# PROPOSED PILE LOAD TEST PROCEDURE AND COMMENTS
# MASSACHUSETTS STATE BUILDING CODE



**BSCES/ASCE Geotechnical Advisory Committee**[1]

## INTRODUCTION

As early as 1979 the Soils Advisory Committee for the State Building Code Commission recognized the need for revision of the pile load-test, Section 722.8 of the State Building Code. A search was made of requirements in other building codes, papers on the subject were studied, and local experience was sought.

The recommended procedure is given in Appendix A. It is urged that interested parties review it as soon as possible and send comments to the Geotechnical Advisory Committee at the BSCES/ASCE headquarters. The procedure will be submitted to the appropriate state office for inclusion in the next revision of the Code.

The purpose of this commentary is to summarize the rationale of the proposed changes and to outline their implications. In an effort to utilize well-known standards, it was decided to use ASTM Test designation D-1143, Standard Method of Testing Piles Under Static Axial Compression Loads, with some modification. The principal recommended changes from the current procedure in the State Code are:

1. The load increments may be applied every one-half or one hour, so that the test may be completed in one day in most cases.

---

[1] S.J. Poulos, Chairman; E.J. Johnson, Vice Chairman; Paul Donahue; Michael Emerson; William Langrill; Asaf Qazilbash; Peter Riordan; Richard Simon; Roy Stiffler; Peter Taylor.

2. Telltales or other instruments will be required for most pile load tests so that the load distribution in the pile can be estimated.

3. A minimum of 100% of the design load must reach the bearing stratum during the test.

4. A method of interpretation of the load test results based on settlement under the design load has been added.

The recommended pile load test procedure will provide equivalent or greater information regarding the behavior of the pile than the current procedure and will result in savings of time and money. Alternate methods of loading, including the current procedure, are permitted under certain conditions.

Section 722.8 of the existing Code will be replaced by the proposed revisions. All other requirements of Section 722 will continue to apply to pile load tests except Section 722.4.

PURPOSE AND PRINCIPLES OF PILE LOAD TESTS

Pile load tests are performed chiefly to determine whether the soil into which the pile is driven can support the design load adequately over the life of the supported structure. During a pile load test the pile material also is tested.

There are four modes of unsatisfactory pile performance that should be considered: (1) the pile material may fail during driving due to the high impulse forces applied, (2) the pile material may fail under the design load, (3) the soil that constitutes the bearing stratum (be it an end-bearing or friction pile or a combination of the two) may fail by undergoing large continuous deformation (the shear strength of the soil is smaller than the applied shear stress in this case) and (4) the deflection of the pile under the design load may be large enough to cause cracking, failure, or other unsatisfactory performance of the supported structure (the deformability of the soil/pile system is too great in this case).

The strength of the pile material itself, items (1) and (2) above, are beyond the scope of this commentary and will not be considered further. The discussion below covers items (3) and (4).

End-bearing piles are driven into dense or stiff soils or to rock. For such piles, the pile butt settlement often reaches values in the range of ½ to 1 inch at loads that are far below the failure load of the bearing stratum. For example, a pile driven into dense sand or glacial till may have a failure load of several hundred tons, whereas a butt settlement of 0.5 to 1 inch may be reached under a load of, say, 100 tons. Because those structures normally supported by piles are relatively stiff and cannot accommodate large differential settlements, the practice has developed to select the design load for such end-bearing piles based on a deformation criterion, e.g., a limiting butt settlement, because it is these settlements that control whether the structure will behave satisfactorily.

On the other hand, friction piles in clay often settle very little until just before failure. Failure may occur abruptly after the deflection reaches only ¼ to ½ inch. In this case, or in any case in which complete failure occurs, the practice has developed in Massachusetts and other states to apply a factor of safety of 2.0 to the failure load to define the allowable design load. This strength criterion is used because, although the deformations are smaller than may be acceptable, good engineering practice requires an adequate factor of safety on the failure load to account for unknowns and uncertainties in the design and construction process.

A multitude of methods have been proposed over the years for interpretation of load tests. The purpose of the interpretation is to define the load at which the pile has "failed" under short term loading. Although bearing failure of the soil and settlement due to deformation of the pile/soil system are two separate controlling criteria for judging the suitability of the behavior of the piles, this point is often obscured in the various methods of pile load test interpretation.

## TIME EFFECTS

A single pile loaded during a short term load test behaves differently from an identical pile within a pile group loaded over a long period.

It may be expected that during a load test, only a portion of the applied test load actually reaches the bearing stratum whereas a much higher fraction may reach it during service due to such factors as:

a. Skin friction which is less significant for pile groups than for single piles.

b. Consolidation and creep of shallow layers that provide skin resistance initially and gradually may shed load to a deeper stratum.

When the full long term load from the structure reaches the bearing stratum, the bearing stratum must have adequate bearing capacity to carry the load and the pile deflection must be within the tolerable limits for the structure. Therefore, it is important that the pile load test be carried out in such a manner that the bearing stratum is tested under the full design load.

While test piles are occasionally cased to the top of the bearing stratum or instrumented to evaluate the load that actually reaches the bearing stratum during a load test, this is the exception rather than the norm. Thus the degree to which the bearing stratum is loaded during a load test usually is not known.

Another important time effect is the settlement that occurs with time due to consolidation of the soil in the bearing stratum or of soil layers below the bearing stratum. The pile load test does not provide any significant information concerning such settlements. They must be computed separately by the engineer and the design should be selected to ensure that the long-term settlements due to consolidation are acceptable for the supported structure.

Settlement can also occur over a long period of time due to creep movement of the soil in the bearing stratum. Creep movement is usually negligible in granular soils, but could be significant in clays. Laboratory tests on clays indicate that the rate of creep movement decreases with time and increases exponentially with increasing load. Thus, if significant creep movement does not occur when the pile is tested to twice the design load, it is unlikely that creep movement will be a problem under the design load.

COMMENTARY ON SECTION 722.8.1 REQUIRED TEST LOAD

> "A single pile shall be load-tested to not less than twice the design load. When two (2) or more piles are to be tested as a group, the total load shall be not less than one and one-half (1½ times) the design load for the group. In no case shall the load reaching the bearing stratum for a single pile or a pile group be less than 100% of the design load."

The requirement that 100% of the design load reach the bearing stratum has been added to this section. Its obvious purpose is to ensure that the bearing stratum itself is tested at least to the design load.

If 100% of the design load does not reach the bearing stratum during the load test, two options exist: (1) the design load could be reduced to the estimated load in the bearing stratum, so long as the settlement criterion is fulfilled; or (2) the test load could be increased in increments until it is determined that the load in the bearing stratum is equal to the desired design load. The latter approach will require continuous evaluation of the load test during the test, with due consideration for the structural capacity of the pile itself. The settlement criterion also must be fulfilled at the test load that is on the pile when the desired design load reached the bearing stratum.

COMMENTARY ON SECTION 722.8.2 INTERNAL INSTRUMENTATION

> "The test pile shall be instrumented in accordance with the requirements in paragraph 4.4.1 of ASTM D1143 to enable measurement or computation of the load in the pile where it enters the bearing stratum.
>
> This requirement is waived for the following cases:
>
> 1) The test pile is installed within a casing that extends to within 10 ft above the bearing stratum.
>
> 2) The pile to be tested has been functioning satisfactorily under load for a period of one year or more.

3) The pile is 30 ft long or less and no appreciable load will be supported above the bearing stratum.

4) The design load of the pile is 35 tons or less."

This section has been added to supplement the current requirements of Section 722.5 "Measurements" in the Massachusetts State Building Code. The required instrumentation will permit assessment of the load in the bearing stratum to determine if the requirements of Section 722.8.1 are met.

The term "bearing stratum" is used in the suggested code provision to mean that stratum which is expected to take the load of the pile during the life of the supported structure. For an end-bearing pile on rock, the rock is the bearing stratum. For an "end-bearing" pile in glacial till or dense sand into which the pile may penetrate 5 to 20 ft or more, the bearing stratum starts at the top of the glacial till or dense sand. For a friction pile, the top of the bearing stratum is the top of that stratum on which the engineer will rely, throughout the life of the structure, to take the load.

Internal instruments are not required for certain pile load tests for the following reasons:

1. Pile within casing: Since there is no support above the bearing stratum internal instrumentation is not required.

2. Existing piles: The difficulties of installing instrumentation within existing piles lead to this exclusion. For special cases, the engineer may wish to devise appropriate instruments.

3. Short piles: In this case, it is assumed that the amount of support above the bearing stratum will be less than 50% of the applied load.

4. Design load less than 35 tons: Pile load tests are not required in this case, except for friction piles that have design loads in excess of 22 tons. For friction piles the deflection needed to develop full friction is small. Therefore, it is probable that at least 50% of the applied load will reach the bearing stratum. Because friction piles with greater capacity than 35 tons are rare in Massachusetts, instrumentation of such pile load tests is desirable.

Interpretation of the data from a single telltale in a pile requires that the modulus of elasticity of the pile and the distribution of skin friction be known. These quantities can be measured directly by using several telltales rather than only one. Instruments for stress measurement in the pile near the bearing stratum will circumvent the requirement for knowing the distribution of skin friction. Even when instruments are used within the pile the load in the bearing stratum can only be estimated.

In spite of these uncertainties, the proposed change requiring load measurements at the bearing stratum will enable the engineering and construction community to gain the experience necessary to understand the soil/pile system. With such data, improvement of the procedures can be made in the future.

COMMENTARY ON SECTION 722.8.3 LOADING PROCEDURE

"Pile load test shall be conducted in accordance with ASTM D1143, Standard Method of Testing Piles under Static Axial Compressive Load, except that the loading and unloading procedures shall be as follows:

1) Apply 25% of the design load every one-half hour. Longer time increments may be used, but each time increment should be the same.

2) At 200% of the design load, maintain the load for a minimum of one hour and until the settlement (measured at the lowest point on the pile at which measurements are made) over a one-hour period is not greater that 0.01 in.

3) Remove 50% of the design load every 15 minutes until zero load is reached. Longer time increments may be used, but each should be the same.

4) Measure rebound at zero load for minimum of one hour.

In no case shall a load be changed if the rate of settlement is not decreasing with time. For each load increment or decrement, take readings at the top of the pile and on the internal instrumentation at 1, 2, 4, 8, and 15 min. and at 15-min. intervals thereafter.

A load greater than 200% of the desired design load may be applied at the top of the pile, using the above loading procedure, to ensure that at least 100% of the desired design load is supported at the bearing stratum.

Other optional methods listed in ASTM D1143 may be approved by the Building Official upon submittal in advance of satisfactory justification prepared by a registered professional engineer who is qualified in this field."

This section supersedes Section 722.4 "Loading Procedure" for pile load tests only. For plate bearing tests, Section 722.4 still applies.

The revised loading procedure will shorten the test duration in general; however, the requirement that 100% of the design load reach the bearing stratum may require an increase in load under certain circumstances.

Optional methods, including the loading procedure required under the existing code, also can be used if approved by the Building Official. Regardless of the loading procedure, the requirement that 100% of the design load must reach the bearing stratum still applies.

Considerable discussion arose about the merits of reducing the duration of each load increment from 4 hours to 0.5 hour. At first some Committee members thought that the longer duration would mean that the test would be closer to the drained condition that will exist ultimately. However, computations based on consolidation theory showed that this was not the case. With either load increment duration, pile load tests in stiff clays or till will be undrained or partially drained, and tests in sands will be drained.

For end bearing piles, the stress distribution at the tip and the pore pressure induced in saturated dense soils are such that the undrained and drained strengths are similar. Thus the pile load test probably gives a reasonable approximation of the ultimate drained capacity.

For friction piles in clay, the pile load test usually yields an underestimate of the long-term capacity because the remolded clay around the pile gets somewhat stronger as time passes.

Thus the application of test loads relatively rapidly, but slowly enough so that dynamic effects are not induced, does not significantly influence the design load that would be selected based on a pile load test for either end-bearing or friction piles.

By decreasing the duration of each load increment, it was argued that creep would not be observed and that one would overestimate the capacity by loading rapidly. This overestimate was judged to be of limited consequence in practice. Because instrumentation is used in the proposed procedure, knowledge of the behavior of the bearing stratum will be improved compared with the current procedure, even though there may be a small uncertainty due to the effect of creep at the butt.

Some members advocated that 2.5-minute time increments between loads should be allowed. This procedure was not adopted for the practical reason that such rapid application of the load increments increases the risk of measurement error and because the economy of completing a test in one day will be achieved with the load increments of ½-hour-duration. It appears, however, that the Quick Load Test (ASTM D1143) is technically suitable.

COMMENTARY ON SECTION 722.8.4 SELECTION OF DESIGN LOAD

> "Provided that the design load does not exceed the load allowed in this section for the type of pile and provided that the design load does not exceed 100% of the load supported in the bearing stratum when the maximum test load is applied, then the design load shall be the greater of the following:

1) Design Load Based on Settlement During Loading:

Fifty (50) percent of the applied test load which causes a gross settlement at the pile cutoff grade equal to the sum of: a) the theoretical elastic compression of the pile in inches, assuming all the load on the butt is transmitted to the tip, plus b) 0.15 inch, plus c) one (1) percent of the pile tip diameter or pile width in inches. If the settlements are so small that the load-settlement curve does not intersect the failure criterion, the maximum applied test load shall be taken as the failure load.

2) Design Load Based on Net Settlement After Rebound:

Fifty (50) percent of the applied test load which results in a net settlement at the top of the pile of ½ in., after rebound for a minimum of one hour at zero load."

This section supersedes the second and third paragraphs of the current Section 722.8.

The proposed change to Section 722.8.4 has the advantage of offering another method of interpretation. Since the method providing the highest design load will govern, the change will liberalize the interpretation of pile load tests. The failure load as determined by either method is based upon butt movements and may be summarized as follows:

A. The load causing a net butt settlement of 0.5 in. after removal of all load and allowing time for rebound.

B. The load causing a gross butt settlement under the design load equal to the elastic compression of the pile (assuming it to act as an unsupported column between the butt and tip) plus 0.15 in. plus 1/100 of the tip diameter.

Method A is based upon the premise that the net butt settlement after rebounding represents penetration of the pile tip due to plastic yield of the soil. A tip penetration of more than 0.5 in. is considered unacceptable. A shortcoming of this method is that the butt settlement may not be directly related to what is happening at the pile tip. For example, very long piles may have a net settlement of 0.5 in. simply because rebounding after unloading has been restrained by negative skin friction, even though the pile tip has not moved. In any case, the net settlement is a conservative estimate of the net movement of the pile tip. Hence this criterion is conservative. In some cases it is too conservative.

Method B, which is sometimes referred to as the Davisson Method[1], is based on the wave equation analysis concept of "quake", which is defined as the deformation required to cause yielding of the soil at the pile tip. Research on wave equation analysis of pile driving indicates that a value of quake equal to 1/100 of the pile tip diameter is a reasonable approximation for most soils. A value of 0.15 in. is added to the dynamic quake value to account for the additional settlements which occur in static load tests due to creep and consolidation. Yield of the soil at the pile tip is assumed to have occurred when the tip settlement, taken as the butt settlement minus the elastic compression of the pile, exceeds the quake plus 0.15 in. This settlement criterion applies to end-bearing piles, but it can also be used for friction piles since the plunging type of failure typical of friction piles results in approximately the same failure load for a wide range of settlement criteria.

A comparison of the Davisson Method with other methods, Fig. 1, indicates that it is conservative. In some cases it is more conservative than Method A.

It is intended that the Davisson Method will be more liberal when interpreting data from long piles, while the use of net settlement will continue to provide more liberal design loads for shorter piles. Neither method is ideal.

The suggested procedure for interpretation of the load settlement data is illustrated in Fig. 2. Both of the plots in Fig. 2 are for the same test. In this case, the allowable design load is controlled by the net settlement criterion and is equal to about 72 tons. Since the net settlement after rebound exceeded 0.5 in., a graphical construction was used to estimate the test load that would have resulted in a net settlement of 0.5 in. This construction is illustrated by the dashed lines in the lower plot. Convenient scales for interpretation of the test data plots are obtained by selecting scales such that the angle α is about 20°.

In general the design load is selected as follows:

1. If it is determined that at least 50% of the maximum applied test load reaches the bearing stratum at the maximum applied load and:

   a) If either of the settlement criteria is satisfied, the design load will be 50% of the maximum applied load.

   b) If neither of the settlement criteria is satisfied, the design load will be 50% of the maximum load for which, by interpretation, either of the settlement criteria will be satisfied.

2. If it is determined that less than 50% of the maximum applied test load reaches the bearing stratum, then:

   a) The design load will be limited to the load reaching the bearing stratum at the maximum applied load, provided either of the settlement criteria is met, or the load reaching the bearing stratum at some lesser load at which the settlement criteria is met.

   b) If the applied load is increased such that 100% of the proposed design load reaches the bearing stratum, the design load will be the load reaching the bearing stratum. The settlement criterion also must be fulfilled at the test load that is on the pile when the desired design load reaches the bearing stratum.

## CONCLUDING REMARKS

A boring should be made close enough to each pile load test so that the soil and/or bedrock conditions at the location of the pile load test will be satisfactorily known.

It should be emphasized that no rigid rule regarding pile load test interpretation should overrule experience and sound engineering judgment. It is expected that there will be situations when the recommended methods will not be the most reasonable. In such cases the Code allows the professional engineer to submit the necessary justifications to the Building Official for a permit to deviate from the Code.

REFERENCES

(1) Fellenius, Bengt H., "Test Loading of Piles and New Proof Testing Procedure," Proceeding ASCE Journal of the Geotechnical Engineering Division, Vol. 101, No. GT9, Sept. 1975, pp. 855-869.

(2) NAVFAC DM-7.2 **Foundations and Earth Structures**, Department of the Navy, Facilities Engineering Command, Design Manual 7.2, May 1982, pp. 7.2-229.

APPENDIX A - PROPOSED REPLACEMENT OF SECTION 722.8 OF THE MASSACHUSETTS STATE BUILDING CODE

722.8 Requirements for Pile Load Tests

722.8.1 Required Test Load:

A single pile shall be load-tested to not less than twice the design load. When two (2) or more piles are to be tested as a group, the total load shall be not less than one and one-half (1-1/2) times the design load for the group.

In no case shall the load reaching the bearing stratum for a single pile or a pile group be less than 100% of the design load.

722.8.2 Internal Instrumentation:

The test pile shall be instrumented in accordance with the requirements in paragraph 4.4.1 of ASTM D1143 to enable measurement or computation of the load in the pile where it enters the bearing stratum.

This requirement is waived for the following cases:

1) The test pile is installed within a casing that extends to within 10 ft above the bearing stratum.

2) The pile to be tested has been functioning satisfactorily under load for a period of one year or more.

3) The pile is 30 ft long or less and no appreciable load will be supported above the bearing stratum.

4) The design load of the pile is 35 tons or less.

722.8.3 Loading Procedure:

Pile load tests shall be conducted in accordance with ASTM D1143, Standard Method of Testing Piles under Static Axial Compressive Load, except that the loading and unloading procedures shall be as follows:

1) Apply 25% of the design load every one-half hour. Longer time increments may be used, but each time increment should be the same.

2) At 200% of the design load, maintain the load for a minimum of one hour and until the settlement (measured at the lowest point on the pile at which measurements are made) over a one-hour period is not greater than 0.01 in.

3) Remove 50% of the design load every 15 minutes until zero load is reached. Longer time increments may be used, but each should be the same.

4) Measure rebound at zero load for a minimum of one hour.

In no case shall a load be changed if the rate of settlement is not decreasing with time. For each load increment or decrement, take readings at the top of the pile and on the internal instrumentation at 1, 2, 4, 8, and 15 min. and at 15 min. intervals thereafter.

A load greater than 200% of the desired design load may be applied at the top of the pile, using the above loading procedure, to ensure that at least 100% of the desired design load is supported at the bearing stratum.

Other optional methods listed in ASTM D1143 may be approved by the Building Official upon submittal in advance of satisfactory justification prepared by a registered professional engineer who is qualified in this field.

722.8.4 Selection of Design Load:

Provided that the design load does not exceed the load allowed in this section for the type of pile and provided that the design load does not exceed 100% of the load supported in the bearing stratum when the maximum test load is applied, then the design load shall be the greater of the following:

1) Design Load Based on Settlement During Loading:

Fifty (50) percent of the applied test load which causes a gross settlement at the pile cutoff grade equal to the sum of: a) the theoretical elastic compression of the pile in inches, assuming all the load on the butt is transmitted to the tip, plus b) 0.15 inch, plus c) one (1) percent of the pile tip diameter or pile width in inches. If the settlements are so small that the load-settlement curve does not intersect the failure criterion, the maximum test load shall be taken as the failure load.

2) Design Load Based on Net Settlement After Rebound:

Fifty (50) percent of the applied test load which results in a net settlement at the top of the pile of 1/2 in., after rebound for a minimum of one hour at zero load.