile will be 20 times the reaction masses assembly. Loading of the pile is monitored using a calibrated load cell and displacement is monitored using a photo voltaic cell laser sensor. All data recorded are digitized and stored in a portable computer connected to the assembly. Figure 1 presents the

schematic diagram indicating the principle of statnamic method.

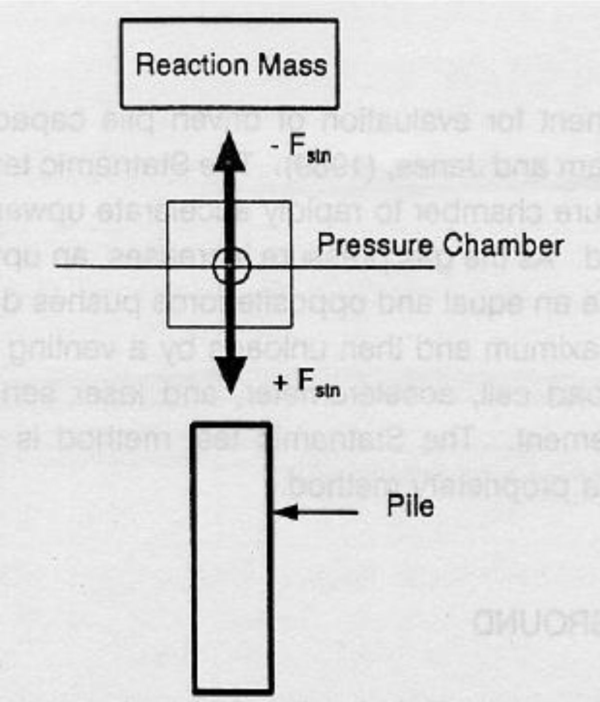

Figure 1: Principle of Statnamic Method

The duration of a statnamic load testing is in the order of 120-150 milliseconds. This produces a dynamic load on the pile top which is enough to allow the pile react as a rigid body without the influence of stress wave propagation within the pile. The soil is in turn loaded with minimum inertial effects and damping.

3.2 Stanamic Method Components

The device as shown in Figure 2 consists of three main parts: Piston Cylinder/silence (Combustion chamber**)**, Reaction masses, Load Cell, Laser Sensor, and Gravel Container.

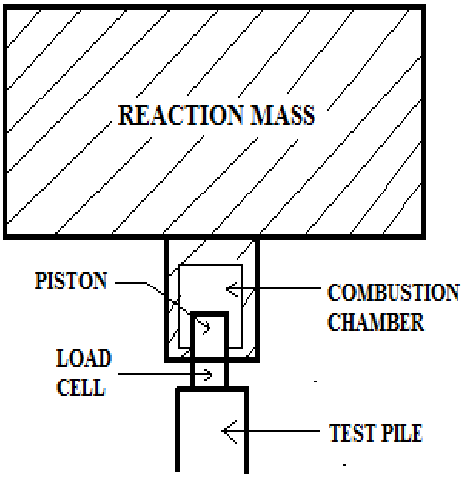

Figure 2: Statnamic Components [4]

3.2.1 Piston

The piston is placed on top of pile inserted inside cylinder. Solid propellant is burned inside the piston to generate a gas pressure.
The piston is mounted horizontally on a foundation using a hemispherical bearing to minimize any eccentricities in the load. While the Figure 3 presents location of piston & Figure 4 presents its installation.

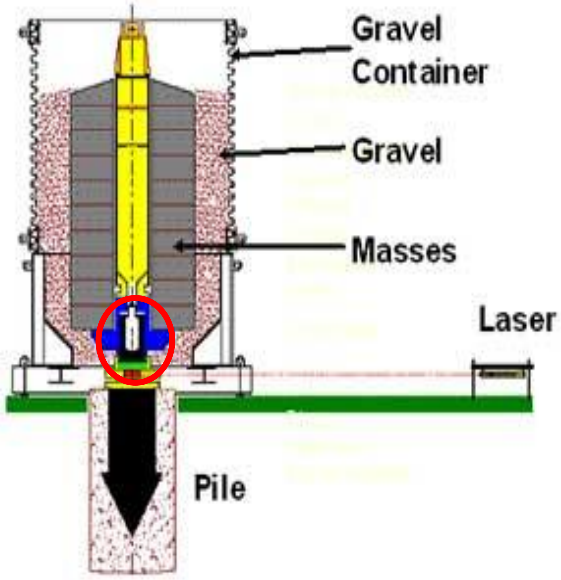

Figure 3: Location of piston [21]

Figure 4: Installation of Piston [1]

3.2.2 Cylinder/Silencer (Combustion Chamber)

It fits over the piston & is accelerated by the expanding gas. The accelerated masses generate a force equal to the mass times acceleration. The force applied to the pile is produced by accelerating a mass upward. This is done by firing a rapid-burning propellant fuel within the combustion chamber, which applies equal force to the mass and to the pile.
After the fuel is burned the gas ports opened, this allows the duration of the load pulse to be long enough to keep the pile in compression throughout the test (maintains rigid body). Figure 5 illustrate the installation of cylinder.

Figure 5: Cylinder Installation [1]

3.2.3 Reaction Masses

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 as shown in Figure 6. The masses are placed on top of the Statnamic silencer. Accelerated at about 20 times the acceleration of gravity in the upward direction. The result is downward force on the foundation of 20 times the weight of the reaction masses.

Figure 6: Reaction Masses [1]

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. It is launched by generating high pressure in the cylinder by burning special fuel. It causes pile to be gently pushed into the soil. For safety reasons, reaction masses are enclosed within a metal casing filled with gravel or other materials used to dampen the return fall of the reaction masses.

3.3 Water as a Reaction Mass

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. Figure 7 demonstrates the use of water as reaction mass.

Figure 7: Water as reaction 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. For offshore works device tested using water as a reaction mass (can apply 14MN) to improve flexibility of device & minimise transportation costs.

3.4 Load and Displacement Measurement

Load cell is used for Load measurement. Ring type load cell as dipicted in Figure 8 is employed.

Figure 8: Ring Type Load Cell [1]

Whereas for measurement of displacement photovoltaic displacement transducer as shown in Figure 9 is used.

Figure 9: Photovoltaic Displacement Transducer [1]

Other deives used for displacement is laser sensor activated via laser projector as presented in Figure 10. Laser reference placed at 10m-20m from the test pile to minimize ground vibration (Brown & Hyde, 2006). It moves with the pile.

Figure 10: Remote Laser Projector [1]

3.5 Methodology

The Figure 11 presents schematic details of device assembly which is self explanatory. All components are handled with a hoisting machine. Reaction masses are sectional and made of concrete, lead, steel and others. Concrete reaction masses can be cast on-site and reused.

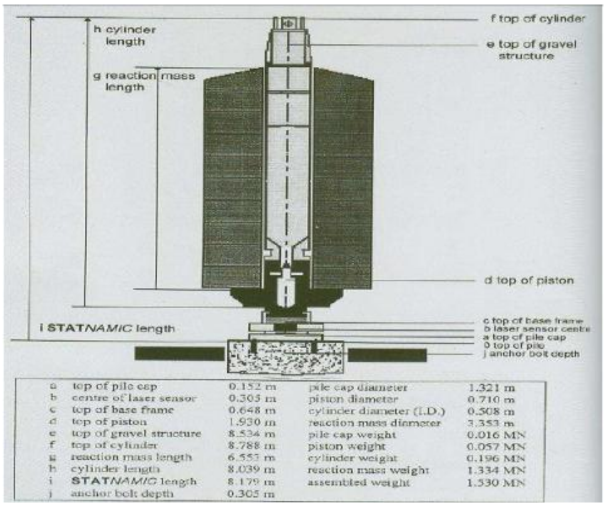

Figure 11: Statnamic Devices Assembly [1]

The statnamic test consists of four stages (refer Figure 12). Firstly placement of reaction mass on top of pile. Secondly burning of solid fuel. Thirdly exertion of upward force on reaction masses and finally felled reaction masses turn back on the pile.

At first solid fuel is burned within a pressure chamber (cylinder & ram) to generate gas pressure. As the pressure increases, an upward force is exerted on a set of reaction masses (from 1-3m) while an equal and opposite force pushes downward on the pile (from 10-100mm).

Then loads ranging from 5 tons up to 5,000 tons are generated (axially or laterally) by propelling a reaction mass upward off the foundation. The load is applied & removed smoothly resulting in load application of 100 to 200 milliseconds. This is 30 to 40 times the duration of dynamic pile load testing. Slow application of axial load & release of compressive forces eliminates tensile stresses, compressing soil & pile as single unit, allowing an accurate measurement of the load-displacement behaviour.

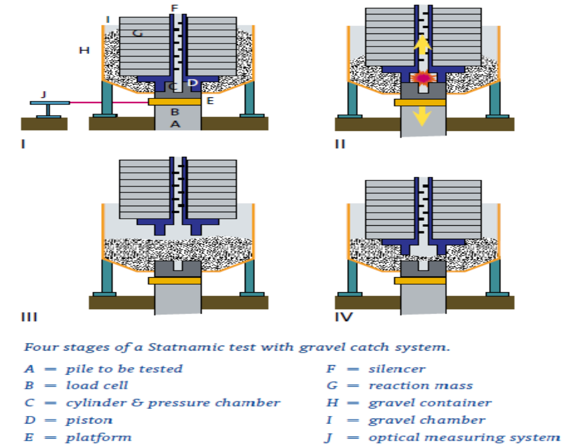

Figure 12: Stages of Statnamic test

Controlled venting of the pressure produces a soft unloading. The duration of load, loading rate & max. load applied is controlled with the piston & cylinder size, mass of fuel, total reaction mass & venting of gases. As the duration of the loading is long, piles less than 40m in length remain in compression throughout, resulting in negligible stress wave effects. Equivalent static pile response (static load-settlement curve) is obtained by Unloading Point Method (UPM). The UPM analysis method was conceived to be simple and based on measured results alone (Middendorp et al, 1992).

3.6 LOAD DURATION

3.6.1 Static Loading

Since velocity and acceleration are near zero throughout a static load test, damping and inertial effects are minimal. However, as the load duration decreases for quick static load tests, results can differ from conventional static tests due to the strain rate dependent nature of soil. Low permeability soils (soft silty or clayey soils) are most susceptible to quick load rates.

3.6.2 High Rate Dynamic Loading (Dynamic Load Tests)

Here the duration of pile loading is of the order of 4 milliseconds. The short duration of loading introduces stress waves to the pile and will unduly affect pile/soil behavior.

3.6.3 Low Rate Dynamic Loading (Statnamic)

The duration of pile loading here is of the order of 120 milliseconds. The load duration, while not of the order of static testing, is still relatively long compared to high rate dynamic testing. Dynamic rate effects are present only in low permeability, cohesive soils and can be measured using existing pile/soil models.

3.6.4 Stress Wave Mechanics

In conventional static loading, the pile compresses as a whole throughout loading and can be considered as a rigid body. As the load duration decreases, however, stress waves are introduced to the pile, effecting pile/soil behaviour. Stress waves propagate along the pile at the speed of sound within the pile. $C = (E/\rho)^{½}$ C = stress wave velocity E = pile/soil system modulus ρ = pile/soil density C is about 3500 – 4000 m/s for reinforced concrete piles and 5000 m/s for steel piles. For long piles(nearly 30m) an initial stress at the pile top will reach the pile toe in approximately 6 milliseconds, corresponding to the pile's nature period, (30/5000 = .006). As said earlier Statnamic loading is on the order of 120 milliseconds, well above the natural period of even the stiffest pile and as stress wave effects are minimized, the pile can be considered as a rigid body and conventional static analytical methods are applied. Although results from Statnamic load tests have shown that rate effects are negligible for piles in very stiff soils and piles end-bearing in rock, rate effects for piles in soft soils have been relatively large and have significantly influenced load-displacement behaviour. The Unloading Point model shown in Figure 13 is a simple method of analysis for determining the static resistance from a Statnamic test. As well, rate effects present during a Statnamic test can be quantified with the Unloading-Point model.

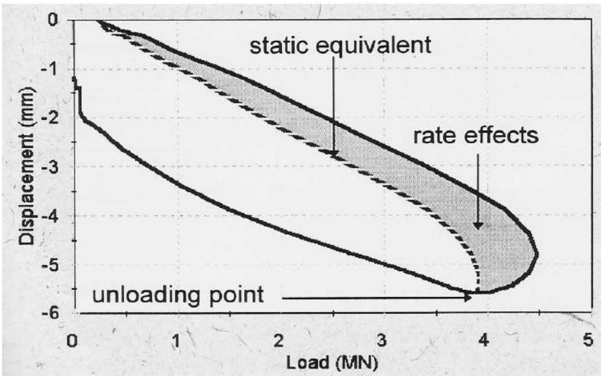

Figure 13: The Unloading Point Model

The rate of increase in pressurized gas production is therefore cubic, characteristic of solid propellant fuel. The Statnamic fuel consists of a number of small, perforated solid pellets. The burn rate depends on several parameters: Chemical composition, Pellet geometry, Temperature, Pressure. Chemical composition is chosen from factory burn trials. Perforated cylindrical pellets are preferred to solid pellets or flat plates because they increase in surface area throughout burning desired for statnamic. Furthermore, using many small pellets instead of one large fuel charge reduces a consistent burn and averages out any imperfections in a single pellet. As expected, the natural burn rate increases as temperature and pressure increases in pressure chamber. Under normal operating conditions, burning will not begin until the fuel temperature reaches 1000°C. The statnamic propellant can be safely handled and will not ignite under spark, friction, or agitation. When under atmospheric conditions, the burn is slow and easily controlled. The fuel can be extinguished with water. Propellant can be transported with minimum preparation stored for long periods of time without concern.

3.7 Data Acquisition and Record

Load and displacement data are measured at the pile top with a calibrated load cell and laser sensor and analyzed by TNO´s Foundation Pile Diagnostic System (FPDS). The load measurements are accurate to within 0.1 % and the displacement measurements are accurate to 0.1mm. A total of 2000 data points are recorded at a sampling rate of 250 microseconds for a total time 0.3 seconds, suitable to record the entire event. The sampling time and total measuring time are variable and can be changed in FPDS. The ignition triggering is also controlled by FPDS.

3.7.1 Load Cell

The statnamic load is measured by a circular load cell, located between the piston and the pile top. A number of strain gauge transducers, mounted on the load cell circumference, reduce the effects if any uneven loading. Loads signal from each transducers are averaged and amplified within the laod cell to reduce error and are further amplified by FPDS.

3.7.2 Load Sensor

Pile displacement is measured with photovoltaic laser sensor (located at the center of the piston base) and a remote reference laser source. During the statnamic event, the change in position of the laser sensor is measured relative to the stationary laser source. Throughout loading, load and displacement signals are digitized and written to a raw data file. After the event, the raw signal voltages are converted to load and displacement values using factory calibration values. Load-displacement graphs are presented immediately on-site. Supplementary graphs, including graphs of velocity and acceleration, are also generated by FPDS. Velocity and acceleration data are to be used for Unloading-Point Analysis to determine static load settlement behavior. During the Statnamic test, several measurements are taken; including the applied load pile head displacement toe accelerometer readings, MUP strains, SUP etc. The typical data acquisition system used to have such test record is shown in Figure 14. Data capture is undertaken using a data acquisition system connected to a PC to automatically produce a Load-Displacement curve (see Figure 15). During application of explosive force, pile moves into ground, generating both static & dynamic resistance. Pile downward movement stops & it rebounds upward to a final position. At point of zero velocity assumption is made that dynamic resistance is zero & that all of the resistance is, therefore, static. This concept is based on assumption that the pile is rigid.

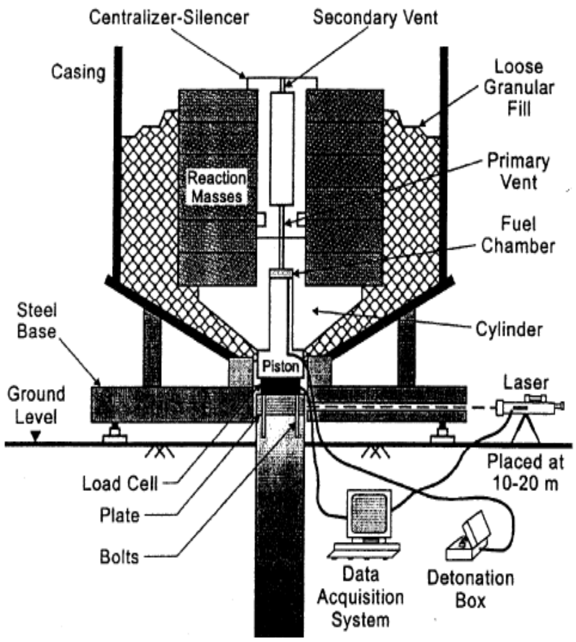

Figure 14: Data Acquisition System [14]

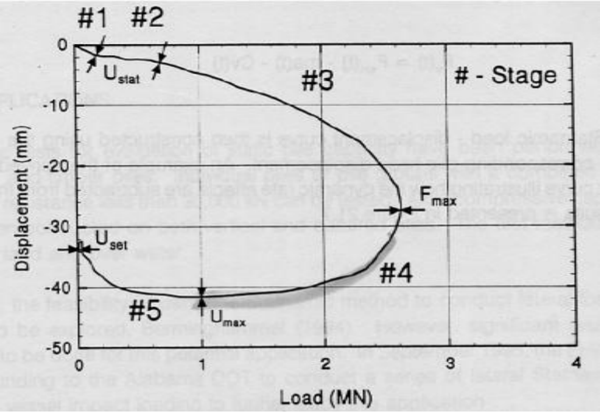

Figure 15: Statnamic Load-Displacement Curve Characteristics

4. COMPARISON BETWEEN DIFFERENT LOAD TESTS

The schematic presentation of comparison between different load tests is depicted in Figure 16 and the description of comparison between static load test, dynamic load test and statnamic load test is mentioned in Table 1.

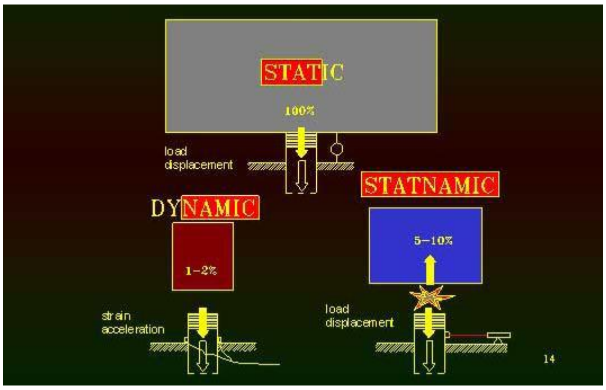

Figure 16: Schematic Comparison of Different Load Tests [21]

Table 1. Comparison Between Load Tests

Sr. No.	Static Load Test	Dynamic Load Test	Statnamic Load Test
1.	Requires reaction beam & hydraulic jack	It requires heavy weight drop hammer	It does not require reaction piles, reaction Beam & hydraulic jack
2.	Effective	Less effective than static	More effective
3.	Expensive	Expensive than static test	Economical than static testing as no reaction system & when multiple load tests are performed on a site or when the test loads are greater than 100t
4.	For bored and driven piles	For driven piles	For drilled shafts & bored piles
5.	Load range 100 KN to 12,000 KN	Weight of hammer used is 3-10 tons	More than 5000 ton
6.	Time required for setup & to perform testing is more	Less than static load test	Very less
7.	Displacement measurements to be noted independently	Displacement measurements to be noted independently	No need to measure displacement
8.	Provides capacity of piles	Provides capacity of piles	Provides important data during pile driving i.e. hammer energy, driving stresses, pile integrity, and driving resistance.

5. CONCLUSION

A study of current status of newly developed and highly sophisticated new technique of testing of pile termed as Statnamic Pile Test is presented. On the basis of data presented in this paper following main conclusions can be arrived at are as follows: Although the statnamic test is new, there are several advantages of using this test than the ordinary maintained load test such as the statnamic test applies loads up to 30 MN and higher. The statnamic test can also be tested on bored piles, drilled shafts, augured cast-in-place piles, micro-Piles, driven piles, prestressed concrete piles, spun cast concrete cylinder piles, pipe piles, H-Piles, mono-tube, taper-tube in clay, silt, rock and sand. This test is economical when compared with conventional pile load tests. However in opinion of authors this test can be used as a supplement test to conventional pile load test but it cannot replace the same due to inherent limitations associated with it.

6. ACKNOWLEDGMENTS

Author thanks everyone who were involved directly or indirectly for their advice, guidance, encouragement and critical evaluation at every stage in the successful completion of this work.

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