Static Testing of Deep Foundations

TECHNOLOGY

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APPLICATIONS

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16. Abstract

A static load test is conducted to measure the actual response of a pile under applied load. Load testing provides the best means of determining pile capacity, and if properly designed, implemented, and evaluated should pay for itself on most projects.

This manual provides guidelines concerning the planning, conduct, and interpretation of results of load tests performed on driven piles and drilled shafts. Axial compressive, axial tensile and lateral pile load tests are covered. The appendices contain a glossary of load testing terminology, guideline specifications, suggested load test procedures, load test reporting requirements, load test forms, and tell-tale details.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.093	metres squared	m²
yd²	square yards	0.836	metres squared	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	kilometres squared	km²
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.028	metres cubed	m³
yd³	cubic yards	0.765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
ha	hectares	2.47	acres	ac
km²	kilometres squared	0.386	square miles	mi²
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F

°F
-40   0   32   40   80   98.6   120   160   200   212 °F
°C -40 -20   0   20   37   40   60   80   100 °C
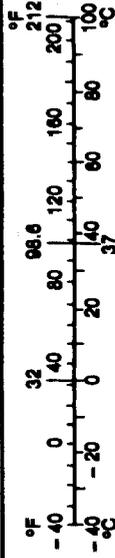
* SI is the symbol for the International System of Measurement

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF MANUAL

A majority of the bridges in the United States are supported on deep foundations*. The economical design and construction of a pile foundation depends on the use of rational procedures to determine pile load capacity. Additional, unwarranted costs can result from either inadequate or overly conservative design and from construction claims related to pile driving difficulties.

A static load test is conducted to measure the response of a pile under applied load. Conventional static load test types include axial compressive, axial tensile and lateral load testing. The cost and engineering time associated with a load testing program should be justified by a thorough engineering analysis and foundation investigation. An adequate pile foundation design requires detailed subsurface exploration, appropriate soil testing, subsurface profile development, static pile analyses and selection of optimum pile type(s).

Static load tests provide the best means of determining pile capacity and, if properly designed, implemented and evaluated, should pay for themselves on most projects. Depending on availability of time and on cost considerations, the load testing program may be included either in the design or in the construction phase. Dynamic load tests, performed in conjunction with static load tests, greatly increase the cost-effectiveness of a pile load test program and should be specified whenever piles installed by impact driving are load-tested.

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*The term piles, unless specifically defined otherwise, refers to both driven piles and drilled shafts.

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Many different procedures have been proposed for conducting pile load tests. The main differences are in the selection of loading systems, instrumentation requirements, magnitude and duration of load increments, and interpretation of results. The objective of this manual is to present a comprehensive, easy-to-follow guide describing the steps required in planning, conducting and interpreting the results of static load tests on driven piles and drilled shafts. It is intended to serve as a reference for experienced engineers and as a learning aid for those not experienced in pile load testing. Types of testing covered include axial compressive, axial tensile and lateral load tests. A brief description of dynamic pile load testing is included in the Appendix.

1.2 PURPOSE OF LOAD TESTING

The purpose of pile load testing (Fuller and Hoy, 1970) can be:

° to develop criteria to be used for the design and installation of the pile foundation, or
° to prove the adequacy of the pile-soil system for the proposed pile design load.

1.3 PREREQUISITES FOR LOAD TESTING

In the planning stage of any load test program, the following will be required:

° Adequate subsurface exploration.
° Well-defined subsurface profile.
° Adequate soil/rock testing to determine engineering properties.

° Static pile analysis results to rationally select pile type and pile length, as well as the load test site(s)

1.4 ADVANTAGES OF LOAD TESTING

Load testing of piles offers several advantages, some of which are:

° Allows a more "rational" design. The pile-soil capacity can be determined much more reliably by applying a test load to a pile than from the results of laboratory tests or based on assumptions.
° Allows use of lower factor of safety. Many pile foundations are designed using a factor of safety of 3. Testing allows the engineer to use a lower factor of safety which translates into cost savings.
° Improved knowledge regarding the behavior of the pile-soil system has the potential of permitting an increase in the design load and a reduction in the number of piles or in a reduction in pile length (for friction piles) with a corresponding savings in foundation costs.
° Verifies that the design load can be attained at selected tip elevation.

Some engineers are hesitant to recommend static pile load tests, and the reasons often cited are:

° Costs involved
° Delays to contractor if done as part of construction contract.
° Delay of project if done in the design phase.

The cost of performing a load test should always be weighed against the benefits to be obtained. A load test costing $100,000 could be considered inexpensive if cost savings in the

millions resulted. Delay of a project during the design or construction phase is most likely to occur in those instances where the decision to perform load tests is made at the last minute. The need for design phase pile load tests should be addressed in the early stages of the design phase, and construction phase load tests should be clearly specified in the contract documents. In this way, the load tests are incorporated into the schedules and unforeseen delays are minimized.

1.5 WHEN TO LOAD TEST

The decision whether or not to initiate a pile load test program on a particular project will be influenced by several factors. The following criteria can be used to assess when pile load testing can be effectively utilized:

° When the potential for substantial cost savings is readily apparent. This is often the case on large projects, either to determine whether friction pile lengths can be reduced, or whether the allowable pile stress can be increased for end-bearing piles.

° When safe pile load carrying capacity is in doubt, due to limitations of an engineer's experience base, or unusual site or project conditions.

° When soil or rock conditions vary considerably from one portion of a project to another.

° When the design load is significantly higher than typical design loads.

° When time related pile-soil capacity changes are anticipated (i.e. setup or relaxation).

° When using precast concrete friction piles - so that piles can be cast long enough to avoid costly and time consuming splicing during construction.

° When new, unproven pile types and/or pile installation methods are utilized.

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- When existing piles will be utilized to support a new structure carrying heavier loads.
- When a reliable assessment of pile uplift resistance or lateral behavior is important.
- When, during construction, the load carrying capacity of a pile by hammer formula or dynamic analysis differs from the estimated ultimate load at the anticipated tip elevation (for example, H-piles that "run" when driven into loose to medium dense sands and gravels).

1.6 EFFECTIVE USE OF LOAD TESTS

1.6.1 During Design

On major projects, the benefit to cost ratio of conducting a load test program in the design phase should be considered. The subsurface profile must be adequately defined to determine the optimal number and locations of load tests as well as the area over which each test can be considered representative for driving of production piles. A design phase static load test program will require highway agencies to prepare and let a construction contract. The unit cost per test will be significantly higher than for tests performed during construction (particularly if over-water testing is involved), due to the mobilization of men, materials and equipment to install a small number of piles. For maximum benefit, the design load test program should be completed at least a year before project advertisement to permit foundation and structural engineers to optimize final design.

Design phase pile load tests offer several advantages:

- Allow load testing of alternate pile types and selection of most economical pile.
- Pile installation information can be made available to bidders - this should reduce their bid "contingency."

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° Greatly reduce potential for claims arising from pile driving problems, especially for piles which are difficult to splice.
° Minimize cost savings for pile foundations (e.g. permit lower factor of safety, permit changes in design load and number of piles, reduce number of orders-on-contract).

1.6.2 During Construction

Typically, the primary purpose of load tests performed during construction is to verify that the design load does not exceed allowable pile capacity (proof testing), particularly if set-up or relaxation is anticipated. For piles installed other than by driving with an impact hammer (e.g. vibrated or auger cast), load tests during construction can be used to confirm that both the soil and the pile can safely sustain the design load.

Construction phase load tests are also commonly used to determine final tip elevation of production piles after test drive piles are evaluated at estimated length.

1.7 LIMITATIONS OF LOAD TESTS

Before discussing the design of a load test program, it is important to recognize that a load test performed on a single pile does not

° account for long-term settlement
° take into account downdrag from settling soils
° take into account the effect of group action
° eliminate the need for an adequate foundation investigation

The above must be considered when using load test results to design or analyze pile foundations.

2. DESIGN ASPECTS OF LOAD TESTING PROGRAM

2.1 DEFINING LOAD TEST OBJECTIVES

As discussed previously, there are several reasons for performing load tests. Design capacity verification (proof testing) requires only the movement at the top to be measured, whereas if the load test is being performed to establish design parameters, complex internal pile instrumentation and a special loading sequence may be necessary. Each load test program should be tailored to the specific project.

The geotechnical engineer who decides on load testing piles without having established a clear goal as to the purpose of the load test is wasting both time and money. Without an objective, there is no reason to proceed. On the other hand, with a well developed goal the many aspects of a load testing program will fall into place:

- ° Subsurface explorations required.
- ° Instrumentation needs.
- ° Number of personnel needed.
- ° Test method.
- ° Timing in design and/or construction phase.

2.2 GEOTECHNICAL REQUIREMENTS

2.2.1 Subsurface Investigations

A sufficient number of subsurface explorations should be progressed throughout the project site in order to establish the full range of existing subsurface conditions. At least one boring should be available at the immediate load test location. The number, depth, spacing and type of explorations (e.g. SPT, undisturbed samples, in-situ testing) to be included in any

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exploration program are so dependent upon site conditions and type of structure that no rigid rules can be established. The reader is referred to the 1988 AASHTO MANUAL OF SUBSURFACE EXPLORATIONS for guidance on the planning of an exploration program.

Some general guidelines are listed below:

Number of Borings

- a minimum of one at each abutment and pier location.
- a minimum of one at each high capacity drilled shaft location.

Depth of Borings

- all explorations must penetrate below the proposed tip elevation of the deep foundation elements.
- the depth of a firm (competent) stratum should be established (must prove that weaker stratum does not exist below).
- if foundation on bedrock is contemplated, must core to a depth sufficient to determine that sound rock has been reached. This depth depends on local geology (e.g., presence of boulders, weathered zones, solution cavities, etc.).

Sampling Interval

- for most cases, soil sampling at 5 ft intervals and at each change in stratum will be adequate.

The presence of groundwater has an effect on the design of pile foundations and the interpretation of pile load tests. The groundwater level encountered during the subsurface exploration

program should be recorded on the drillers' log. In soils that possess high permeabilities (sands, gravels), the water level recorded will most likely be indicative of the actual groundwater conditions. For borings progressed through soils having low permeabilities (silts, clays), the groundwater conditions noted on the drill logs should be verified using observation wells or piezometers.

2.2.2 Determination of Engineering Properties

Soil Classification

Soil samples obtained from borings should be classified in accordance with the Unified Soil Classification System. Coarse grained soils are classified based on their particle size and shape of the grain size distribution curve. Fine grained soils are classified as to their position on the plasticity chart. Classification of the samples permits the engineer to estimate the engineering properties of soils. Classification is strongly encouraged especially when laboratory (consolidation, strength) or field (vane, pressuremeter, etc.) testing is not contemplated, as is often the case.

Cohesionless Soils

The Standard Penetration Test (SPT) is the most widely used method in the United States to determine the engineering properties of cohesionless soils, in which undisturbed samples are not easily obtained. The test was primarily developed for sands. For cohesionless soils other than sands, the N values obtained must be used with caution. With correct interpretation, the SPT test provides a good evaluation of soil properties for cohesionless soils.

Another in-situ test that has been gaining acceptance is the Static Cone Penetration Test (CPT). The version most widely used in the United States is the Dutch Cone Penetrometer which has been standardized by ASTM D3441-86. The CPT test closely replicates the static loading applied to pile foundations. The ability of the CPT test to measure skin friction is a big advantage in the design of pile foundations. The drawbacks of the test are the inability to push the cone in dense or coarse soil deposits and that samples are not retrieved as in the case of the SPT test. The Cone Penetration Test must be accompanied by borings in order to positively identify the soil types encountered.

Cohesive Soils

Whenever pile foundations are contemplated in or through these types of soils, the results of Standard Penetration Testing should not be relied upon. Instead, the strength and consolidation characteristics should be determined by laboratory testing of undisturbed samples and/or by in-situ tests. In cases where very soft clays are encountered, in-situ vane shear testing should be performed.

2.2.3 Pile Design

Pile design requires the geotechnical engineer to satisfy two criteria, namely,

(1) The design load should not exceed a specified percentage of the ultimate capacity (i.e. have an adequate factor of safety), and

(2) The movement of the pile under the working load should not exceed a specified limit determined by structural requirements.

The value of the allowable load to be used for design would then be the lower value obtained from the above criteria.

Axial Compressive Loads

Under this mode of loading, piles derive their resistance (Figure 1(a)) from

° end bearing, or
° skin friction, or
° a combination of the two

The ultimate bearing capacity is commonly expressed as

$$Q_{uc} = Q_p + Q_f$$

where, Q_{uc} = ultimate bearing capacity
Q_p = ultimate tip resistance
Q_f = ultimate shaft resistance

It is recommended that static analyses be performed in accordance with FHWA's MANUAL ON DESIGN AND CONSTRUCTION OF DRIVEN PILES (Vanikar, 1985) or DRILLED SHAFT MANUAL: VOL I - CONSTRUCTION PROCEDURES AND DESIGN FOR AXIAL LOADING (Reese, 1977).

Axial Tensile Loads

The ultimate uplift capacity of piles can be estimated in a similar manner to ultimate bearing capacity. Tip resistance is zero, except for belled drilled shafts. The uplift is resisted by side friction and the weight of the pile (Figure 1(b)) and is expressed by

$$Q_{uu} = Q_{su} + W_p$$

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VERTICAL LOADS

AXIAL COMPRESSIVE

(a)
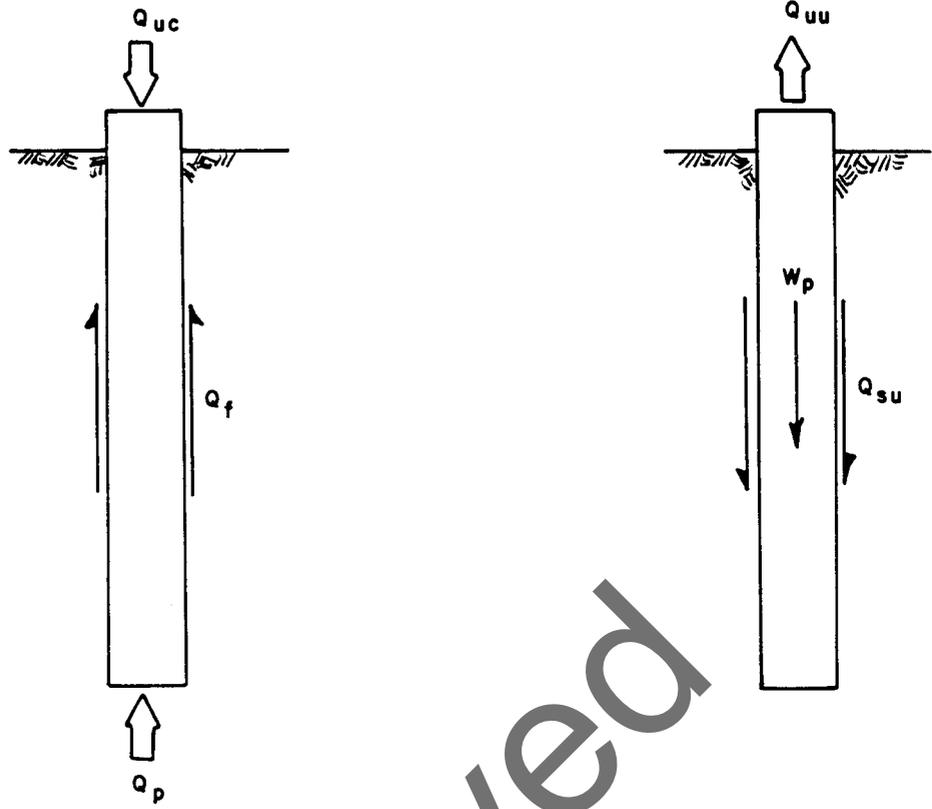
AXIAL UPLIFT

(b)

LATERAL LOAD
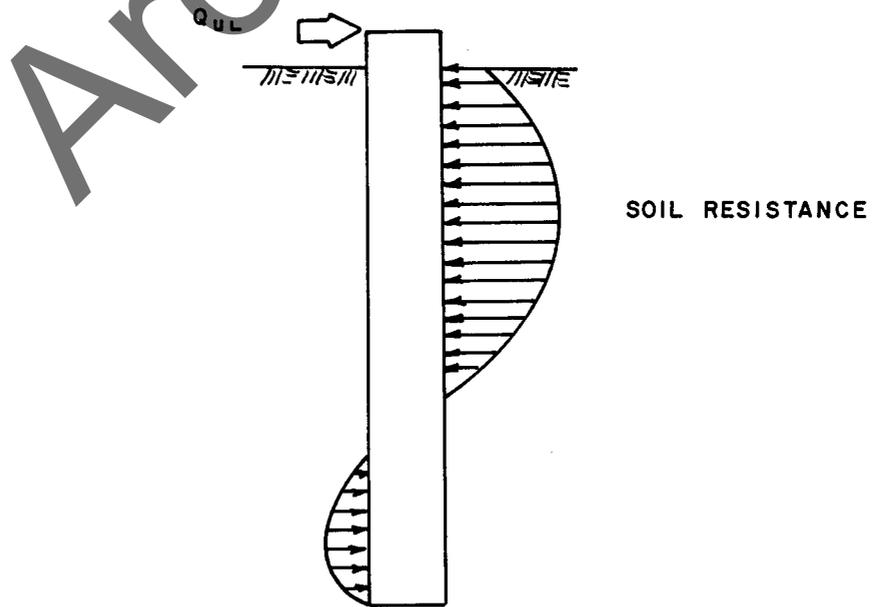
SOIL RESISTANCE

(c)

Figure 1.   Pile Capacities (a) Compressive (b) Uplift (c) Lateral.

where,

Q_{uu} = ultimate uplift capacity

Q_{su} = ultimate shaft resistance in uplift

W_p = weight of pile

It is recommended that analyses be performed as recommended in FOUNDATION ANALYSIS AND DESIGN (Bowles, 1977).

Lateral Loads

Piles can resist lateral loads in two ways:

° by being driven on a batter such that all or part of the lateral load from the structure is included in the axial load.

° by the combined action of the piles' inherent structural rigidity and the resistance mobilized by the surrounding soil as the pile deflects (Figure 1(c)).

The capacity of a batter pile to resist lateral loading axially is found by first adding the lateral load vectorially to the vertical load and then calculating the axial capacity of the pile as for a vertical compression or tension pile.

The lateral load on a batter pile in excess of that taken axially, as well as the lateral load on a vertical pile, have to be resisted by the second mechanism, i.e., the combined action of the structural rigidity of the pile and the resistance mobilized in the surrounding soil. The resistance that is developed depends on a number of factors that can be classified as soil, pile or load parameters.

It is recommended that the p-y curve method (see Figure 2) described in the HANDBOOK ON DESIGN AND CONSTRUCTION OF PILES AND

P = LATERAL LOAD APPLIED TO PILE

y = DISPLACEMENT OF PILE UNDER LATERAL LOAD

p = SOIL RESISTANCE DEVELOPED AT DISPLACEMENT = y

(AFTER REESE, 1984)
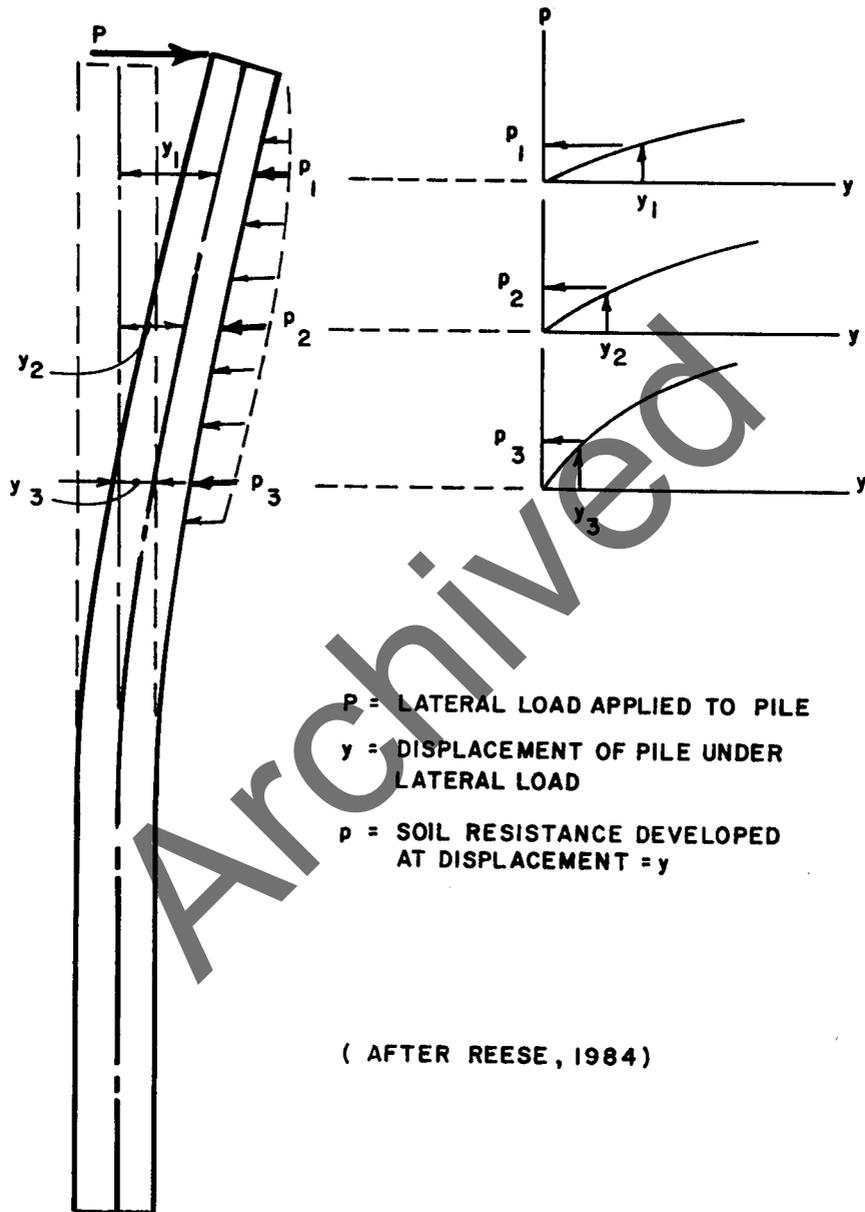
Figure 2.   Use of Soil Response (p-y) Curves to Determine Displacement and Soil Resistance for a Laterally Loaded Pile

DRILLED SHAFTS UNDER LATERAL LOAD, FHWA-IP-84-11 (Reese, 1984) be used to calculate the lateral resistance of vertical piles. The behavior of batter piles subjected to loads other than axial loads should also be analyzed by this method with the appropriate modifications (Appendix 6, Reese, 1984). The reference also presents a method of analyzing groups composed of both vertical and batter piles.

2.3 LOAD TEST DETAILS

2.3.1 Methods of Load Application

Axial Compression

Three methods can be used to apply axial compressive loads to piles:

° apply load directly onto a platform which rests on the pile head

° jack against a loaded platform

° jack against a beam anchored by piles or ground anchors

The method of loading a pile is normally left up to the contractor, however, the engineer should always review the contractor's proposed procedure. The method selected by the contractor will be dependent on

° availability of time

° availability of equipment and materials

° maximum load to be applied

° site characteristics (vertical and horizontal restrictions, existing utilities, bodies of water)

Typical arrangements for an axial compressive test are shown in Figures 3 through 5. In Figure 3(a) and Figure 5(a) the

CONCRETE BARRIERS

CROSS BEAMS

STIFFENER PL.

TEST BEAM

JACK

TIMBER CRIBBING
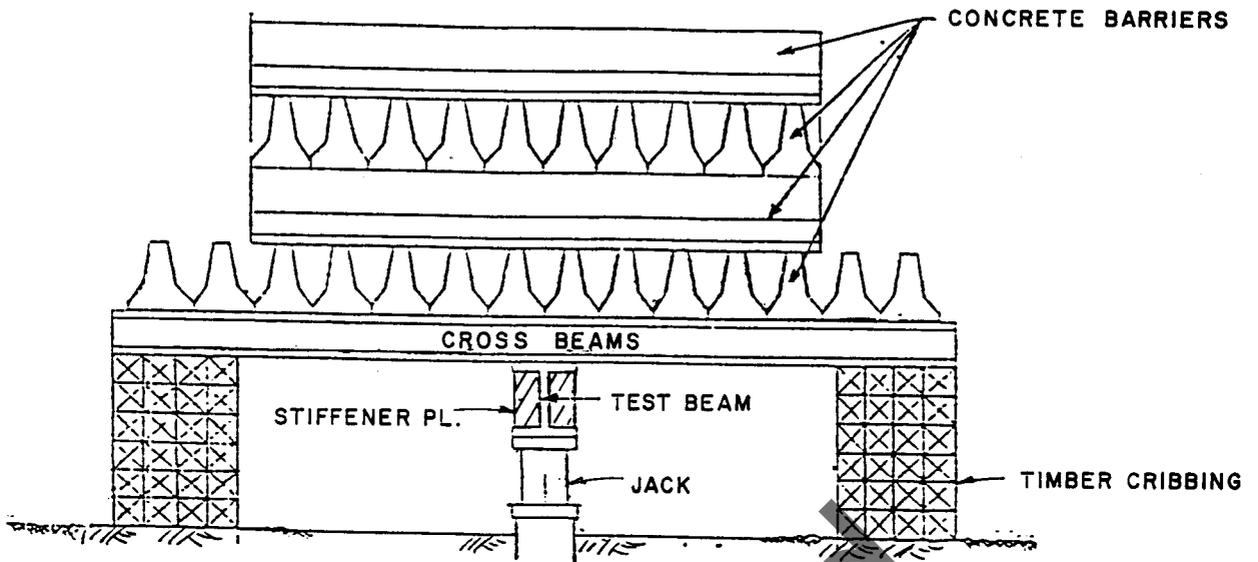
(a)
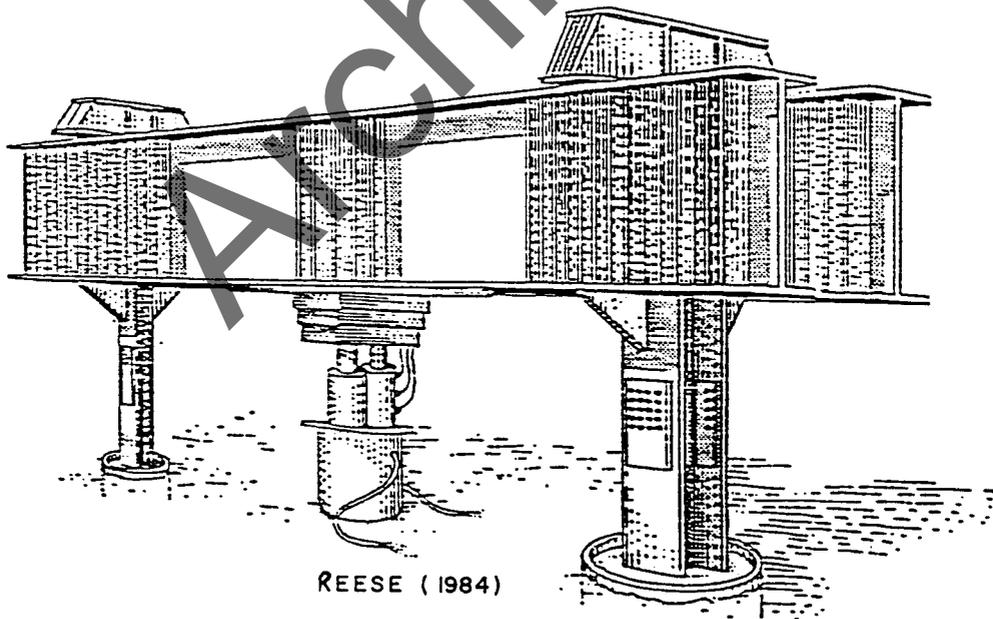
REESE (1984)

(b)

Figure 3. Typical Arrangements for an Axial Compressive Load
Test (a) Dead Load (b) Anchor Pile

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TIMBER CRIBBING

TIE DOWN ANCHORS

4° 10°

(a)

1000 TON LOAD FRAME
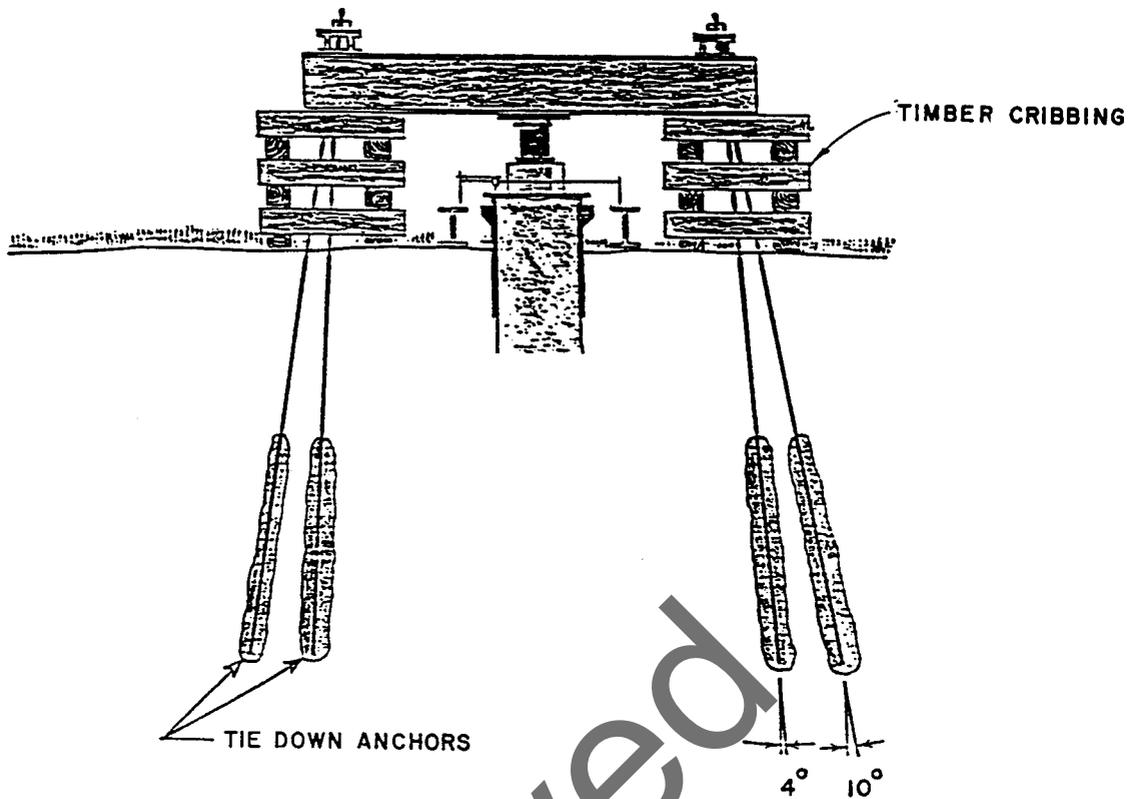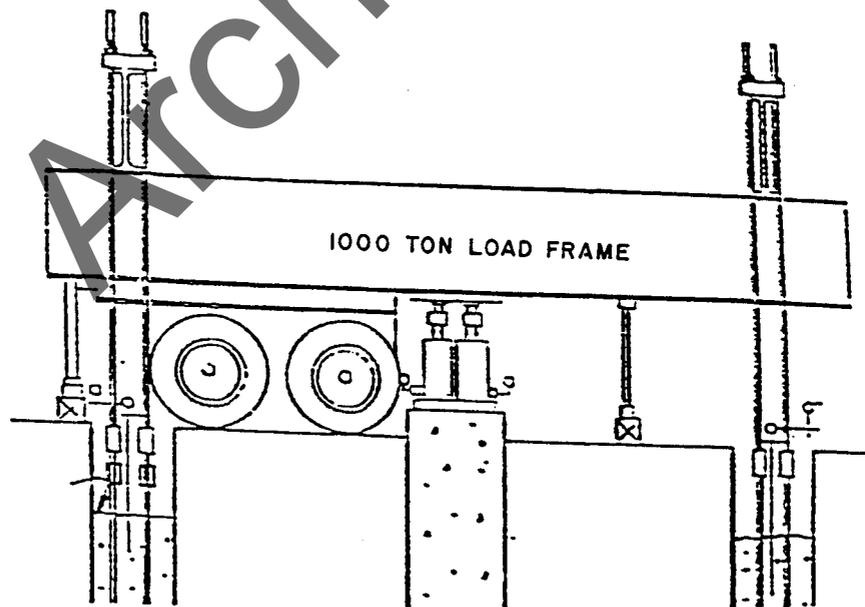
(b)

Figure 4. Typical Arrangements for an Axial Compressive Load
Test (a) Tie Down Anchors (b) Mobile Reaction Beam

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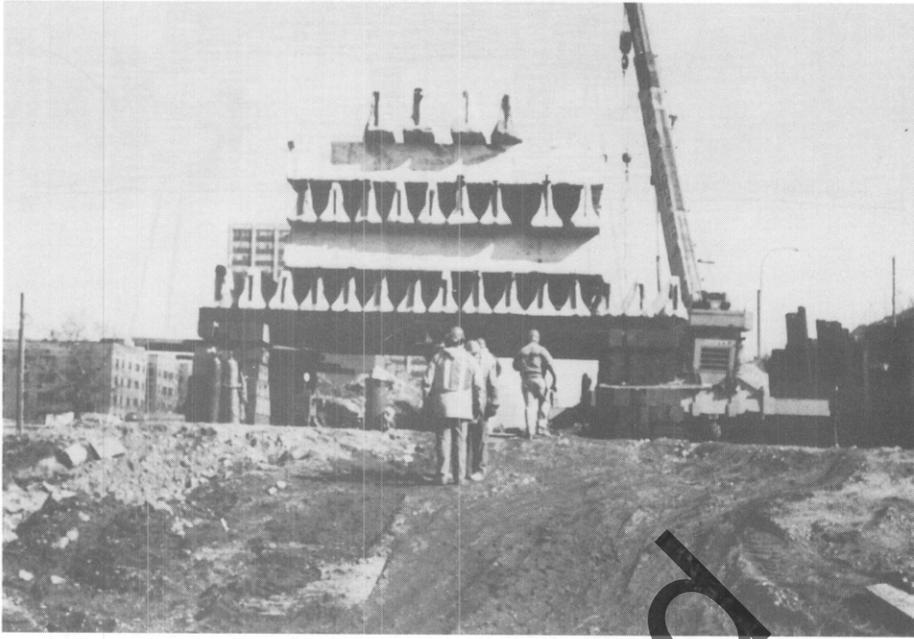
(a)
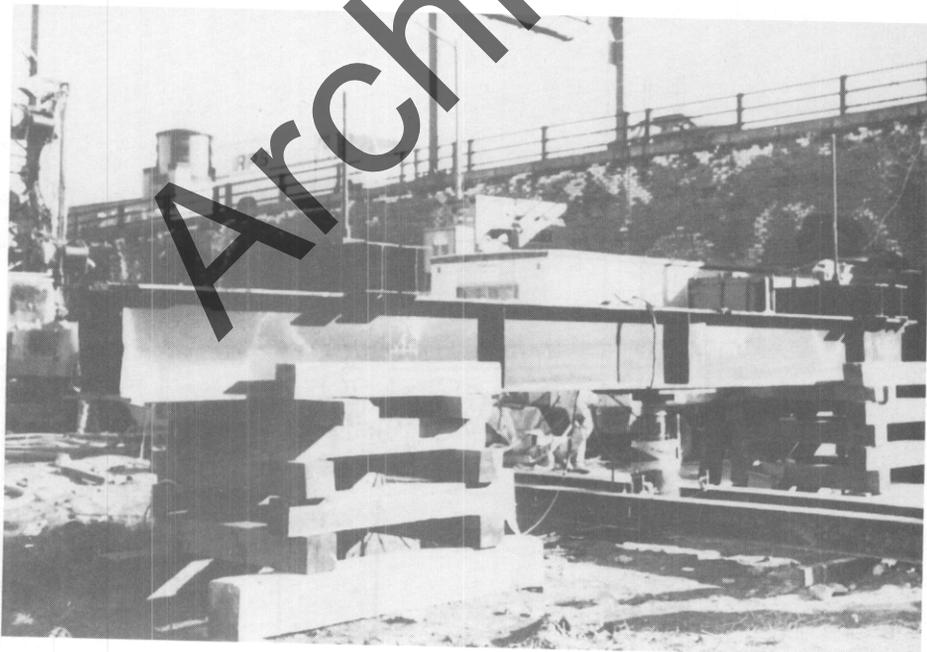
(b)

Figure 5. Axial Compressive Load Test Setup (a) Dead Load
(b) Tie-Down Anchors

hydraulic jack reacts against a dead weight, in this case median barriers, stacked on a platform. In Figure 3(b) the hydraulic jack reacts against a reaction beam connected to a pair of anchor piles while 4(a) shows the test beam connected to ground anchors, Figure 4(b) shows a mobile reaction beam used by the FHWA for demonstrating load test procedures to state agencies. The reaction beam is designed to apply loads of up to 1,000 tons to test piles.

Axial Tensile

In an axial tensile test, the load is normally applied to the test pile by jacking against a reaction frame or locking nut supported by one or more test beams centered over the test pile using one or more jacks. The test beams are usually supported by timber cribbing that has been erected on firm level ground. The test area may require material removal to obtain a firm level ground surface. In the event that the upper foundation soils are very compressible, reaction piles could be installed to provide support for the test beam(s). The height of the cribbing or reaction pile stickup should be such that enough clearance exists between the bottom of the test beam and top of the test pile. This clearance is very important in that if sufficient clearance is not provided, the test pile could come in contact with the bottom of the test beam, terminating the test.

Typical arrangements for the tensile load test are shown in Figure 6. In all cases, the reactions are transmitted to the ground through timber mats.

Lateral Load

The most common method of testing a pile under lateral load is that of using another pile as the reaction. Three possible lateral load test setups consisting of two-pile arrangements are
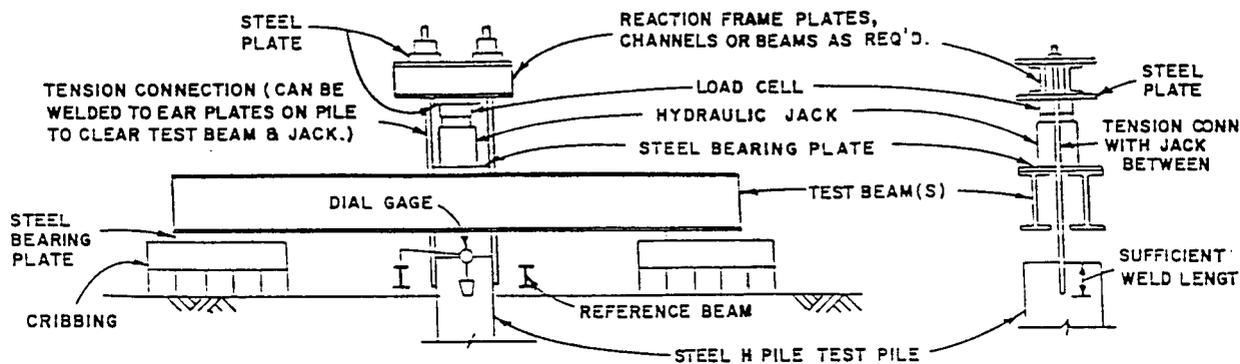
TWIN TEST BEAMS
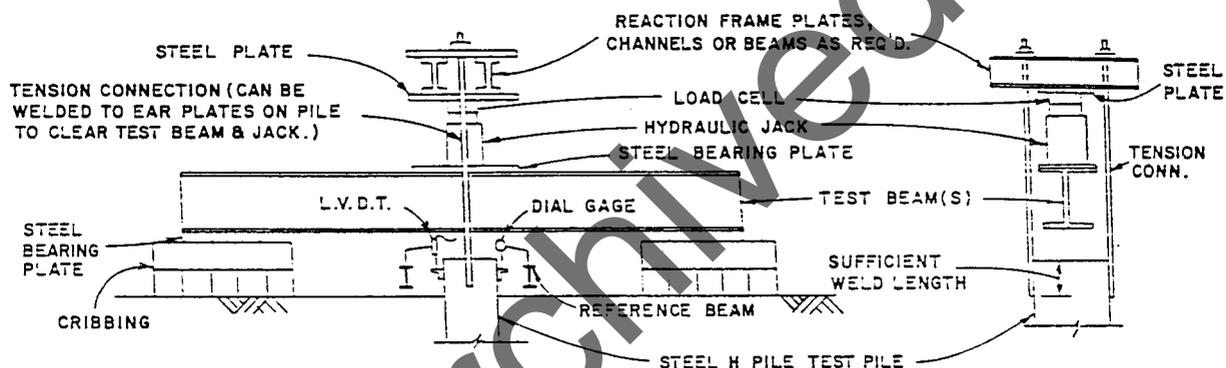
SINGLE TEST BEAM
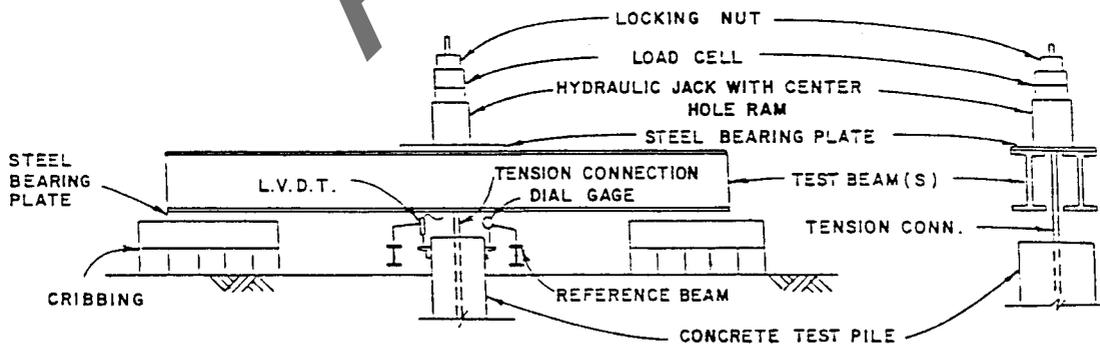
TWIN TEST BEAMS

Figure 6. Typical Arrangements for an Axial Tensile Load Test

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shown in Figure 7. The pile head is free to rotate and the loads are applied as near the ground surface as convenient. The load is applied by using a hydraulic jack. Figure 8 shows an example of the test arrangement shown schematically in Figure 7(c). Note the support that is required for the hydraulic jack and strut arrangement.

2.3.2 Load Test Setup

The Test Pile

The test pile should be of the same type, cross-section and length as the piling that is proposed for the permanent foundation. In addition, the test pile should be installed with the same equipment and procedures as is proposed for the production piles. Complete records should be maintained during the installation of the piles. The test pile must be monitored for heave, beginning immediately after driving and periodically until testing begins.

Reaction Members

Piles or ground anchors which are used as test load reaction members should be designed to resist the forces created by the test load. Reaction piles utilized as part of the proposed foundation should be installed to the same requirements as the test pile unless deeper embedments are needed for uplift resistance. The use of permanent piling as reaction piles will require that the pile head movements be monitored during the progression of the load test.

Anchor piles that have been installed by driving and during an axial compressive test undergo irrecoverable upward movement can often be redriven. This is not generally the case for non-driven piling and therefore should be a consideration in

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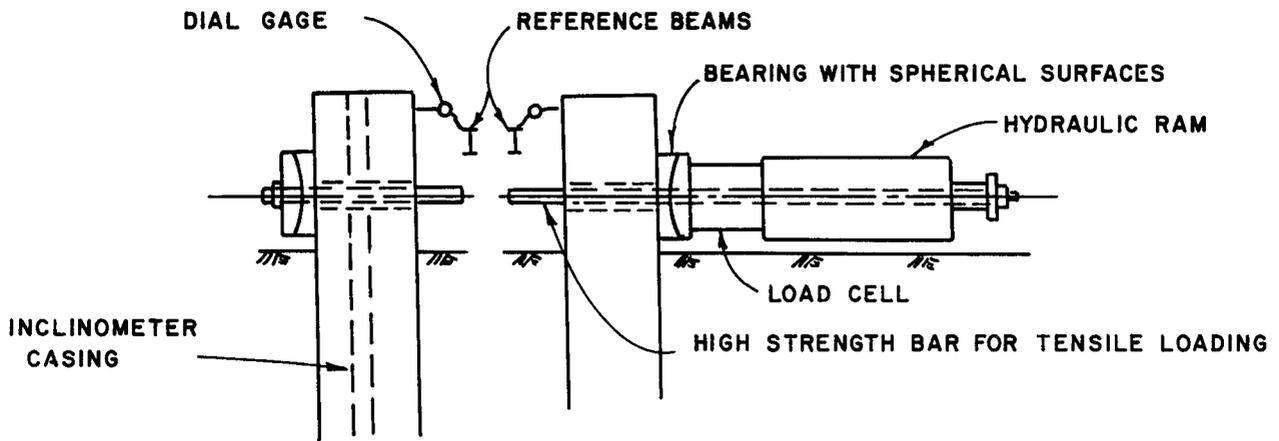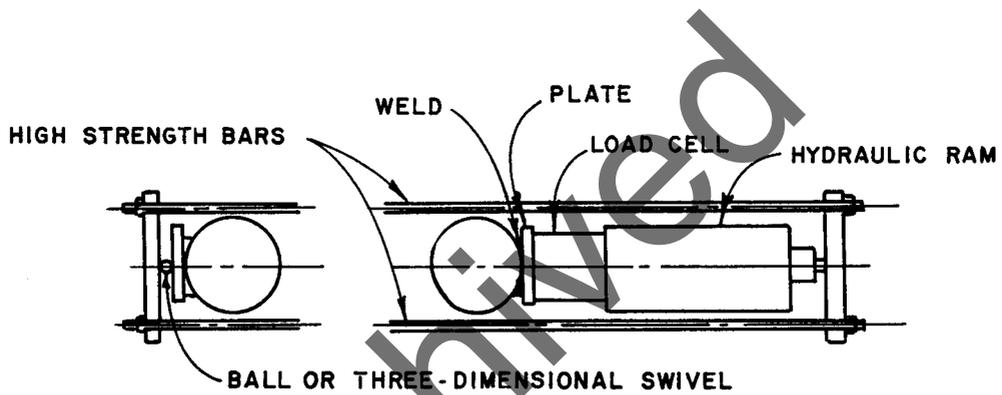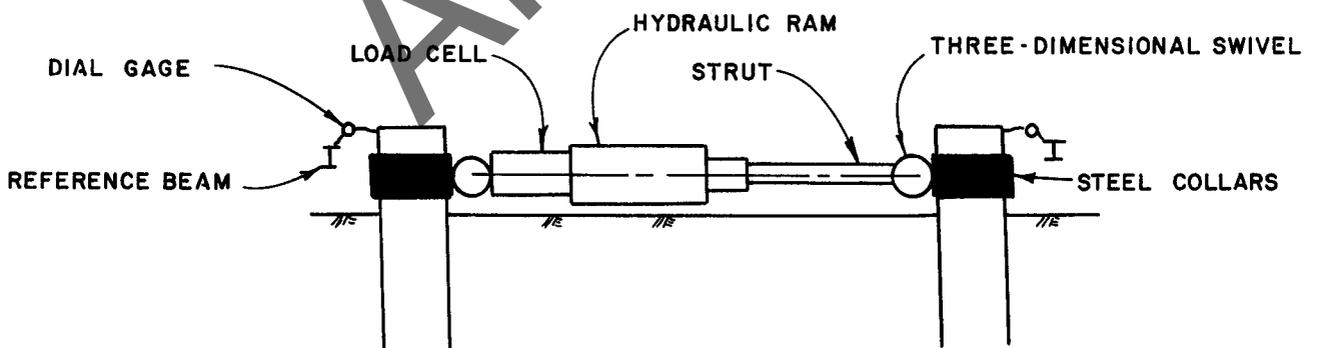
Figure 7. Three Lateral Load Test Setups

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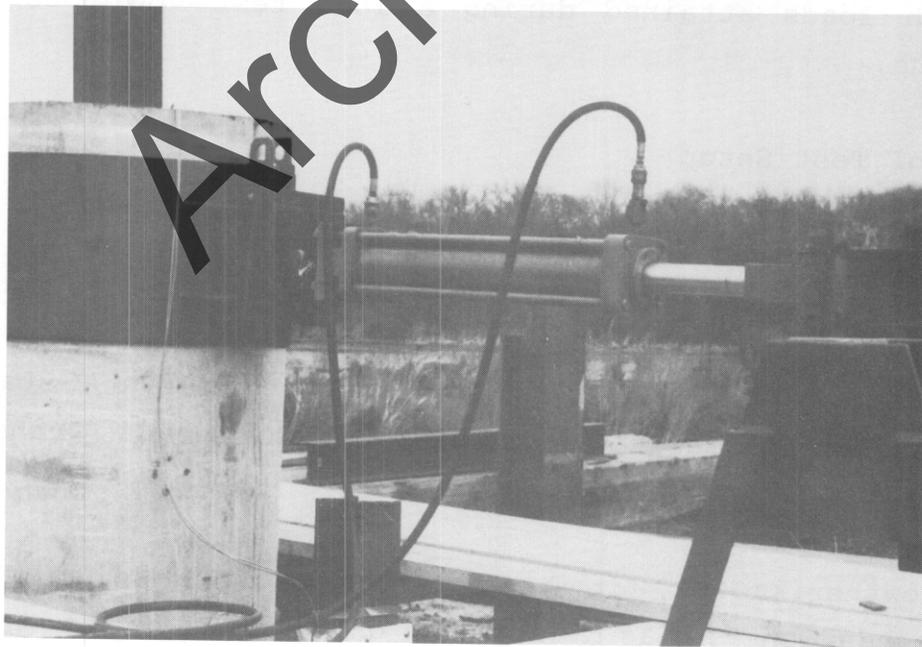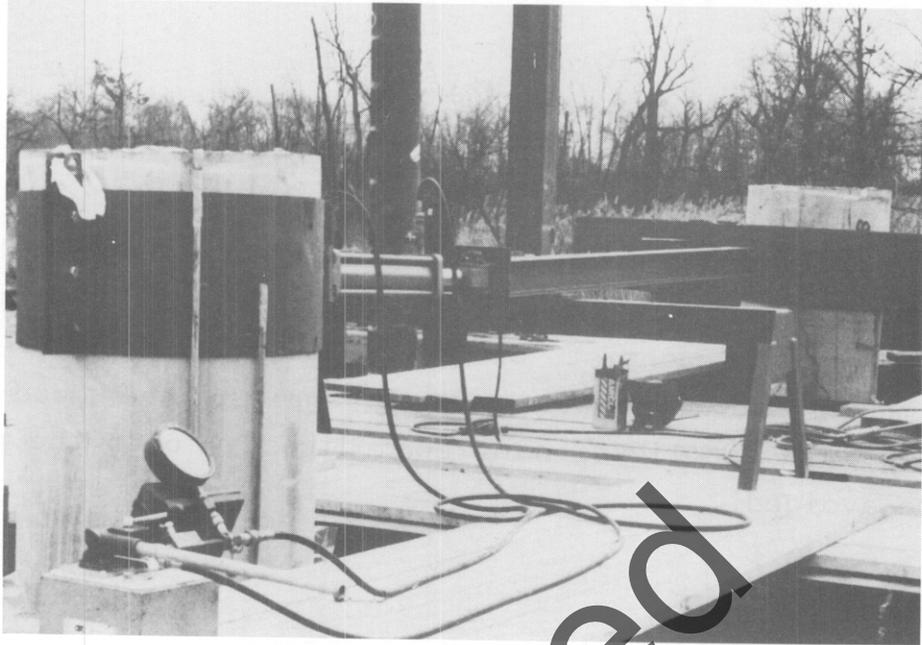
Figure 8. Lateral Load Test Setup

deciding whether or not to use production piles as part of the reaction system.

Loaded Platform

The loaded platform for an axial compressive load test can be used to transmit load directly into the test pile or to provide a reaction for the hydraulic jacks. The load placed on the platform can consist of steel ingots, precast concrete blocks, water tanks, etc. Jacking against the dead load is preferable. The application of load directly onto the pile head should be avoided.

Reaction Beam

The reaction frame for transmitting loads should be structurally designed to withstand loads up to the maximum test load without excessive deflection. Close attention must be given to the design and fabrication details because frame failure under the high loads attained during a load test would be extremely hazardous.

Design of Test Setup

The pile load test setup should be designed for the maximum anticipated applied load. All materials used in the construction of the load test arrangement (reaction beams, transfer beam, connections, etc.) should conform to the relevant standards of the American Association of State Highway and Transportation Officials (AASHTO).

Crowther (1990), in his textbook titled "Load Testing of Deep Foundations", has a section on the design of test beams, tie-down straps and connections to anchor piles. Several detailed examples are shown for the design of load test setups. In

sizing a test beam, Crowther recommends that the following guidelines:

- ° A beam size that has a depth no greater than 3 times its flange should be selected.
- ° Flange widths should be held to a minimum of 12 inches.
- ° Web stiffeners (minimum 1/2 inch thick) at the midpoint of the beam and at each end under the tiedown straps should be used. If single thread bar type reaction connections are used, web stiffeners should be used on each side of the thread bar.

The author also recommends that the design of load test setups be performed by a licensed structural engineer.

2.3.3 Load Test Procedures

Axial Compression Tests

Procedures for conducting axial compressive load tests on piles are presented in ASTM D 1143 (Standard Test Method for Piles Under Axial Compressive Load). The most commonly used test methods are the:

- ° Maintained Load (ML) Test
- ° Quick Load (QL) Test
- ° Constant Rate of Penetration (CRP) Test

Maintained Load Test

Test Load: 200 percent of the design load
Load Increments: 25 percent of the design load
Load Duration: until rate of settlement has decreased to 0.001 ft/hr or for 2 hrs whichever occurs first

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Other: The 200 percent load is maintained for 24 hours

Test Duration: from 48 hours

Quick Load Test

Test Load: 300 percent of design load or carried to failure

Load Increments: 10-15 percent of the design load

Load Duration: 2.5 minutes

Test Duration: 3-5 hours

Constant Rate of Penetration Test

Test Load: Carried to failure

Load Increments: none

Other: The pile head is forced to settle at a predetermined rate and the force that is required to achieve the penetration is recorded.

Fellenius' (1975) comparison of the required time and typical load-movement behavior for the load test procedures just described is presented in Fig. 9(a) and (b). Note that CRP and QL tests can be performed in a fraction of the time required for the ML test.

The QL and CRP tests thus offer the following advantages over the ML test:

° A load test can be performed in a matter of a few (1-4) hours compared to over a day (24-48 hours).

° Construction delay to the project is reduced.

° Load testing becomes feasible on smaller projects.

° The tests result in more nearly "undrained" conditions of shear failure. (Static analyses generally utilize undrained soil strength parameters during design.)
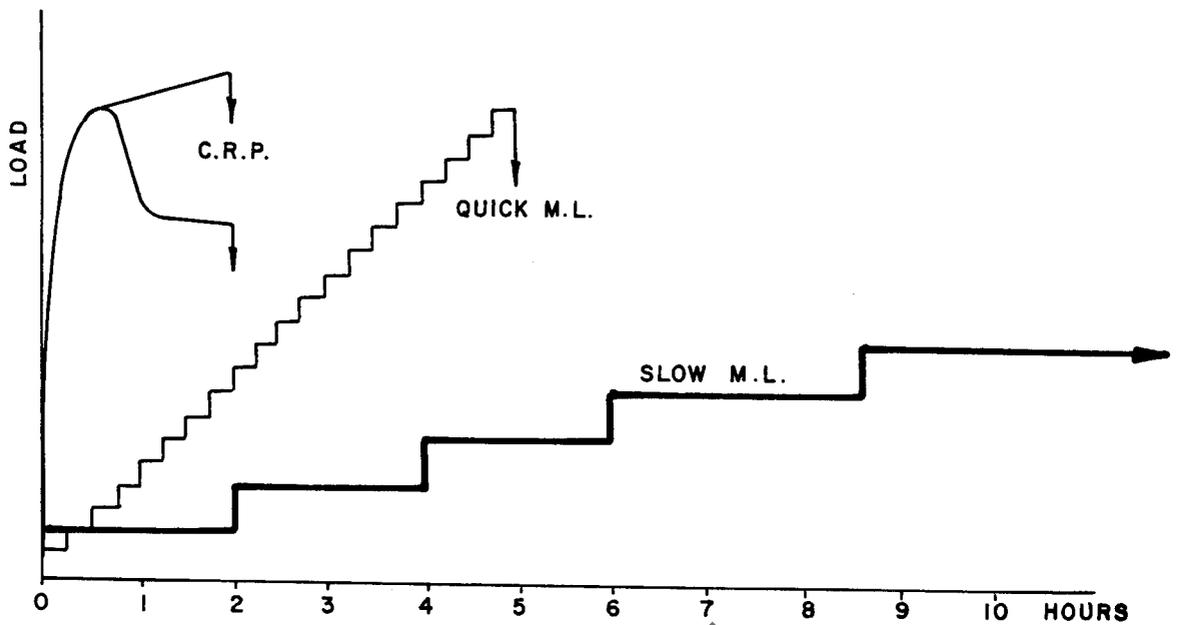
(a)
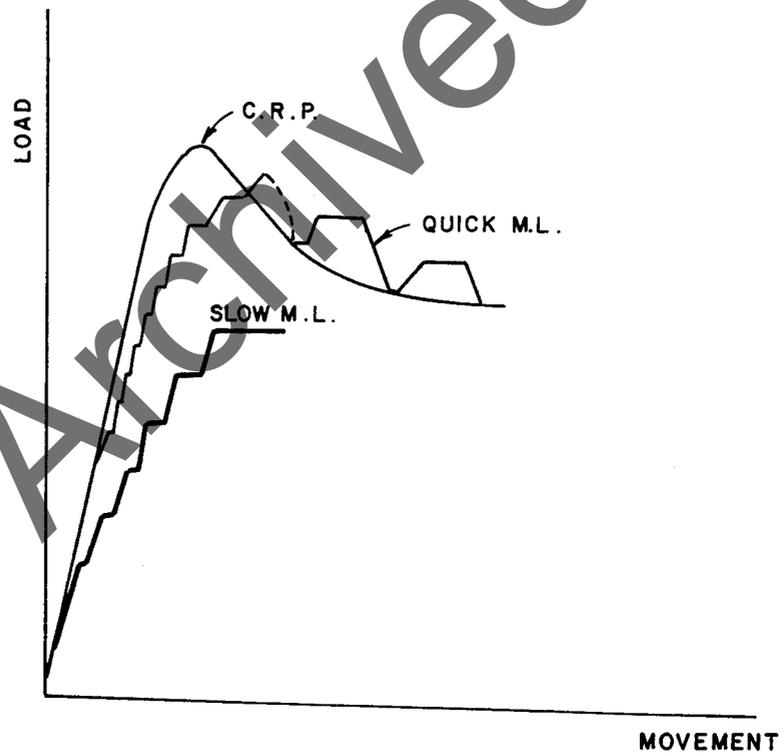
(b)

(AFTER FELLENIUS, 1975)

Figure 9.   Comparison of (a) Required Time and (b) Typical
Load-Movement Behavior for Three Test Procedures

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The CRP test is best suited for friction piles but is seldom used for end bearing piles due to the high loads necessary to cause constant penetration. If the load test requires that the pile be internally instrumented (more than just a telltale at the pile tip), the use of the QL test method is recommended to provide adequate time to record instrument readings. The QL test is described in more detail in THE TEXAS QUICK-LOAD METHOD FOR FOUNDATION LOAD TESTING-USERS MANUAL, FHWA-IP-77-8, (Butler and Hoy, 1976). The CRP test requirement for taking several measurements simultaneously can prove to be difficult.

The ML, CRP and QL tests should all be regarded as tests of short duration which may not reflect long term pile settlements of either individual piles or groups. Any attempt to determine long term settlement by means of a load test would be uneconomical for design purposes because of the excessive amount of time that would be required. Fellenius (1980) states that in those cases where a study of the time dependent or drained conditions, creep, etc. is desirable, the test duration would have to be measured in weeks, months or even years. He further goes on to say that the test duration for the presently used ML test is therefore vastly inadequate and results only in confusion.

Axial Tensile Tests

The load test procedures as presented for the axial compressive tests are applicable for the uplift test with the difference that the applied load is directed upwards. Additional loading procedures can be found in the ASTM Standard D-3689 (Standard Method of Testing Individual Piles Under Static Axial Tensile Load).

Lateral Load Tests

Test Load: 200 percent of anticipated design lateral load
             or other (see below)

Load Increments: 12.5 percent of test load for standard
                   loading schedule, 25 percent of test load
                   for cyclic loading schedule.

Load Duration: 30 minutes and other.

The standard method of testing piles under lateral loads as described in ASTM Designation D 3966 (Standard Method of Testing Piles Under Lateral Load) has been recommended for use by Vanikar (1985).   The method presented herein, which is a modification of the ASTM method, emphasizes the evaluation of the response of the pile-soil system to lateral loading instead of the determination of the lateral load capacity of the system.   This permits the test results to be extended to pile arrangements and loading conditions not duplicated in the test.

The method presented herein differs from the ASTM method in the following respects:

1.   The use of an inclinometer (to evaluate the p-y behavior of the pile/soil system) has been changed from optional to strongly recommended.

2.   Emphasis on the p-y behavior of the pile/soil system permits the elimination of expensive test set-ups that attempt to duplicate the in-service applied moment and restraint conditions.

3.   A method is presented of adjusting the design lateral load when calculating the test load to ensure that the lateral deflection of the pile as tested is of similar magnitude as that in service (see Section 2.3.6 Special

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Considerations for Lateral Load Tests). This minimizes differences between as-tested and in-service behavior that can result from the non-linearity of the p-y curves.

4.   The loading schedules have been simplified to aid in interpretation of the test results. The modified loading schedules permit the observation of pile/soil behavior under a single step-wise applied load and under an increasing number of load repetitions. Tests to investigate other loading conditions (surge loading, reversed loading) may occasionally be desirable. The need for such tests is quite infrequent and presupposes the presence of a person able to design a loading sequence and interpret the ensuing results. Setups for reversed loading tests are described and shown in the ASTM specification.

When the lateral load-deflection relationship to a specific magnitude of pile movement is required, the test load should be calculated from the stated pile movement based on the known pile properties and on estimated p-y curves for the soil.

Test Method Specifications

Methods of performing axial compressive, axial tensile and lateral load tests are presented in a specification format in Appendix B of this manual. The test methods, with the exception of the lateral load test method, are consistent with those presented in the ASTM standards. These specifications can be incorporated into a load testing specification for the majority of the tests that are performed. It is not the intent of this manual to create new standards, but instead to focus in on requirements for most routine pile load tests. For load tests other than those discussed in this manual, the reader is referred

to the latest ASTM standards. No single specification can be applied to all load test situations, therefore modifications to suit specific project requirements may be necessary.

2.3.4 Location and Number of Tests

Load tests should be located in areas where the subsurface conditions have been ascertained by means of explorations and are known to reflect subsurface conditions at the sites where the corresponding production piles will be installed.

The number of load tests to be performed should be determined by the geotechnical engineer. The basis for making this determination will be dependent on:

° variability of subsurface conditions throughout the project site, e.g. uniform conditions may indicate that one test will be sufficient, while variable conditions could indicate the need for several tests.

° pile loadings, e.g. design loads higher than those conventionally used may require additional tests.

° type of pile being installed, e.g. unfamiliarity with pile or new pile installation techniques may require an increased number of tests.

2.3.5 Magnitude of Test Load

In practice, piles are often tested to twice the design load. This does not permit a determination of the pile/soil capacity and negates design knowledge obtained from a load test that could otherwise be used to reduce the number or the length of production piles. Whether testing is done during the design phase or during the construction phase, every effort should be made to test the piles to failure. Load testing to failure, when practical, is recommended since this discloses the real safety

factor inherent in the design and therefore may lead to a more economical redesign.

2.3.6 Special Considerations for Lateral Load Tests

Combined loads (lateral, vertical and moment) that production piles will have to support are difficult and expensive to duplicate on a test pile. While this is generally of no significance for an evaluation of the axial load bearing capacity of a pile, the situation is much different with respect to its lateral and moment resistance. Two piles installed in the same soil and resisting equal lateral loads but different bending moments will experience much different deflections and stresses. In addition, concrete piles that may develop a cracked section and, consequently, a reduction in stiffness in a lateral pile load test may not do so in service when supporting axial compressive as well as lateral loads.

In view of the above, lateral load tests should be used primarily to:

° determine p-y curves (Reese, 1984) for use in design.
° verify during construction the appropriateness of p-y curves used in design.

Consequently, piles used in lateral load tests should be instrumented to determine the deflected shape of the pile to a depth of 10 to 20 diameters. Tests in which only the lateral deflection at the top of the pile is measured are seldom justified (Price et al, 1987).

The rotation of the pile head in the lateral pile load test is often measured by dial gages installed at two different heights above ground surface. The results obtained from these measurements are quite difficult to interpret (Hirany and

Kulhawy, 1989) and do not eliminate the need to measure lateral deflections of the pile at points below the ground surface.

Lateral movement of a pile results from a combination of the lateral load applied to the pile and the moment generated at the top of the pile either by the point of application of the lateral load being above the ground surface or by restraint against rotation at the top of the pile. A free-headed partially embedded pile will be displaced a greater amount by a lateral load applied at some distance above the ground surface than by the same load applied at ground surface. Reese's p-y method of analyzing the lateral load behavior of piles is based on non-linear soil response (i.e., the "modulus" of the soil decreases with increasing deflection). In order to ensure that the soil behavior at the design lateral load in service will correspond to that observed in the lateral load test, the pile deflections when tested and in service have to be of similar magnitude. An approximate method to achieve this is by using the following relationship (Franke, 1973) to calculate an adjusted design lateral load:

$$P_{DD} = P_D \ (1 + Y_M/Y_F)$$

where,

P_{DD} = adjusted design lateral load

P_D = design lateral load, based on a structural analysis of the foundation

Y_M = pile top deflection calculated by Reese's method for design moment alone, using assumed p-y values

Y_F = pile top deflection calculated by Reese's method for design lateral load alone, using assumed p-y values. (Note that Y_M and Y_F can be of opposite sign).

The adjusted design lateral load, when applied to the pile at or near ground surface, will result in approximately the same

amount of pile deflection as the pile would experience when acted on by the combination of lateral load and moment that it has been designed for the test load (P_T) should then be twice the adjusted design lateral load:

$$P_T = 2 \times P_{DD}$$

Other points to consider in planning, performing and interpreting lateral load tests are

° The test should be located in the area with the weakest soil profile within a depth below ground surface equal to five times the pile diameter since pile response to lateral loads is most strongly dependent on the properties of the soils within this depth interval.

° Surface soils which are only partially saturated but can be expected to become saturated at a future time, should be saturated (by ponding) before the lateral test is performed.

° For optimum reliability of the test results, the test pile should have the same diameter, the same length, and the same stiffness and be installed in the same fashion as the production piles.

° The actual concrete strength at the time of testing, determined from laboratory tests, should be used in analyzing the results of a load test.

° Long-term lateral loads on piles in cohesive soils will lead to pile movements due to dissipation of pore pressures. Such movements may be estimated by soil mechanics analytical methods and/or by performing long-term tests. The required duration of load application should be

calculated by soil mechanics methods. Piezometers for pore pressure determination adjacent to piles should be used with caution because the disturbance from their installation may affect the stress-deformation properties of the soil.

° In applying the results of lateral load tests to the design of pile foundations, group action of piles must be considered (Bogard and Matlock, 1983; Ochoa and O'Neill, 1989).

2.3.7 Measurement of Load and Movement

Instrumentation

A key element in the design of a load test program is that of instrumentation. Failure of the pile instrumentation to function properly leads to unusable data or, even worse, the interpretation of "bad" information that could potentially lead to an unsafe design.

The following section discusses the types of instrumentation that are most commonly used on pile load tests. Because of the many types of instrumentation available and because geotechnical instrumentation is a specialty topic, the discussion is limited. For more detailed information concerning the various instruments and their uses, the reader is referred to Dunnicliff's text titled GEOTECHNICAL INSTRUMENTATION FOR MONITORING FIELD PERFORMANCE (Dunnicliff, 1988).

Because geotechnical instrumentation is a specialty, the services of a "geotechnical instrumentation specialist" should be sought, particularly when internal pile (non-routine) instrumentation is called for. Proper instrument selection and installation are necessary to withstand loads applied during handling and

driving operations. Damaged instrumentation cannot be repaired after the pile is driven. Depending on test requirements, the "specialist" can provide the following services:

- ° select the best suited instrument for a particular pile type
- ° determine the number of instruments required
- ° determine the requirements for backup (redundant) instrumentation
- ° prescribe proper installation procedures or perform the actual installation
- ° supervise handling and installation of instrumented piles
- ° specify calibration requirements
- ° design the remote monitoring program
- ° provide instruction on taking readings

Several factors must be considered in the selection of instrumentation for piles. In approximate decreasing order of importance these factors include (Hirsch et al, 1970):

- ° the accuracy of the unit
- ° its reliability or resistance to failure
- ° its influence on the measured system
- ° simplicity of operation under field conditions
- ° ease of installation
- ° readily available maintenance
- ° auxiliary equipment necessary for operation
- ° costs
- ° salvage value

Load At Pile Head

Calibrated Hydraulic Jack/Load Cell. Calibrated hydraulic jacks have a twofold purpose in the load testing of piles: as a means of applying loads to the pile head and to determine the

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load applied by measuring the pressure of the jack fluid. Dunnicliff (1988) states that reliance on the measured pressure in the jack fluid as the sole method can lead to significant inaccuracies (±10 to 25 percent) due to the following factors:

- ° misalignment of load,
- ° off-center loading,
- ° non-parallel bearing plates,
- ° transverse relative movement of bearing plates,
- ° temperature changes, and
- ° pressure gage inaccuracies.

When used in load testing of piles, the effect of these inaccuracies will be on the unsafe side during loading, with pressure gage readings larger than actual applied load. During unloading, pressure gage readings will be smaller than the actual load.

A calibrated load cell connected in series with a hydraulic jack should be used when load is to be measured at the pile head. In addition, a swivel head (spherical bearing) should always be used to minimize the effects of eccentric loading. Figures 10 and 11 show a typical arrangement used in an axial compressive test.

Load Along Pile Shaft

Strain Rods. Strain rods are simple mechanical devices also known as "telltales" that are used to measure compression in concrete or steel. The device consists of a small-diameter steel rod that is fixed at a selected point (Figure 12) along or within the pile. This rod is encased in a slightly larger pipe or tube and is extended up to the pile top. During telltale installation, care must be taken to ensure that the telltale rod is allowed to move freely in the pipe or tube. Dial gages are used to measure the deflections at the top of the rod. The telltale
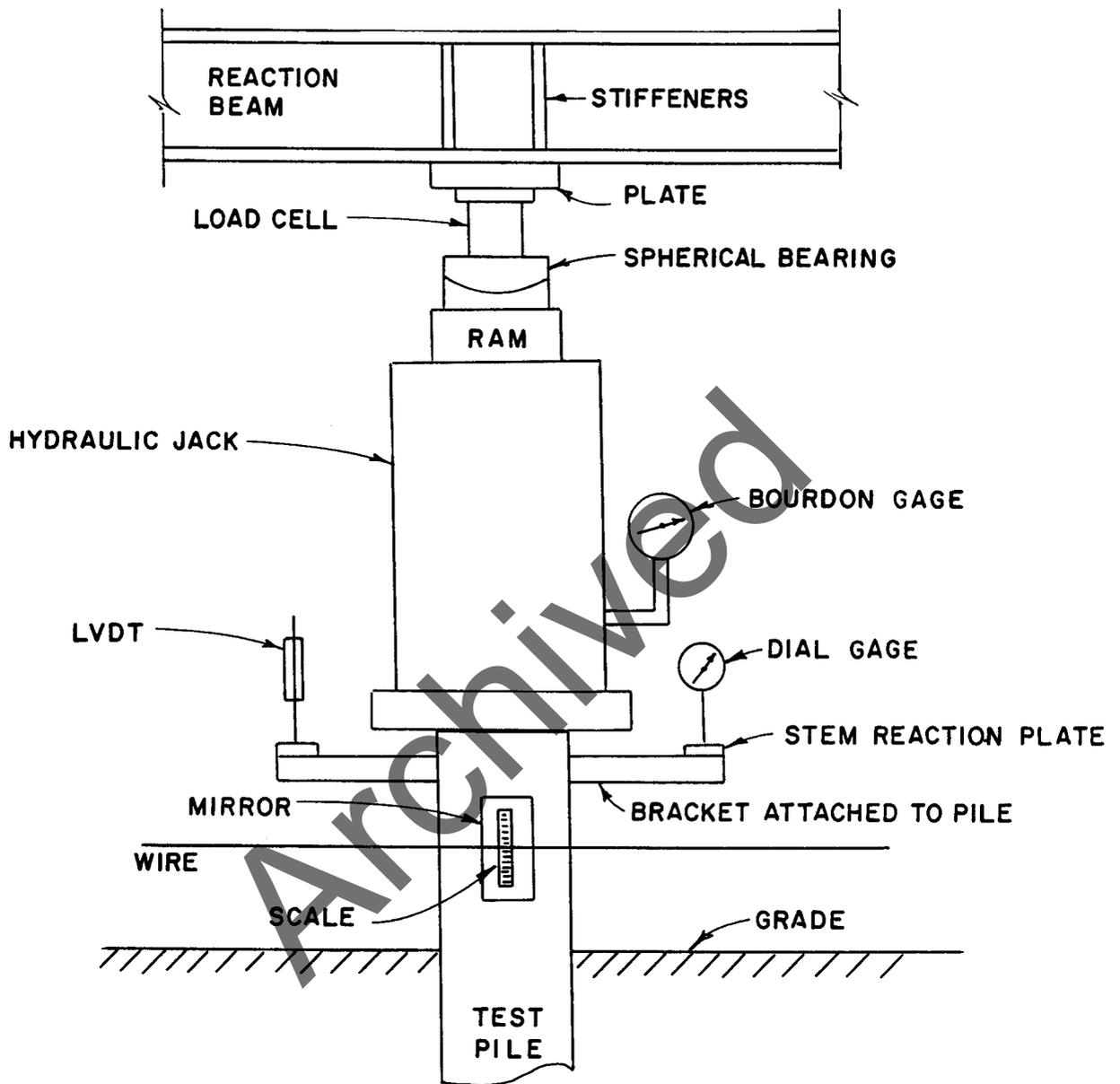
Figure 10. Typical Arrangement for Applying Load in an Axial Compressive Test
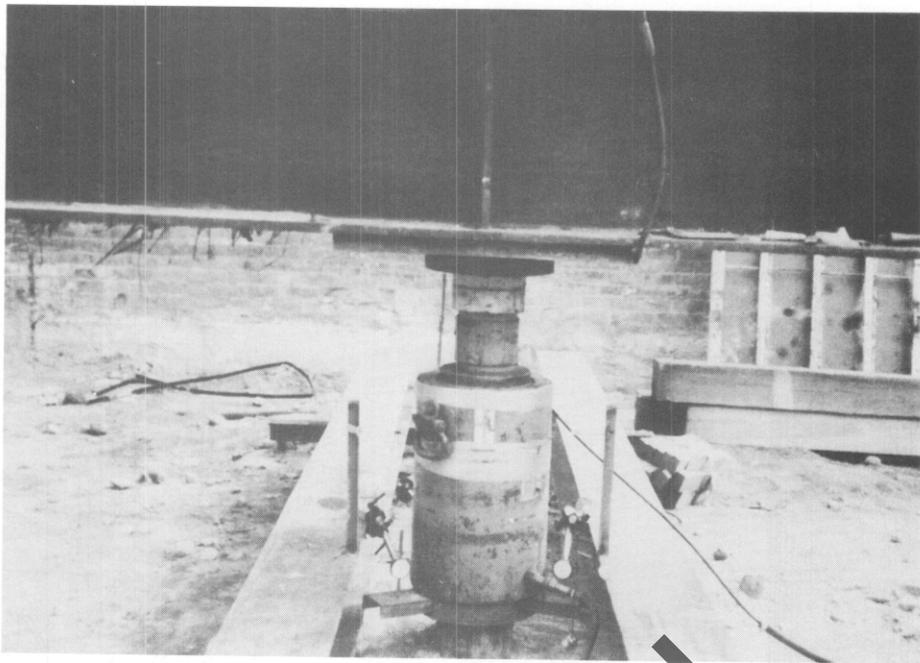
(a)
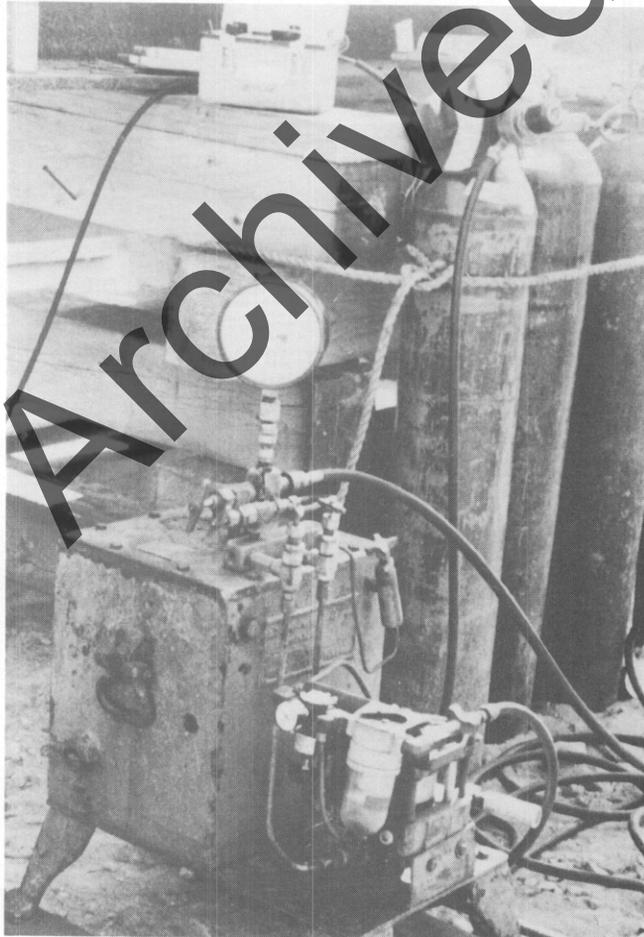
(b)

Figure 11.   (a) Load Cell-Hydraulic Jack Arrangement (b) Gas
Operated Device That Controls Hydraulic Jack

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PIPE PILE

NO. 3 REBAR TELLTALE

1/2" POLYETHYLENE PIPE

FILL W/SAE 40 OIL

WORM DRIVE HOSE CLAMP

5/8" MACHINE BOLT

PILE WALL

2 1/2"

(AFTER MANUEL, 1983)

(a)

UNSTRAINED TUBE

SPACE FILLED WITH OIL

PROTECTIVE OUTER COVERING

UNSTRAINED TUBES

PROTECTIVE OUTER TUBING

DRILLED SHAFT

SPACE FILLED WITH GREASE

1" DIA x 2" IRON PIPE SLEEVE

LEFT HAND THREADED END

THEAD HOLE TO FILL

3" DIA. x 3/8" STEEL PLATE

(REESE, 1984)

(b)

Figure 12.   Telltale System Details for (a) Pipe Pile and (b) Drilled Shaft

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measurements can be referenced to the reference beam or the pile top. If they are referenced to the top of the pile, a direct measurement of the elastic shortening under load can be obtained. Use of telltales does not provide direct measurement of strain at a point along the pile, but instead measures the total deformation (change in length) over the finite distance between telltales.

A telltale located at the bottom of a pile (Figure 13) will provide information regarding the movement of the pile tip and the amount a pile shortens or elongates when compared to the total pile movement. If telltales are placed at various points along the pile length, the distribution of load transferred to the soil along the pile shaft can be determined.

The average load carried in the pile can be determined through the use of telltales by the following expression (see Figure 14).

$$P_{avg.} = A_p E_p \frac{R_1 - R_2}{L}$$

where,

    L = length of pile segment measured between two telltales under no load conditions

    A_p = cross-sectional area of pile

    E_p = modulus of elasticity of pile

    R_1 and R_2 = the deflection readings of telltales at depths 1 and 2

    P_{avg} = average load in the pile between the telltales.

The amount of load being transferred into the soil through skin resistance can be determined by subtracting pile loads, determined by the above expression, from the total applied load.

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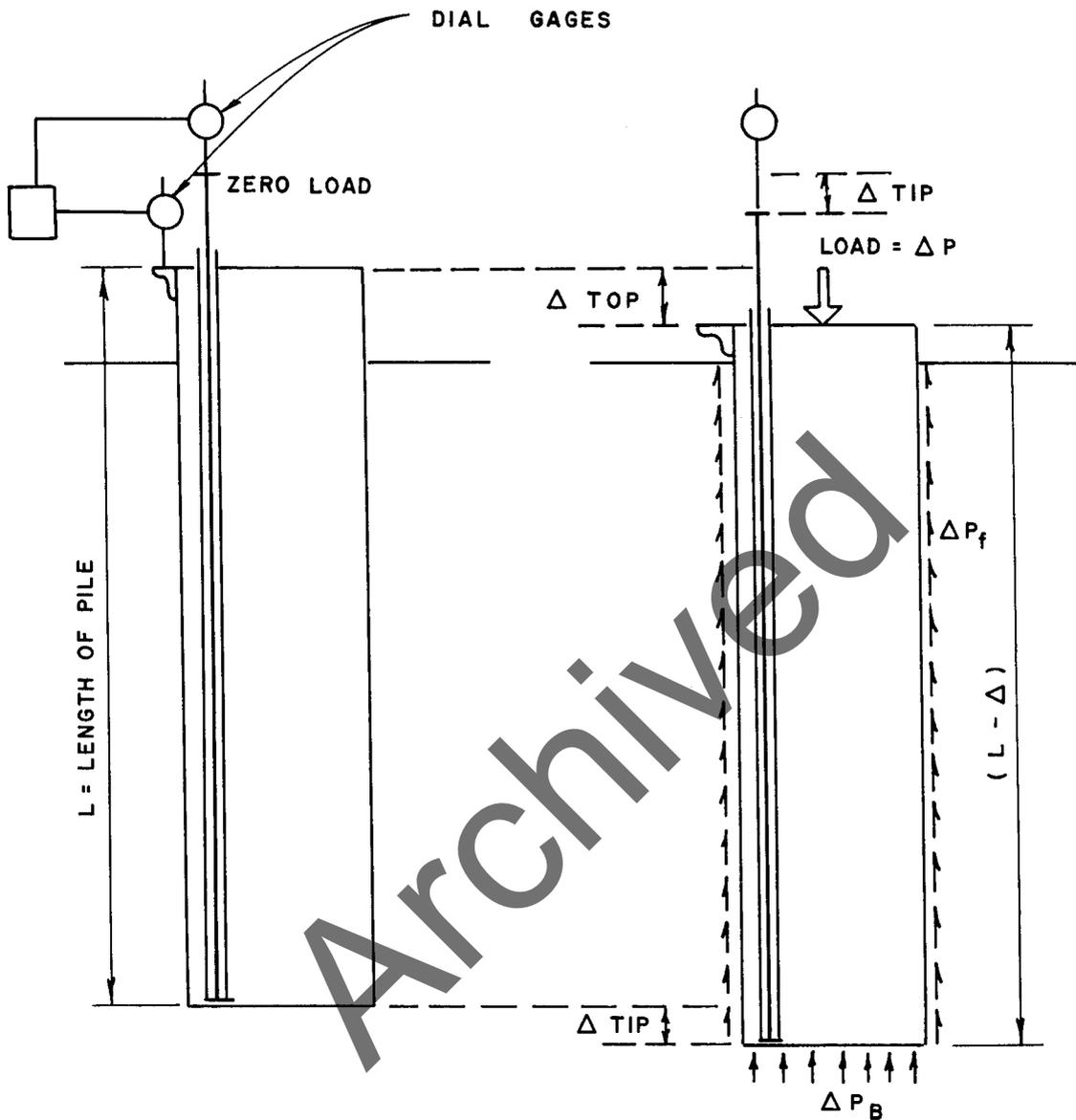
(1) ELASTIC COMPRESSION OF PILE $= \Delta_{TOP} - \Delta_{TIP} = \Delta$

(2) $\Delta P = \Delta P_f + \Delta P_B$

$$\Delta P_B = \Delta \left(\frac{AE}{L} \right)$$

$$\therefore \Delta P_f = \Delta P - \Delta P_B$$

Figure 13. Analysis of Pile Movement with Telltale Located at Pile Tip

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DIAL GAGES RESTING ON
TOP OF TELLTALE RODS

TELLTALES IN SLEEVES

AVG. LOAD ASSUMED TO
ACT MIDWAY BETWEEN
TELLTALE LOCATIONS

R_1

L

R_2
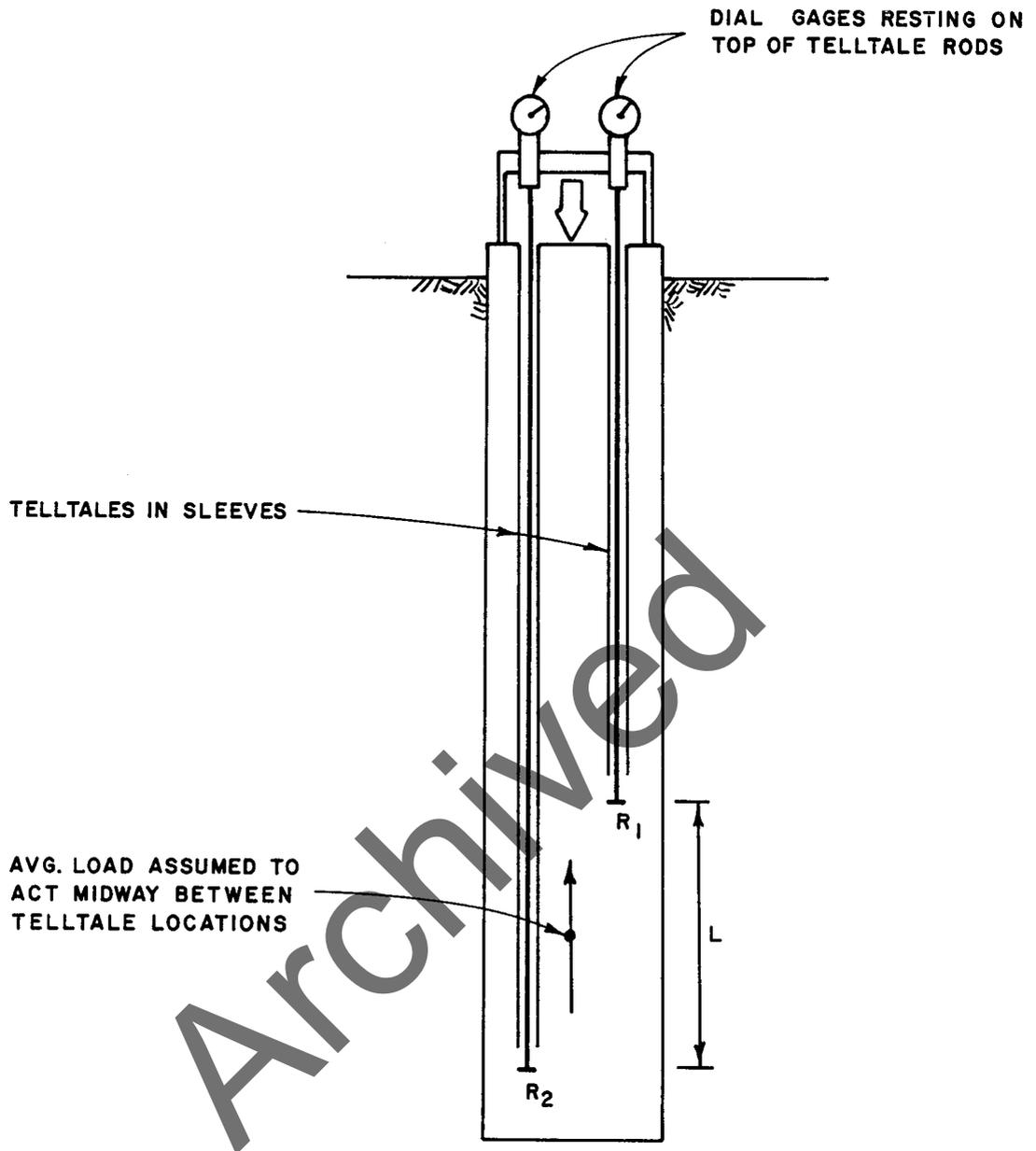
WHEN LOAD IS APPLIED A CHANGE IN LENGTH L WILL
OCCUR = DIFF. IN TELLTALE READINGS = $R_1 - R_2 = \Delta L$

$$\therefore \ P_{AVG} = (\frac{\Delta L}{L}) \ AE$$

Figure 14. Pile Movement Measurements Used to Determine Load
in Pile

Additional telltale details for cast-in-place piles, steel H-piles and timber piles can be found in Appendix E of this manual.

Strain Gages. Another type of device used in determining loads within a pile is the strain gage. Two types that are commonly used are electric resistance strain gages and vibrating wire strain gages.

The axial load (P) in a pile at the location of the strain gage can be determined by the following expression

$$P = \epsilon EA$$

where,

ϵ = strain measured by strain gage

A = cross-sectional area of pile

E = modulus of elasticity of pile material

The strain gages are attached to driven piles prior to installation and therefore should be properly protected. For cast-in-place piles the gages are attached to the longitudinal reinforcing bars and the wire is brought up through a PVC casing. Moisture is one of the main causes of strain gage failures and therefore moisture protection is required.

Embedment Strain Gages. The primary application of embedment strain gages is measurement of strain in concrete. Embedment strain gages are usually tied to nearby reinforcing bars. Sister bars and Mustran cells are embedment strain gages commonly used in determining loads in drilled shafts.

A sister bar consists of a strain gage (vibrating wire or electrical resistance) usually mounted near the center of a short section of reinforcing bar. The bar behaves similarly to the

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reinforcing steel in the structural member. An example of a sister bar arrangement is shown in Figure 15(a).

The Mustran cell was developed by The University of Texas (Barker and Reese, 1969) primarily for measuring strains in drilled shafts. The cell consists of a steel bar, with resistance gages attached, housed in a protective rubber sheath. A Mustran cell arrangement is shown in Figure 15(b). Detailed information concerning the construction of a Mustran cell and the installation procedure is presented by Owens and Reese (1987).

Vertical Movement at Pile Head

Pile head movements can be measured by the following methods:

1. Dial gages or LVDT'S (linear variable differential transformers) mounted (Figs. 16 and 17) on an independent support system (reference beam).

2. Direct leveling using a surveyor's precise level and rod referenced to a fixed datum (benchmark).

3. Tightly stretched high tensile (e.g. piano wire) wire (Fig. 18) which is positioned against a mirror and scale attached to the pile.

The pile head movements are normally measured by the use of dial gages. LVDT's (the electronic equivalent of mechanical dial gages) have also been used instead of the mechanical gages. The LVDT is an electro mechanical device that converts mechanical movement to an electrical signal. The LVDT produces an electrical output proportional to the displacement of its movable core. Its sensitivity is comparable to that of a dial gage. Survey methods and the use of the wire, mirror and scale are considered
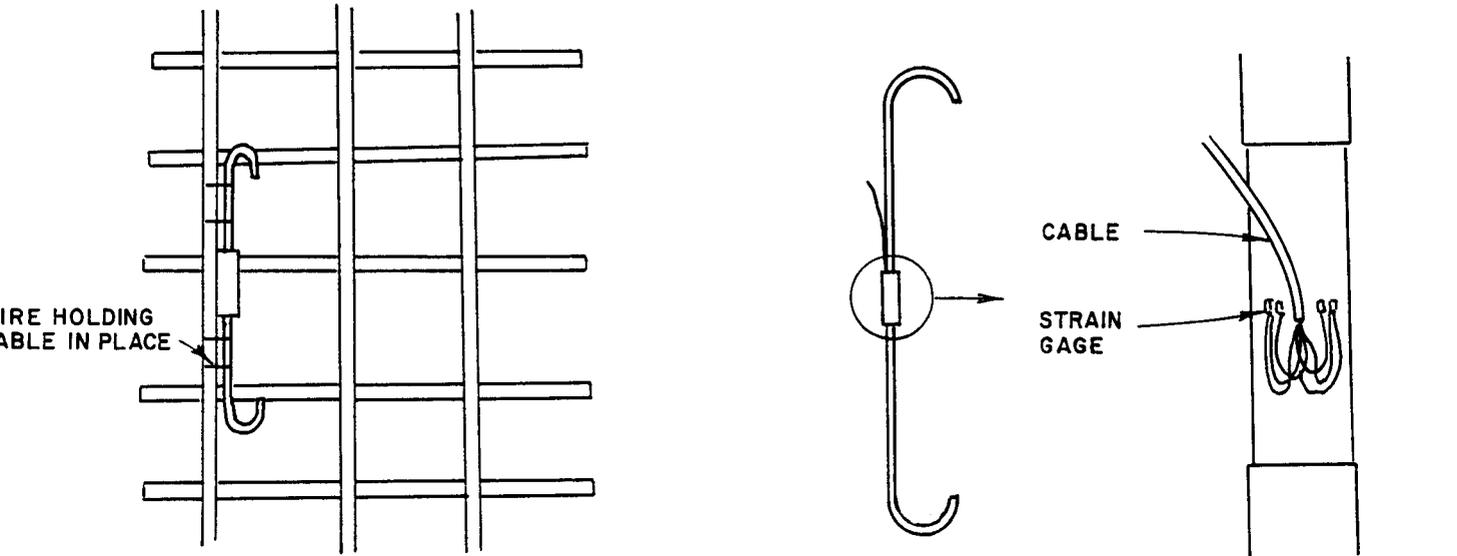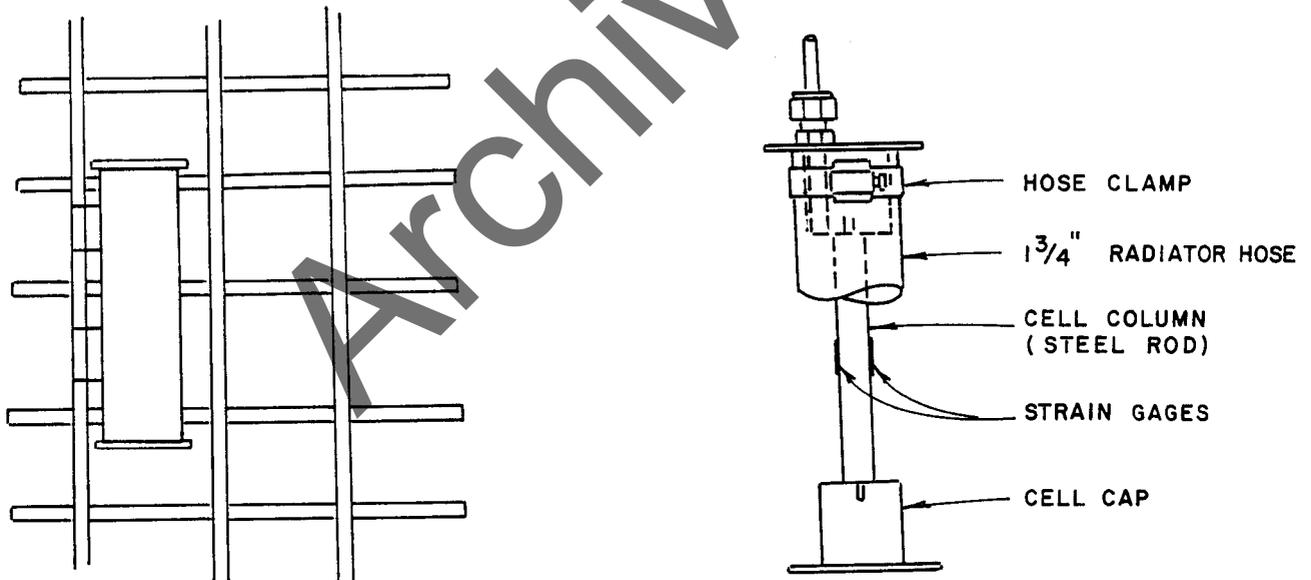
Figure 15.   Embedment Strain Gages (a) Sister Bar (b) Mustran Cell

PLAN

SECTION A-A
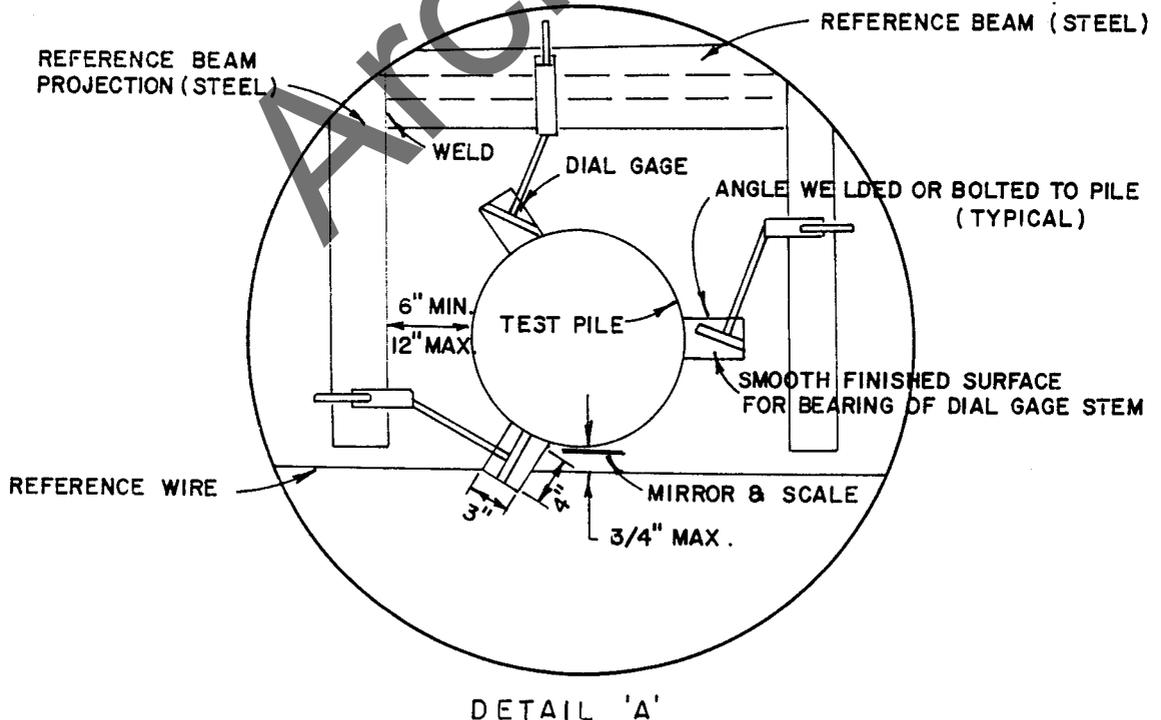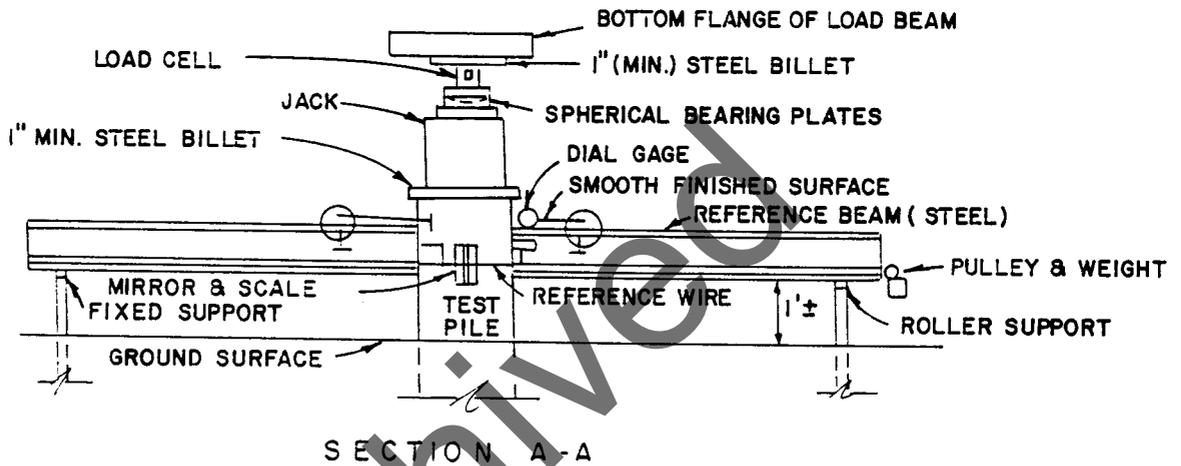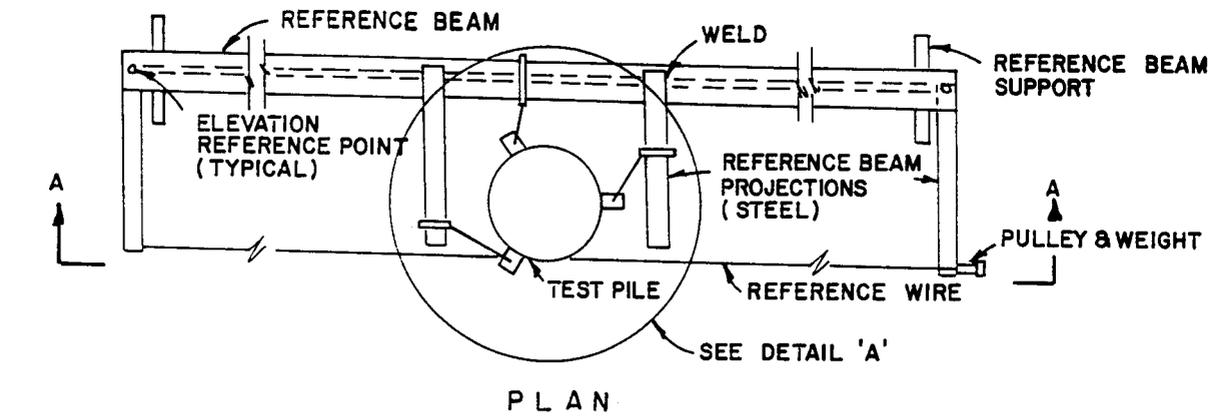
DETAIL 'A'

Figure 16.   Dial Gage Arrangement Details

47
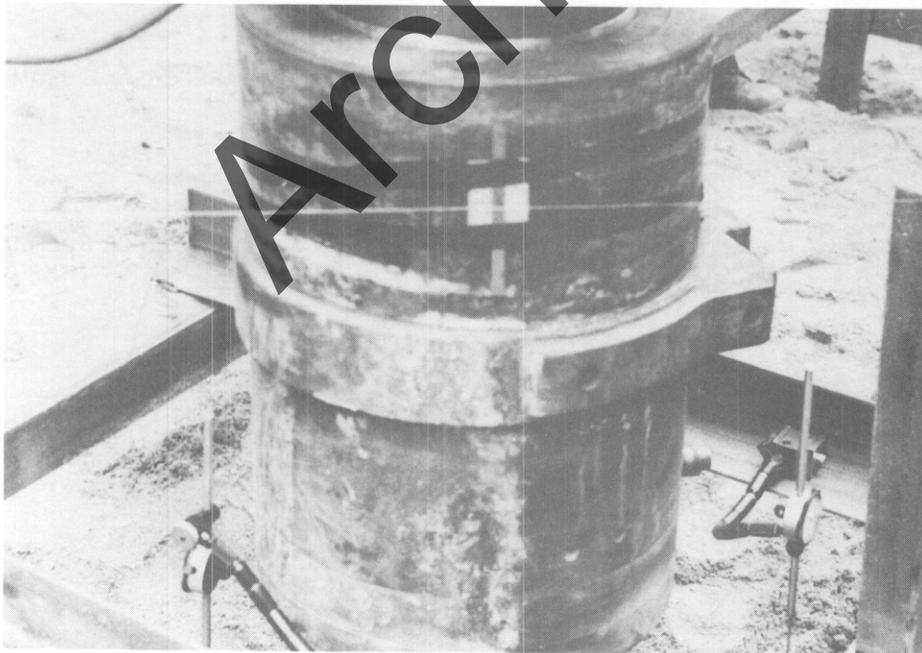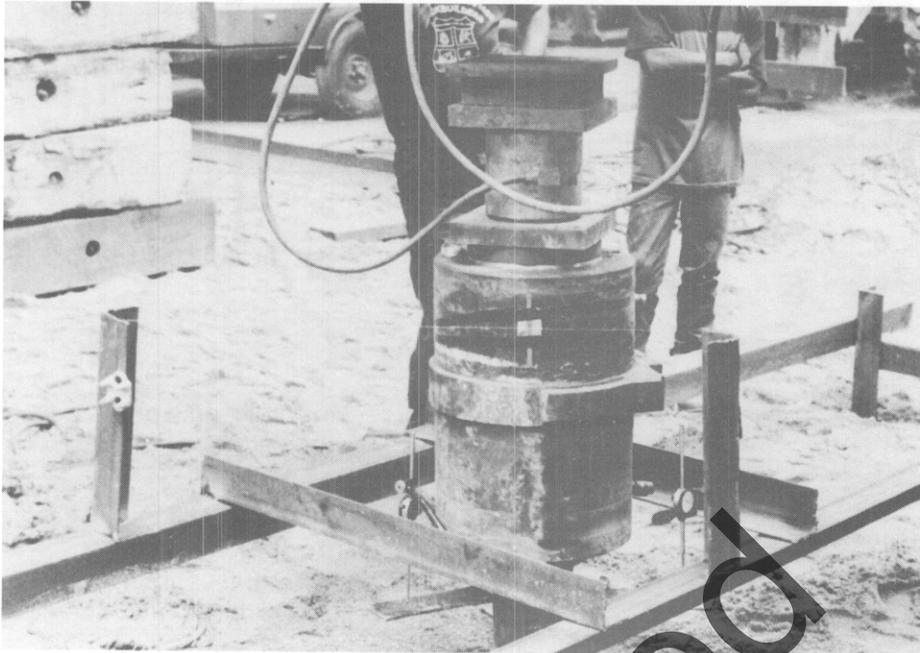
Figure 17. Dial Gage Arrangement

(COMPRESSION AND TENSION TEST)

(a)

SCALE ON TOP OF PILE   SCALE ON BRACKET
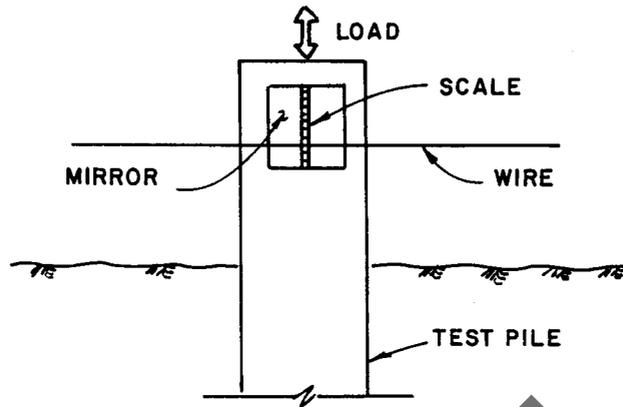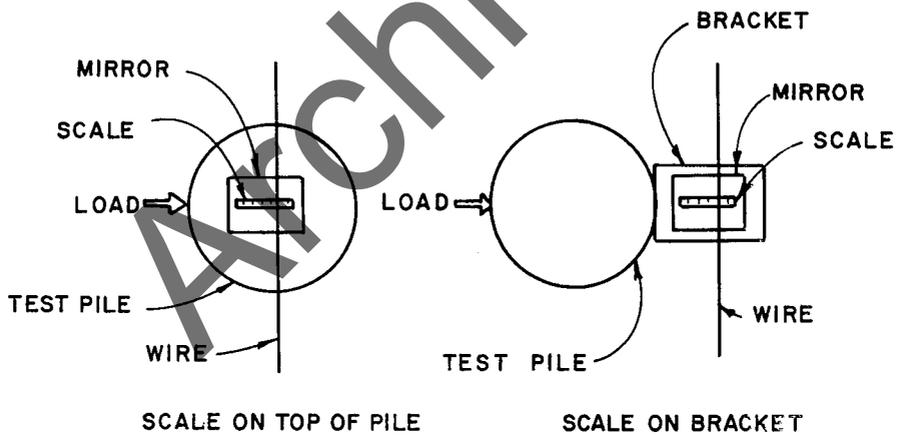
(LATERAL LOAD TEST)

(b)

Figure 18.   Wire Gage Details (a) Compression and Tension Test
             (b) Lateral Load Test

backup instrumentation in the event that the reference beam is disturbed and should not be used as primary measurement systems.

One advantage of using an LVDT instead of a dial gage is the ability of the LVDT to be monitored remotely. The readout unit can be located away from the test pile and reaction system. Another advantage would be the potential the LVDT has for incorporation with a computerized data acquisition system. Figure 19 shows how an LVDT would be attached to a pile in order to measure pile head movement.

The following points need to be considered with regard to the reference beam:

° the beam should be supported in such a manner as to not be influenced by the test equipment (movements of test pile, anchor piles, cribbing) (Fig. 20(a)).
° the movement of the beam should be monitored throughout the test by the use of survey or other appropriate methods.
° the beam should be protected from the influences of weather, particularly the sun (temperature changes will cause the beam to deform) (Fig. 20(b)).
° personnel not associated with the conduct of the load test should be kept away (individuals have been observed on more than one occasion using the reference beam as a footrest).

The reference beam is a simple setup, yet by not adhering to the general guidelines listed in the previous paragraph, the results of the load test could be rendered useless. Therein lies the need for <u>always</u> having backup measuring systems (redundancy).

MAGNETIC CORE

L.V.D.T.

ZERO REFERENCE
SUPPORT

BRACKET ATTACHED
TO PILE

TEST PILE

SOIL
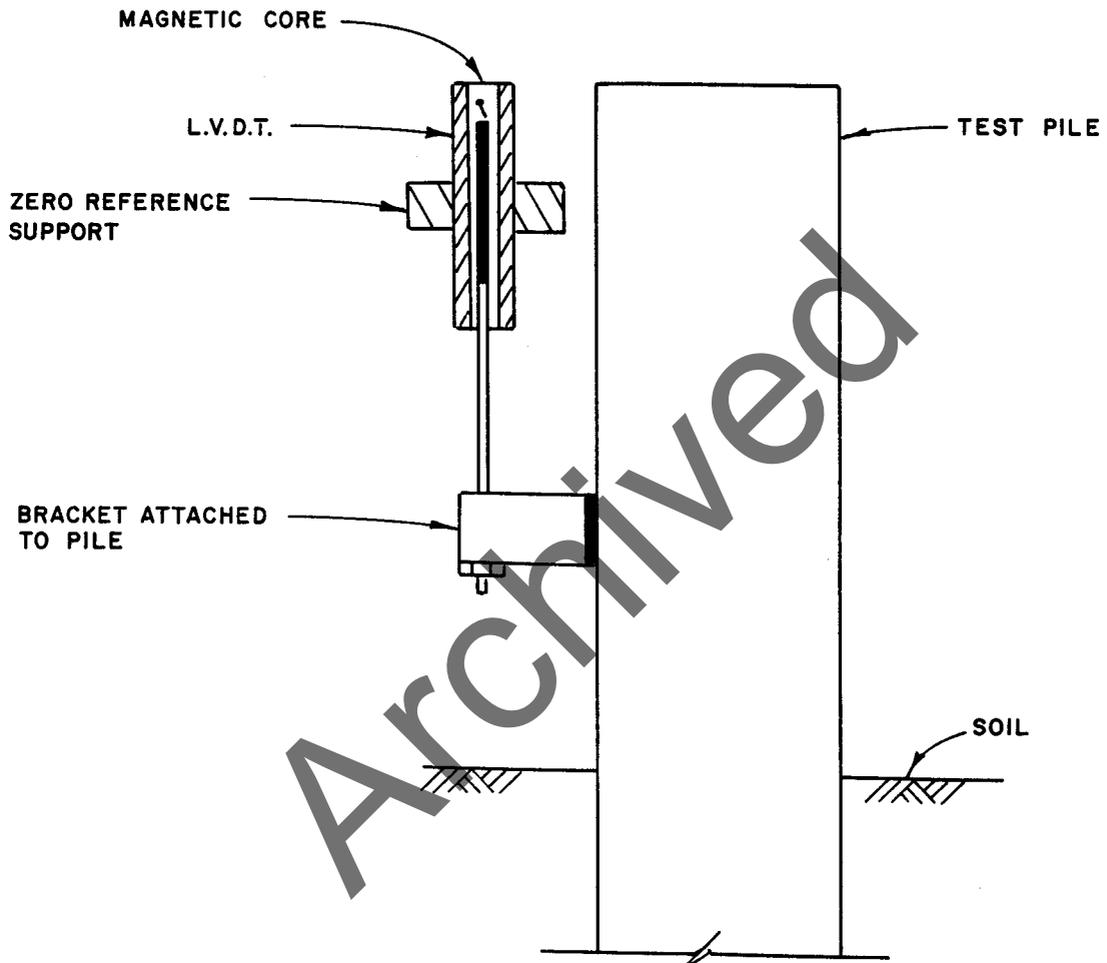
(HIRSCH et. al., 1970)

Figure 19.   Linear Variable Differential Transformer (LVDT)
Attached to Pile to Measure Movement

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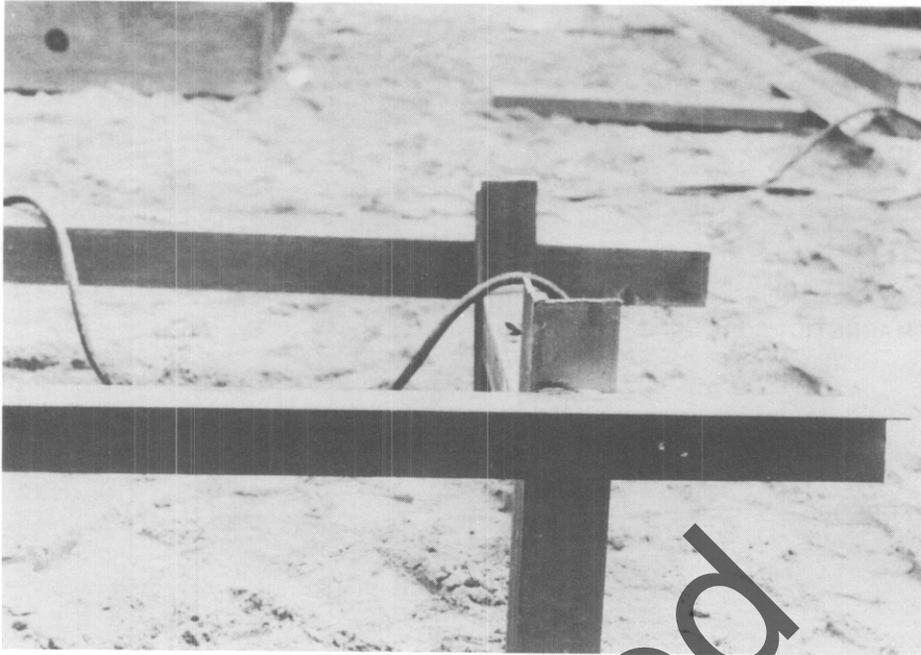
(a)

(b)

Figure 20.   (a) End Support of Reference Beams,   (b) Protection
            of Instrumentation

Lateral Movement At Pile Head

The lateral movement of the pile head can be measured using the same apparatus as for measuring vertical movements except that the dial gages and wire/scale must be oriented differently (Fig 18(b)).

Lateral Movement Along Pile

Lateral movement along the pile shaft can be calculated from tilt measurements taken before and after the load is applied. Tilt along the pile shaft can be measured using an inclinometer system which consists of a casing and tilt sensor(s). The permanent grooved casing is embedded in (Fig. 21a) or attached to (Fig. 21b) the pile.

Tilt measurements can be obtained by fabricating a string of sensors which, once lowered down the casing, remain fixed during the course of the test (Fig. 22). As an alternate, a travelling sensor can be lowered and raised through the casing. Although more hardware is required, the former method is preferable because it is more accurate (Dunnicliff 1988), less labor inten-sive and more amenable to remove data collection. Another deficiency is introduced into the latter method by the time lag between the tilt readings made near the bottom of the pile and those made near its' top. In soils with time-dependent deforma-tion properties, this results in a conservative estimate of the lateral resistance of the foundation soil. The lateral movements vs. time relationship measured at the pile head can be used to compensate, at least partially, for this error.

If an accurate and reliable determination of the bending moment in the pile is especially important, the use of strain gages, in addition to the inclinometer, may be considered. Unless in-house expertise in the installation and monitoring of

GRADUATED ELECTRICAL CABLE

TORPEDO CONTAINING TILT SENSOR

TEST PILE

CONCRETE

COUPLING

GUIDE PIPE

Σ L SIN θ

ACTUAL VERTICAL ALIGNMENT OF GUIDE PIPE (EXAGGERATED)

DISTANCE BETWEEN SUCCESSIVE READINGS

L SIN θ

θ

TRUE VERTICAL

GUIDE PIPE

GUIDE WHEELS

TORPEDO

(a)

INCLINOMETER CASING

A - A

TEST PILE

ANGLE FIXED TO OTHER SIDE

INTERMITTENT WELD

BOTTOM OF DUCT CLOSED

PROTECTIVE SHOE

(b)

Figure 21.   (a) Inclinometer and Method of Determining Vertical Alignment of Inclinometer Guide Pipe (Casing) and (b) Inclinometer Attached to H-Pile.

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LOCATE HORIZONTAL
SURFACE GAGE AT
THIS LEVEL

TILT SENSOR

INTERVAL LENGTH (VARIES)

EXTENSION TUBE
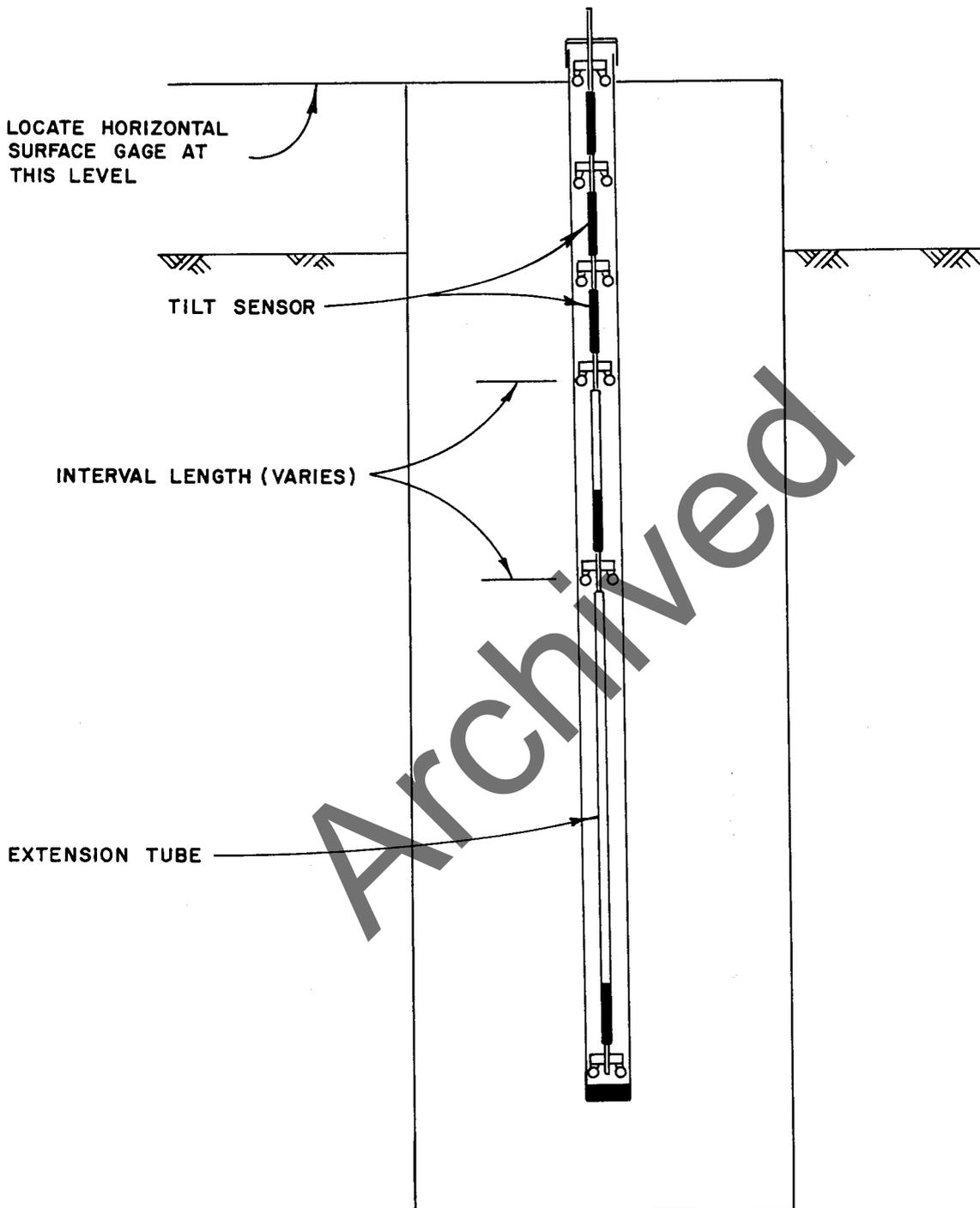
Figure 22.   Fixed Inclinometer System

strain gages is available, the services of an instrumentation specialist (not the contractor performing the load test) should be engaged. The use of strain gages will significantly increase the cost of a load test and the time required to prepare the test pile for testing (Price et al., 1987).

Level of Instrumentation

The amount of instrumentation the engineer specifies for a load test will be dependent on what information concerning the pile-soil system is required to accomplish the goals of the load test program.

Figures 23 and 24 show the information gain based on the amount of instrumentation used in an axial compressive load test and a lateral load test. Merely measuring the pile head movement under an applied load yields very little information concerning how a pile performs. Pile head movement measurements alone might be considered adequate when proof testing is called for but not when pile-soil interaction information is needed. The installation of too much instrumentation, particularly on small diameter piles, may affect the elastic properties of the pile and therefore complicate the interpretation of the data obtained.

All axial compressive pile load tests should be instrumented with a telltale (preferably two) at the tip. This additional information concerning pile tip movement will greatly add to an understanding of the distribution of soil resistance on the pile and of pile performance in general.

Construction Considerations

When internal instrumentation is to be used in the conduct of the pile load test, great care must be taken to protect the instrumentation. The following should be adhered to.
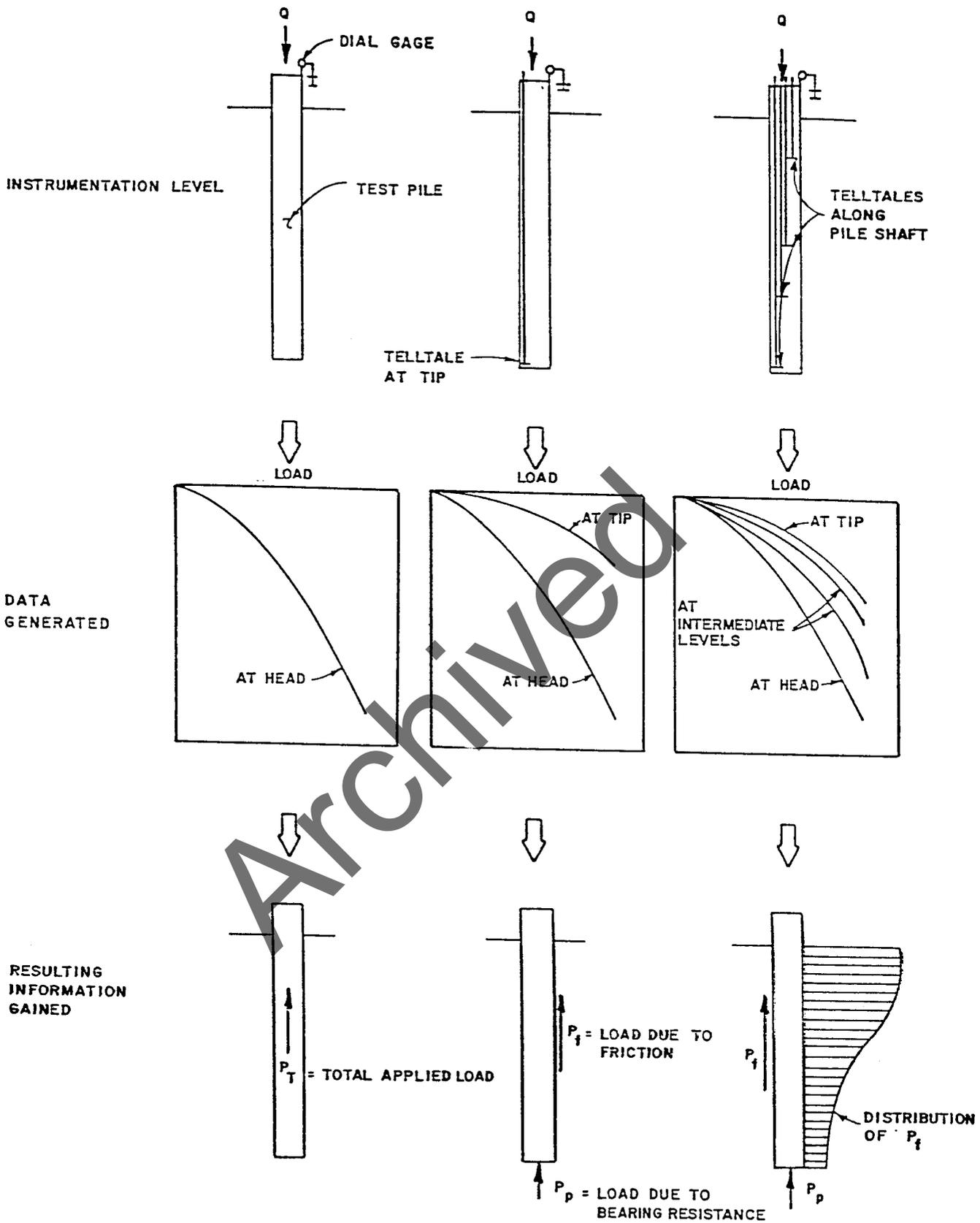
Figure 23. Information Gain Based on Level of Instrumentation in Axial Compressive Load Test
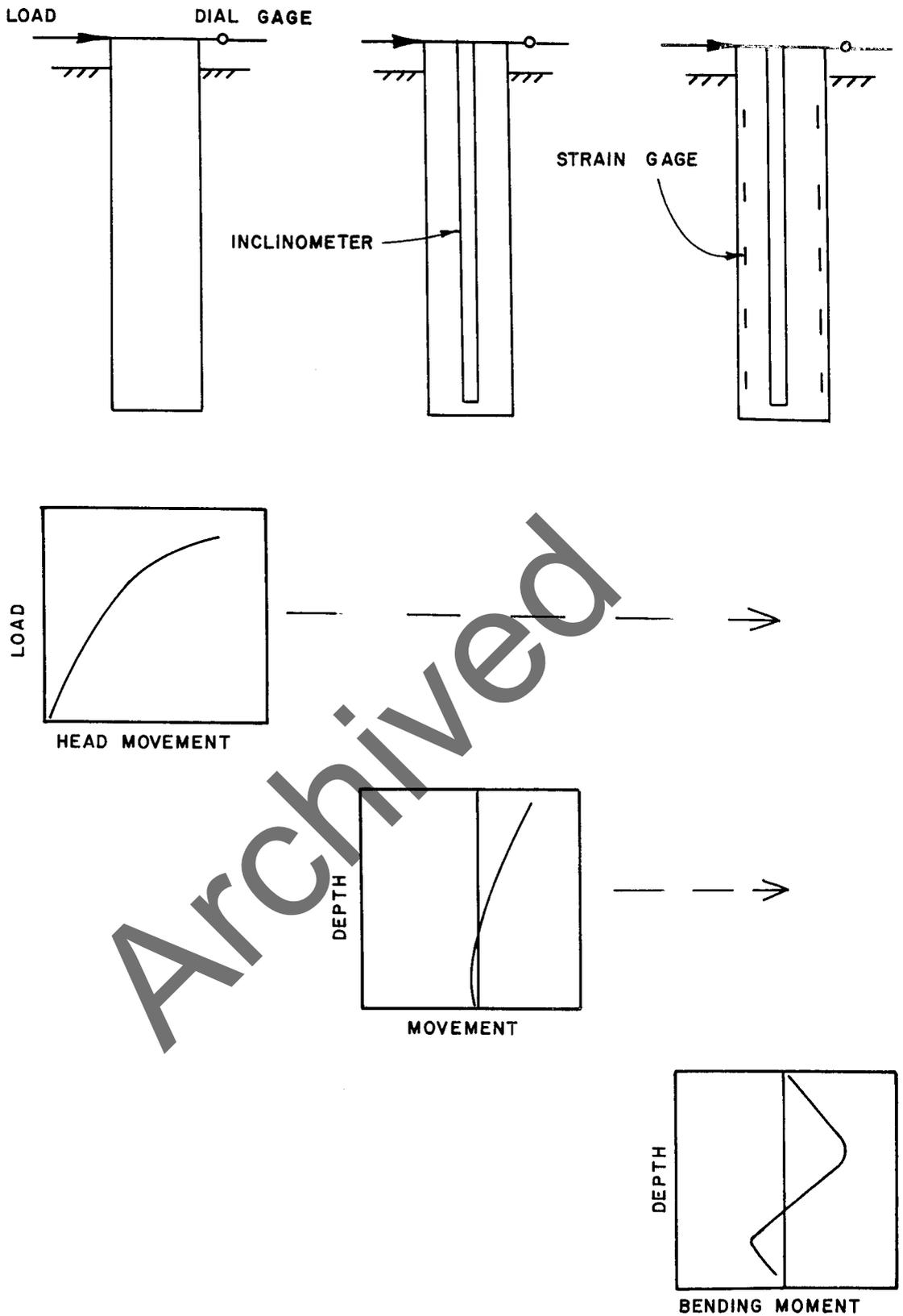
Figure 24.   Information Gain Based on Level of Instrumentation in
             Lateral Load Tests

° The casings used for telltales and inclinometers should be well protected at the pile top in order to prevent intrusion of foreign matter (soil, concrete, etc.).

° Concrete used for piling should be placed by tremie method. Under no circumstances should concrete be placed by free fall as strain gages attached to the sides of the pile or to reinforcing steel could be affected.

2.3.8 Data Collection and Presentation

Depending on the purpose of the load test and the required instrumentation, a considerable amount of data can be generated. To obtain maximum use of the data collected, records must be kept in an intelligent and orderly manner. Load testing data forms can be found in Appendix D. Records must be kept in such a manner that the data can be understood without further inquiry and chance for misinterpretation.

A summary of the results of all observations should be assembled within one document in tabular form. Numerical data should be complete. Failure to indicate vital information, such as telltale elevations, and initial readings, could potentially invalidate the data collected during the progression of the load test.

The data must be presented in an easily understandable manner. This can be accomplished by displaying the data in a graphical format. The results of load tests are normally presented in the following forms

° Load vs. Movement (Fig. 25(a))
° Movement vs. Time (Fig. 25(b))

Figures 26 and 27 show how the results generated from axial compressive, axial tensile and lateral load tests can be presented.

LOAD

ΔQ1   ΔQ2   ΔQ3   ΔQ4 ΔQ5   ΔQ6   ΔQ7   ΔQ8

MOVEMENT

ΔQ = LOAD INCREMENT

Δ_i = IMMEDIATE MOVEMENT UPON LOAD INCREMENT APPLICATION

Δ_t = MOVEMENT WITH TIME UNDER CONSTANT LOAD INCREMENT

Δ_i
Δ_t

LOAD - MOVEMENT CURVE

(a)

TIME (LOG SCALE)

10   100   1000   24 hr

MOVEMENT

ΔQ1
ΔQ2
ΔQ3
ΔQ4
ΔQ5
ΔQ6
ΔQ7
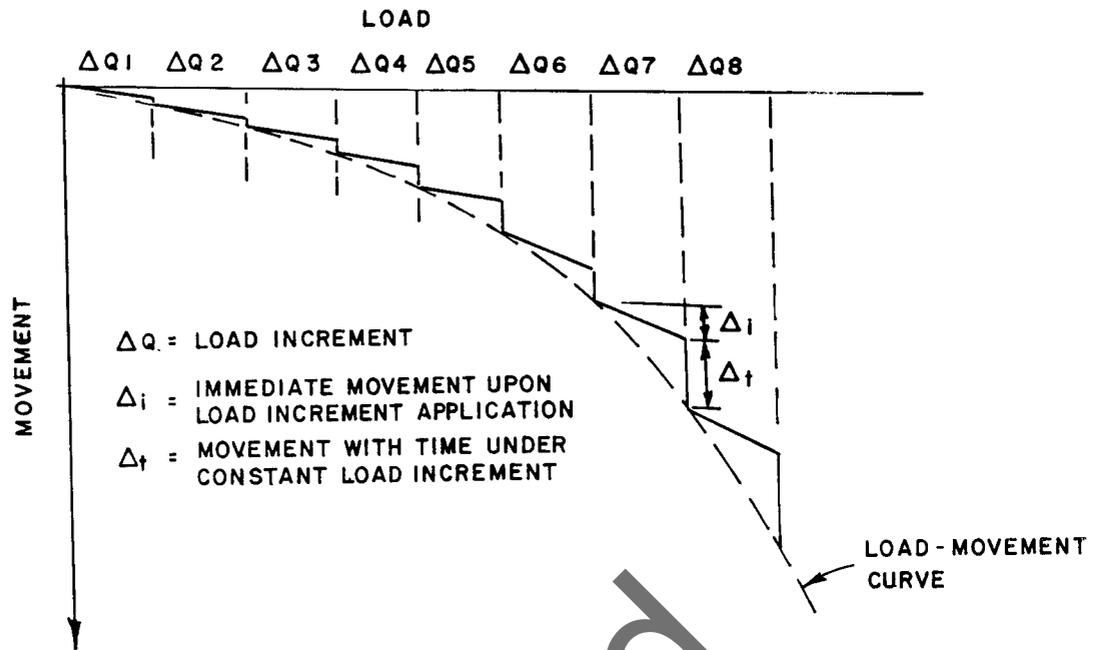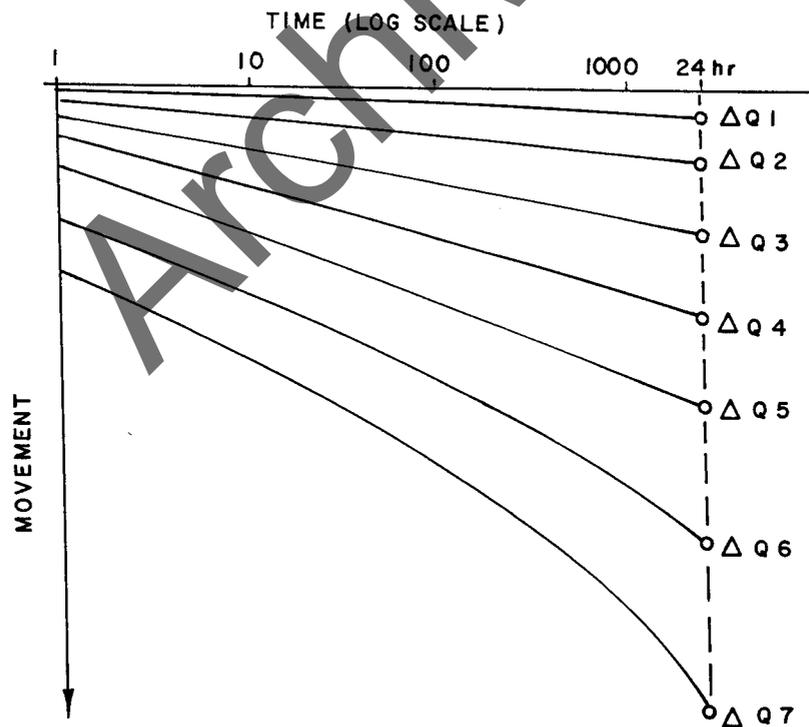
Figure 25.   (a) Load-Movement Curve (b) Time (log-scale)-Movement Curve

60
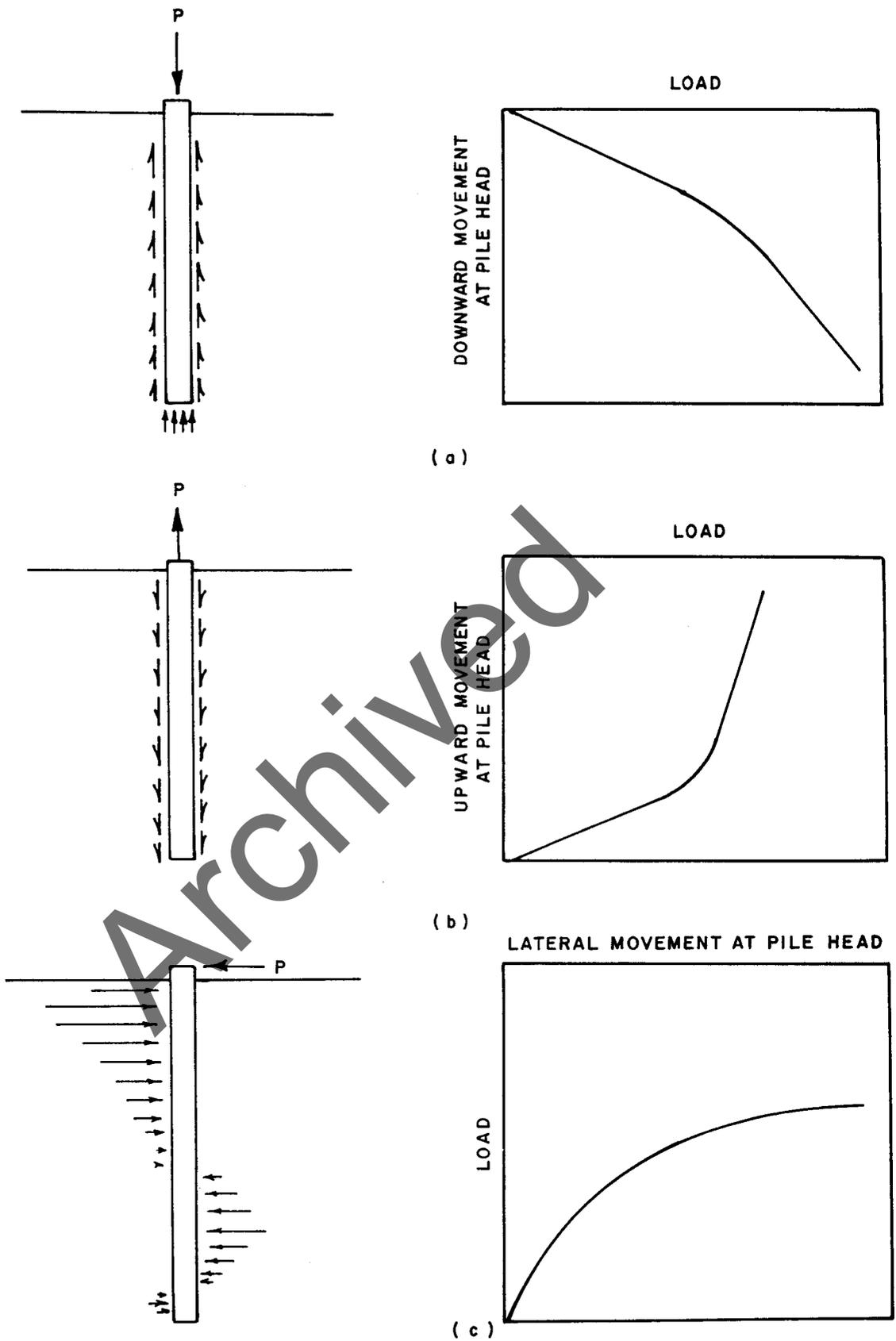
Figure 26.   Typical Load Movement Curves at Pile Head for
(a) Axial Compression (b) Axial Tension
(c) Lateral Load

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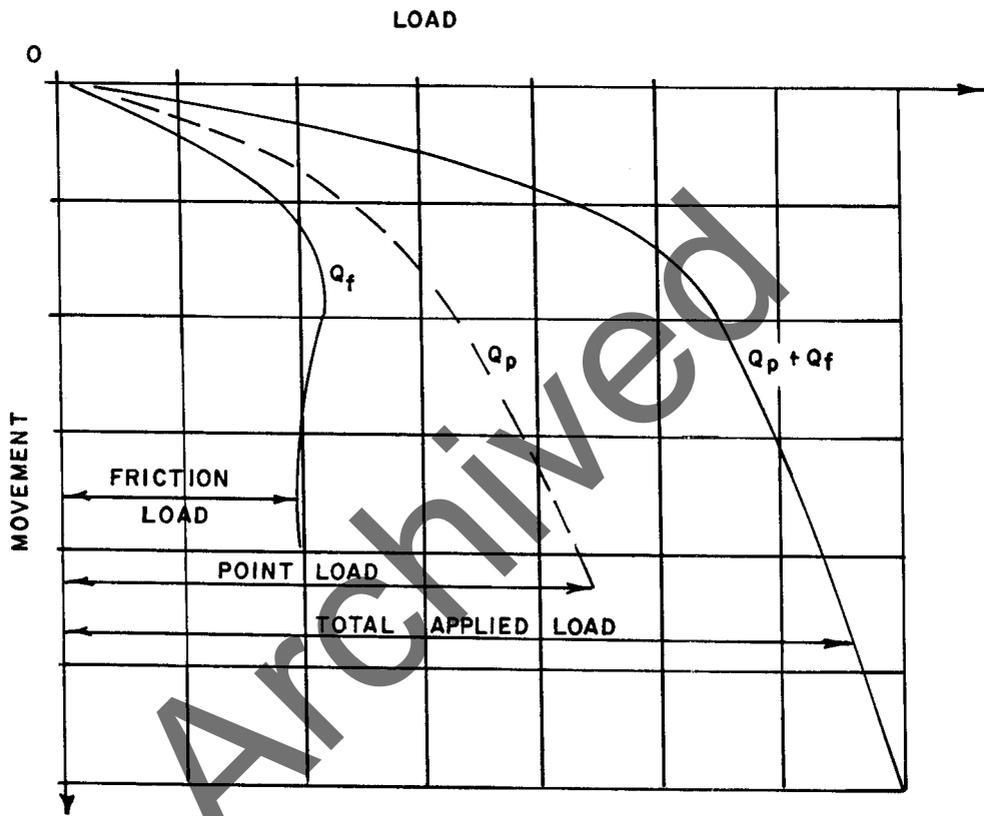
Figure 27. Typical Load-Movement Curve Depicting Portion of Load
Carried by Skin Friction and at Point

2.4 INTERPRETATION OF LOAD TEST RESULTS

Interpretation of load test results begins with an evaluation of the load-movement curve to determine the allowable capacity of the pile. The term allowable capacity, when used in this manual, is defined quite simply as the ultimate capacity divided by a specified factor of safety.

The problem arises as to what constitutes failure or ultimate capacity of a test pile. Ideally, failure would be defined as that point along the load-movement curve where the test pile experiences continuous movement at no increase in load (plunging in the case of an axial compressive test). In practice, particularly in cohesionless soils, plunging is not often observed, and therefore a means of defining failure load is required. Fellenius (1980) states that for a failure definition to be useful it must be based on some mathematical rule and generate a repeatable value that is independent of scale relations and the opinion of the individual interpreter. Numerous rules for determining failure loads based on the results of load tests, particularly for axial compressive tests, can be found in the literature (Chellis 1961; Vesic 1977; Fellenius 1980; Hirany and Kulhawy 1989). They will be discussed later on in the manual. The authors find that "interpreted failure load," as suggested by Hirany and Kulhawy (1989), is an appropriate term to use when rules are used to establish the failure or ultimate load.

Proper definition is imperative to communicate the results of load tests to others. The following are some general rules to follow when interpreting load test results:

° The term "failure load" should be avoided and "interpreted failure load" used if failure (i.e. plunging of pile during axial compression test) has not occurred.

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- ° The method of defining the interpreted failure load should be stated (e.g. Davisson Method, etc.)
- ° Any attempt to extrapolate an interpreted failure load which is greater than the maximum test load should be avoided. The failure load should be established by measurements and not from hypothetical models.
- ° When a pile has been loaded to a percentage of the design load or to the capacity of the loading system and "interpreted failure" has not occurred, the term "maximum test load" should be used.
- ° In selecting the allowable capacity for a pile, the method used should be clearly stated (e.g. "allowable capacity is equal to one-half the maximum test load").

2.4.1 Elastic Shortening

In order to aid in the interpretation of an axial compressive load test, the theoretical elastic shortening of the pile should be determined. This can be accomplished with the following expression:

$$e_s = \frac{Q\,L}{A_p E_p} \quad \text{(end bearing pile)}$$

where, e_s = elastic shortening
  Q = applied load
  L = pile length
  A_p = cross-sectional area of pile
  E_p = elastic modulus of pile material
    E_s = elastic modulus of steel
    E_c = elastic modulus of concrete

For piles composed of two materials, such as a concrete filled pipe pile or a heavily reinforced drilled shaft, the area of the steel is converted to an equivalent concrete area:

$$A_{trans.} = A_c + A_s \; (E_s/E_c)$$

The value of e_s computed is the amount of elastic shortening a pile undergoes for the condition when the full load reaches the pile tip (i.e. zero skin friction). In the case of a pile that derives some or all of its support from skin friction, the elastic deformation of the pile will be less than that of a pile whose support is strictly in end bearing. The elastic deformation of a pile, taking into account, in a simplified manner, the distribution of applied load to the surrounding soil vice skin friction (Fig. 28), can be determined by the following expression;

$$e_s = (Q_p + \alpha_s \; Q_s) \; \frac{L}{A_p E_p}$$

where,

    Q_p = point load transmitted to the pile tip

    Q_s = shaft friction load

    α_s = 0.0 for no shaft friction (end bearing pile)

          0.5 for uniform distribution of shaft friction

          0.67 for triangular distribution of shaft friction starting from zero friction at pile head to a maximum value at pile point.

          0.33 for triangular distribution of shaft friction starting from a maximum at pile head to zero at the pile point

Utilizing the above expression for the case where the pile is a friction pile (no end bearing) and where the skin friction is uniformly distributed throughout the length of the pile one can see that the elastic deformation will be exactly one-half of that obtained for an end bearing pile.

For short piles (less than 35 feet), the exact amount of elastic shortening that occurs is relatively unimportant
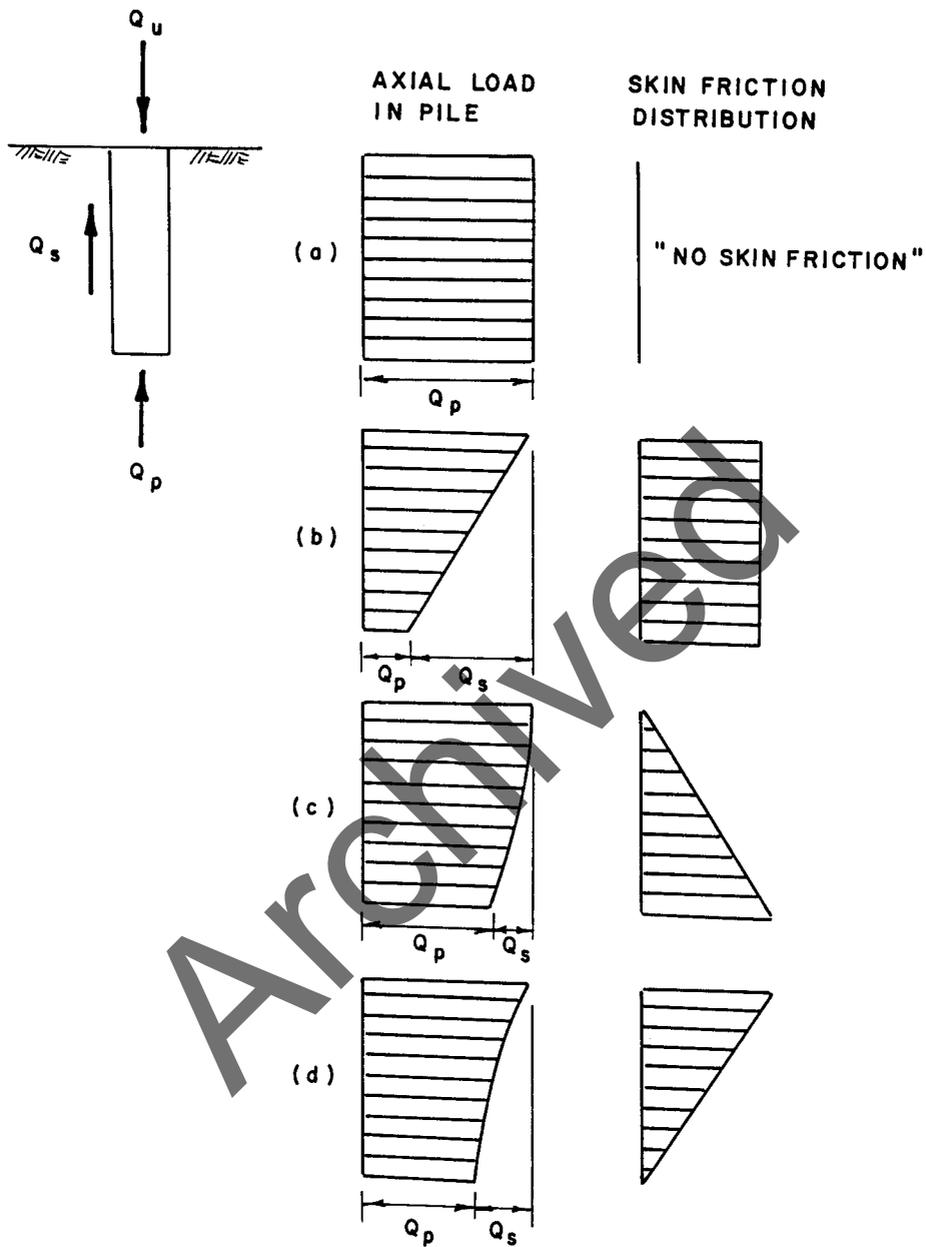
Figure 28. Load Transfer Curves of a Single Pile for Some Simple Distributions of Skin Friction

(Tschebotarioff, 1973) but does become an important consideration in evaluating apparent axial pile movement under test load for longer piles.

The cross sectional area of a pile (A_p) and the modulus of a pile (E_p) are important in evaluating the results of load tests. These values must be accurately determined to reliably determine pile load distribution with depth, the elastic shortening of a pile and the load transfer characteristics, based on telltale or strain gage data.

The area and elastic modulus of specified steel piles (H-piles, unfilled pipe) for all practical purposes could be considered constant and are well known. For concrete filled pipe piles or drilled shafts, the value of the concrete modulus is uncertain because stress levels vary from location to location. The accuracy of assumed values for A_p and E_p is questionable for uncased concrete piles (auger-cast, mini, pressure-injected, post grouted drilled shafts). Further uncertainties in the pile properties arise when instrumentation represents a major portion of the pile cross section. Therefore the cross-sectional area of the pile should be taken into consideration when selecting the amount of instrumentation.

A diagram (Brierley et al., 1979) that is helpful in analyzing the pile behavior compares actual elastic deformations to the theoretical deformation (Fig. 29(a)). The actual pile deformation at any load can be determined by subtracting the amount of movement at the pile tip from the measured pile top movement. The engineers can therefore get an idea as to whether the pile is mostly friction or end bearing. Determination of the movement at the pile tip requires the use of telltales (strain rods).

Another method (Lacey, 1979) of presenting the elastic shortening information is as shown in Figure 29(b). The slope of

ELASTIC DEFORMATION (INCHES)

THEORETICAL - FRICTION PILE

THEORETICAL - END BEARING PILE
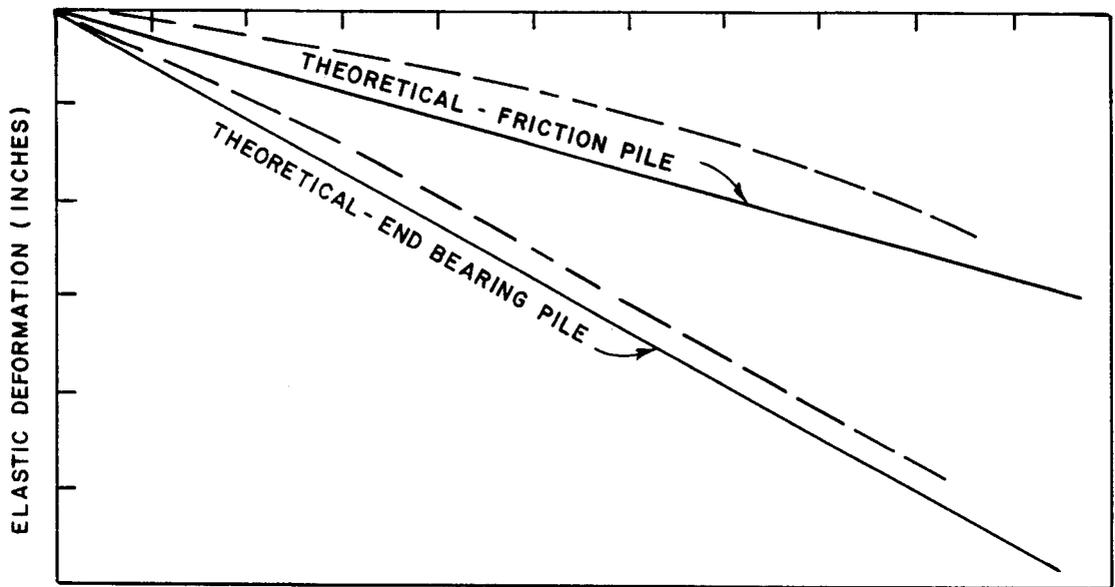
(a)

PILE SHORTENING BETWEEN PILE TOP AND PILE DEPTH (INCHES)

DEPTH BELOW PILE TOP (FEET)

ELASTIC LINE (ASSUMING NO SKIN FRICTION)
AT APPLIED LOAD

TELLTALE
READINGS

PILE TIP
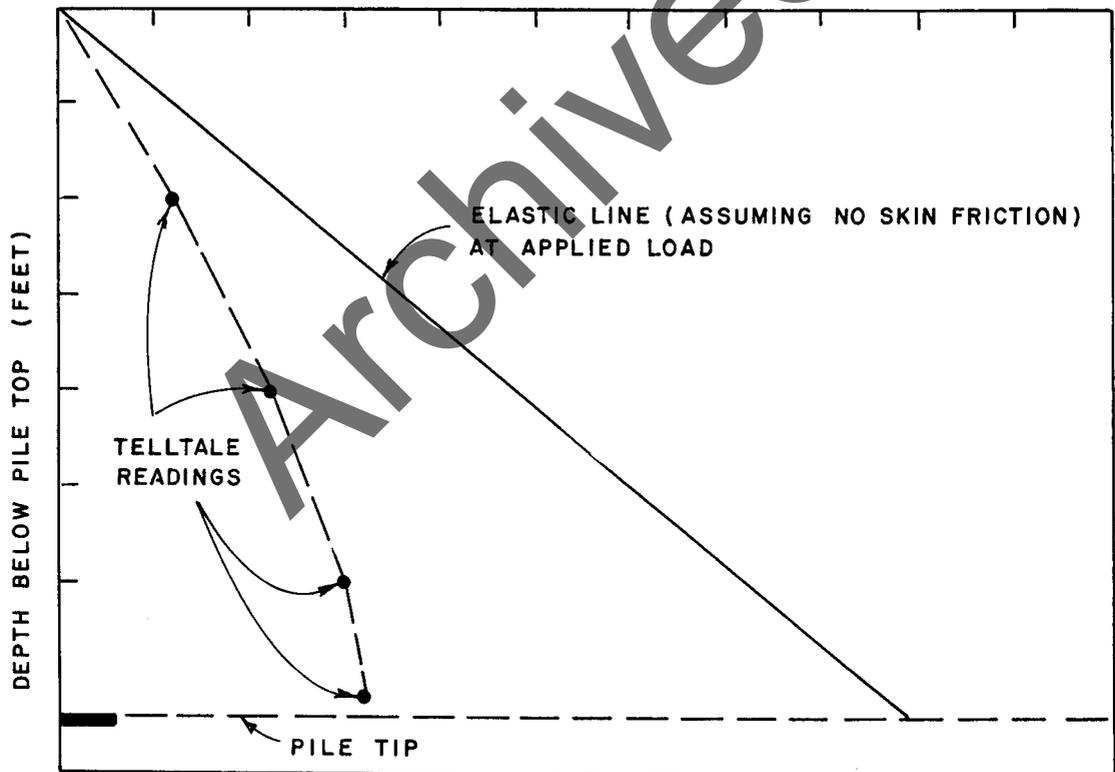
(b)

Figure 29.   Analysis of Pile Shortening Information Obtained
Through Telltale Data (a) Load vs. Elastic
Deformation (b) Pile Shortening vs. Depth Below
Pile Top

the line between the telltales is an indication of the rate at which load is being lost into the soils above the bearing strata. The uniform progression of the telltale information (taking into account the soil profile) is also an indication of the reliability of the results.

2.4.2 Load Transfer

When an axial load is applied to a vertical pile, a certain percentage of the applied load is transferred into the soil surrounding the pile shaft with the remainder being transmitted through the pile and into the tip. This transmission of applied load to the foundation soil through skin friction and end bearing resistances is commonly referred to as load transfer. The distribution, particularly in skin resistance, is dependent on the following (D'Appolonia, 1968):

- ° initial state of stress and condition of soil
- ° the strength and compressibility of the soils and the changes that occur with pile installation and with time
- ° the material, size, shape and length of the pile
- ° the method of pile installation (e.g. driving, vibrating, boring, jacking, etc.)
- ° the interactions between the pile and the soil that are time dependent (negative skin friction, disturbed soil adjacent to pile, relaxation, creep, groundwater fluctuations)

If the information needed from a load test is to be used for design of production piling, an evaluation of the load transfer characteristics of the pile-soil system is required. Load transfer characteristics help the designer identify properly the significant characteristics of the supporting soils.

The determination of load transfer with depth along the pile shaft is achieved by use of internal instrumentation. Instrumentation can consist of telltales (strain rods), electrical strain gages or load cells, or some combination thereof located at various depths (Fig. 30) along the pile shaft.

Figure 31 shows the load distribution obtained on an internally instrumented drilled shaft at various increments of loading. Analysis of these curves would be used to determine the skin friction characteristics of the soil for pile design. Calculation of skin friction could be performed as shown in Figure 30.

2.4.3 Methods of Interpretation

Axial Compressive Tests

The following methods are often used in establishing failure loads for piles that undergo axial compressive tests:

Offset Limit (Davisson, 1972)

The failure load is defined as corresponding to the movement which exceeds the elastic compression of the pile, when considered as a free column, by a value of 0.15 inches plus a factor depending on the diameter of the pile (D/120, where D = diameter of pile in inches).

This method has been suggested for application to the results of the Quick Load (QL) test.

De Beers Method (Fellenius, 1980)

The load-movement values are plotted on a double logarithmic diagram, where the values can be shown to fall

70
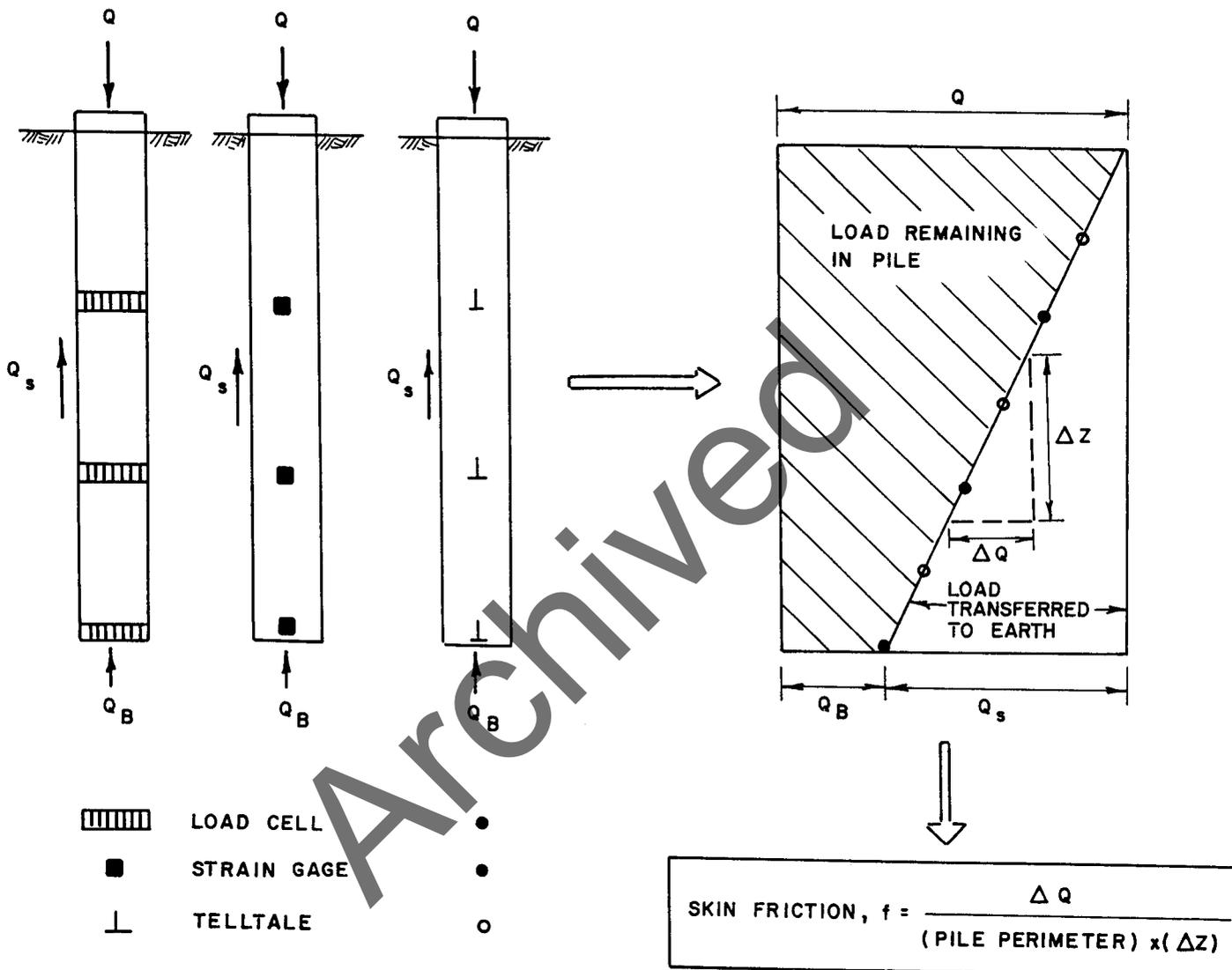
Figure 30. Instrumentation for Determining Load Transfer and Skin Friction

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Applied Load, kips

Depth, ft
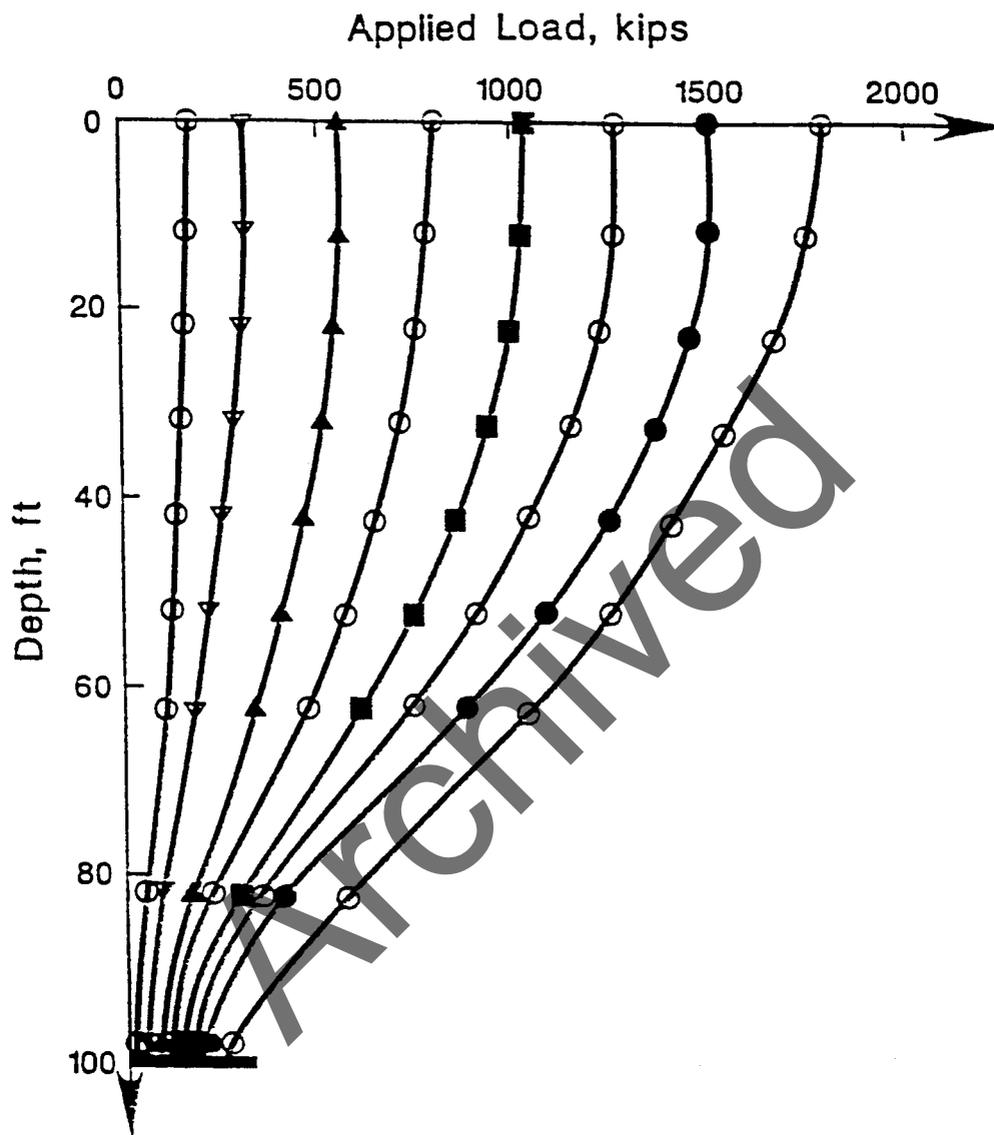
(REESE, 1984)

Figure 31. Load Distribution Obtained by Instrumenting a Drilled
Shaft with Mustran Cells

on 2 straight lines. The intersection of the lines corresponds to the failure value.

De Beer pointed out that the interpreted failure value is conservative, and should not be called ultimate failure. This method has been proposed for use with the Maintained Load test.

90% Criterion (Brinch Hansen, 1963)

The failure load is defined as the load at which the movement is twice that obtained for 90% of that load.

This criterion has been proposed for use with the Constant Rate of Penetration test (CRP) regardless of soil type.

Slope and Tangent (Butler and Hoy, 1977)

The failure load is defined as the load at the intersection of a line tangent to the initial straight line portion of the load-movement curve and a line tangent to the load-movement curve where its slope reaches 0.05 inches/ton (0.01 inches/ton for drilled shafts).

This criterion has been recommended for use on Quick Load tests.

Fellenius (1975) examined 8 methods of defining failure of a pile and showed a 40 percent spread between the interpreted lowest and highest values. Van Weele (1982) applied 12 criteria (Vesic, 1975) to two tested piles and observed a difference of 100 percent between the lowest and highest values. With these kinds of variations in the interpretation of failure load, it becomes imperative that geotechnical engineers be very explicit

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in stating how a failure load is to be determined from the results of any load test.

Allowable capacity is normally determined by dividing the "interpreted" failure load by some suitable factor of safety. The factor of safety most commonly used is 2.0, but larger factors of safety may be required:

- ° for friction piles in clay, where group settlement may control
- ° where total settlement that can be tolerated by the structure is exceeded
- ° for piles installed by methods other than impact driving
- ° where soil conditions are extremely variable
- ° where limited load testing will be performed

If a safety factor of 2 is chosen, the allowable capacity is defined as 50 percent of the failure load. It is recommended that the failure load for the pile be defined as follows: for piles 24 inches or less in diameter or width, the failure load of a pile tested under axial compressive load is the load that produces a movement of the pile head equal to

$$S_f = S + (0.15 + 0.008D) \quad \text{(See Figure 32)}$$

where S_f = movement of pile head (in inches)
D = pile diameter or width (in inches)
S = elastic deformation of total pile length (in inches)

For piles greater than 24 inches in diameter or width

$$S_f = S + D/30$$

The computed allowable capacity represents the maximum "safe" value with respect to pile bearing. A smaller value for

TYPICAL TEST PLOT
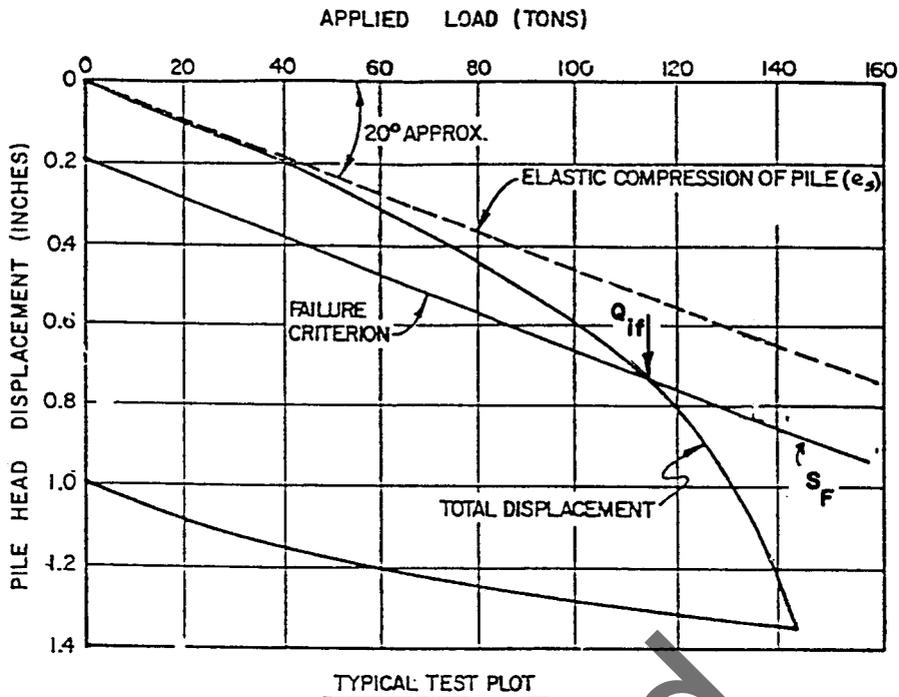
1. Calculate elastic compression of pile (e_s) when considered as a free column by:

$$e_s = \frac{Q\,L_p}{A_p\,E_p}$$

Q = test load, lbs
L_p = pile length, in. (for end-bearing pile)
A_p = cross-sectional area of pile material, sq in
E_p = Young's Modulus for pile material, psi

2. Determine scales of plot such that slope of pile elastic compression line is approximately 20°.

3. Plot pile head total movement vs. applied load.

4. Unless "plunging" failure occurs, the "interpreted failure load," Q_{if}, shall be that load which produces a movement of the pile head equal to:

$S_F = e_s + (0.15 + 0.008D)$ for pile diameter or width <24 inches
$S_F = e_s + D/30$ for pile diameter or width >24 inches

5. Plot failure criterion as described in (4) parallel to line of pile elastic compression. Intersection of failure criterion with observed load-movement curve defines "interpreted failure load, Q_{if}.

6. Where observed load-movement curve does not intersect failure criterion, the factor of safety will be applied to the maximum test load to determine the allowable capacity.

7. Apply factor of safety to "interpreted failure load" to determine the allowable capacity.

Figure 32.   Interpretation of an Axial Compressive Pile
Load Test

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the allowable capacity may be selected to limit pile settlement to a tolerable value (Figure 33).

Axial Tensile Tests

The load-movement (upwards) curve for an axial tensile test is similar to that obtained in an axial compressive test. Failure defined by sudden upward movement, occurs more distinctly than observed in an axial compressive test, because the capacity of the pile relies solely on friction.

Lateral Load Tests

The results of lateral load tests should be interpreted based on the method of non-linear soil response curves (p-y curves) (Reese, 1984). Normally the interpretation will consist of a comparison of the actual behavior of the pile as measured in the test to the theoretical behavior of the pile for assumed soil response curves (Price et al., 1987). This comparison (see Figure 34) should be used to determine the p-y curves to be used in design or, if the pile is tested during construction, the validity of the p-y curves on which in the design was based.

The lateral deflection of a pile increases under repetitive loading (Long and Reese, 1983). The cyclic loading schedule for the test method in the appendix has been designed to permit an evaluation of the behavior of the pile as influenced by the magnitude of the cyclically applied load and by the number of loading cycles. By considering the rate of increase in deflection with the number of load cycles, a p-y curve can be established that takes into account repetitive loading effects.
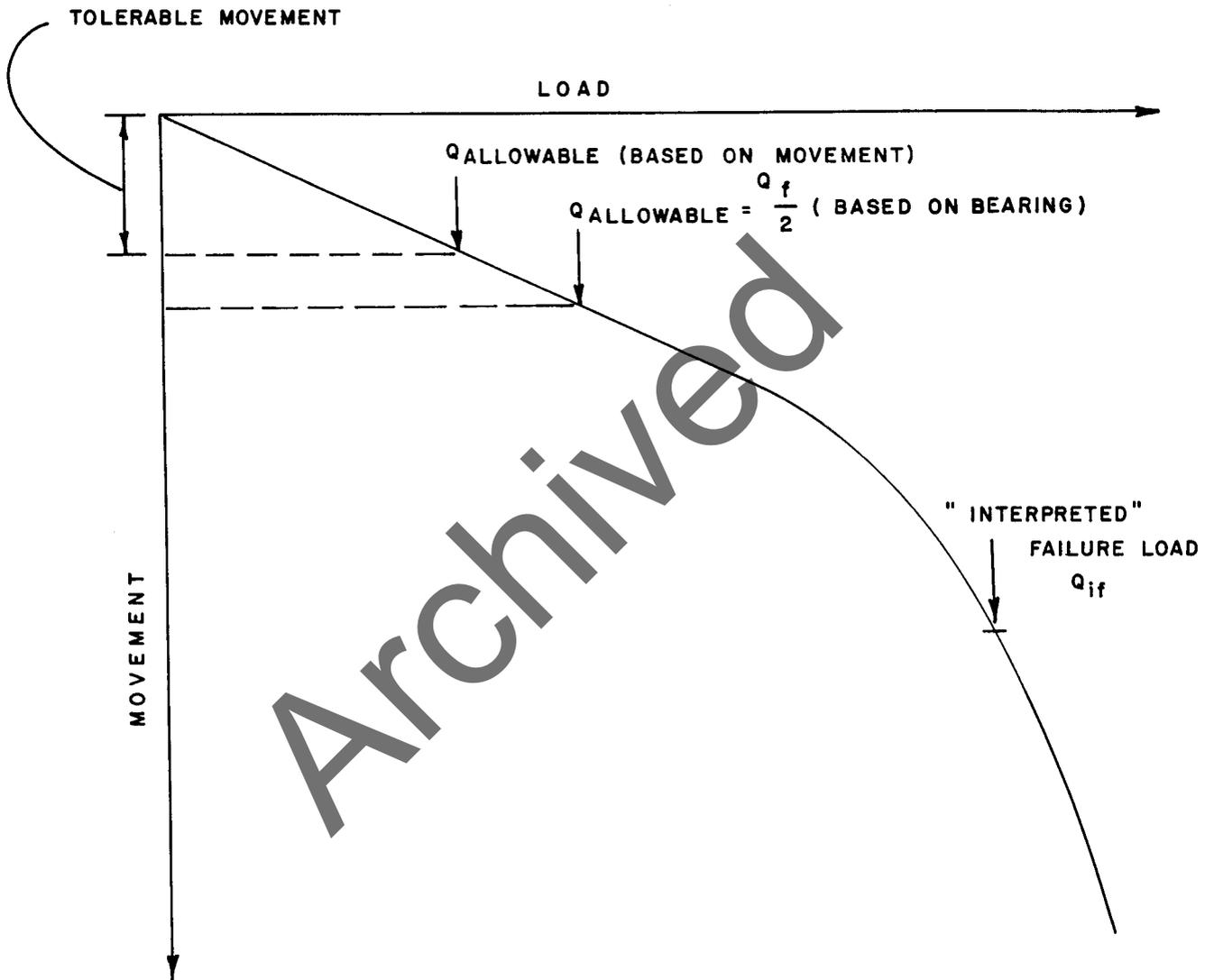
Figure 33.   Selection of Allowable Capacities

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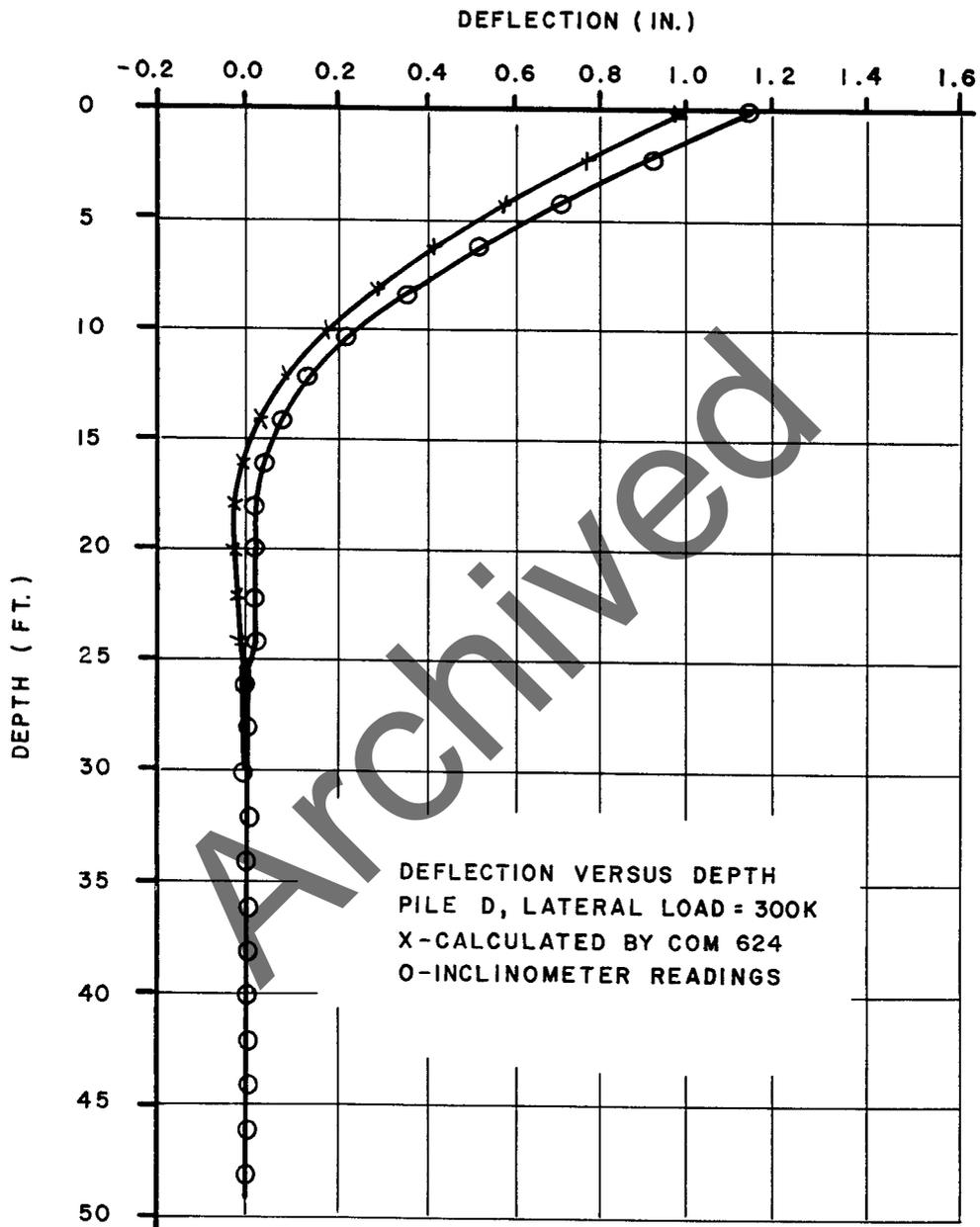
Figure 34. Measured vs. Calculated Lateral Deflection of Pile

2.4.4 Factors that Influence Interpretation

Negative Skin Friction

The possibility of and the effects of negative skin friction (or downdrag) should never be overlooked. Downdrag can develop when a pile is installed in

- ° an area covered by or adjacent to recent fill, under the load of which the soil beneath the fill has not yet consolidated
- ° an area that will have to support increased surface loads in the future

As the soil consolidates, the soil around the pile moves downward with respect to the pile and adds load to the pile. This additional load can sometimes exceed the actual design load. Because this action takes place over a long period of time, a pile load test will not properly evaluate the allowable load which can be supported by a pile experiencing downdrag. When contemplating load tests on piles subject to downdrag, only load carried by the pile below the compressible zone should be considered. A load test in which the compressible zone is isolated from the pile must be conducted. This can be accomplished by either providing a pile sleeve (Fig. 38(b)) to the top of the bearing stratum and then conducting the pile load test or instrumenting the pile at the top of the bearing strata to separate non-contributing skin friction resistance. NAVFAC DESIGN MANUAL 7.2, FOUNDATIONS AND EARTH STRUCTURES presents a suggested procedure (Fig. 35) for analyzing a load test where downdrag acts on a pile by measuring movement of the pile tip.

1. IF SKIN FRICTION ACTING ON TEST PILE MAY BE REVERSED IN THE PROTOTYPE BY CONSOLIDATION OF MATERIALS ABOVE THE BEARING STRATUM, ANALYZE LOAD TEST TO DETERMINE RELATION OF LOAD VS SETTLEMENT FOR PILE TIP ALONE.
2. COMPUTE THEORETICAL ELASTIC SHORTENING ASSUMING SEVERAL POSSIBLE VARIATIONS OF SKIN FRICTION ON PILE AS SHOWN BELOW FOR A CYLINDRICAL PILE.
3. COMPARE THEORETICAL WITH OBSERVED ELASTIC SHORTENING AND DETERMINE PROBABLE VARIATION OF SKIN FRICTION ON PILE. USING THIS VARIATION OF SKIN FRICTION, COMPUTE LOAD AT TIP.

CYLINDRICAL PILE: MODULUS OF ELASTICITY = E

C_A = MAXIMUM SKIN FRICTION

BEARING STRATUM

DIVISION OF APPLIED LOAD BETWEEN TIP LOAD AND SKIN FRICTION

INTENSITY OF SKIN FRICTION

R = RADIUS   A = AREA   F = TOTAL SKIN FRICTION
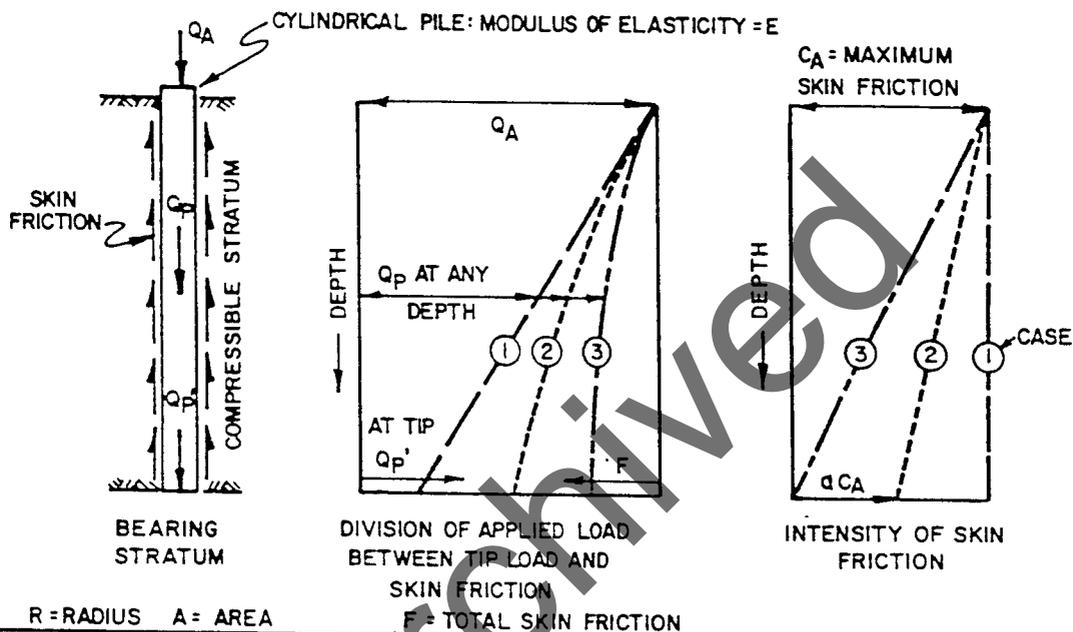
δ_E = ELASTIC SHORTENING OF PILE WITH LOAD Q_A AT BUTT AND $Q_P{'}$ AT TIP.

CASE ① , SKIN FRICTION CONSTANT WITH DEPTH :
$$\delta_E = (Q_A - \pi R C_A L)\frac{L}{AE}$$
$$Q_P{'} = \frac{2 AE \delta_E}{L} - Q_A$$

CASE ② , SKIN FRICTION DECREASING TO $a C_A$ AT TIP :
$$\delta_E = \left(Q_A - 2\pi R C_A L\left(\frac{a+2}{3(a+1)}\right)\right)\frac{L}{AE}$$
$$Q_P{'} = \frac{3AE \delta_E}{L}\left(\frac{a+1}{a+2}\right) - Q_A\left(\frac{2a+1}{a+2}\right)$$

CASE ③ , SKIN FRICTION DECREASING TO ZERO AT TIP :
$$\delta_E = \left(Q_A - \frac{4\pi R C_A L}{3}\right)\frac{L}{AE}$$
$$Q_P{'} = \frac{3 AE \delta_E}{2L} - \frac{Q_A}{2}$$

(NAVFAC DM7.2)

Figure 35.   Load Test Analysis Where Downdrag Acts on Pile

Residual Stresses

During pile driving, skin friction along the pile shaft and tip resistance act upwards. When the driving process stops, the skin friction will be reversed due to rebound of the soil and of the pile material itself. Compressive stresses will be locked into the pile and these locked-in stresses are commonly referred to as residual stresses.

If skin friction and end bearing values obtained from load tests are to be used to design production piles, then residual stresses should be considered Fig. 36 in determining the design skin friction and end-bearing stresses (Rieke and Crowser, 1987). Several methods of measuring residual loads have been presented in the FHWA Report BEHAVIOR OF PILES AND PILE GROUPS IN COHE-SIONLESS SOILS (Briaud, et al 1985).

Excess Pore Water Pressures

Piles that are installed by driving through clays or loose to medium dense saturated sands and silts may temporarily reduce the shearing resistance of the soils due to a buildup of excess pore water pressures. With time the excess pore pressures eventually dissipate and the soils regain a considerable portion of their in-situ shearing resistance. This phenomenon is common-ly referred to as "soil freeze" or "pile setup". Load tests performed on piles immediately after being driven would most likely result in underestimating the capacity of the pile soil system. Ideally then, the load test should be performed when the excess pore pressures have dissipated. This may not always be practical since in normally consolidated clays from 2 months to 2 years or more may be required for full dissipation, as opposed to sands and silts where dissipation can occur within a few hours after driving. In any event a waiting period between driving of test pile and actually performing the load test is recommended.

ERRONEOUS LOAD DISTRIBUTIONS
OBTAINED IF RESIDUAL LOADS
ARE NOT TAKEN INTO ACCOUNT

ULTIMATE LOAD

RESIDUAL LOAD

MEASURED

TRUE

TENSION

CORRECT LOAD
DISTRIBUTIONS
OBTAINED WHEN
RESIDUAL LOADS
ARE TAKEN
INTO ACCOUNT

ULTIMATE
LOAD

RESIDUAL LOAD

MEASURED

TRUE
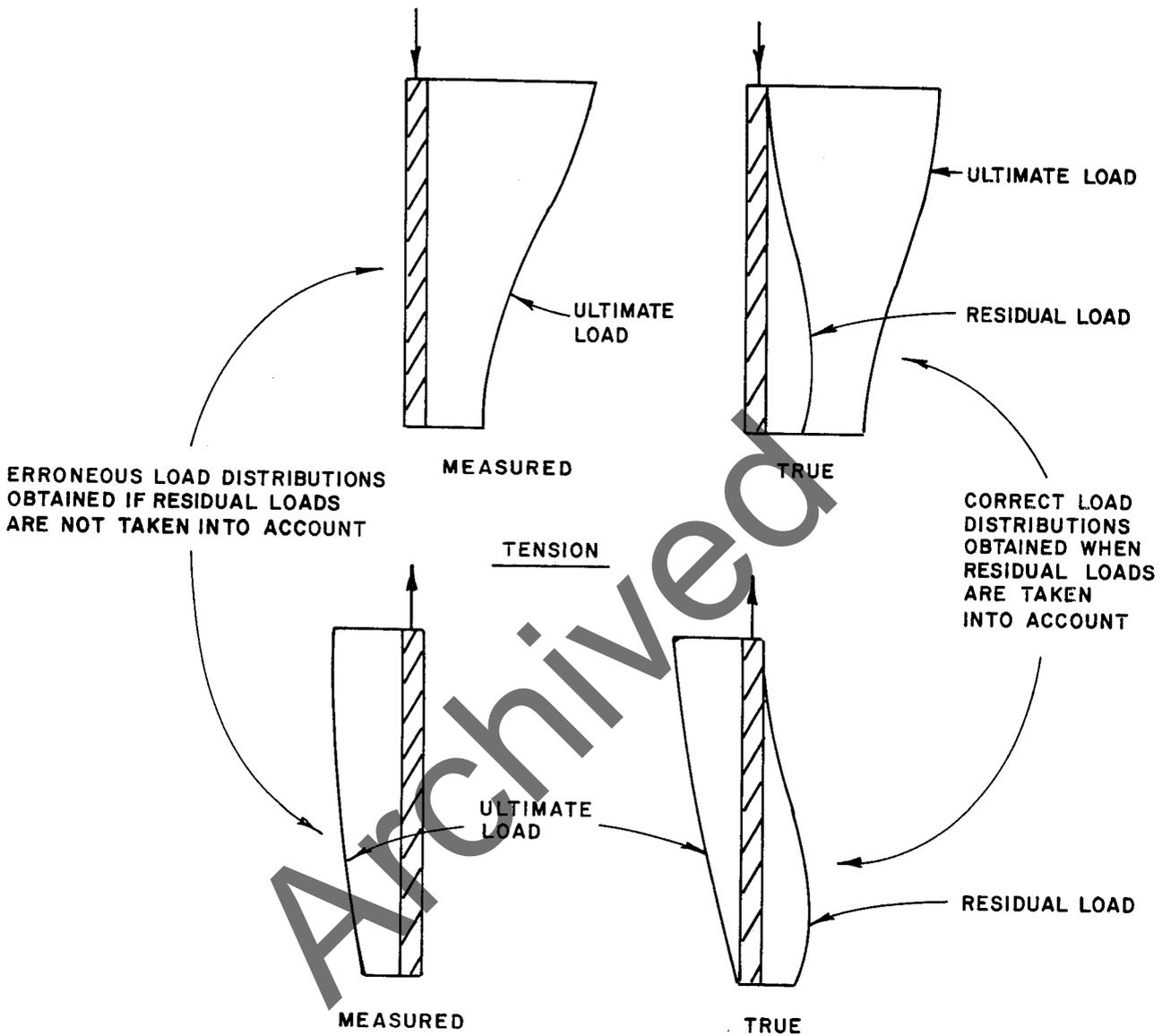
(AFTER BRIAUD AND TUCKER,1984)

Figure 36.   Influence of Residual Loads on Instrumented Pile Data

From a practical stand point waiting periods of between 7 to 10 days are commonly used.

In the instance where the test pile has been selected from a group of piles, the excess pore pressures may be significantly higher and slower to dissipate (Dunnicliff, 1988) than for a single pile. If considered important, piezometers should be installed so that the effective stresses at the soil-pile contact can be evaluated. Piezometers should be of a type having a short response time and should be located equidistant from adjacent piles. While the greatest amount of information is obtained if piezometers are installed prior to driving of piles, this may not be desirable if the piezometers cannot be protected from damage.

Soils such as submerged dense fine sands and inorganic silts can exhibit a high resistance to pile driving as a consequence of the development of negative pore pressures. With time these negative pore pressures dissipate with a decrease in the shearing resistance along the pile shaft and therefore decreased capacity. This phenomenon is commonly referred to as "relaxation" and can also take place beneath the tip of the pile. As in the case of soil setup, it is usually advisable to wait a few days before beginning the load testing.

Change in Groundwater Conditions

The possibility of change in groundwater conditions at any project site should be considered when evaluating the results of the pile load test. If the pile is tested at a groundwater condition different than what was used in the design of the pile, interpretations, particularly in granular soils could be misleading. The changes in groundwater conditions could be brought about by:

   ° excavating for a deep sewer, subway, tunnel, etc.

- ° installation of wells
- ° contractor dewatering
- ° tidal fluctuations

## Reaction Piles - Timber Cribbing - Tiedowns

During the progression of a load test, stresses are transferred from the reaction members (piles or timber cribbing) to the surrounding soil (Fig. 37(a) and (b)). These stresses can have an influence on the behavior of the test pile. Therefore, reaction members must be located well away from the test pile.

<u>ASTM D 1143-81 requires that a clear distance from the test pile to the reaction piles of at least five times the maximum diameter of the largest anchor or test pile be maintained. In no case should the clear distance be less than 7 feet</u>.

An alternative to reaction piles would be to use ground anchors (Fig. 37(c)) that develop their uplift capacity in a deeper soil stratum (or rock) such that no true bond exists between the anchor and soil to a depth below the level of the base of a test pile. In this case the anchors could be placed closer to the test piles than reaction piles. However, construction disturbance around the test pile should be avoided.

Change in Grade

There are situations when the contractor may wish to install the piles from the original grade and excavate to the bottom of proposed footing at a later date and cut off the excess pile. This occurred on a project where 8-5/8 inch diameter mini-piles were being installed. The contractor chose this route because of mobility difficulties. The testing of the piles was performed in the material that would at a latter date be excavated to a depth of approximately 10 feet.
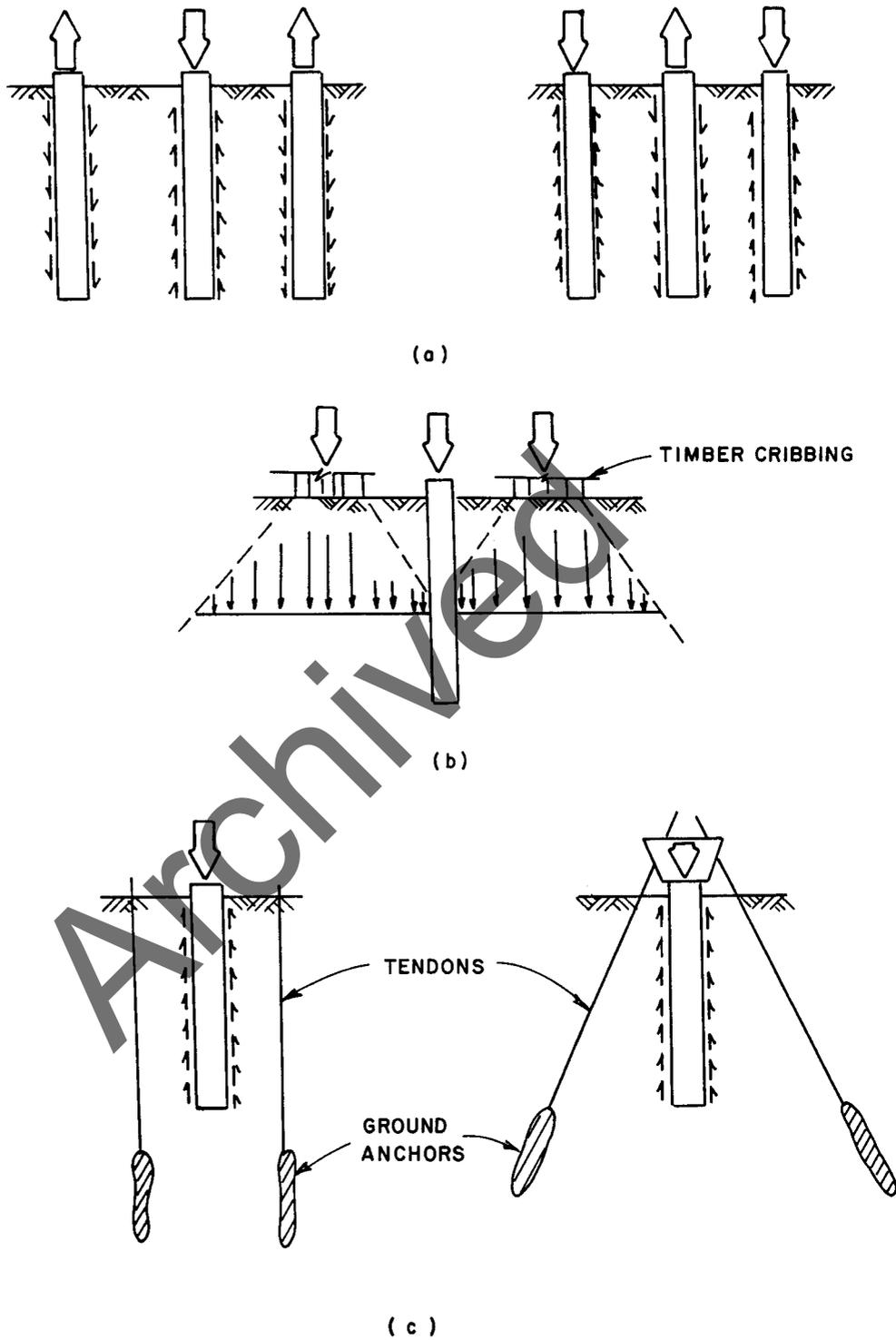
Figure 37.   Influence of (a) Reaction Piles (b) Timber Cribbing
and (c) Ground Anchors on Test Pile During Load Test

In interpreting load test data one must consider the effect the material to be excavated has on the load test results, since additional resistance that should not be counted on has been included. A way of compensating for this would be to sleeve the pile (Fig. 38(a)) to the bottom of the proposed excavation. In this way the frictional resistance offered by the upper material would be eliminated.

Scour

If scour is a concern in design, procedures must be used in the test to account for pile resistance in the scour zone. As in the case of change in grade, a sleeve (Fig. 38(a)) could be utilized to eliminate the effects of side friction offered by the soil in the potential scour zone. Instrumentation could also be used in the test pile to determine load transfer at the scour depth.

Problems Associated with Non-Driven Cast-in-Situ Piles

The following difficulties that present themselves when attempting to evaluate uncased concrete piling have been presented by Lamb (1979):

° possible disturbance in the tip area during early stages of casting.
° uncertainty in evaluating skin friction due to difficulty in determining friction factor at the concrete or grout-to-soil contact.
° variable lateral pressures compared with displacement type piles.
° lack of driving record (with driven piles, driving records provide some indication of resistance).
° possibility of "necking" or discontinuity in pile as cast

STEEL SLEEVES

SCOUR DEPTH OR
FUTURE EXCAVATION

SAND

A   A

TEST STRATA

(a)

FILL

SOFT CLAY

FUTURE DOWNDRAG
LOAD

SAND

TEST STRATA

(b)
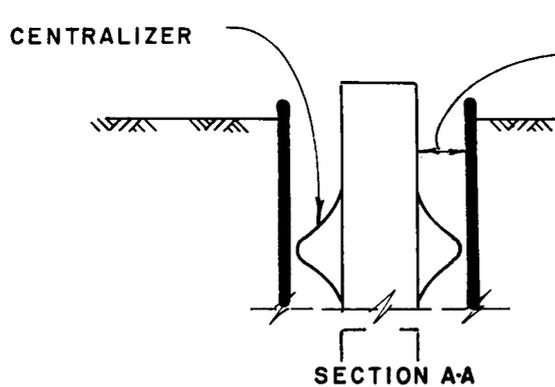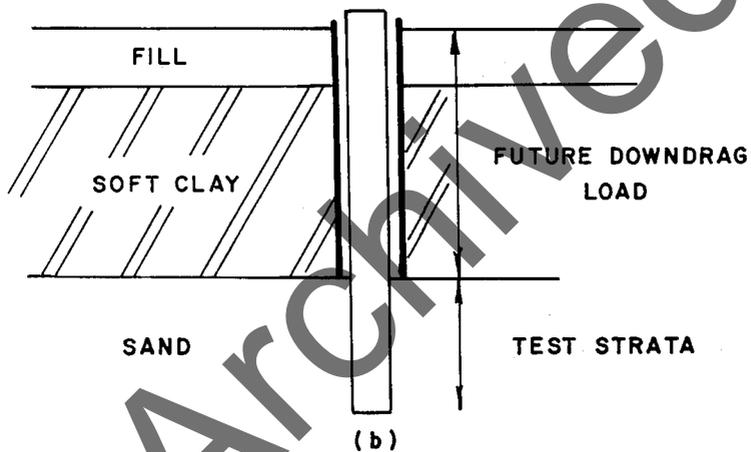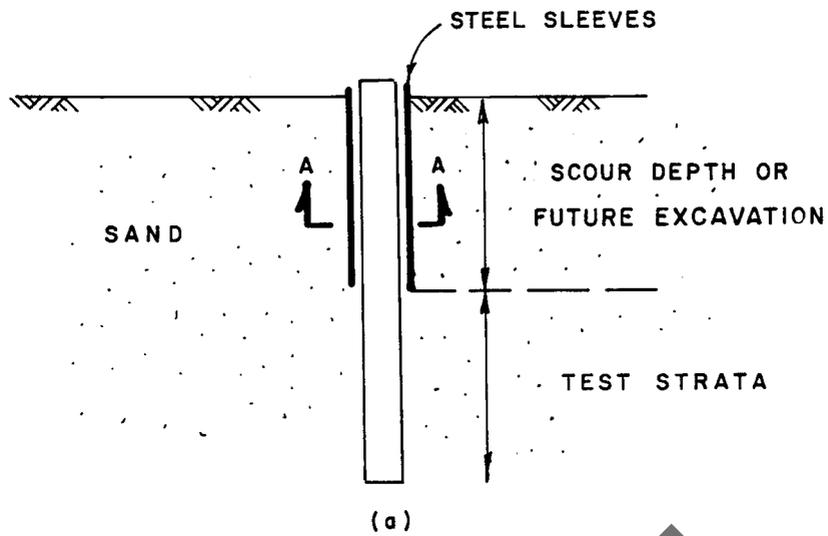
CENTRALIZER

IF THIS SPACE IS TO
GREAT, PILE BUCKLING
COULD OCCUR, TO PREVENT:

1. MINIMISE SPACE
2. USE RIGID "CENTRALIZERS"

SECTION A·A

Figure 38.   Load Test Setup Using Sleeves when (a) Scour is of
Concern, (b) Downdrag Loads are of Concern

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° difficulty in assuring centering of reinforcement often inserted into concrete/grout after installation).

Figure 39 depicts some of the situations mentioned. This type of piling requires extremely good inspection control. Lamb states that modifications to ASTM D-1143 or the development of additional standards are desirable to provide for the proper testing of these piles. His recommendations concerning the testing of these pile types are:

° Load tests should be run to failure when pile continuity is an issue.
° Reliable techniques for checking pile continuity should be included in the test program.
° Procedures for pull-out tests should be included. Detailed pull-out tests would be very useful for evaluation of the pile-soil behavior of uncased piles.

2.5 CONTRACT REQUIREMENTS

Once it has been decided that pile load test(s) are required, plans and specifications must be developed. The plans and specifications must convey the requirements of the load test to potential bidders and establish a precise picture of the work to be performed for the contractor and construction personnel.

Plans should show:

° Test location(s)
° Drill hole locations
° Design and test loads
° Site restrictions (e.g., utilities, ROW)
° Instrumentation layout (e.g. strain gages/tell tales)
° Pile type, dimensions, tip and top elevations

TEST PILE AS DESIGNED

DISTURBED BELOW TIP
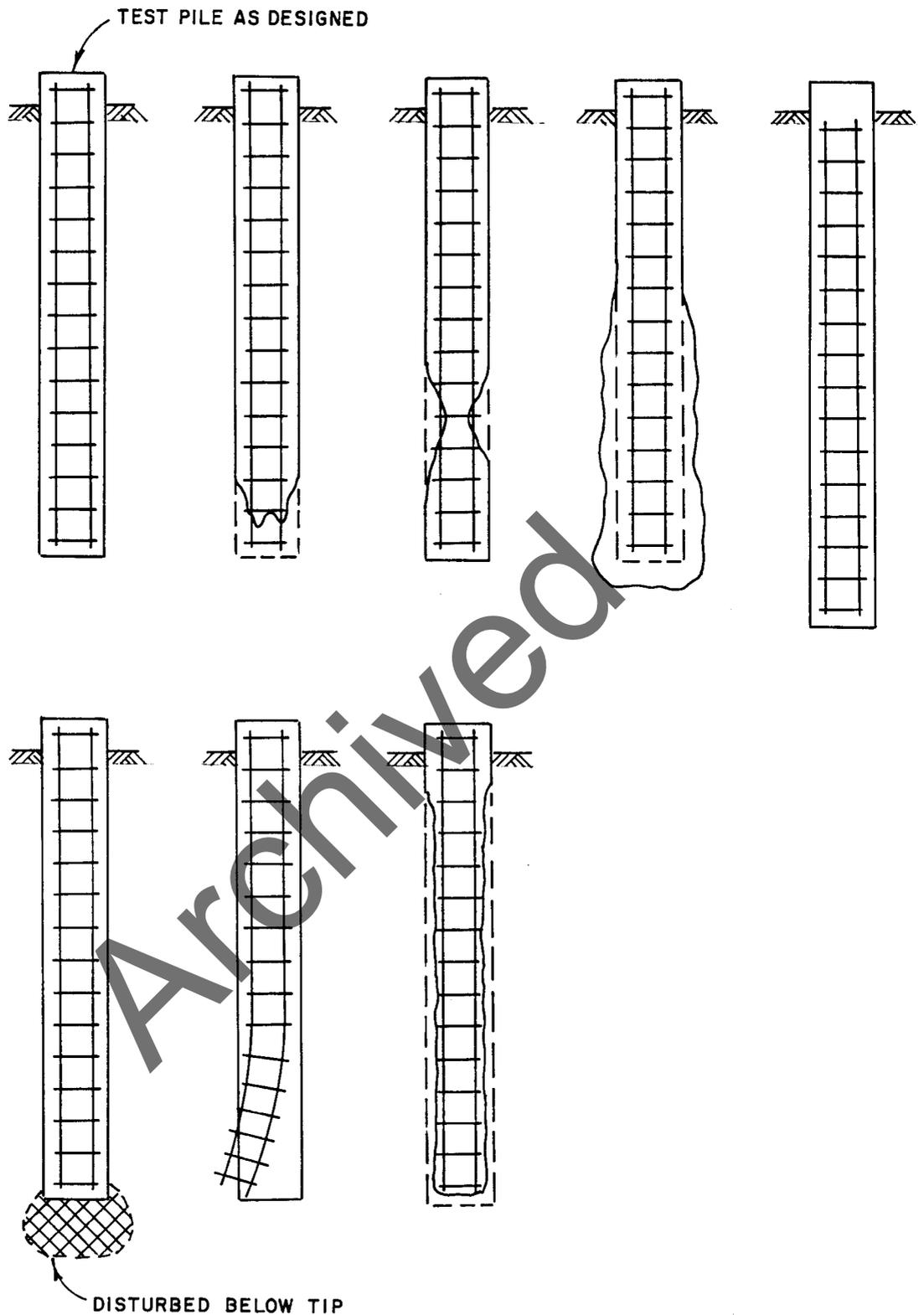
Figure 39.   Possible Defects of Uncased Concrete Piles That
             Affect Pile Load Test Results and Interpretation

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Specifications should include:

° Type of test
° Test loads
° Test method
° Instrumentation requirements
° Prequalification of contractor
° Submittal requirements
° Safety requirements
° Material requirements
° Monitoring and reporting responsibilities
° Method of payment
° Special installation procedures

On Design-Construct or Value Engineering submissions, the contractor may have to prove by a load test that his pile can support the allowable load. If this is the case, the method of determining the "failure" and "allowable" load must be explicitly stated in the specification.

Guideline specifications are presented in Appendix A. The design engineer should use this guideline specification as a tool to aid in the development of a specification for a particular project. Load test report requirements can be found in Appendix C.

2.6 ASSIGNMENT OF RESPONSIBILITIES

Plans and specifications by themselves are no guarantee that the intent of the load test(s) will be accomplished. It is highly recommended that prior to the start of any testing a meeting should be held between all the interested parties. The purpose of the meeting would be to:

- ° correct any deficiencies noted in the plans and specifications
- ° clarify particular aspects of the test(s) that may be warranted
- ° make sure that all involved parties have a clear understanding of the purpose of the test(s) and of their responsibilities
- ° establish lines of communications

With lines of communications established and test responsibilities assigned, the chances of accomplishing the test goals are greatly improved. The assignment of responsibilities for a typical load test program would be as follows:

Geotechnical Engineer

- ° Defines scope and purpose of load test
- ° Prepares drawings and specifications to implement load test
- ° Selects test locations
- ° Specifies test method
- ° Defines acceptance criteria
- ° Specifies instrumentation requirements
- ° Interprets test results
- ° Provides technical supervision during test

Contractor

- ° Understands purpose and intent of load test
- ° Designs and constructs test frame
- ° Performs test
    - Supplies personnel
    - Takes readings
    - Prepares reports

Inspector/Engineer-in-Charge

° Understands purpose and intent of load test
° Verifies that test is performed according to plans and specifications.

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3. SAFETY CONSIDERATIONS

Worker safety at pile load test sites must receive special attention because of the high loads in tension and compression in the load test members. Safety precautions should be taken both in the design of the test setup and in performing the test.

Design of Test Setup

° The load frame and its supports should be designed by a licensed Professional Engineer.

° Allowable stresses for the respective materials should not be exceeded in design.

° The bearing capacity of the soil should be considered in designing the load frame supports.

° If a dead load is used as the reaction, sufficient excess dead load should be provided to keep the test setup stable. If the maximum anticipated test load is KxP where P is the design load, provide a dead load of at least (K+1)xP.

° Bar or strand tiedowns, used for reaction, should be designed so as not to exceed 60 percent of the Guaranteed Ultimate Tensile Strength (GUTS) at the maximum test load. All tiedowns should be proof-tested to 80 percent of GUTS.

° Lateral load tests where the load is applied by pulling on the test pile are less likely to result in an unstable eccentric loading condition than tests where the load is applied by pushing against the test pile and preferred for that reason.

Testing

°   The test load should not be permitted to exceed the load for which the test setup was designed.

°   All jacks, load cells, blocking and struts should be aligned so as to minimize eccentric loading.

°   "Housekeeping" of the test site is important. Tools and materials should not be permitted to lie on the ground. The ground surface should be smooth and level. Access should not require stepping over beams or wires.

°   The wearing of hardhats should be enforced.

°   Personnel should keep clear of all beams, tiedowns an hydraulic hoses, especially while the load is being increased.

°   Monitor all reaction piles or supports. Continuous jacking required to maintain a load may be caused not only by failure of the pile-soil system but also by yielding of the load frame or tiedowns.

4. LOAD TEST COSTS

It is not possible to make specific comments concerning the cost of pile load tests as there are a number of factors that affect the cost. Contacting contractors and geotechnical consultants who normally perform load tests in a given locality is usually the most reliable way of estimating load test costs.

The cost of performing a load test is affected by the following:

° Personnel requirements
  Work rules (union vs. nonunion) vary across the country and therefore the number of workers required to install the test pile and construct the load test arrangement can vary from place to place. In addition, the wages of the personnel can vary considerably. The cost will also be affected by the number of people necessary to run the test. In many cases, the contractor will hire outside consultants to perform the test.

° Type of test
  A Maintained Load (ML) test will cost more than either a CRP or QL test. The ML test could take several days to complete versus the 1 to 4 hours for the others.

° Test load
  The magnitude of the test load will dictate the structural requirements of the load test setup. Large test loads will require more complex test arrangements.

° On land or over water
  Performing a load test over water is considerably more expensive than on land. Barges become necessary. Depending on depth of water, the stability of the test

pile can be critical because a certain length will not be laterally supported. Design of the test setup becomes considerably more complicated than one on land for the same test load.

° Instrumentation requirements
The use of strain gages, inclinometers, and load cells within the pile will increase the cost of the load test compared to just monitoring the pile head movements. The services of a geotechnical instrumentation specialist will most likely also be required.

° Time delay to contractor
If the contractor perceives that the load tests proposed on a project could affect his other operations, the expenditures due to these potential delays will most certainly be reflected in the load test cost.

° Rural vs. urban setting
Performing a load test in an open field will cost less than in a city environment. In a city, the cost of implementing a maintenance and protection of traffic scheme during the construction of the load test setup could be considerable.

° Design vs. construction
Pile load tests performed during the design phase, especially over water, will usually cost more than load tests performed during construction. The major cost component is that of mobilization.

° Experience and ingenuity of contractor
The contractors' experience will always affect the cost of load testing.

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GLOSSARY OF TERMS

Allowable Capacity	The ultimate capacity divided by a safety factor.
Design Load	The maximum load per pile used in the design of a structure. It should be equal to or smaller than the allowable capacity.
Downdrag	The transfer of load to a pile by means of negative skin friction when soil settles in relation to the pile.
Elastic Shortening	Reduction in length of a pile due to load. An important factor in evaluating apparent pile movement under a test load.
Freeze	See Setup.
Jacking	A means of transferring load to a pile from either dead weight or a reaction platform in the performance of a pile load test.
Non-Production Pile	A pile installed prior to the start of the piling portion of the contract for the purpose of establishing or verifying the pile design.
Pile Head	The top of the pile.
Pile Skin	The pile's outside surface between head and toe.
Pile Toe	The bottom end of a pile also called "tip".
Proof Load	A load applied to a selected production pile to confirm that it is suitable for the load application intended.
Reaction Pile	An individual pile which provides all or a part of the reaction load required for the load test on a test pile. During this process, the reaction pile can be subjected to axial compression, axial tension or lateral load.

Reaction System	An arrangement of dead weight, piles, ground anchors or cribbing (footings) that provides a reaction for the applied test load.
Rebound	Amount of upward movement of the head of a pile following conclusion of test; upward movement of the head of a pile after a downward movement under the impact of a pile hammer.
Settlement, Gross	Total downward movement of a pile under applied load.
Settlement, Net	The permanent movement recorded at the head of a pile at a specified period after removal of all the test load, when movement has effectively ceased.
Setup	The increase on load-carrying capacity after driving or during interruptions in driving due to soil pore pressure changes, soil remolding, stress redistribution, etc. Also called Freeze.
Skin Friction	The soil resistance acting on the pile skin.
Test Pile	An individual pile which is observed to determine its behavior under static axial compression, axial tension or lateral load.
Ultimate Capacity	The load at which the resistance of the soil to the motion of a pile becomes fully mobilized.
Uplift Capacity	The resistance of piles to pulling out of the ground.
Working Load	The actual load supported by a pile in service.

APPENDIX A

LOAD TESTING SPECIFICATION
GUIDELINE

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STATIC PILE LOAD TEST SPECIFICATION GUIDELINE

ITEM _____ , **STATIC PILE LOAD TEST**

> Comment: Identify load tests other than axial
> compressive by adding (TENSILE) or (LATERAL
> LOAD) after STATIC PILE LOAD TEST.

DESCRIPTION. Under this work, the Contractor shall furnish all testing materials, equipment and labor necessary to properly perform static pile load tests on piles indicated in the plans or as ordered by the Engineer.

The Contractor shall engage the services of a professional engineer, licensed to practice in the State of _____ and experienced in all aspects of pile load testing and acceptable to the Engineer, to supervise and inspect the load test and to prepare a final report of test results, as outlined in the FHWA STATIC PILE LOAD TEST MANUAL. The Contractor's agreement with the licensed professional engineer shall provide for additional technically qualified personnel to be at the test site at all times during testing to assure that the load is being maintained and to record data.

The Contractor shall provide complete protection at all times for the pile, supports, and reference beam from wind, direct sunlight, frost action, and other disturbances. The Contractor shall also maintain an air temperature in the immediate vicinity of test pile and reference beam of not less than 50°F throughout the duration of the test and provide a thermometer to monitor temperature. To accomplish this, the Contractor may be required to provide heat and to construct a suitable test enclosure of fiber board, polyethylene, canvas, or other materials acceptable to the engineer-in-charge. The contractor shall provide adequate lighting for the duration of the test.

Unless permitted by a Special Note in the Contract Documents or in writing by the Engineer, no production piles shall be driven before the Engineer has evaluated the results of the pile load test and notified the Contractor of the findings in writing. The Engineer will notify the Contractor within ten calendar days of receiving the Final Report for the load test.

> Comment: Modify number of calendar days prior to notification as necessary.

MATERIALS. All materials used in the construction of the load test arrangement shall conform to the relevant standards of the American Association of State Highway and Transportation Officials (AASHTO).

CONSTRUCTION DETAILS. Each test shall be performed in accordance with the requirements of the appropriate test method as presented in the FHWA STATIC PILE LOAD TEST MANUAL.

Waiting Period

A minimum waiting period of seven days shall be observed between installing the last pile in the load test system and commencing the test. The load test system may be set up during this period. The primary and auxiliary systems of measurement may also be set up during this period.

> Comment: If a waiting period longer than seven days is desired, the minimum length of waiting period should be changed accordingly.

Test Pile

The test pile shall be of the same type and cross-section as the piling to be used in the foundation and shall be installed with the same equipment and to the same criteria that will be used to install production piling.

The test pile shall be cut off in such a manner as to ensure a planar cutoff surface which is perpendicular to the longitudinal axis of the test pile.

Apparatus for Applying Loads

The Contractor shall furnish and construct a suitable reaction frame or load platform to provide a _____ ton reaction load. The Contractor shall submit to the Engineer, for review and approval, plans for the reaction frame or load platform and written details for the procedure and set-up for performing the pile load test. The reaction frame shall be designed by a structural engineer registered to practice in the State of _____ and shall conform to the requirements hereinafter specified.

Anchor piles not incorporated into the structure shall be removed or cut off at least one foot below the bottom of the footing, or below finished ground elevation if outside the footing area, upon completion of the load testing.

Instrumentation

The test pile shall be equipped with two telltales near the pile tip as detailed on the plans. The readings of tip movement will be taken simultaneously with the measurements of applied load and movement.

> Comment: Depending on the requirements of the individual test, substitute or additional instrumentation requirements should be specified here.

Loading Procedure

Comment: Specify the required loading procedure.

METHOD OF MEASUREMENT. The quantity of load tests to be paid for will be the number of load tests completed and accepted, except that load tests made at the option of the Contractor will not be included in the quantity measured for payment

The cost of installing anchor and test piling that are not part of the permanent structure will be included in the unit price bid for each load test. Anchor and test piling which are part of the permanent structure will be paid for under the appropriate pay item.

BASIS OF PAYMENT. The unit price for each test shall include the cost of all equipment, materials and labor necessary to successfully complete each test.

APPENDIX B

TEST METHODS
AXIAL COMPRESSIVE TEST
AXIAL TENSILE TEST
LATERAL LOAD TEST

AXIAL COMPRESSIVE TEST METHOD

1. OBJECTIVE

The purpose of this test method is to establish procedures for testing vertical piles to determine the response of the pile to a static compressive load.

2. METHODS OF LOAD APPLICATION

2.1 Types of Reaction Load

Load shall be applied to the pile by jacking against a reaction using one or more hydraulic jacks. The reaction shall be provided by one of the following methods, or a variation thereof approved in writing by the Engineer.

Reaction Frame

The reaction frame shall include two or more anchor piles installed after the test pile and located a clear distance of at least 5 times the maximum diameter of the largest anchor or test pile but not less than 10 feet from the test pile or reference beam supports. The frame shall be constructed of girders of sufficient strength and section for the load and of load transfer beams which are attached to the upper ends of the anchor piles. This reaction frame shall be designed to resist four times the maximum pile design load shown on the plans.

Weighted Box or Platform

A test box or test platform shall be constructed over the test pile, supported on cribbing or on other piles installed after the test pile and located a clear distance of at least 5 times the maximum diameter of the largest anchor or test pile

but not less than 10 feet from the test pile or reference beam supports. The Contractor shall load the test box or platform with earth, sand, concrete, water, pig iron, or other suitable material to a total weight of at least four times the maximum pile design load shown on the plans.

Alternate Methods

The Contractor may request approval for supplying the reaction for the test load by another method. In this case the Contractor shall submit in writing a summary of the alternate loading system with appropriately detailed drawings for approval by the Engineer.

2.2 Load Application System

The load shall be applied by means of one or more hydraulic jacks, having a total capacity of at least four times the maximum pile design load shown on the plans. Travel of the jack(s) shall be a minimum of 6 in., and in no case less than 25 percent of the test pile's maximum cross section dimension. The jack(s) shall have spherical bearing plates, to bear firmly and concentrically against the pile bearing plate and load-beam bearing plate. Load application shall be controlled by an automatic load maintaining pump with manual supplement. The system's pressure gage shall be such that the pressure reading corresponding to the maximum pile design load shown on the plans shall be between one-fourth and one-third the maximum gage pressure. A load cell, either electric or hydraulic (unless either type is specifically called for in the contract documents) shall be utilized to measure strains for load monitoring during the load test.

The load-application system shall consists of several elements, arranged and constructed as follows:

1. The pile top shall be cut off and capped so as to provide a level bearing surface perpendicular to the axis of the pile. The cap shall consist of a steel plate for H-piles and of neat cement paste for concrete piles, timber piles or cast-in-place piles filled with concrete;

2. Use a solid steel billet of sufficient thickness (under no circumstances less than 1 in.) as a bearing plate between the capped pile and the jack base to distribute the load over the entire cross-section of the pile;

3. Place the hydraulic jack system (jack, spherical bearing plate and load cell) between the bearing plate on the pile and the center of the underside of the load beam;

4. Use another solid steel billet of sufficient thickness (under no circumstances less than 1 in.) as a bearing plate between the load beam and the jack ram to distribute the load over the entire width of the load beam;

5. Construct the system so that all components are centered along the longitudinal axis of the pile to assure the application of a concentric axial load;

6. Immediately before starting the load test, verify that at least 1 in. of clear space exists between the upper bearing plate and the load beam.

3. INSTRUMENTATION

3.1 Measurement of Load at Pile Head

The jack, jack pressure gage and load cell shall be calibrated as a unit. A second pressure gage (a backup gage) shall also be calibrated as a unit with the jack and the load cell. The calibration shall be performed not more than 30 days prior to the test and be certified in writing by an independent testing laboratory.

3.1.1 Hydraulic Jack(s)

Jacking capacity shall be at least four times the pile design load shown on the plans. The jacks shall have a minimum ram travel of 6 inches. The hydraulic jacks shall be calibrated to an accuracy of not less than 5 percent of the applied load.

3.1.2 Load Cell(s)

Properly constructed load cell(s) shall be used in series with the hydraulic jack(s). Load cell(s) shall be calibrated prior to the test to an accuracy of not less than 2 percent of the applied load.

3.2 Measurement of Vertical Movement of Pile Head

A primary and a secondary monitoring system as described in this section shall be established prior to the start of the test.

3.2.1 LVDT'S

The Contractor shall provide a primary system consisting of three LVDT's and a readout unit for monitoring movement of the pile top.

The LVDT's shall be DC/DC type displacement transducers with at least 6 inches of travel and have a linearity of 0.5 percent or less. The readout unit shall be capable of monitoring the output from at least 3 DC/DC type LVDT's and have a minimum display of 3-1/2 digits.

The alignment and attachment of the LVDT's will be the same as that stated below for the dial gages. The mounting hardware should be of non-magnetic materials such as brass, aluminum or 303 series stainless steel.

3.2.2 Dial Gages

The Contractor shall provide a primary system consisting of three dial gages for monitoring movement of the pile top. The gages shall have at least 2 inches of travel, an adequate number of suitable gage blocks to increase the travel to at least an additional 4 inches, and a precision of 0.001 inches.

Align the dial gages parallel to the longitudinal axis of the test pile and the axis of load application. Attach the gages to a simply supported reference beam, which is to be completely independent of the test pile and the loading apparatus. Embed the reference beam supports at least 2 ft. into the ground, at a clear horizontal distance of not less than 10 ft. (or as shown on the plans) from the closest face of the test pile and from any reaction piles or supports for the weighted box or platform. Maintain a clear distance of 6 to 12 inches from the test pile to the reference beam or any projection used for supporting a dial. The beam and projections should be at approximately the same elevation as the attachments to the pile on which the dial gages will bear. Attach the dial gage supports to the reference beam so as to allow the stem of each gage to rest on an attachment to the pile sides. These attachments shall be steel angles, approximately 3 in. by 4 in. with the 4-in. dimension projecting from

the pile. For round piles these attachments shall be placed at a 120° spacing and equal radial distance from the test pile. For piles of other cross-section the attachments shall be placed at convenient locations as approved by the Engineer. The surfaces on which the gage stems bear shall be smooth-finished such as glass or sheet acrylic, attached by plaster of paris or other suitable material.

3.2.3 Wire, Mirror and Scale (as secondary system only)

Pile movement may be determined by means of a single strand of wire drawn in front of a graduated scale mounted on a mirror. This scale shall be at least 6 in. long, machine-divided in graduations of 0.01 in. and mounted on a 3 in. by 6 in. mirror with metal-and-glass bonding adhesive or electrical tape. Attach the mirror directly to the pile, so oriented that the mirror face is parallel to the reference beam. Mount the wire between the ends of the reference beam, with one end fixed and the other placed over a pulley with a weight to maintain tension. The wire should be level and located within 3/4 in. of the mirror face.

3.2.4 Level (as secondary system only)

A level and leveling rod with a vernier target that can be read to 0.001 feet may be used. Determine settlements by readings on the two fixed independent benchmarks and on an established scale or fixed point on the pile top.

3.3 Measurement of Load and Vertical Deflections along Pile Shaft

Load-deflection instrumentation along pile shaft shall be as required on the plans and as described in this section.

3.3.1 Strain Rods (Telltales)

The strain rod or telltale shall consist of a metal rod or pipe sheathed in a protective housing. The bottom of the telltale, including the inner rod and sheath, shall be attached to the pile as shown on the plans or as ordered by the Engineer. Attach the telltale dial gages to the reference beam. The gage readings will be used to determine net settlement of the point(s) under investigation.

3.3.2 Strain Gages

Strain measurements on the pile may be required by a special note in the contract documents. These measurements are for determining elastic shortening of the pile.

3.4 Primary and Auxiliary Instruments

The apparatus for measuring load and movement shall consist of primary system, at least one auxiliary system, and a network of settlement reference points.

4. LOADING PROCEDURES

4.1 Maintained Load

Unless failure occurs first, load the pile to 200 percent of the pile design load shown on the plans, applying the load in increments of 25 percent of the individual pile design load. Maintain each load increment until the rate of settlement is not greater than 0.01 in. per hour but not longer than 2 hours. Remove the total test load anytime after 12 hours if the settlement at the pile head over a 1 hour period is not greater than 0.01 inches; otherwise allow the total load to remain on the pile for 24 hours. After the required holding time, remove the pile test load in decrements of 25 percent of the total test load with 1 hour between decrements.

4.2 Quick Load

Load is applied until either a plunging failure occurs or the capacity of the test equipment is reached. Increments of load should equal 10 to 15 percent of the design load (5 to 10 tons for piling and 25 to 50 tons for drilled shafts and high capacity piles); however, these may be increased by up to 100 percent at the beginning of the test but should be decreased to the minimum increment as plunging failure occurs. A constant time interval of two and one-half minutes is used throughout the test.

4.3 Constant Rate of Penetration

Load the pile until either a plunging failure occurs or the capacity of the test equipment is reached. Apply the load so that the pile top experiences a constant rate of deflection with time. Loads may be applied by means of a mechanical loading system which will cause a constant rate of deflection with time.

The rate of pile deflection, n in inches per minute is determined by the following relationship:

$$n = k \frac{PL}{AE} \quad \text{inches per minute}$$

where,

> k = A soil constant (0.1 for cohesionless soils, 0.04 for cohesive soils, or as specified)
> P = Maximum design load of the pile (as shown on plans)
> L = Length of pile, inches
> A = Cross-sectional area of pile, square inches
> E = Modulus of elasticity of the pile, kips per square inch

5. MEASUREMENT OF MOVEMENTS

5.1 General

Take required readings at gauges or reference points as nearly simultaneously as possible. Clearly indicate and explain any adjustments made during the test to the instrumentation or to the data recorded in the field.

5.2 Maintained Load Procedure

Take readings of time, load, and movement, and record them before and after the application of each load increment or removal of each load decrement.

5.3 Quick Load Test Procedure

Take readings of time, load, and movement and record immediately before and after the application of each load increment.

5.4 Constant Rate of Penetration Loading Procedure

Take readings of time, load, and movement and record at least every 30 seconds.

AXIAL TENSILE TEST METHOD

1. OBJECTIVE

The purpose of this test method is to establish procedures for testing vertical piles to determine the response of the pile to a static tensile load.

2. METHODS OF LOAD APPLICATION

2.1 Types of Reaction Load

The Load shall be applied to the pile by jacking against a reaction using one or more hydraulic jacks. The reaction shall be provided by a frame that is supported either by timber cribbing or piles.

Reaction Frame

The reaction frame shall be supported by timber cribbing on firm level ground or by piles. The face of these supports shall be located a clear distance of not less than 10 ft. from the test pile. The frame shall be level in both directions and centered over the test pile. The support piles or timber cribbing height above the top of the test pile shall be a distance sufficient to provide clearance between the test beam and test pile greater than the amount of anticipated movement of the test pile. The frame shall be constructed of girders of sufficient strength and section for the test load, load transfer beam and equipment that are supported by the cribbing or piles.

This reaction frame shall be designed to resist four times the maximum pile design load shown on the plan.

Alternative Methods

The contractor may request approval for supplying the reaction for the test load by another method. In this case, the Contractor shall submit in writing a summary of the alternative loading system with appropriately detailed drawings for approval by the Engineer.

2.2 Load Application System

The load shall be applied by means of one or more hydraulic jacks, having a total capacity of at least four times the maximum pile design load shown on the plans.

Travel of the jack(s) shall be a minimum of 6 in., and in no case less than 25 percent of the test pile's maximum cross section dimension. The jack(s) shall have spherical bearing plates, to bear firmly and concentrically against the reaction frame bearing plate. Load application shall be controlled by an automatic load maintaining pump with manual supplement.

The system's pressure gage shall be such that the pressure reading corresponding to the maximum pile design load shown on the plans shall be between one-fourth and one-third the maximum gage pressure. A load cell, either electric or hydraulic (unless either type is specifically called for in the contract documents) shall be utilized to measure strains for load monitoring during the load test(s).

The load application system shall consist of several elements, arranged and constructed as follows:

1. The pile top shall be cut-off level and perpendicular to the axis of the pile. The cut-off elevation shall be such that a sufficient length of pile is exposed to

allow the application of brackets for the LVDT's and dial gage. A greater exposed length may be acquired for H-piles due to the welding of the tension connection to the test piles.

2. Use a solid steel billet of sufficient thickness (under no circumstances less than 1 in.) as a bearing plate between the test berm(s) and timber cribbing or support piles. An addition solid steel billet (same thickness as above) is placed on top of the test beam to provide a base for the jack to transfer the reaction load to the test beam.

3. Place the hydraulic jack system (jack, load cell and spherical bearing if appropriate) on top of the steel bearing plate on the test beam and centered over the test pile.

4. A solid steel billet of sufficient thickness (under no circumstances less 1 in.) is placed on top of the spherical bearing or load cell to provide load transfer from the jacking system to the test pile. If a center-hole jack is used, then the bearing plate will require a hole or gap larger enough to allow a tension bar to pass through the jack to the center of the test pile.

5. Center a reaction frame (consisting of a plate, channels or beam) over the jacking system and secure it to the test pile via tension connection straps or bars welded to the test pile or with bars or cables embedded in the test pile. If a center-hole jack is used, a reaction frame is not required; the tension bars or cables are passed through the jack to the center of the pile.

There shall be sufficient clearance between the tension connection and jacking system to provide free movement slippage, rupture or excessive elongation of the connection under the maximum test load.

3. INSTRUMENTATION

3.1 Measurement of Load at Pile Head

3.1.1 Hydraulic Jack(s)

The jack, jack pressure gage and load cell shall be calibrated as a unit. A second pressure gage (a backup gage) shall also be calibrated as a unit with the jack and the load cell. The calibration shall be performed not more than 30 days prior to the test and be certified in writing by an independent testing laboratory.

Jacking capacity shall be at least four times the pile design load shown on the plans. The jacks shall have a minimum ram travel of 6 inches. The hydraulic jacks shall be calibrated to an accuracy of not less than 5 percent of the applied load.

3.1.2 Load Cell(s)

Properly constructed load cell(s) shall be used in series with the hydraulic jack. Load cell(s) shall be calibrated to an accuracy of not less than 2 percent of the applied load.

3.2 Measurement of Vertical Movement of Pile Head

A primary and a secondary monitoring system as described in this section shall be established prior to the start of the test.

3.2.1 LVDT'S

The Contractor shall provide a primary system consisting of three LVDT's and a readout unit for monitoring movement of the pile top.

The LVDT's shall be DC/DC type displacement transducers with at least 6 inches of travel and have a linearity of 0.5 percent or less. The readout unit shall be capable of monitoring the output from at least 3 DC/DC type LVDT's and have a minimum display of 3-1/2 digits.

The alignment and attachment of the LVDT's will be the same as that stated below for the dial gauges. The mounting hardware should be of non-magnetic materials such as brass, aluminum or 303 series stainless steel.

3.2.2 Dial Gages

The Contractor shall provide a primary system consisting of three dial gages for monitoring movement of the pile top. The gages shall have at least 2 inches of travel, an adequate number of suitable gage blocks to increase the travel to at least an additional 4 inches, and a precision of 0.001 inches.

Align the dial gages parallel to the longitudinal axis of the test pile and the axis of load application. Attach the gages to a simply supported reference beam, which is completely independent of the test pile and the loading apparatus. Embed the reference beam supports at least 2 ft. into the ground, at a clear horizontal distance of not less than 10 ft. (or as shown on the plans) from the closest face of the test pile and from any reaction piles or cribbing. Maintain a clear distance of 6 to 12 inches from the test pile to the reference beam or any projection used for supporting a pile. The beam and projections should

be at the approximately the same elevation as the attachments to the pile on which the dial gages will bear. Attach the dial gage supports to the reference beam so as to allow the stem of each gage to rest on an attachment to the pile sides. These attachments shall be steel angles, approximately 3 in. by 4 in. with the 4-in. dimension projecting from the pile. For round piles these attachments shall be placed at a 120° spacing and equal radial distance from the test pile. For piles of other cross-section, the attachments shall be placed at convenient locations as approved by the Engineer. The surfaces on which the gage stems bear be smooth finished such as glass or sheet acrylic, attached by plaster of paris or other suitable material.

3.2.3 Wire, Mirror and Scale (as secondary system only)

Pile movement may be determined by means of a single strand of wire drawn in front of a graduated scale mounted on a mirror. This scale shall be at least 6 in. long, machine-divided in graduations of 0.01 in. and mounted on a 3 in. by 6 in. mirror with metal-and-glass bonding adhesive or electrical tape. Attach the mirror directly to the pile, so oriented that the mirror face is parallel to the reference beam. Mount the wire between the ends of the reference beam, with one end fixed and the other placed over a pulley with a weight to maintain tension. The wire should be level and located within 3/4 in. of the mirror face.

3.2.4 Level (as secondary system only)

A level and leveling rod with a vernier target that can be read to 0.001 feet may be used. Determine movements by readings on the two fixed independent benchmarks and on an established scale or fixed point on the pile top.

3.3 Primary and Auxiliary Instruments

The apparatus for measuring load and movement shall consist of a primary system, at least one auxiliary system, and a network of settlement reference points.

4. LOADING PROCEDURES

4.1 Maintained Load

Unless failure occurs first, load the pile to 200 percent of the anticipated design load, applying the load in increments of 25 percent of the design load. Maintain each load increment until the rate of movement is not greater than 0.01 inches/hour but not longer than 2 hours. Provided that the test pile has not failed, remove the test load anytime after 12 hours if the top of pile movement over a 1 hour period is not greater than 0.01 inches; otherwise allow the total load to remain on the pile for 24 hours. After the required hold time, remove the test load in decrements of 25 percent of the test load with 1 hour between decrements.

4.2 Quick Load

Load is applied until failure occurs or the capacity of the test equipment is reached. Increments of load should equal 10 to 15 percent of the design load (5 to 10 tons for piling and 25 to 50 tons for drilled shafts and high capacity piles); however these may be increased by up to 100 percent at the beginning of the test but should be decreased to the minimum increment as failure occurs. A constant time interval is used throughout the test.

4.3 Constant Rate of Uplift

Test the pile at an uplift rate within a range of 0.02 to 0.04 inches/minute or as otherwise specified. Vary the applied load as necessary to maintain the specified uplift rate. Continue loading the pile until no further increase in the load is necessary for continuous pile upward movement at the specified rate unless the capacity of the loading apparatus is reached. Hold the load required to achieve the specified uplift rate until the total pile withdrawal is at least 8 inches or 25 percent of the average pile diameter or diagonal dimension, whichever is less, after which release the load.

5. MEASUREMENT OF MOVEMENTS

5.1 General

Take required readings at gauges or reference points as nearly simultaneously as possible. Clearly indicate and explain any adjustments made during the test to the instrumentation or to the data recorded in the field.

5.2 Maintained Load Procedure

Take readings of time, load and movement, and record them before and after the application of each load increment or removal of each load decrement.

5.3 Quick Load Procedure

Take readings of time, load, and movement and record them immediately before and after the application of each load increment.

5.4 Constant Rate of Uplift Procedure

Take readings of time, load, and movement and record them at least every 30 seconds.

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LATERAL LOAD TEST METHOD

1. OBJECTIVE

The purpose of this test method is to establish procedures for testing vertical or batter piles to determine the response of the pile(s) to a static lateral load or to a series of repeated lateral loads.

2. METHODS OF LOAD APPLICATION

2.1 Types of Reaction

Load shall be applied to the pile(s) by jacking against a reaction using a hydraulic jack. Unless the plans stipulate a specific type of reaction, the reaction shall be provided by one of the following methods or a variation thereof approved in writing by the Engineer.

Deadman

Where site conditions permit, a deadman may be constructed of timber, concrete, steel or other approved material bearing against compacted soil or the sides of an excavation. The deadman shall be designed so as to provide the necessary reaction without requiring jack travel in excess of that available.

Reaction Pile(s)

One or more vertical or batter piles, or a combination of the two, may be installed to provide the reaction.

Alternate Methods

The Contractor may request approval for supplying the reaction for the test load by another method. In that case, the Contractor shall submit in writing a summary of the alternative loading system with appropriately detailed drawings for approval by the Engineer.

2.2 Distance Between Test Pile(s) and Reaction

If the load is applied by pushing against the reaction, the minimum distance between the test pile and the reaction shall be 5 ft. or five test pile diameters, whichever is greater. If the load is applied by pulling against the reaction, the minimum distance between the test pile and the reaction pile or deadman shall be the greatest of the following:

1.   10 ft.
2.   ten test pile diameters
3.   five times the depth of the base of the deadman below ground elevation at the test pile plus five test pile diameters.

2.3 Load Application System

The load shall be applied by means of a hydraulic jack having a total capacity of at least 2 times the specified maximum test load. Travel of the jack shall be a minimum of 6 inches. Unless cables or prestressing strand are used to apply a tensile lateral load, the jack load shall be transferred to the test pile and the reaction by means of spherical bearings to bearing plates that bear firmly and concentrically against the test pile and the reaction. Bearings and bearing plates shall be of steel and of sufficient size to accommodate the testing equipment used and to transmit the applied lateral loads without detrimentally high

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unit pressures. For tests on single piles other than square piles, the head of the pile shall be capped so as to provide a plane vertical bearing surface for the bearing plate or the bearing plate shall be set in high-strength grout or adequately welded to the side of the pile using suitable filler material to provide full bearing against the pile.

Load application shall be controlled by an automatic load maintaining pump with manual supplement. The system's pressure gage shall be such that the pressure reading corresponding to the maximum test load will be between 40 and 60 percent of the maximum gage pressure. An electric load cell shall be placed in series with the jack and shall be utilized for load monitoring during the load test.

3. INSTRUMENTATION

3.1 Measurement of Load

3.1.1 Hydraulic Jack

Jacking capacity shall be at least twice the specified maximum test load. The jack shall have a minimum ram travel of 6 inches. The hydraulic jack and the pressure gage shall be calibrated as a unit by an independent testing laboratory within 30 days of use to a minimum accuracy of 5 percent of the maximum test load.

3.1.2 Load Cell

An approved electric load cell shall be used in series with the hydraulic jack. The maximum capacity of the load cell shall be not less than 125 percent, nor more than 250 percent of the test load. The load cell shall be calibrated by an independent

testing laboratory within 30 days of use to a minimum accuracy of 2 percent of the maximum test load.

3.2 Measurement of Lateral Movement of Pile Head

3.2.1 General

A primary, one or more secondary systems and an inclinometer shall be used to measure the lateral movement of the pile. The primary system shall utilize LVDT's (linearly variable differential transformers) or dial gages. The secondary system shall consists of either dial gages (if LVDT's are used for the primary system), a wire, mirror and scale, or a transit and scale.

The reference beam for LVDT's or dial gages shall be supported on supports firmly embedded in the ground a minimum clear distance of 10 feet (or as shown on the plans) from the test pile. The reference beam shall be oriented perpendicular to the line of load application and located a sufficient distance from the pile to avoid interference with the test pile throughout the test. The surfaces on which the gage stems bear shall be smooth finished, such as glass or sheet acrylic, attached by plaster of paris or other suitable material.

Measurements of vertical and side movements of the test pile may reveal eccentric loading or abnormal behavior of the test pile. Such measurements are recommended to determine the precise response of the test pile to the lateral load.

3.2.2 LVDT's

The Contractor shall provide a primary system consisting of three LVDT's and a readout unit for monitoring the pile top.

The LVDT's shall be DC/DC type displacement transducers with at least 6 inches of travel and have a linearity of 0.5 percent or less. In addition, they shall be spring loaded or have a core with a threaded connecting rod, either of which allows the LVDT's to function horizontally.

The readout unit shall be capable of monitoring the output from at least 3 DC/DC type LVDT's and have a minimum display of 3-1/2 digits.

The mounting hardware should be of non-magnetic materials such as brass, aluminum or 303 series stainless steel.

3.2.3 Dial Gages

Dial gages shall have at least 2 inches of travel, an adequate number of suitable gage blocks to increase the travel to at least 6 inches, and a precision of 0.001 inches. The dial gages and LVDT'S shall be attached to the reference beam (with stems bearing against the pile or the cap) or to lugs attached to the test pile (with stems bearing against the reference beam). The gages and LVDT'S shall be mounted with stems horizontal and in line with the applied load.

3.2.3 Wire, Mirror and Scale (as secondary system only)

Pile movement may be determined by means of a single strand of wire drawn in front of a graduated scale mounted on a mirror. This scale shall be at least 6 in. long, machine-divided in graduations of 0.01 in. and mounted on a 3 in. by 6 in. mirror with metal-and-glass bonding adhesive or electrical tape. Attach the mirror directly to the pile, so oriented that the mirror face is parallel to the reference beam. Mount the wire between the ends of the reference beam, with one end fixed and the other

placed over a pulley with a weight to maintain tension. The wire should be level and located within 3/4 in. of the mirror face.

3.2.4 Transit and Scale

A scale shall be mounted horizontally on the side or the top of the test pile parallel to the line of load application. A permanent transit station and a backsight or foresight shall be established outside the immediate test area on a line perpendicular to the applied load and passing through the scale.

3.2.5 Inclinometer

Inclinometer casing shall be attached to the pile. The type of casing to be furnished, the method of attachment and the type of readout and appurtenant equipment shall be in accordance with the details and notes included in the contract documents.

4. LOADING PROCEDURES

4.1 Standard

Unless failure occurs first, apply and remove the total specified test load as follows:

Standard Loading Schedule

% of Specified Test Load	Load Duration (minutes)
5	-
12.5	30
25	30
37.5	30
50	30
62.5	30
75	30
87.5	30
100	60
75	30
50	30
25	30
5	-

4.2 Cyclic

Unless failure occurs first, apply and remove the total specified test load as follows:

Cyclic Loading Schedule

% of Specified Test Load	Load Duration (minutes)
5	-
25	30
5	5
25	5
repeat for a total of 10 cycles	
50	30
25	5
50	5
25	5
repeat for a total of 10 cycles	
75	30
50	5
75	5
repeat for a total of 10 cycles	
100	30

75	5
100	5
repeat for a total of 10 cycles	
100	60
75	5
50	30
25	5
5	-

4.3 Limiting Lateral Movements

Terminate test if an unsafe eccentric loading condition develops as a result of high or out-of-line pile movements.

5. MEASUREMENT OF MOVEMENTS

5.1 General

Take required readings at gauges or reference points as nearly simultaneously as possible. Clearly indicate and explain any adjustments made during the test to the instrumentation or to the data recorded in the field.

5.2 Measurement Frequency

5.2.1 LVDT and Dial Gages

Record readings as follows:

a)   5 minute load duration - immediately before and after application or removal of a load increment.

b)   30 minute load duration - 1, 2, 4, 8, 15 and 30 minutes after application or removal of a load increment.

c)   60 minute load duration - as for 30 minute load duration with an additional reading at 60 minutes.

5.2.2 Wire, Mirror and Scale

Take readings by lining up the wire with its image in the mirror. Record readings immediately before and after application or removal of a load increment.

5.2.3 Transit and Scale

Record readings immediately before and after application or removal of a load increment.

5.2.4 Inclinometer and Strain Gages

Obtain and record inclinometer and/or strain gage readings, starting immediately after application or removal of a load increment, whenever the load duration is 30 minutes or greater.

APPENDIX C

LOAD TEST REPORT REQUIREMENTS

LOAD TEST REPORTS

The following documentation shall be prepared by the contractor for each load test:

- ° Pre-Installation Report
- ° Post-Installation Report
- ° Certification of Loading Devices
- ° Final Report

1. Pre-Installation Report

Before the Contractor receives permission to install the test pile, he shall submit a report to the Engineer who will require five working days for review. The test pile shall be installed only after the Engineer has approved the details of this report in writing. The pre-installation report shall include the following information:

a. A description of the equipment to be used for pile installation.

b. A description of the test pile, including its type, the pile material, wall thickness, tip and top details and the diameter and length.

c. A description of the method of testing, including the following:

   1) type and amount of dead-load reaction, or size and description of reaction frame and the location, type and length of reaction piles,

   2) method of supporting reference beam and measuring devices, showing distances from the test pile and anchor piles (or the supports for a reaction) and its height above ground,

   3) capacity of pressure gages and hydraulic jacks.

2. Post-Installation Report

Prior to the start of the pile load test, the Contractor shall submit to the Engineer and include in the final report the following:

For driven piles:

a. the test pile driving or re-driving records, including blows per foot throughout the length driven and final driving resistance in blows per inch for the last 18 in.;

b. actual rate of hammer operation during test pile driving,

c. embedded length of pile,

d. length of pile tested and

e. methods employed by the Contractor to prevent pile rebound immediately after driving.

For non-driven piles:

a. Pile dimensions.

b. Type of excavating methods used.

c. Description of materials encountered during excavation.

d. Description of groundwater conditions encountered.

e. Length of temporary and/or permanent casing placed.

f. Details of steel reinforcement

g. Quantity of cement grout or concrete used.

h. Type of cement grout or concrete used.

i. Details of any obstructions encountered and time in overcoming them.

j. Details of major interruptions to the construction process.

3. Certification of Loading Devices

The Contractor shall engage an independent testing laboratory to calibrate the hydraulic system, jack(s), and pressure gage(s) within 14 days of starting the test. Calibration includes readings for loading and unloading. Loading system accuracy shall be within 5 percent of the load applied. The Contractor shall submit calibration data to the Engineer before any load testing, and include a copy of the jack certification and of the load calibration curve in the final report.

No recalibration of the above elements will be required for more than one load test on the same project providing the following conditions are satisfied:

a. the equipment which has been calibrated and approved is not removed from the project for use elsewhere until all load tests are completed,

b. the calibrated equipment is carefully stored and properly maintained between tests in a manner approved by the Engineer,

c. the calibrated equipment is not subjected to abuse of any kind while maintained for use on a specific project,

d. the time period between load tests using the approved calibrated equipment on the same project does not exceed 1 month and

e. readout results are ascertained to the required accuracy criteria.

4. Final Report

A final report shall be prepared by the Contractor for each load test and shall at a minimum contain the following information:

a. **General**

   1) Project Name
   2) Project Location
   3) General Contractor
   4) Pile Contractor
   5) Inspector
   6) Dates piles installed and tested

b. **Site Information**

   1) Subsurface information - based on the boring log of the nearest drill hole
   2) Elevation of ground and ground water during test
   3) Weather conditions

c. **Pile Information**

   1) Type
   2) Installed length
   3) Remarks concerning any unusual events during pile installation.

d. **Load Test Information**

   1) Description of the test apparatus and the loading and movement procedure used
   2) A copy of the time-movement data collection sheets exactly as filled out in the field
   3) A graphic representation of the test results in the form of load-movement curves

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APPENDIX D

LOAD TESTING DATA FORMS

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RECORD OF FOUNDATION TEST LOAD

Loading No. ____

TEXAS QUICK TEST LOAD METHOD

County _____ Control _____ Structure _____

Highway No. _____ Project _____ Structure No. _____

Bent No. _____ Foundation No. _____ Sta. _____ Rt. _____ Lt. _____

Foundation Size & Type _____ Total Length _____ Design Load _____

Foundation Tip Elevation _____ Effective Penetration _____ Ground Elevation _____

Hammer Type & Size _____ Dynamic Resistance _____

Time Test Began _____ Date _____ Resident Engineer _____

Time	Time Interval	Load Added	Total Load	Extensometer Readings		Total Gross Settlement - Inches		
Min.	Min.	Tons	Tons	Dial 1	Dial 2	Dial 1	Dial 2	Average

Remarks: _____

_____

District _____

Date _____

By _____

SM 380a (2/74)
N.Y.S. D.O.T.

PILE LOAD TEST
TIME - SETTLEMENT DATA SHEET

BRIDGE DESIGNATION: _____

PILE LOCATION: _____

PILE NO.: _____

PILE LOAD TEST NO.: _____

PILE TIP ELEVATION: _____

DATE: _____

PREPARED BY: _____

COMPUTED BY: _____

CHECKED BY: _____

JOB STAMP

| ELAPSED TIME	READ TIME	JACK GAGE READ. (P.S.I.)	JACK LOAD TONS	LOAD CELL READ.	LOAD CELL TONS	DIAL READINGS - (IN.)			MEAN (IN.)	DEFL. (IN.)	TELL TALES - (IN.)				REMARKS
						A	B	C			READ	DEFL.	READ	DEFL.	

LATERAL PILE LOAD TEST
TIME - DEFLECTION DATA SHEET

DATE: _____
PREPARED BY: _____
COMPUTED BY: _____
CHECKED BY: _____

BRIDGE DESIGNATION: _____
PILE LOCATION: _____
PILE NO.: _____
PILE LOAD TEST NO.: _____

SEE OTHER SHEETS FOR INCLINOMETER AND / OR STRAIN GAGE READINGS.

PROJECT

ELAPSED TIME	READ TIME	JACK GAGE READ. (P.S.I.)	JACK LOAD TONS	LOAD CELL READ.	LOAD CELL TONS	DIAL READINGS - (IN.)			MEAN (IN.)	DEFL. (IN.)	REMARKS
						A	B	C			

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LATERAL PILE LOAD TEST
INCLINOMETER DATA SHEET

PROJECT

BRIDGE: _____   DATE: _____

PILE LOCATION: _____   PREPARED BY: _____

PILE NO: _____   COMPUTED BY: _____

PILE LOAD TEST NO: _____   CHECKED BY: _____

LOAD INCREMENT: _____   TO _____

A	B	C	D	E	F	G	H
DEPTH	PROBE DEPTH (A+I)	READING (NORMAL)	READING (180)	READING AVERAGE (C-D)/2	READING INITIAL	CHANGE (E-F)	TOTAL DEFLECTION
0							
2							
4							
6							
8							
10							
12							
14							
16							
18							
20							
22							
24							
26							
28							
30							
32							
34							
36							
38							
40							
42							
44							
46							
48							
50							
52							
54							
56							
58							
60							
62							
64							
66							
68							
70							
72							
74							
76							
78							
80							

1. ALL UNITS ARE IN FEET.
2. I = INCLINOMETER STICK-UP - ONE FOOT.
3. TO CALCULATE TOTAL DEFLECTION, ACCUMULATE CHANGE DOWNWARD.
4. TOTAL DEFLECTION AT DEPTH = 0 IS THE DEFLECTION FROM THE HORIZONTAL SURFACE GAGE.
5. FOR INTERVAL OTHER THAN 2 FEET, MULTIPLY CHANGE BY INTERVAL / 2.

INCLINOMETER CASING

STICK-UP

TOP OF PILE

LATERAL PILE LOAD TEST
FIXED INCLINOMETER DATA SHEET

PROJECT

BRIDGE DESIGNATION: _____

PILE LOCATION: _____

PILE NO.: _____

PILE LOAD TEST NO.: _____

LOAD INCREMENT: _____ TO _____

DATE: _____

PREPARED BY: _____

COMPUTED BY: _____

CHECKED BY: _____

READ TIME: _____

INTERVAL NUMBER	DEPTH (FEET)	INTERVAL LENGTH (FEET)	(UNLOADED) TILT (INS/FT)	(LOADED) TILT (INS/FT)	CHANGE (INS/FT)	INTERVAL DEFLECTION (INCHES)	TOTAL DEFLECTION

APPENDIX E

TELLTALE DETAILS

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WELD ALL AROUND OPENING ⑯

3/16"

SMOOTH SURFACE FOR DIAL GAGE ⑲

BEARING PLATE

EXISTING GROUND SURFACE

3'-0" ±

1'-6" ±

SEE DETAIL 'A'

VARIES

SEE DETAIL 'C'

BOOT PLATE

SEE DETAIL 'B'

1/4" STD. PIPE ⑰

1" TO 2 1/2" STEEL ELBOW OR EQUIVALENT. ⑮

1/4" STEEL ELBOW ⑭

1/4" STD. PIPE ⑫

1" CLOSE NIPPLE ⑬

1" STD. UNION ⑪

1" STD. PIPE ⑩

1/4" CAST IRON STD. COUPLING ⑨

1" STD. COUPLING AS REQ'D. ⑧

2" x 2" x 1/4" STEEL PLATE ⑱

1 1/4"

GENERAL ARRANGEMENT
NOT TO SCALE

DETAIL 'A'
NOT TO SCALE

3/8" STD. PIPE ⑩

1" STD. PIPE ④

1" STD. STEEL PIPE CAP WITH FLAT BOTTOM TACK WELDED TO BOOT ⑤

1/4"

3/16"

BOOT PLATE ATTACHED TO PILE ⑥

DETAIL 'B'
NOT TO SCALE

NOTES:

A.) THE NUMBERING SYSTEM ① , ② , ETC. INDICATES THE ORDER IN WHICH THE INSTRUMENT IS INSTALLED. IF ONLY ONE TELLTALE AT THE TIP IS USED, START WITH STEP NUMBER④.

B.) STEPS ① THROUGH ⑦ SHALL BE PERFORMED PRIOR TO DRIVING THE TEST PILE.

C.) PRIOR TO STEP NUMBER ⑨, THE GUIDE PIPE SHOULD BE FILLED WITH LIGHTWEIGHT OIL, APPROXIMATELY 3 PINTS PER 10 FEET OF GUIDE PIPE.

D.) WELDING SHALL BE DONE WITH PROPERLY DRIED 5/32" ⌀ E7018 ELECTRODES.

E.) CONCRETE FILLING NOT SHOWN.

3/8" STD. PIPE ⑩

1" STD PIPE ①

1/4"

5/16"

5/16"

5/16"

1" STD. PIPE CAP ②

SEAT CUT FROM STRUCTURAL MEMBER ③

FULL PENETRATION BUTT WELD (VERTICALLY WELDED PRIOR TO DRIVING) ⑦

BACKING RING

DETAIL 'C'
NOT TO SCALE

Telltale details for cast-in-place piles.

PLAN
NOT TO SCALE

A ← | A ←

TOP RESTRAINT-DETAIL "A"

7/8"
7/8"
1" φ HOLE DRILL OR CUT
3" X 3" X 1/4" PLATE ⑥

1/2 BLOCK WEDGE-DETAIL "B"

CHAMFER EDGE TO FIT AGAINST THE PILE.
CUT 2 1/2" X 2 1/2" X 5" STEEL BLOCK DIAGONALLY IN HALF ①

TELLTALE ROD DIAL SUPPORT ARM-DETAIL "C"

L = LENGTH SHALL BE SUFFICIENT TO EXTEND BEYOND THE FLANGE OF THE TEST PILE
1/4" THICK PLATE
SMOOTH SURFACE FOR DIAL GAGE
1" X L X 1/4" PLATE
3/8" STD. PIPE
1/4"

SEE DETAIL 'C'
SEE DETAIL 'A'

3" LENGTH OF 1 1/2" STD. PIPE OR 3"-1 1/2" NIPPLE PLACED 10' O.C. BEGINNING AT THE 1/2 BLOCK WEDGE AT THE TELLTALE LOCATION ③ (TELLTALE GUIDES)

3/8" STD. PIPE (TELLTALE ROD) ⑤

2 1/2" X 2 1/2" X 1/2" ANGLE (TELLTALE CHAMBER) ④

1/2 BLOCK WEDGE SEE DETAIL 'B' ②

24"
4"
5/16"
5/16" ⎯ 1 1/2-24
5/16"
5/16"
24"
3/8"
SEAL WELD
SEE NOTES ON CONTRACT PLANS
BOTTOM OF PILE

WELDING DETAILS AND MATERIALS ARE SYMMETRICAL ABOUT CENTERLINE.

SECTION A-A

WELDING SHALL BE DONE WITH PROPERLY DRIED, 5/32" φ E7018 ELECTRODES

✳ TO BE ADJUSTED TO FIELD CONDITIONS

NOTES: THE NUMBERING SYSTEM ① , ② ETC. INDICATES THE ORDER IN WHICH THE INSTRUMENT IS INSTALLED.

STEPS ① THROUGH ④ SHALL BE PERFORMED PRIOR TO DRIVING THE TEST PILE.

Telltale details for steel H-piles.

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CUT-OFF ELEVATION

SECTION 1-1
NOT TO SCALE

PLUGGED 3/4" GUIDE PIPE IN ROUTED GROOVE
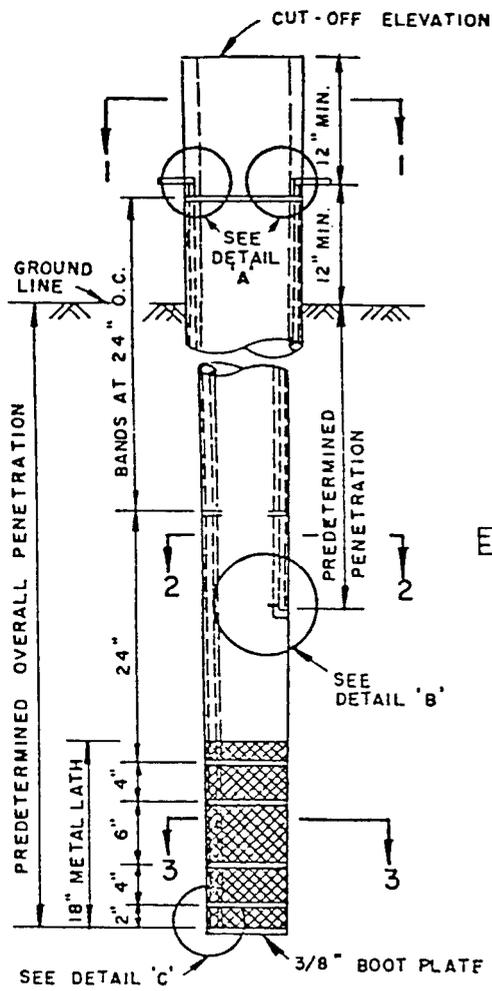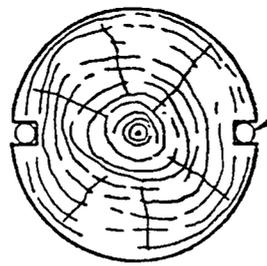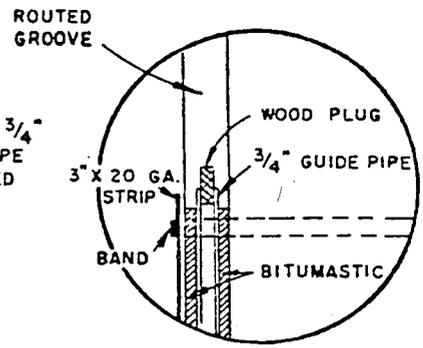
DETAIL 'A'
NOT TO SCALE
(SEE NOTE)

WOOD PLUG
3/4" GUIDE PIPE
3" X 20 GA. STRIP
BAND
BITUMASTIC
ROUTED GROOVE

1/2" MIN.

3/8" TELLTALE PIPE IN 3/4" GUIDE PIPE IN BITUMASTIC FILLED ROUTED GROOVE COVERED BY 3" X 20 GA. STRIP

1/4" PIPE

SECTION 2-2
NOT TO SCALE

20 D NAIL THRU BOOT PLATE
3" X 20 GA. STRIP
METAL LATH
120° 120° 120°
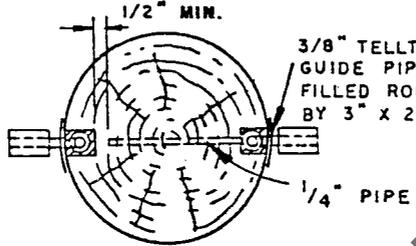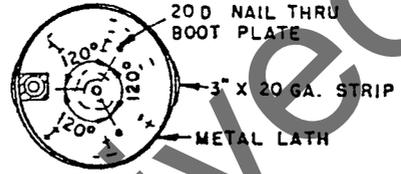
SECTION 3-3
NOT TO SCALE

DETAIL 'B'
NOT TO SCALE

ROUTED GROOVE
BITUMASTIC
3/4" GUIDE PIPE
1/4" PIPE - DRIVE FIT IN PREBORED HOLE
3" X 20 GA. STRIP
3/4" X 1/4" TEE
PLUG

GENERAL ARRANGEMENT
NOT TO SCALE
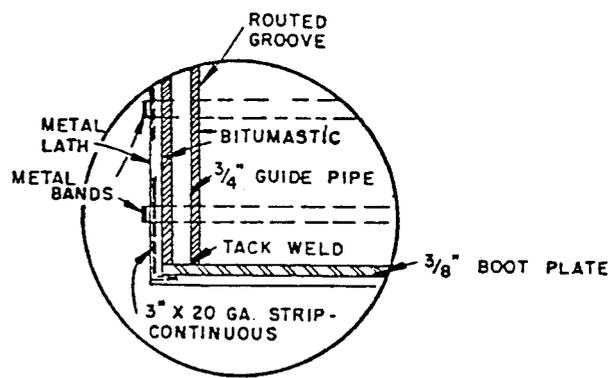
12" MIN.
12" MIN.
BANDS AT 24" O.C.
GROUND LINE
SEE DETAIL A
PREDETERMINED PENETRATION
PREDETERMINED OVERALL PENETRATION
24"
SEE DETAIL 'B'
18" METAL LATH
4"
4"
6"
2"
4"
2"
SEE DETAIL 'C'
3/8" BOOT PLATE

NOTE:
AFTER DRIVING TEST PILE, FILL 3/4" GUIDE PIPE WITH LIGHTWEIGHT OIL, APPROXIMATELY 1 PINT PER 10 FEET INSERT 3/8" TELLTALE PIPE AND ATTACH DIAL GAGE TO TELLTALE PIPE.

DETAIL 'C'
NOT TO SCALE

ROUTED GROOVE
METAL LATH
METAL BANDS
BITUMASTIC
3/4" GUIDE PIPE
TACK WELD
3/8" BOOT PLATE
3" X 20 GA. STRIP - CONTINUOUS

Telltale details for timber piles.

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APPENDIX F

DYNAMIC PILE LOAD TESTING

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DYNAMIC PILE LOAD TESTING

Dynamic pile load testing is the estimation of static axial compressive pile capacity from dynamic measurements of pile strain and acceleration. A method to accomplish this, called the Case Method, was developed at Case Institute of Technology in a research project funded by the Ohio Department of Transportation and the Federal Highway Administration (Ref. 1).

Dynamic pile load testing is generally used in conjunction with the computer programs WEAP (Wave Equation Analysis of Piles) and CAPWAP (Case Pile Wave Analysis Program). WEAP predicts, based on assumed soil resistance distribution and soil damping parameters, the driving resistance at which the required pile capacity will be attained, as well as the driving stresses in the pile and provides information that can be used to evaluate the adequacy of the proposed pile driving system. CAPWAP is used to analyze the data from a dynamic pile load test in order to determine (1) a better estimate of the static pile capacity and (2) the soil damping parameters and soil resistance distribution acting on the pile during the test (Ref. 1).

TEST PROCEDURE

Before the start of testing, two strain transducers and two accelerometers are securely attached to opposite sides of the pile near its top. These gages are connected to the pile analyzer (Figs. F-1 and F-2). A separate device, such as an oscilloscope may be used to display the data being analyzed and a portable tape recorder may be used to store the data. These functions are integrated into the pile analyzer in the case of newer equipment.

As the pile is struck by a pile hammer, the strains and accelerations detected by the corresponding gages on the pile are

LEADS

PILE HAMMER

CRANE

ARRANGEMENT FOR ATTACHING TRANSDUCERS
(See Figure F-2. for Schematic Diagram)

DATA RECORDING PROCESSING AND MEASURING EQUIPMENT (See Figure F-2.)
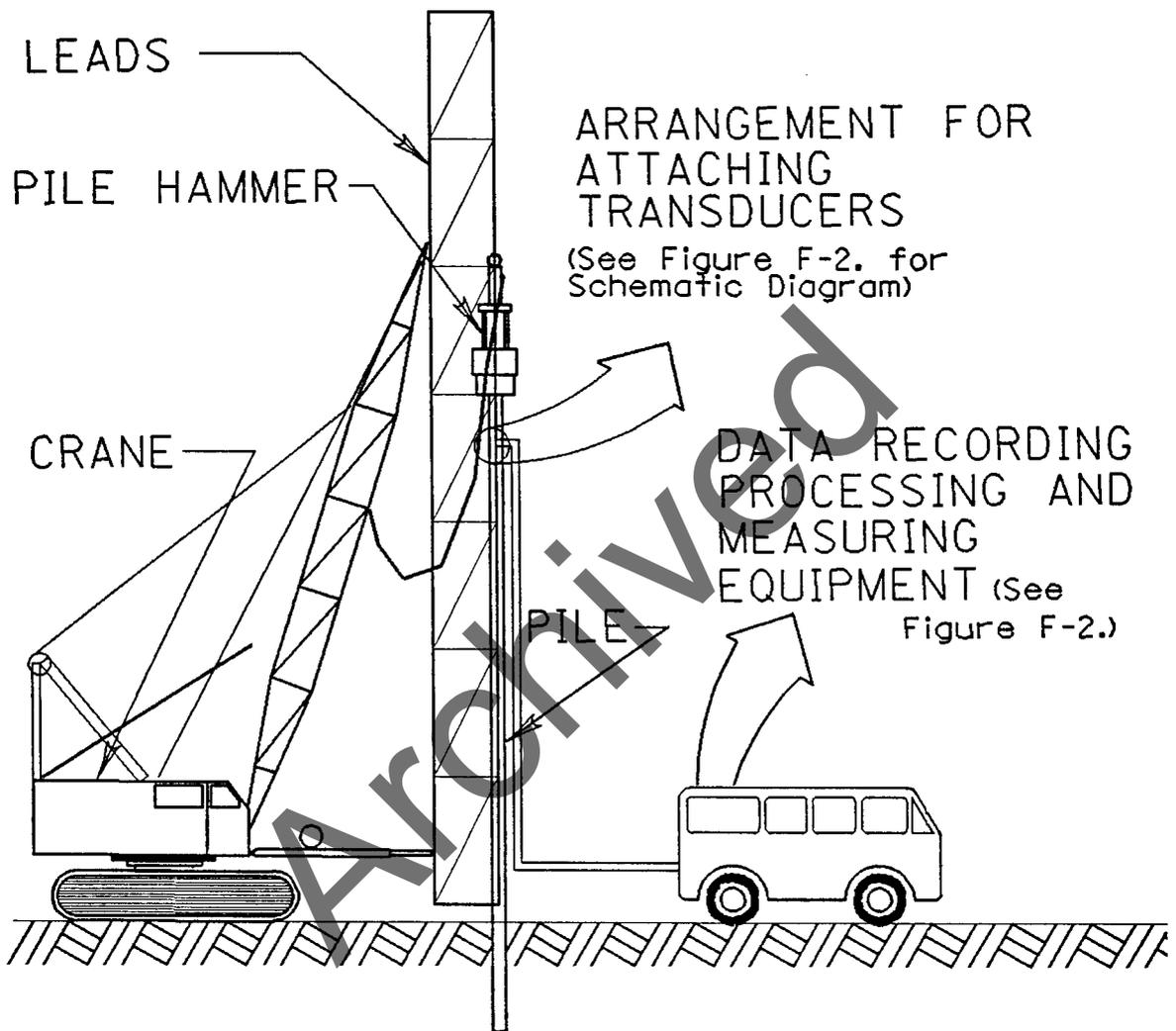
PILE

(After ASTM Designation: D4945-89)

FIG. F-1. Typical Arrangement for Dynamic Pile Load Testing

B= WIDTH OR DIAMETER

STRAIN TRANSDUCERS

ACCELEROMETERS

ACCELERATION SIGNALS (2)

PILE CONNECTION DEVICE

3xB Preferred

1-½xB (Min.)

STRAIN SIGNALS (2)
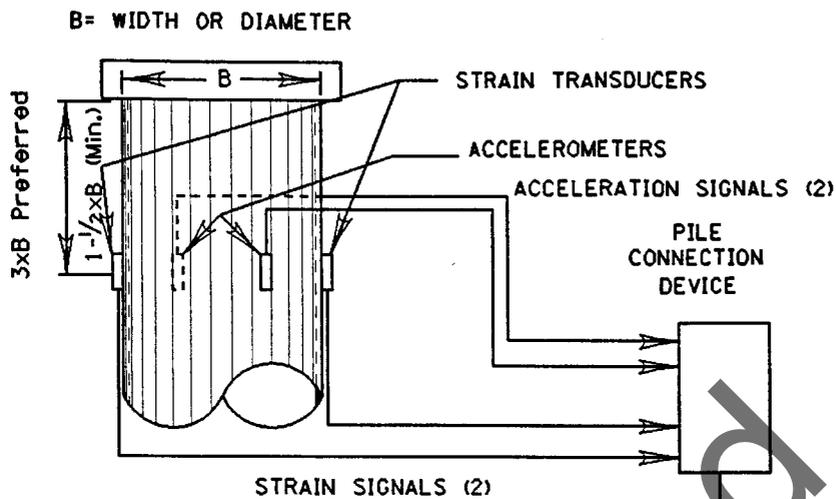
These units may be replaced by one or more computers.

APPARATUS FOR REDUCING AND PROCESSING DATA

RECORDING APPARATUS

DISPLAY APPARATUS
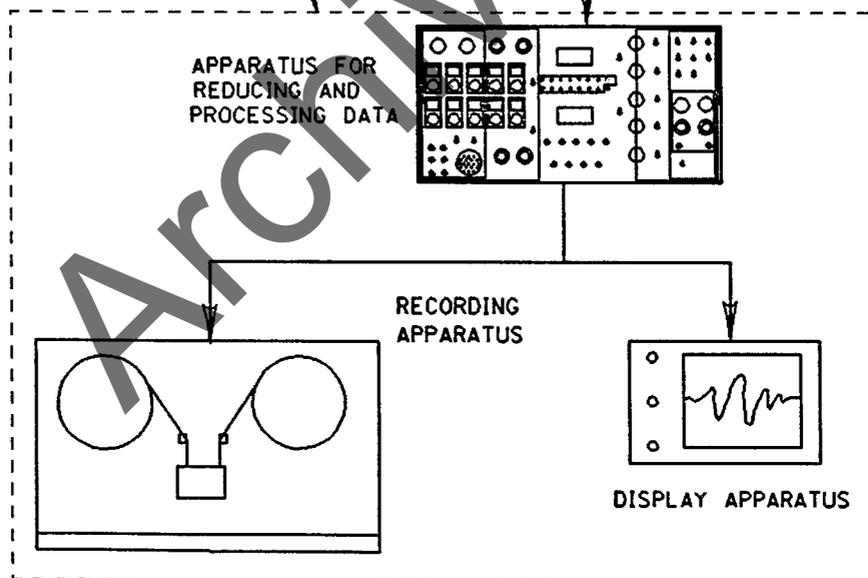
(After ASTM Designation: D4945-89)

FIG. F-2. Schematic Diagram of Equipment for Dynamic Pile Load Testing

converted by the pile analyzer into forces and velocities. The latter quantities are processed, using the Case Method, to obtain an estimate of the static pile capacity at the time of testing and other information useful for the control of pile installation and for pile design. The additional information obtained and displayed includes the force and velocity at the top of the pile throughout the duration of the hammer impact (Fig. F-3). An experienced operator can use this data to evaluate the functioning of the pile driving system and the condition of the pile.

ASTM has published a Standard Test Method for High-Strain Dynamic Testing of Piles, which contains a detailed description of the equipment requirements and the test procedure for dynamic pile load testing (Ref. 2).

APPLICATIONS

Dynamic pile load testing costs much less and requires less time than static pile load testing. It also provides important information regarding the behavior of the pile-soil system and the pile driving system that is not available from a static pile load test. Consequently, dynamic pile load testing has many applications:

° as a supplement to static pile load testing on major projects, thereby permitting a reduction in the number of static tests,

° on small scale projects where static pile load tests are difficult to justify economically,

° on projects, such as off-shore installations, where full scale static pile load tests are not feasible,

° to monitor driving stresses and pile integrity,

IMPACT EVENT

MOMENT OF IMPACT

FORCE

VELOCITY x EA/c

TIME (ms)

MAGNITUDE OF FORCE AND VELOCITY x EA/c
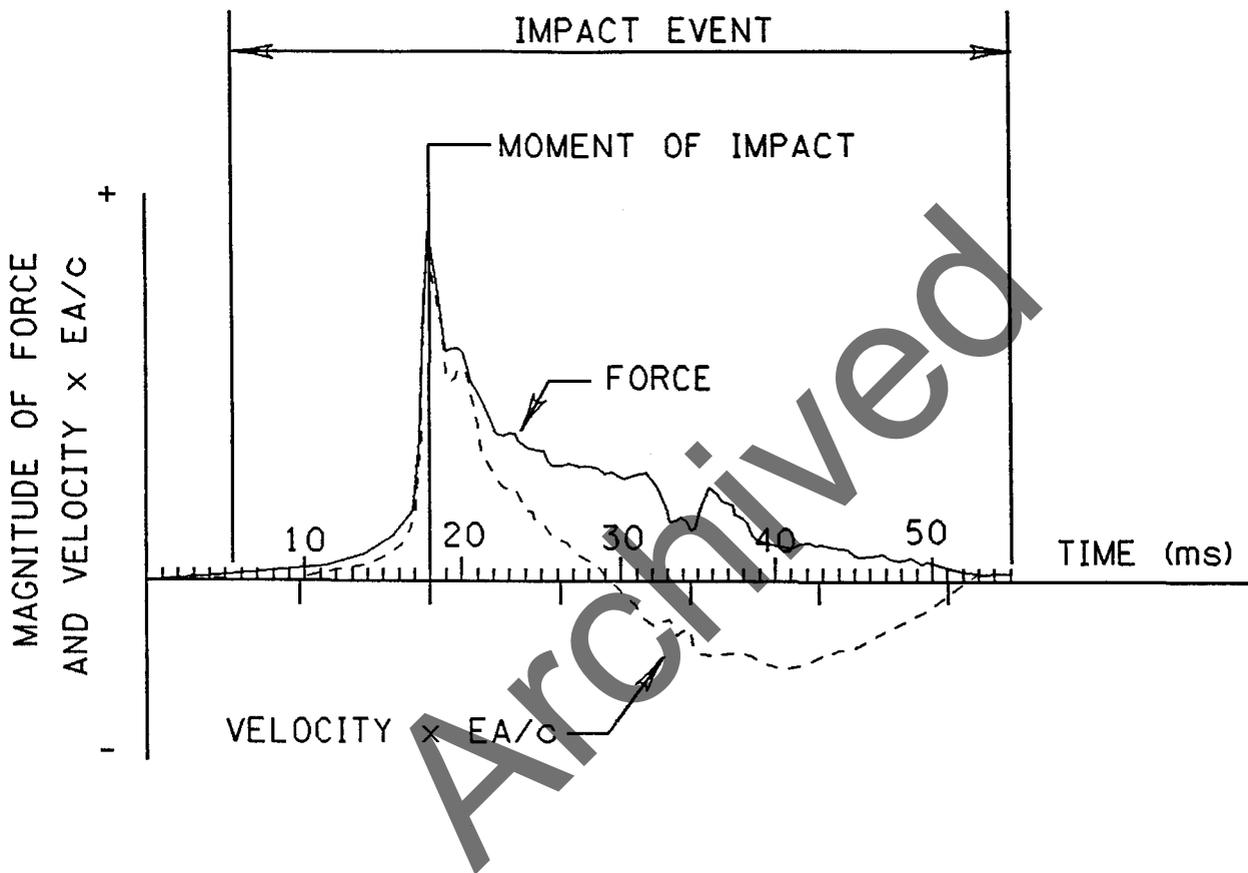
(After ASTM Designation: D4945-89)

FIG. F-3. Typical Force and Velocity Traces Generated by the Pile Analyzer

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° to evaluate hammer performance,

° to obtain, by means of CAPWAP, a more valid soil resistance distribution and more appropriate soil damping parameters for future WEAP analyses,

Piles installed by means other than driving can be tested dynamically if they will not be damaged by a hammer blow that has sufficient energy to mobilize the pile capacity.

INTERPRETATION OF RESULTS AND CORRELATION
WITH STATIC PILE LOAD TESTS

The results of dynamic pile load tests should be interpreted by an experienced tester who has had the opportunity to observe and evaluate the results from many dynamic load tests and can detect the signs, not always readily apparent, of unusual soil-pile response, pile damage, erratic hammer operation or testing equipment malfunction. In addition to experience, familiarity with the underlying principles of the method is a must.

Interpretation of the results of dynamic pile load tests also requires an awareness of the differences in behavior of a pile when it is struck by a pile hammer and when it is subject to static or nearly static loading in service or in a static load test. Unless these differences are recognized and accounted for, correlations of the results from dynamic pile load tests versus those from static pile load tests may exhibit large discrepancies. The most common sources of discrepancies and some methods of dealing with them are described below.

Incorrectly assumed soil damping parameters. This source of discrepancy can be minimized by performing a CAPWAP analysis on the results of a dynamic pile load test to determine more appropriate damping parameters.

Time-related changes in pile capacity. Depending on soil type and pile characteristics, the capacity of a pile may increase or, less commonly, decrease with time. The principal causes are time-related changes of pore water pressure in the soil. The effects can be assessed by restriking the pile at various time intervals after driving and comparing the capacity against that obtained during the initial drive. The pile capacity should be determined during the first few blows of the restrike. When comparing the results of dynamic testing against

those of a static pile load test, at least one dynamic test should be performed after completion of static testing.

Pile hammer does not move pile sufficiently to mobilize full toe-bearing. Frictional resistance between a pile and the surrounding soil is mobilized at a fraction of the pile movement necessary to mobilize full toe resistance. It is generally considered that at a penetration resistance of 10 blows/inch or higher, the pile does not move sufficiently to mobilize full toe resistance. This results in an underestimate of the toe capacity. For many types of piles, the estimate can be improved by performing a CAPWAP analysis both for the initial drive and for the restrike data. The toe capacity derived from the initial drive is combined with skin resistance from the restrike to obtain the total pile capacity. However, this method may not be applicable for open-ended pipe, H-piles, and precast cylinder piles. In the case of these piles, only the structural area of the pile is mobilizing the toe bearing during installation. This is a significantly lower value than what may be experienced in the static load test, since the soil will adhere to the pile with time and create a plug.

If dynamic pile load tests are performed and interpreted by experienced and knowledgeable testers, the correlation between pile capacities determined from static and dynamic pile load tests is good (see Fig. F-4). It should be kept in mind that significantly different pile capacities will often be determined from the results of a single static pile load test, depending on the method of interpretation used. The correlation would not be as good for open-ended and H-piles. However, dynamic load tests on these types of piles would, in general, underestimate the static pile capacity.

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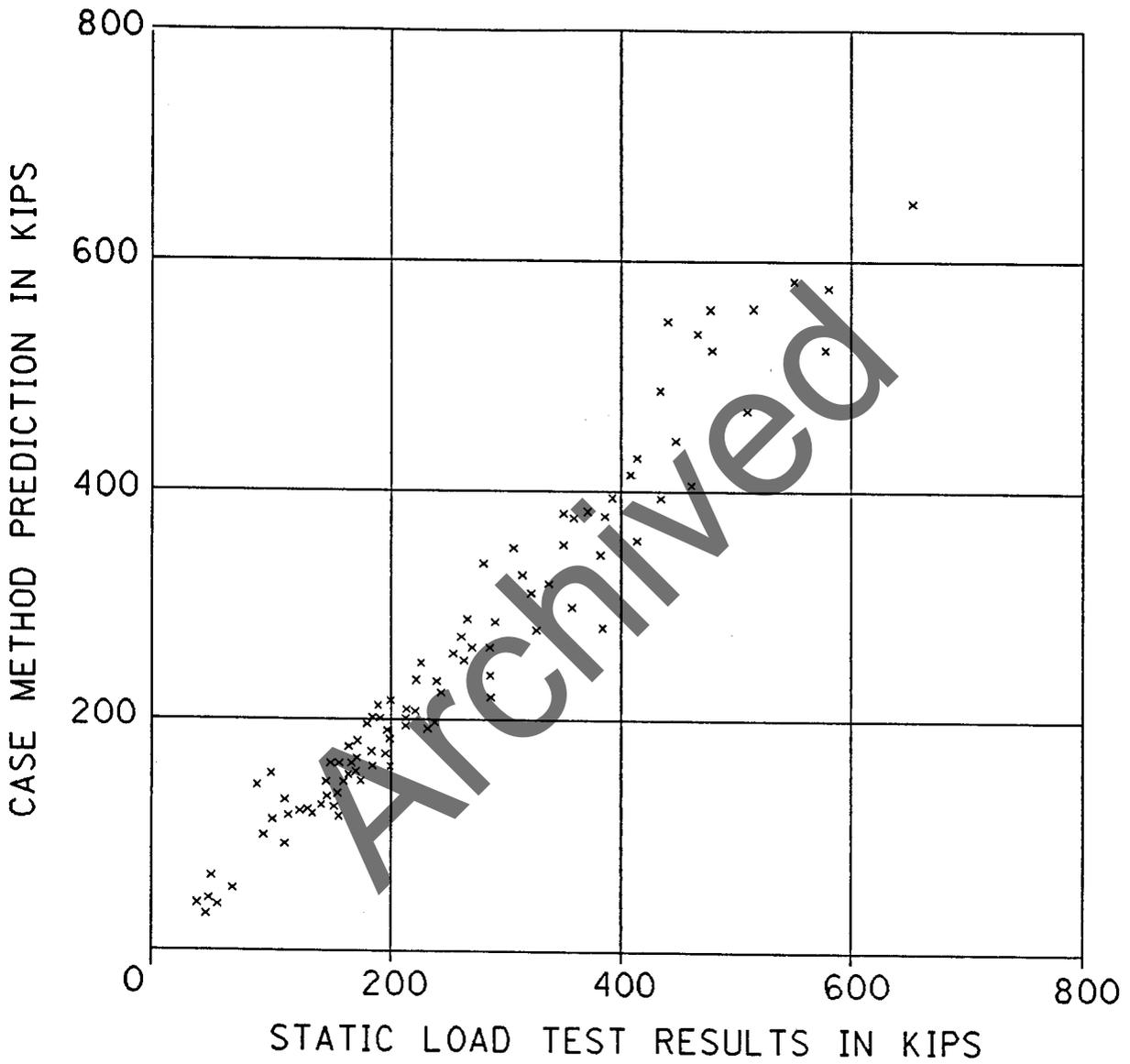
(From Rausche et al., 1985)

Fig. F-4. Case Method Pile Capacity
Compared with Static Load Test Results

RESPONSIBILITY

The responsibilities in dynamic pile load testing are distributed among three parties:

- The owner or his representative

- The contractor and his pile driving subcontractor

- The engineer performing the test, if other than the owner's representative

The owner or his representative contracts with the engineer supplying the dynamic pile load testing services. The owner or his representative also provides pile inspection and prepares a complete driving log.

The contractor supplies, in addition to the pile and the pile driver, access to the pile, a source of power and an appropriate enclosure for the testing equipment when necessary.

The testing engineer supplies the analyzer system and collects the data for the test. He is provided with a completed copy of the driving log and prepares a report of the testing, including any CAPWAP results and plots where applicable.

REFERENCES

1. Goble, G. G., "Modern Procedures for the Design of Driven Pile Foundations", DFI/NCSU/ASCE Seminar on Design and Construction Options for Heavy-Load Bearing Foundations, Raleigh, NC, 1988.

2. ASTM Designation: D4945-89, Standard Test Method for High-Strain Dynamic Testing of Piles.

3. Rausche, F., et al., "Dynamic Determination of Pile Capacity," J. Geotech. Engrg., ASCE, 111(3), March 1985, pp. 367-383.