Statnamic Load Testing Overview

INTRODUCTION

Statnamic load testing has been used extensively all over the world on bridges, high rise condominium structures, office towers, military facilities, Corps of Engineers flood control structures, water and wastewater facilities and various other commercial structures. **Statnamic Load Testing is a recognized test method by the American Society for Testing and Materials designation number ASTM D7383-08.** Statnamic load testing is routinely used as an alternate to ASTM D1143 (Compression), ASTM D3689 (tension), ASTM D3966 (lateral) and ASTM D 1194 (plate load test). It can also be a higher quality alternate to ASTM D4945 (high strain dynamic).

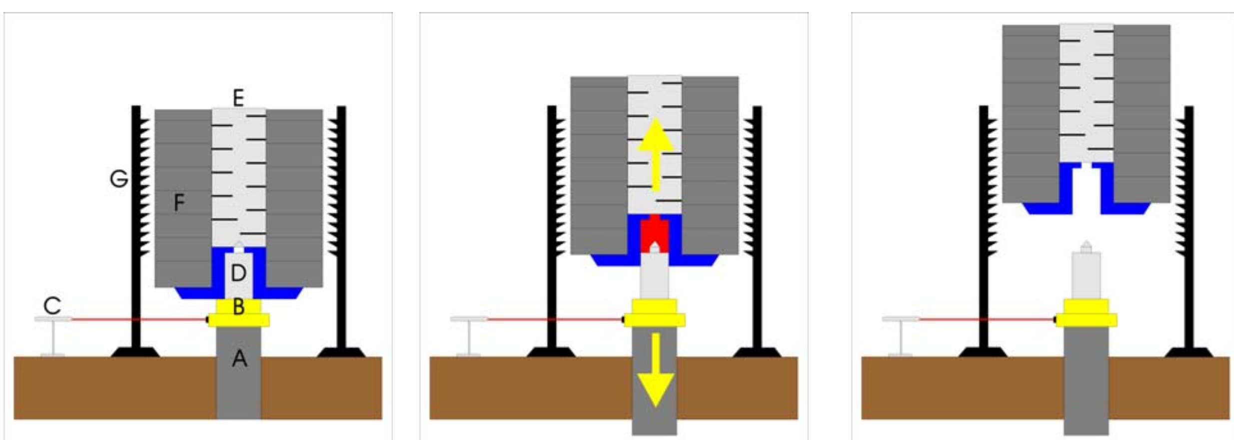
In the realm of load testing an assortment of test methods are available for foundations. Each methodology has is merits as such many issues play into the selection of the most appropriate method. These methods have historically been divided into two categories: static or dynamic. Recently a new classification of testing denoted as rapid load testing has emerged, which combines many of the benefits of the previous methods. Static load tests are thought to provide the most reliable results and the analysis is straightforward. However, the tests are costly and time consuming. Additionally, they are not immune to side effects such as influence from reaction piles, maintaining independent displacement measurements and precision of load measurement (e.g. indirect load measurement via pressure). Dynamic testing, which was developed for driven piles, is considered less reliable (AASHTO, design codes) and is used only as an estimate of capacity. Mainly, because the analysis is complex and relies heavily on user dependent modeling and parametric estimates to which there is no unique solution. Its requirements for capacity analysis are only satisfied for uniform piles reducing its reliability for use on cast-in-place foundations. For driven piles, however, it is a very efficient and economical means of testing. It also provides a wide variety of other important data during pile driving, i.e. hammer energy, driving stresses, pile integrity and driving resistance. Statnamic load testing, a rapid load test, combines the simplicity of static analysis with the efficiency and cost effectiveness of dynamic testing.

STATNAMIC METHOD DESCRIPTION

The Statnamic load test is based on Newton’s second and third laws which state that force is equal to mass times acceleration (F=MA) and that for every action there is an equal and opposite reaction. Loads ranging from 5 tons up to 5,000 tons are generated (axially or laterally) by propelling a reaction mass upward off the foundation. Since the mass is in contact with the foundation prior to the test, the force associated with propelling of this mass acts equally and oppositely onto the foundation. Statnamic load testing requires no reaction piles, no reaction beam, no hydraulic jack, and is set up in a fraction of the cost and time.

A speciel fuel is burned to generate gas pressure inside a cylinder and ram (analogous to a gas actuated jack). As the pressure builds, it reacts against a heavy mass above the pile (typically 5 to 7 percent of the desired test load). The pressure builds rapidly which propels the reaction mass upward, in turn a downward load is simultaneously applied to the pile top which is many times greater than the weight of the reaction mass. The fuel type produces a smooth increasing force and controlled venting of the pressure produces a soft unloading. The load produced is not an impact but rather an impulse load typically with a duration on the order of 1/2 second or less. Load is measured with a calibrated load cell and displacement is measured with a photo-voltaic sensor triggered by a stationary laser reference. Three motion sensors (accelerometers) provide redundant measurement of displacement at the pile top. The fuel weight to load relationship provides redundancy in load measurement. Gas pressure can be measured providing additional redundancy of load measurement. Note that the upward acceleration of the reaction mass is not significant in the analysis of the foundation, only a by-product of the load produced.

Stages of a Statnamic Load Test



Before the test - reaction mass is in contact with pile.

A - Foundation Member
B - Calibrated Load Cell
C - Laser Displacement System
D - Piston & Cylinder
E - Silencer
F - Reaction Mass
G - Catch Mechanism

Burning fuel creates high pressures simultaneously propelling the reaction mass up and loading the pile in downward compression. The applied load and pile displacement are measured using high precision instrumentation and a data acquisition system.

After the load test, the reaction mass is safely caught using hydraulic systems or by mechanical means. It is easily lowered for cyclic loading on the same pile.

Statnamic load testing requires no reaction piles, no reaction beam, no hydraulic jack, and is set up in a fraction of the cost and time. The Statnamic device is set up on the pile top and includes a calibrated load cell and displacement measuring system.

During a Statnamic test, a high-speed data acquisition system scans and records the load cell, displacement transducers, accelerometers and embedded strain gages (if any). The test measurements provide a high degree of resolution fully defining the piles load and deflection response with as many as 100,000 data points recorded during a typical ½ second test. Because the duration of the axial Statnamic test is adequately longer than the natural period of the foundation element, the entire foundation remains in compression. Thus, stress waves do not exist and a simple model can be used to determine the static capacity. However, the measured Statnamic force is not simply the foundation capacity but must be corrected for inertia and damping forces through the fundamental equation of motion (below). The damping value is quantified using principles of the Unloading Point Method (UPM) proposed by Peter Middendorp of TNO Building and Construction Research. Please contact Applied Foundation Testing for detailed information regarding the UPM. The curves in Figure 2 illustrate the measured Statnamic data and the derived static response using the UPM.

$$F_{STATIC}=F_{STN}-ma-cv$$

Where

F_{STATIC} = the derived static load (kx)
F_{STN} = the measured Statnamic force (load cell)
ma = the measured inertia
cv = the foundation/soil damping

and

m = mass of the foundation
a = acceleration of the foundation
c = foundation/soil damping coefficient
v = velocity of the foundation

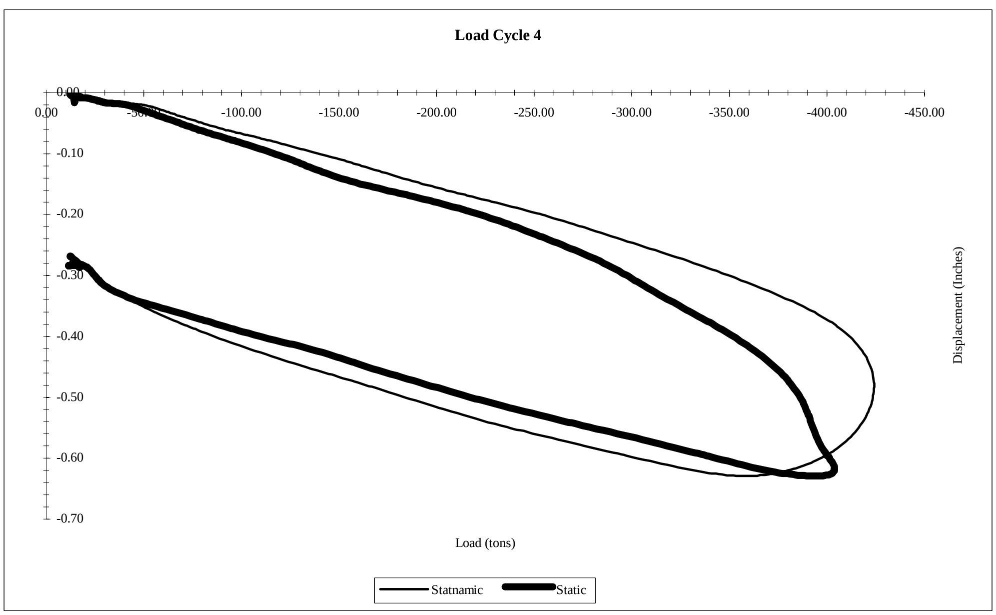


Figure 2. Thin line shows Statnamic measured load (with inertia and damping). Thick line shows only static component of foundation behavior.

STATNAMIC ACCURACY, RELIABILITY AND RECOGNITION

Statnamic load testing has been used extensively all over the world on bridges, high rise condominium structures, office towers, military facilities, Corps of Engineers flood control structures, water and wastewater facilities and various other commercial structures. Statnamic Load Testing is a recognized test method by the American Society for Testing and Materials designation number **ASTM D7383-08** and is routinely used as an alternate to ASTM D1143 and ASTM D 1194.

Innovations in Statnamic analysis have paved the way for new, more accurate, methods of evaluating axial Statnamic load test results. A modification of the UPM, the Segmental Unloading Point Method (SUP) allows acceleration distribution throughout the foundation to be better quantified, therefore, refining the ability to determine the static response of the foundation. As a result, determining the capacity of foundations previously considered troublesome or insolvable using the standard method is now routinely evaluated. The powerful SUP method has sound theoretical background and proven correlation with static load tests. The SUP method used in conjunction with rate of loading factors documented in several independent University studies show that Statnamic load testing has great statistical reliability when compared with conventional static load test results. Please contact AFT for information on these studies.

The NCHRP and FDOT/University of Florida research focuses on the comprehensive study of data collected from 34 deep foundations load test sites where both Static (SLT) and Statnamic (STN) testing was conducted. The main bearing soil strata of each pile was divided broadly into four subgroups: rock, sand, silt, and clay. As the nature of Statnamic testing induces loading rate effects, the affect in various soil types was therein considered. A rate effect factor was introduced to unify the reliability and statistical probability of failure as outlined by FHWA (1998) for Load and Resistance Factor Design. Based on the ratio of SLT to STN and the standard deviation of the data set, a resistance factor was determined for Statnamically load tested foundations. The results of this study are summarized in Table 1 below. Included in this table are the bias factors (λ), standard deviations, and calculated resistance factors (ϕ) for each soil subgroup, as well as the entire study (All Soils). This summary shows a good correlation between the STN and SLT capacities for Rock and Sand indicated by a bias factor nearly equal to 1.0 and a standard deviation less than 9%. The results also show a relatively good correlation between the STN and SLT capacities for Silt and Clay with bias factors larger than 1.0 and standard deviations less than 12%. The combined values of all soil types show that the STN capacity analysis method performs very well with a bias factor slightly larger than 1.0 and a standard deviation of less than 10%.

Table 1 Results Summary

	Rock	Sand	Silt	Clay	All Soils
Bias Factor, λ	0.999	0.994	1.041	1.035	1.017
Standard Deviation	0.068	0.083	0.116	0.119	0.097
Resistance Factor, ϕ	0.739	0.726	0.737	0.730	0.734

STATNAMIC HISTORY IN THE U.S.

1) Invented in 1989 by Patrick Birmingham of Birminghammer Foundation Equipment in Hamilton, Ontario. Data acquisition and analysis were simultaneously developed by The Netherlands Organization for Building Construction and Research (TNO).
2) FHWA began experimenting with Statnamic at the I-49/I-20 Interchange in Shreveport, Louisiana in February of 1991. In the three years that followed, several FHWA demonstration projects included Statnamic, but only for experimentation.
3) In 1994, North Carolina Department of Transportation Geotechnical Engineers became the first in the USA to use Statnamic load testing as a true design tool for the Neuse River Bridge and New River Bridge projects. Both design phase test programs.
4) Florida Department of Transportation in 1994 became the second to use Statnamic load testing when Engineers, William F. “Bubba” Knight, Ching Kuo and Terry Puckett specified its use on the Victory Bridge, Gandy Bridge and Hillsborough River Bridges.
5) In 1997, the Florida based company Applied Foundation Testing, Inc. was formed. Their primary interest is to advance the use of Statnamic load testing and provide Statnamic load testing as a turnkey service to anyone.
6) In 1997, Dr. Dan Brown at Auburn University developed the analysis procedure for lateral Statnamic load tests.
7) In 1999, The University of South Florida in conjunction with AFT and Berminghammer completes development of the Modified Unloading Point Method (MUP) and the Segmental Unloading Point (SUP).
8) 2008 – ASTM standard D7383-08 for Statnamic Load Testing approved.
9) Over 500 technical papers have been presented on the subject and numerous research programs are continually being carried out around the world.
10) Over 2000 Statnamic tests have been performed in the USA from 1997 to 2007 and well over 5000 performed worldwide. FHWA, approximately 25 State Department of Transportation agencies, Numerous US Army Corps of Engineers projects and several hundred private entities have been involved in Statnamic load test programs.

COSTS OF STATNAMIC LOAD TESTING

Many factors influence the cost of load testing including required test capacity, required instrumentation, test type, single or multiple load cycles, special work hours, union agreements, construction phasing, etc. In addition load testing costs are often skewed or front loaded because it is an early work item and can provide necessary cash flow to a contractor at the beginning of a project. This leads to the general perception that load testing is expensive. When in fact load testing, if properly designed, can lead to significant costs savings.

Overall, Statnamic testing is more economical than static testing and is always much quicker because reaction piles and a reaction system do not need to be constructed. Moreover, the actual test time is much quicker and the monitoring and report is usually included in the cost of the Statnamic test. The cost for Statnamic testing, however, begins to become significantly more economical than static testing when multiple load tests are performed on a site or when the test loads are greater than 100 tons.

ADVANTAGES

1) Statnamic load testing does not require installation of reaction piles, reaction beam system, no hydraulic jack, and no reference beam.
2) Faster to set up and perform test than static testing.
3) More economical than static testing and.
4) A direct measurement of load and displacement suggests that the precision of measurement of Statnamic testing is higher than those measuring only strain or hydraulic jack pressure.
5) Embedded strain instrumentation can be installed to allow measurement of load distribution, toe displacement and accurate separation of side shear and end bearing components.
6) It requires no special construction procedures so installation is more representative of actual production pile construction. This allows Statnamic to be used for random quality control testing and for problematic foundations.
7) Side effects from installation of reaction piles or reaction pile spacing relative to the test pile are completely eliminated.
8) Capable of loading to 5,000 tons or greater with same equipment.
9) Cyclic loading is performed very quick and easy.
10) It is the most repeatable of any test method.
11) Statnamic analysis is not effected by uncertainties in pile properties because top load and displacement are measured directly with a calibrated load cell and displacement sensor. This makes it particularly attractive over dynamic methods for testing non uniform piles.
12) Does not require complex user dependent signal matching analysis to which there is no unique solution.
13) The duration of the axial Statnamic test is longer than the natural period of the foundation element precluding formation of stress waves. The entire foundation remains in compression during the test, Therefore, no damaging tensile stresses exist like those of a dynamic test.

14) Statnamic poses no greater danger to foundation integrity than does an equivalent static test. Therefore can be used on production piles.
15) Versatile and applicable to any deep or shallow foundation system. Statnamic is readily adaptable to lateral load testing, batter piles and group load testing on land or over water.

STATNAMIC EQUIPMENT

The photographs below show the most commonly used for Statnamic load testing. Statnamic load testing equipment, data acquisition, and analysis is constantly evolving to become more efficient, more cost effective and more accurate. The basic core components of the Statnamic load test device, i.e. piston, cylinder and reaction mass have not changed, except scaling up for larger test capacities. Currently, many innovations in setup efficiency and means of catching a heavy mass have been made using hydraulics and mechanical means. These advances have contributed to greater economy and testing efficiency. Ultimately resulting in significantly more site data at a fraction of the cost of static load testing.

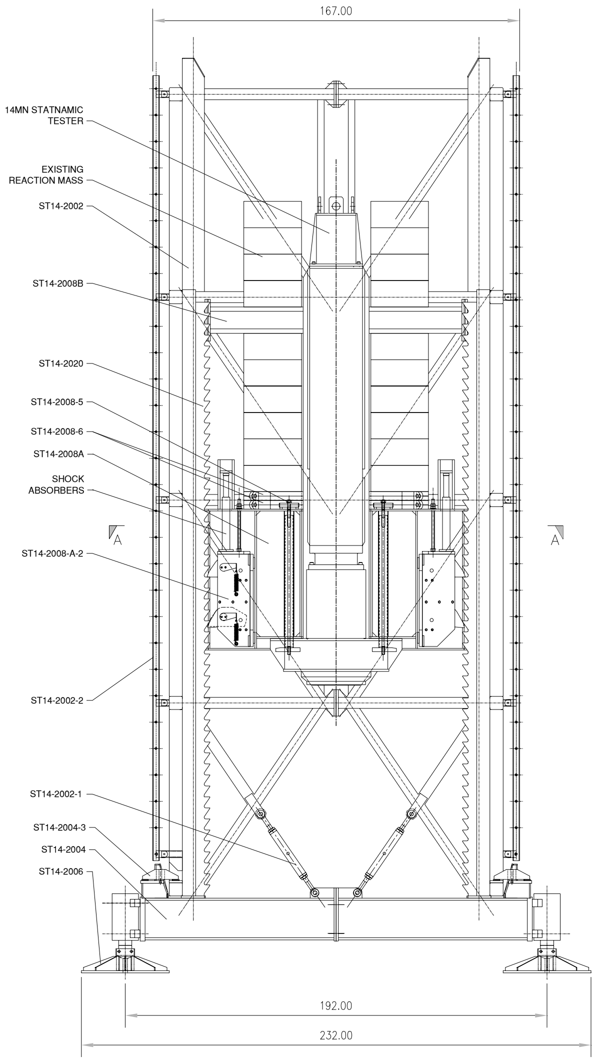
500 ton Statnamic device w/ hydraulic catch
2,000 ton Statnamic Device w/ mechanical catch
5,000 ton Statnamic Device

(Right). Comparison of 500 ton static test and 500 ton Statnamic load test. (Newark Airport)

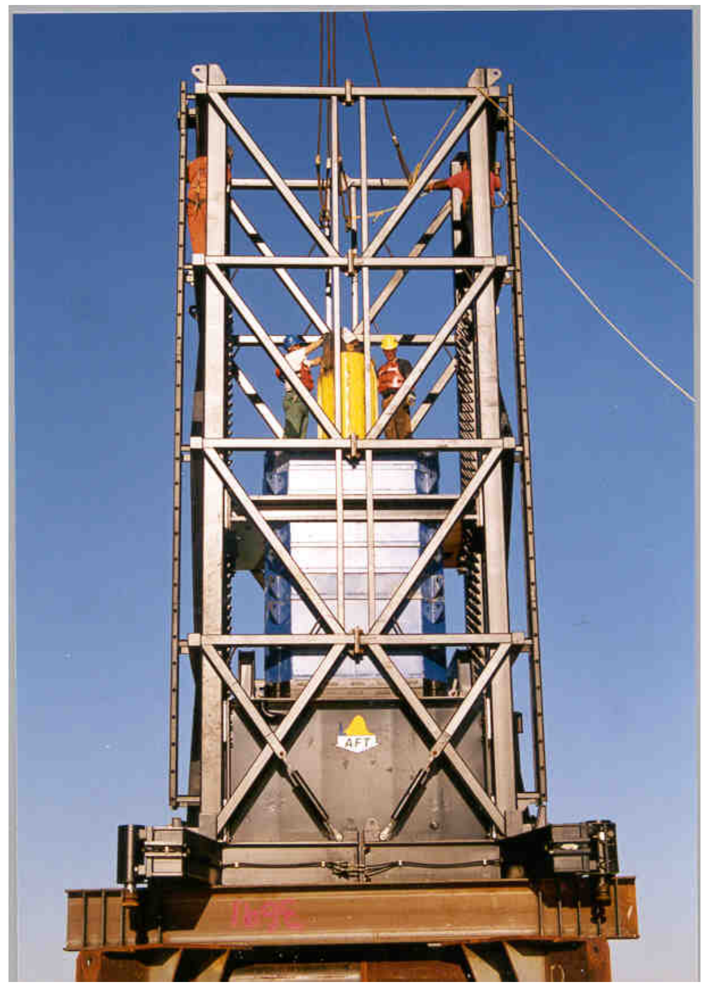
(Below) 500 ton Statnamic Load Test. (Mathews Bridge)

2000 Ton Device

In April 2000, the 2000-ton Statnamic mechanical/pneumatic catch device shown below, made its debut. This has substantially reduced the setup effort consequently making mid range (500 to 2000 ton) Statnamic load testing more economical. Just as pile capacities increase, so does the need for efficient high capacity load tests.



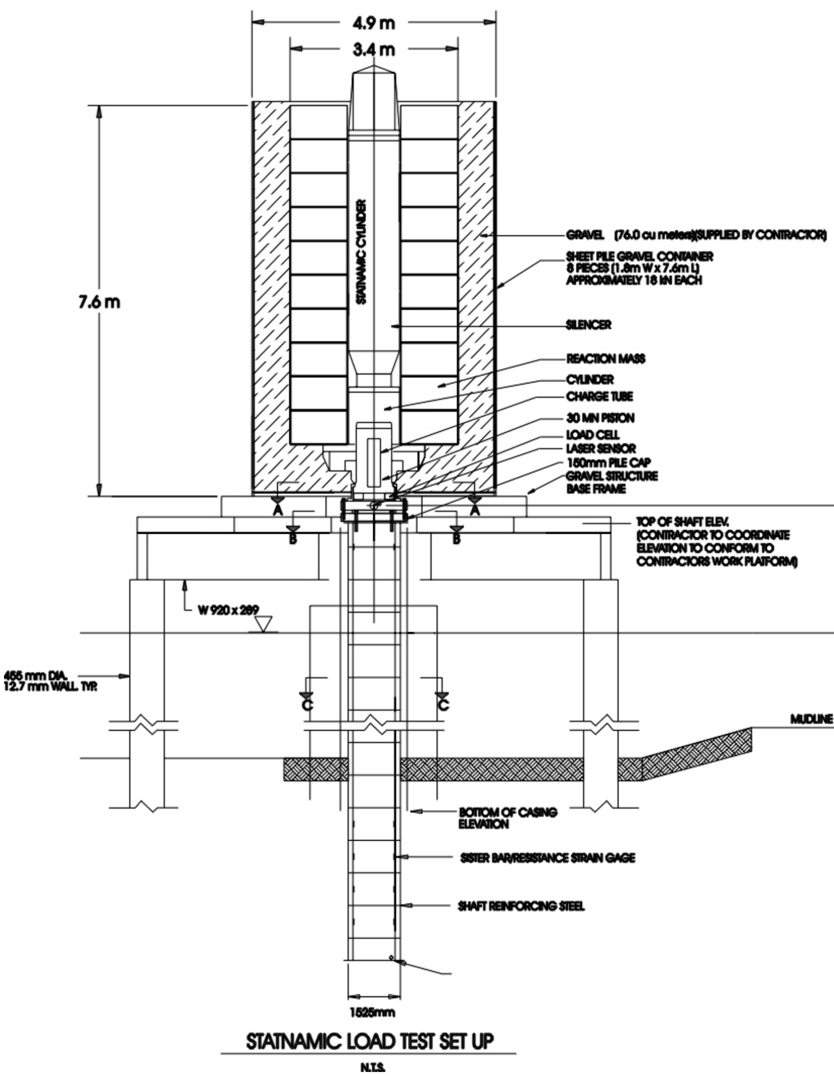
ELEVATION



2000 ton Statnamic device w/ mechanical catch. Shown above fitted to a false work frame for an over water test. (St. George Island Bridge – Florida Department of Transportation).

5000 Ton Device

The largest Statnamic device available can provide a test load of 5000 tons shown below. This device is encompassed by a modular containment structure that is the basis for catching the reaction mass after the Statnamic load test. The annular space between the reaction masses and the containment cell is filled with readily available gravel as shown in the cross section below. When the masses are propelled upward, the gravel simply fills the void created under the masses, thus catching the 150 ton mass. The gravel catch system is fairly low tech but it is an economical means of catching 150 tons in mid-air. In addition, the gravel can be reused after the test for many other things on a construction site. Set up time for this test device has been streamlined by heavy repetition. As with the smaller Statnamic devices, the goal is to construct a mechanical catch system for the 5000 ton Statnamic device as well.



5000 ton Statnamic device w/ gravel catch system over water application (17th Street Bridge, Ft. Lauderdale, FL – Florida Department of Transportation).

LATERAL STATNAMIC LOAD TEST EQUIPMENT

Lateral Statnamic load testing is a significant contribution to the engineering community since it models more closely lateral loading events, i.e. wind, seismic, ship impact, wave action, etc. and it **does not require the construction of a costly reaction shaft**. An analysis method developed at Auburn University allows quantification of both dynamic and static lateral capacity components from a Statnamic lateral load test. The same Statnamic equipment used to perform axial load tests is assembled horizontally on a special “sled”. The lateral load produced is transmitted to the foundation through a large hemispherical bearing that is forgiving to rotations typical of lateral load tests. Specialized down hole inclinometer instrumentation has been patented to measure rapid lateral foundation responses during these Statnamic tests which is shown in Figure 29. Full-scale lateral load tests are possible like the world record 1100-ton lateral Statnamic load test shown in below. Lateral Statnamic load tests may be performed between loads of 15 tons to 2000 tons. Lateral load testing accounts for approximately one third of all Statnamic load tests.

1100-ton lateral Statnamic load test performed on a pair of drilled shafts for the US 17 Bridge over the Northeast Cape Fear River in Wilmington, North Carolina.

1100-ton Lateral load test in progress.

60 ton lateral Statnamic load test on a driven pile (Route 40 over Nottoway River – Virginia Department of Transportation).

350 ton lateral Statnamic load test on a 6 foot diameter drilled shaft (I-95 Ramp – Rhode Island Department of Transportation).

DATA ACQUISITION

Standard Statnamic instrumentation consisting of a high quality load cell, photovoltaic displacement sensor (activated via laser projector) and a servo accelerometer has not changed over the years. However, this instrumentation has been augmented with additional accelerometers at the pile head. Also, the majority of all load test programs incledes strain gages and toe accelerometers cast within concrete piles or mounted on steel piles to provide subsurface foundation measurements. Thus, a more powerful data acquisition sysytem was required. Now, Redundant data systems are used for positive acquisition of the data. The original data acquisition termed FPDS developed by The Netherlands Organization (TNO) is shown at left and the powerful MEGADAC system is shown at right. The MEGADAC is capable of measuring almost every type of geotechnical or structural instrument either static, Statnamic or dynamic. It is capable of monitoring several hundred channels at virtually any sampling rate up to 5000 per second or more if required. It is not uncommon to record a hundred thousand data points during a half second load test. Such precision maps out foundation response subtleties with great resolution. All the data is readily available in ASCII format allowing efficient data regression. This device is probably the most versatile monitoring system on the market today.

TNO FPDS at left and MEGDAC system at right.

STATNAMIC INSTRUMENTATION

Statnamic load cells are made by two notable instrumentations companies, Geokon and George Kelk, Inc. These load cells are calibrated on a regular basis. Direct pile top displacement measurements are recorded by the photovoltaic sensor excited with a laser projector. Acceleration measurements are recorded top at several locations around the pile top. These highly accurate accelerometers also provide displacement measurements.

Statnamic piston mounted on shaft top. Load is generated in the piston, which is measured directly by the load cell (housed in a shroud) beneath the piston. The laser displacement sensor is also included in the piston (which moves with the pile).

Statnamic photovoltaic displacement transducer (left) and remote laser projector (right).

Statnamic ring type Load Cell (left) and a capacitive accelerometer (right).

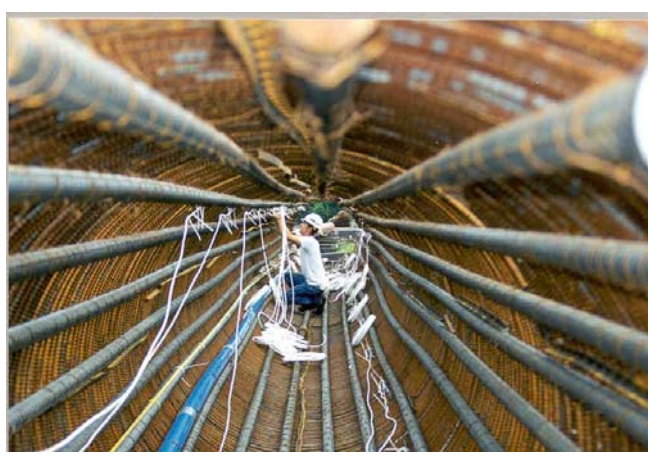
EMBEDDED INSTRUMENTATION

Applied Foundation Testing's Tampa, Florida office has an instrumentation laboratory/fabrication facility. We mainly construct instrumentation for use on our own projects, but have also supplied instrumentation to other consultants, contractors and owners. This unique situation provides us the capability to ensure the quality of instrumentation used on our projects. It also allows us to respond very quickly to short notice circumstances. We can also readily ustomize our testing equipment or construct instruments for special applications. AFT routinely provides "turnkey" testing, instrumentation, and analysis packages. Our most commonly constructed instrumentation includes the following:

Full bridge sister bar resistance strain gages for deep foundation load testing.
Quarter bridge sister bar resistance strain gages for deep foundation load testing.
Weldable type resistance strain gages for steel pile deep foundation load testing.
Accelerometer based motion sensor assemblies.
Resistance type piezometers.
Pressure transducer assemblies.
Specialize in custom field installation applications.

Applied Foundation Testing instrumentation construction below.

(below) Sisterbar resistance strain gage instrumentation for drilled shaft foundations.

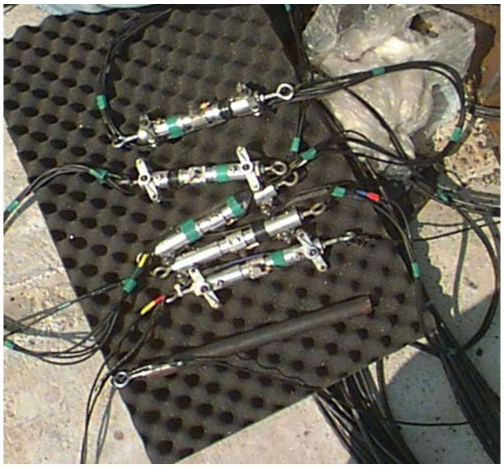


Sisterbar resistance strain gage and toe accelerometer instrumentation for prestressed concrete pile.

Installation of resistance strain gages on large diameter pipe pile foundation.

LATERAL STATNAMIC LOAD TEST INSTRUMENTATION

New instrumentation has been developed for lateral Statnamic load testing which is shown below. These Downhole Lateral Motion Sensor (DLMS) devices are installed in standard inclinometer casing and record lateral displacement of a foundation during a rapid lateral load test.



Downhole Lateral Motion Sensors (DLMS) at left being installed in inclinometer casing at right.

LVDT's and string potentiometer mounted to independent reference beam for lateral Statnamic test.

APPLICATIONS

Statnamic results are not affected by non-uniform cross-section since the load and displacement are measured directly with a load cell and displacement transducer. This is one reason it is particularly applicable to drilled shafts, augered cast-in-place piles, and shallow foundations. The most common foundation types tested in the United States are listed below.

- Bored Piles
  - Drilled Shafts
  - Augered cast-in-place Piles
  - Micro-Piles
- Driven Piles
  - Prestressed Concrete Piles
  - Spun Cast Concrete Cylinder Piles
  - Pipe Piles
  - H-Piles
  - Monotube, Tapertube
- Shallow Foundations
  - Plate Load Tests
  - Stone Columns
  - Vibro Concrete Columns
- Lateral Load Testing
  - Single
  - Groups
- Existing Production Foundations