

Standardization and Codification of Dynamic Pile Testing

A Worldwide Review

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SYNOPSIS

Because of their simplicity and economy, dynamic pile tests are conducted on thousands of construction sites every year in many different countries. The tests include high strain testing which requires that a heavy mass is dropped onto the pile top while measurements of force and velocity are made near the pile top. Data interpretation then assesses bearing capacity, pile integrity, pile stresses and hammer performance, the latter two items if the test is performed during pile installation. The low strain dynamic test, typically performed with a small hand-held hammer, also measures velocity and sometimes force and then interprets the data for pile integrity. A third, frequently performed, dynamic test is Cross-Hole Sonic Logging which requires that at least two tubes are installed in a drilled shaft prior to pouring the concrete and that stress pulses are sent from one tube to the other. The arrival time of the pulse at the receiver tube, indicates the quality and integrity of the concrete between the tubes.

Foundation engineers in several countries have now established certain standards, design or construction specifications or building codes by which these tests are to be conducted or which outline when and for what purpose these tests are admissible as design aids or for quality control. A survey of published documents of various countries is presented.

INTRODUCTION

Dynamic Pile testing has been routinely used for quality assurance for the past 25 years in many countries. However, standardization of the various test procedures and their consideration in various specifications or codes has only begun during the past 10 years, these methods had reached a certain state of maturity. Obviously, enhancements and improvements of these methods are still being made and it is hoped that standardization does not impede progress. Indeed, engineers sometimes deviate from the standardized procedures and incorporate in their reports results which are based on advanced testing and analysis procedures.

This paper describes the standardization approach taken for a variety of dynamic pile tests in several countries. It also shows the extent to which the methods have been incorporated in the codes of practice. However the preparation of codes and standards is an ongoing process and therefore this paper may not be complete.

There are many countries where dynamic test methods are used without the benefit of regulation by either standards or codes. In countries with dynamic pile test standards, building codes may not specifically implement these tests into building practice. Reversely, building codes or design specifications may refer to dynamic pile test methods that are not standardized, leaving the profession in doubt as to the test benefits. It is hoped that the summary in this paper will be of help to those whose practice is either completely unstandardized and requires references to international codes or to those involved in the preparation or updating of their own codes, specifications and standards.

In this paper the term **standard** refers to a document that summarizes minimum requirements that have to be met for a valid test. Thus, standards typically describe the commonly adopted practice or state of the art of a test

method. On the other hand, the term **code** will mean in this paper a recognized design or construction practice or a specification. A code therefore may adopt a test method as a tool in the design or construction control process and may require that such a test is conducted according to a certain standard. Sometimes a standard cannot be clearly distinguished from a code.

In many countries, standard or code documents are protected by copyright laws. The authors therefore ask the readers to approach the issuing bodies for official copies (see the reference section.)

TEST METHODS

Only the most commonly encountered methods for dynamic pile testing are considered in this paper. They have in common that a stress or sound wave is introduced into the pile material and that this stress wave produces measurable wave reflections and/or clearly measurable responses at another point of the pile.

High Strain Dynamic Pile Load Testing (HST)

This method was developed during the late 1960s at Case Institute of Technology in Cleveland, OH (16). While this test is usually called for as a means of load testing, it may also serve for pile integrity assessments. For that reason, HST may be referenced both as a dynamic load test or as an integrity test.

HST requires the measurement of pile top force and velocity under the impact of either a pile driving hammer or a heavy drop weight. Both measurement and the simplified closed-form **Case Method** analysis are performed by in a digital device such as a Pile Driving Analyzer® that conditions, displays, stores and processes the data. In most cases, the data is further interpreted using a signal matching program such as CAPWAP (30). There are variations of the equipment and analysis methods used, however, to be valid, such different

approaches must be able to demonstrate their correlations with static test results.

Low Strain Dynamic Pile Integrity Testing (LST)

Developed by CEPTB, France (28), and TNO, Netherlands (32), this method is also known as the Pile Integrity Test (PIT). The method is based on the measurement of pile top motion, either acceleration or velocity, caused by the impact of a small hand-held hammer. One special evaluation technique requires the measurement of the hammer force. The former method is known as the **Pulse Echo Method**, the latter as the **Transient Response Method**. A digital device serves for data processing and display of the measured variables. Reflections from cross sectional variations and/or from the pile end produce variations of the pile top motion and allow for an approximate evaluation of the pile shaft geometry or quality. While the Pulse Echo Method requires that pile top velocity is plotted as a function of time, the Transient Response Method converts both force and velocity to the frequency domain and then considers the mobility which is velocity divided by force. The velocity records can be further analyzed to yield an estimate of pile shape.

Cross Hole Sonic Logging (CSL)

This method, first described by Paquet in 1969 (27), generally applies to drilled shafts and requires that tubes are installed in the shafts prior to pouring the concrete. The tubes are filled with water and, some time after the concrete has set, a transmitter is lowered in one tube and a receiver in a neighboring tube. Pulses typically generated at 20 to 50 mm vertical intervals by the transmitter arrive at the receiver at a time which is a function of the quality of the concrete between the tubes. A major defect may not allow the stress wave to travel to the receiver tube at all and thus a late or low signal would be interpreted as a shaft defect.

STANDARDS AND NORMS RELATING TO DYNAMIC PILE TESTING

Tables 1 and 2 summarize most documents discussed in this paper for dynamic load test and pile integrity tests, respectively. Since HST is used for both dynamic load testing and integrity testing, Table 2 contains a Method column which indicates the techniques discussed in the document.

Test Standards

Several test standards exist. For example, HST has been standardized in Australia by AS 2159-1995 (7), Section 8.4; in Brazil by NBR-13208 (4); in China by JGJ 106-97 (21); in the US by ASTM D4995-97 (5); in the UK by an Institution of Civil Engineers (ICE) Specification for Piling (18). In Germany the German Society of Geotechniques E.V. (DGEG) developed a "Recommendation" for HST (14).

Examples for LST standards are in Australia AS 2159-1995, Section 8.5 (7); in the US ASTM D5882 (6); in China JGJ/T93-95 (22); in France Norme Française NFP94-160-2 and -4; in the UK the ICE Specification for Piling (18). Again a "Recommendation" has been written in Germany (15).

CSL is included in China's JGJ/T93-95 (22); also for CSL a specific standard is Norme Française NFP94-160-1 (23).

In the UK, ICE has included CSL in their Specification for Piling (18).

Codes and Specifications

Several national codes include dynamic pile testing as an alternative to other construction control procedures (Brazil (3), China (20)).

The development of modern pile test methods was paralleled in several countries by changes from allowable stress or allowable capacity methods to partial safety factor concepts. This concept considers quality control during construction in the design process. The assessment of partial safety factors for dynamic pile testing has been included in Australia's national code as well as in the design specifications of various organizations (e.g., Ontario Bridge Code in Canada, AASHTO, in the US).

AUSTRALIA

AS 2159 (7) is the Australian Standard entitled *Piling-Design and Installation*. According to the definition used in this paper this document includes both a code and a test standard. The code portion applies to HST and is based on the partial safety factor concept, formulating geotechnical and structural design requirements and also imposes limits on driving stresses. In this regard it is noteworthy that AS 2159 distinguishes between calculated, e.g. by wave equation analysis, and measured driving stresses. Measured stresses may be 10% higher than those determined by pure analysis.

The code requires that the geotechnical strength, R_d , is less than the design action effect (factored load). The geotechnical strength is calculated from the ultimate geotechnical strength, R_{ug} , by multiplication with a geotechnical strength reduction factor, ϕ_d . This factor may be chosen from a range which is, for example, 0.7 to 0.9 for piles statically tested to failure and 0.65 to 0.85 for piles dynamically tested to failure. The dynamic tests must then include full signal matching analysis such as CAPWAP. The higher values of the ranges may be chosen if either 3% (15%) or more of all piles on a site are statically (dynamically) tested. If neither static nor dynamic tests are performed at a site, then the geotechnical strength reduction factors may be as low as 0.4 depending on the type of soil and the type of geotechnical data available. (Note: capacity or strength reduction factors from different codes cannot be directly compared because of differing load factors.)

The test standard section separately discusses HST and LST or CSL. For HST details of pile top preparation and sensor attachment are discussed followed by a section on hammer energy required for testing. The code stipulates that the static resistance component activated during the dynamic test is at least 150% of the design action effect (factored load). Finally, AS2159 calls for an experienced, professional engineer to carry out the dynamic tests.

A second, widely used code in Australia, is *Austrroads Bridge Design Code 1992*. Part 3, Foundations, briefly describes PDA testing and CAPWAP analysis.

Table 1: Major Standards or Codes for Dynamic Load Testing

Country	Reference	Title
Australia	Australian Standard AS 2159-1995	Piling-Design and Installation
Brazil	NBR-6122	Design and execution of foundations
Brazil	NBR-13208	Dynamic testing of piles
China	JGJ 94-94	Technical Code for Building Pile Foundation Chapter 9: Inspection and Acceptance of Pile Foundation Engineering 9.2: Testing of Bearing Capacity of Single Pile
China	JGJ 106-97	Specification for High Strain Dynamic Testing of Piles
Germany	Recommendations by the Committee 2.1 of the DGGT for the impact testing of piles	Dynamic Pile Load Test-Draft Sept. 1997
Canada	Government of Ontario, Ministry of Transportation	Ontario Highway Bridge Design Code, 3 rd Edition
UK	Institution of Civil Engineers; Specification of Piling	Ch. 11: Indirect Methods for Testing Piles 11.2 Dynamic Pile Testing
USA	ASTM D 4945-89	Standard Method of Test for High Strain Dynamic testing of Piles
USA	AASHTO LRFD, 1994	Bridge Design Specifications, American Association of State Highway and Transportation Officials

Table 2: Major Standards or Codes for Pile Integrity Testing

Method	Country	Reference	Title
LST, CSL	Australia	Australian Standard AS 2159-1995	Piling-Design and Installation
LST, CSL	China	JGJ 94-94	Technical Code for Building Pile Foundation Chapter 9: Inspection and Acceptance of Pile Foundation Engineering 9.1: Quality Inspection of Pile Installation
LST, CSL	China	JGJ/T 93-95	Specification for Low Strain Dynamic Testing of Piles
LST	France	Norme - Française NFP 94-160-2; NFP 94-160-4	Soil: investigation and testing Auscultation of buried work Method by reflection/impedance
CSL	France	Norme Française NFP 94-160-1	Soil: ... (see above) Sonic core test
LST, HST	Germany	DGGT	Empfehlung Integritätsprüfungen
LST, CSL	UK	Institution of Civil Engineers (ICE)	Specification of Piling
LST	USA	ASTM D 5882	Standard test method for low strain integrity testing of piles.

BRAZIL

In Brazil dynamic load testing has been routinely performed since the mid 1980s. Integrity testing has been introduced later, and therefore not much code work has been conducted for LST or CSL. The codes and standards are published by the Brazilian Association of Technical Codes (Associação Brasileira de Normas Técnicas - ABNT), and are accepted country-wide. The design and execution of foundations are governed by code NBR-6122 (3). The standard for HST is outlined on NBR 13208 (4).

The new revision for code NBR-6122 was published in 1996. It specifies a safety factor of 3.0 for shallow foundations, 2.0 for piles and caissons without load tests and 1.6 for piles and caissons with load tests. In the case of deep foundations, the code does not specify how many or what kind of tests would allow for a reduced safety factor. This decision has to be made by the designer of the foundation, probably with the participation of the other parties involved.

For precast concrete piles, if no load tests are done, the working stress cannot exceed 6 MPa using the full (plugged) section in the case of hollow piles. However, if bearing capacity is adequately verified, then the maximum work load can be calculated considering a maximum structural concrete strength of 35 MPa. The bearing capacity has been adequately verified if at least 1% of the piles (or a minimum of 1 pile) with the same characteristics on a job are tested statically or 3% (or a minimum of 3 piles) are tested dynamically.

NBR 13208, the standard for HST, was published in October of 1994. The main guidelines observed in writing the standard were:

- It should apply to all kinds of piles, provided that the possibility exists of determining their geometric characteristics and of submitting them to an impact force.
- Transducers for deformation, acceleration or displacement can be used.
- To evaluate the load capacity, tests should be made during a restrike, after a *long enough* waiting period. The usual procedure (in Brazil) of applying blows with increasing energy of a drop hammer can be used, provided it can be proved that phenomena like relaxation that may affect the interpretation do not occur.
- Any kind of equipment can be used, provided it is adequate for the specific test conditions. It may be operated by any person, provided that *up-to-date procedures are used that follow the designer's recommendations*.
- Simplified methods, such as the "CASE METHOD" allow for the evaluation of the bearing capacity within a range of values. *For a more precise and reliable evaluation of the bearing capacity, the results obtained by a simplified method, for each group of piles with the same characteristics on a job, should be checked by at least one analysis of the "CAPWAP" kind or by a static loading test.*
- The standard should describe the test in general terms, allowing for different testing technologies. Reporting requirements should be extensive.
- Special emphasis should be given to the quality of the data.

CANADA

The Canadian Geotechnical Society in its 3rd edition of the Canadian Engineering Manual (11), describes and endorses dynamic pile analysis and testing methods and recommends a factored capacity where the capacity reduction factor is called "Performance Factor". This multiplier is, for example, 0.5 for routine static tests, 0.6 for highly technical static tests and 0.5 for dynamic testing and analysis.

The Ontario Bridge Code (17) assigns multipliers to the loads (e.g., 1.2 for concrete dead load and 1.4 for live load) and resistance factors, for the resistance of materials. For jobs where static tests are performed, the test capacity is multiplied by 0.6, for dynamic testing by 0.5 and for a mere static analysis by 0.4. The commentary of the code implies that several dynamic tests should replace a single static test. This code also suggests that piles are not designed with stresses calculated from the factored resistance values that exceed 100 MPa for steel and 15 MPa for concrete. Furthermore, driving stresses are limited to 90% of steel yield strength and 60% of concrete compressive strength.

CHINA

China has been particularly active in the area of dynamic pile load testing and pile integrity testing using both low strain and cross hole methods. In the last ten years, several departmental and local specifications, that are informal, have been compiled in order to promote the application of dynamic pile testing methods. JGJ 94-94 (20), listed in Tables 1 and 2, is the first code in which dynamic pile testing is permitted to be adopted in pile foundation engineering. It is also the first foundation design code that is based on the partial safety factor concept.

Dynamic Load Testing

In regard to pile capacity testing, *dynamic tests should not be used to evaluate the design capacity in preliminary tests in accordance with JGJ 94-94, but only to inspect and accept the quality of production piles in the following cases:*

1. *For first grade building pile foundations where a preliminary static loading test has been done.*
2. *For second grade building pile foundations where a preliminary static loading test has been done.*
3. *For second grade building pile foundations without preliminary static loading test, if none of the following conditions exist:*
 - *The geological conditions are complex;*
 - *The reliability of construction quality is low;*
 - *The reliability of capacity determination is low;*
 - *The number of piles is large.*
4. *For third grade building pile foundations.*
5. *As supplementary testing in addition to a static loading test.*

JGJ 106-97 (21) is the HST standard in China. Its enforcement began in December 1997. This standard limits the simplified Case Method to the following cases:

- Only for medium and small diameter piles;
- For the drilled shaft, only if the cross sections of the shaft are almost regular with the material and quality uniform;
- If the static loading test has not been done, the Measured Curves Matching Method (say CAPWAP) should be adopted to determine the J_c (damping) value. The number of piles for which signal matching is done should be at least 30% of the total piles and no less than 3 piles;
- The Case Damping Factor of the production piles, for the same pile type and size at the same site, should be consistent and the difference between extreme values and the average value should not be more than 0.1.

The number of piles in the sampling test may not be less than 2% of the total piles and should be no less than 5 piles in routine inspection. If there is any serious problem, the whole pile foundation engineering must be evaluated. In these cases, the number of test piles should be decided according to the actual situation, generally there should be more than 10% of the total piles and no less than 10 piles.

Integrity Testing

Item 9.1.4 of JGJ 94-94 (20) gives the prescription to the integrity testing: *Quality inspection of pile installation should be executed for foundation engineering of first grade buildings, complex ground conditions or unreliable pile installation quality. Quality inspection may be carried out by reliable dynamic testing methods. Coring and cross hole sonic logging may be used for large-diameter piles. The number of piles to be tested is decided by the designer as the situation requires.*

JGJ/T 93-95 (22) is the professional standard for LST and CSL in China. Its enforcement began in December 1995. Both the Pulse Echo Method and the Transient Response Method of LST are listed in the standard, while the former is more commonly used than the latter. When interpreting the pile integrity, analyses are mainly performed in time domain and the frequency domain analysis is a necessary supplement. *The number of piles to be tested should be at least 20% of the total piles and no less than 10 piles. If more than 30% of the tested piles are found to be substandard, twice as many piles should be tested. If there are still more than 30% of the piles substandard, all the production piles should be tested. This method can be applied to friction piles with a length to diameter ratio less than 30 and 40 end-bearing piles with an L/D ratio below 50.*

In China, to be certified for dynamic pile testing, personnel must pass both a qualification test and a technical examination, organized by competent authorities.

FRANCE

Because of its early involvement in the development of the integrity test methods it is not surprising that **Norme Française** now contains standards for LST by pulse echo method (24), for LST by transient response method (25) and for CSL (23). There is also a standard for the parallel seismic method which is not covered in this paper because of its relatively infrequent application. The Norme Française standards are relatively concise and, most importantly, include a form on which to report the test results. The French standard requires for the LST Pulse

Echo Method a transform of the velocity signal to the frequency domain.

GERMANY

In Germany, DIN 1054 (12) and EC 7 (13), regulate pile design and installation of both driven and cast-in-place piles. With LST integrity testing being used in Germany since 1975 and HST dynamic load testing since 1980, it also became necessary to formulate a test standard. However, the number of testing experts and the frequency of testing was relatively limited and the German Society for Geotechniques therefore decided to write a "Recommendation" as a first step towards test standard and code. A first release was issued in 1986, a revision in 1991 and a new version in 1997. The first release dealt with both HST and LST in the same document; experience prompted the 1997 rewrite which divided the Recommendation into two parts: Integrity Testing and Dynamic Load Testing.

Dynamic Load Testing

Part 1 of the 1997 Recommendation deals with dynamic load testing by HST (14); it outlines testing process and data processing method and recommends capacity evaluation by CAPWAP. One section explains the circumstances under which results can be used as proof tests within the frame work of the safety related concepts of DIN 1054 and EC 7. Accordingly, results from CAPWAP can take the place of static loading tests, provided they are verified in comparative static loading tests and long term settlements can be assessed from reliable geotechnical information.

Integrity Testing

The Recommendations (15) discuss several modes of testing (e.g., HST, LST) and possible result presentations, including estimates of pile shape and the accuracy of these assessments. Although the committee did agree that integrity testing would increase the reliability of a foundation, it did not agree on a safety factor reduction.

MEXICO

A Construction Manual published by the National Chamber of the Construction Industry describes HST according to Case Method and CAPWAP (10).

NORWAY

In Norway a document exists, called **Peleveiledningen** (29), which was issued by the Norwegian Geotechnical Society and provides guidance for design of piles. This non-official document recommends a minimum partial factor of safety of 1.5, if PDA measurements and wave propagation theories (e.g., CAPWAP) are used to assess pile bearing capacity. For static testing this factor is at least 1.4.

SWEDEN

In Sweden HST (Case Method and CAPWAP) is almost exclusively used because 95% of all piling are prefabricated from either steel, concrete or timber. Dynamic load tests are done at approximately 40% of all piling sites. Static loading tests are only rarely performed; today dynamic load testing has taken over construction control. Calibration of dynamic test method has been accomplished with a number of static loading tests during the past 20 years.

Recommendations for HST were written beginning in the late 1970s and early 1980s by IVA Pålkommissionen (The Royal Swedish Academy of Engineering Sciences; Commission on Pile Research (19)). That standard was never finalized, however, the companies working with HST use Type Approval from the National Building Administration.

More recently, the SGI (Swedish Geotechnical Institute) has written a handbook called Pålgrundläggning (Pile Foundations) which includes recommendations for HST (26).

For highway bridges, the National Code BRO 94 (8) was released by Vägverket (Swedish National Road Administration) and for railway bridges the National Code BV Bro released by Banverket (Swedish National Rail Administration (9)). These codes give partial safety factors depending on amount of dynamic testing performed at a site.

Several handbooks and manuals for piling have been issued by IVA Pålkommissionen. Some of these publications, all written in Swedish, present case studies with HST and also recommendations for the interpretation of LST (Rapport 89, Integritetskontroll av pålar med stötvågmätning (19)).

UK

In 1988 the Institution of Civil Engineers (ICE) published a Specification for Piling, which covers both HST and LST or CSL in Chapter 11 under the title Indirect Methods for Testing Piles (18).

Dynamic Load Test

The specification describes test and reporting requirements in general terms. An introductory comment concerns differences between static and dynamic load test results: *The results directly obtained refer to dynamic loading conditions. Information in terms of static load testing requires soil- and pile-dependent adjustments, and corroboration from experience may be required to correlate testing of this kind with normal static load tests.* A commentary, entitled Guidance on Dynamic Load Testing of Piles addresses benefits and limitations of the test and briefly discusses preconstruction testing, construction control testing, either during pile installation or after a waiting time.

Integrity Testing

The following comment from the introductory section, appropriate for LST is insightful: *The constituent material of any pile should have a large differential modulus of elasticity compared to the ground in which it is embedded.* Another comment concerns the limits of the method: *It must be emphasized that the results of integrity-testing need to be interpreted by engineers with the requisite specialist experience, and that all methods have limitations.*

Finally, in a general description of the tests, the specification addresses the difficult problem of who should pay for testing in case defects are indicated by the test.

In the event that integrity tests indicate potential defects in the a pile and that other subsequent tests prove the piles to be defective, then the costs for all further testing,

investigation, remedial works and/or replacement of the defective pile should be borne by the Contractor. If, following investigation, the subsequent tests do not reveal significant defects, the cost of such further tests, investigations and reinstatement should be borne by the Employer.

The Construction Industry Research and Information Association (CIRIA) has published a comprehensive report entitled **Integrity Testing in Piling Practice** (31). Actually, this document also includes static and dynamic load testing. Descriptions of theory, test setup and interpretation of both CSL and LST are included. In addition, recommendations are given for the specification of non-destructive testing. Because of its completeness and because of the status of CIRIA in the UK, this report may be referred to as a test standard.

USA

Dynamic Load Testing

In the United States, test standards of the HST and LST test methods have been written by ASTM. Building codes have been prepared by various groups of building officials.

ASTM D4945 (5) describes the minimum requirements for the test equipment including dynamic loading device, minimum requirements for sensors and their calibration, the method of data evaluation (e.g. computer analysis) and reporting. Under 4. *Significance and Use*, ASTM D4945 states: *4.1 This test method is used to provide data on strain or force and acceleration, velocity or displacement of a pile under impact force. The data may be used to estimate the bearing capacity and the integrity of the pile, as well as hammer performance, pile stresses, and soil dynamics characteristics, such as soil damping coefficients and quake values. This test method is not intended to replace Test Method D 1143, (the ASTM standard for static loading).*

The American Association of State Highway and Transportation Officials (AASHTO), is a regulatory body whose general recommendations are usually accepted by most State Highway Departments. In their 1992 edition of the *Standard Specification for Highway Bridges* (2) (an allowable stress/capacity specification), AASHTO suggests dynamic or static loading tests to verify pile integrity when the design stress in the pile exceeds 25% of the yield strength in steel piles. The specification includes a section 4.5.10 *Dynamic Monitoring: Dynamic monitoring may be specified for piles installed in difficult subsurface conditions such as soils with obstructions and boulders, or a steeply sloping bedrock surface to evaluate compliance with structural pile capacity. Dynamic monitoring may also be considered for geotechnical capacity verification where the size of the project or other limitations deter static load testing.* The LRFD (Load and Resistance Factor Design) Bridge Design Specification, currently under preparation, assigns reduction factors (based on the construction control method) for their resistance factors which are governed by the capacity determination method. For example, for construction control by dynamic formula the resistance factor is multiplied by .8, for PDA testing of 2 to 5% of piles by .9 and if CAPWAP is also used on the tested piles then there is no reduction.

Integrity Testing

ASTM D5882-96 (6) considers both the Pulse Echo Method and the Transient Response Method although the mathematical or reporting requirements are not specifically described for the latter method. This test standard includes under 4. *Significance and Use: 4.1 Low strain integrity testing provides velocity and force (optional) data on structural elements (that is, structural columns, driven concrete piles, cast in place concrete piles, concrete filled steel piles, timber piles, etc.). This data assists evaluation of pile integrity and physical dimensions (that is, cross sectional area and length), continuity, and consistency of the pile material. This test method will not give information regarding the pile bearing capacity.*

SUMMARY

Several test standards and codes written for or referencing dynamic pile testing methods have been presented and briefly discussed. Probably several new standards or codes will be developed within the next few years. It is hoped that the documents presented here will help to improve construction practice and aid in the writing of new and improved guidelines.

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