INSPECTOR'S MANUAL
FOR
DRIVEN PILE FOUNDATIONS

DEEP FOUNDATIONS
INSTITUTE

INSPECTOR'S MANUAL FOR DRIVEN PILE FOUNDATIONS

prepared by the

DRIVEN PILE COMMITTEE

of the

DEEP FOUNDATIONS INSTITUTE

Second Edition 1997
(First Edition 1979)

DEEP FOUNDATIONS INSTITUTE
120 Charlotte Place, Third Floor
Englewood Cliffs, NJ 07632
Phone: (201) 567-4232 ✦ Fax: (201) 567-4436

Printed in Canada

PREFACE

This ***Inspector's Manual for Driven Pile Foundations*** provides basic information for the Pile Inspector about site investigation, pile types, wave equation analysis, test piles, dynamic and static load tests, pile driving hammers, and other required equipment for the installation of bearing piles. The Inspector should realize this is a basic overview and not an exhaustive treatment. Other reference material will be of benefit and the Inspector is encouraged to seek out this extra material contained in the suggested reference list.

This manual is made available through the Deep Foundations Institute to familiarize or refresh the Inspector with the fundamentals of driven pile foundations. It is intended to reflect widely accepted industry practices, but in no way supersedes or take the place of existing laws, codes, specifications, or practices that may apply to the agency or party responsible for the pile project and whose guidance is generally final.

Driven Pile Committee, January 1997

All DFI publications including this ***Inspector's Manual for Driven Pile Foundations*** are available from:

The Deep Foundations Institute
120 Charlotte Place, Third Floor
Englewood Cliffs, NJ 07632

Phone: (201) 567-4232 ✧ Fax: (201) 567-4436
Email: dfihq@soho.ios.com
Website: http://www.dfi.org

ACKNOWLEDGEMENTS

Some revision of the Inspection and Testing Committee's 1979 edition was performed in 1991 with no final product resulting; it was extensively revised in 1996 by the Committee on Driven Piles. All contributors are commended for their volunteer efforts.

1996 CONTRIBUTORS to *INSPECTOR'S MANUAL for DRIVEN PILE FOUNDATIONS*

Jim Graham, (Chairman), *Heller and Johnsen*
Garland Likins, (Editor), *Pile Dynamics*
Steve Borg, *New York Department of Transportation*
Tom Candler (1991) & David Coleman, *Millgard Corp.*
Derek Collins, *Franki Northwest Company*
Carroll Crowther (1991), *Carroll L. Crowther, Inc.*
Jerry DiMaggio, *Federal Highway Administration*
Peter Edinger & Joel Moskowitz, *Mueser Rutledge Consulting Engineers*
Mike Engestrom, *Nucor-Yamato Steel*
Bengt Fellenius, *Urkkada Technology*
Manny Fine & Geordie Compton, *Deep Foundations Institute*
Robert Gauer & Jeff Ness, *Fugro McClelland (Southwest)*
Jeff Goodwin, *Loadtest*
Richard Hoener, *L.G.Barcus & Sons*
Peter Middendorp, *TNO Building and Construction Research*
Sharon Naramore, *Caltrans*
Robert Pierry, *Roger Bullivant of Texas*
Frank Rausche & Mohamad Hussein, *Goble Rausche Likins and Assoiates.*
Earl Seck, *Contech Construction Products*
Richard Short (1991), *Peter Kaldveer and Associates*
Emad Shublaq, *PMRT Management Consulting*
Kathy Ulrich, *Maryland State Highway Administration*
John White, *American Piledriving Equipment*
Byrl Williams, *American Piledriving*
Donald York (1991), *Port Authority of NY & NJ*

OTHER 1996 DFI DRIVEN PILE COMMITTEE MEMBERS:
William Bermingham, Dale Cunningham, John Dougherty, Alan Fisher, Donald Johnson, Ed Keary, David Kozera, William Kruse, William Loftus, William Lytle, Michael McDowell, Al Neumann, Stan Merjan, Jarrod Sigsby, Scott Whitaker, Henry Whitty, Max Williams, Earnst Winter, Keith Yeary, Kiho Yoon

1979 DFI INSPECTION & TESTING COMMITTEE MEMBERS:
William Loftus *(Chairman)*, Roger Brown, Bruce Cooper, Lynn Doyle, John Dunham, Bengt Fellenius, David Friels, Gary Johnson, Earl Seck.

OTHER 1979 CONTRIBUTORS:
Robert Compton, Harry Davis, Joseph DeSalvo, John Dougherty, Charles Guild, George Goble, Richard Goettle, Samuel Hung, Hal Hunt, Gay Jones, Paul Kozicki, Norman Liver, Richard Moulton, Bernard Rainey, Henry Salver

TABLE OF CONTENTS

Conversion Factors - SI Metric Units

The principal feature of the Standard International System which causes difficulty is the use of newtons (N) as the unit of force, taking the place of the kilogram-force (kgf); the term kilogram being considered as a unit of mass. Note that it takes 9.806650 newtons to equal 1 kgf (the gravitational constant).

The following table presents conversion factors to four significant figures:

From:	To:	Multiply by:	Reciprocal
	LENGTH CONVERSIONS		
feet (ft.)	meter (m)	0.3048	3.281
inches (in.)	millimeters (mm)	25.40	3.937×10^{-2}
miles	kilometers (km)	1.609	0.6214
	AREA CONVERSIONS		
foot^2 (sq.ft.)	meter^2 (m^2)	9.291×10^{-2}	10.76
inch^2 (sq.in.)	meter^2 (m^2)	6.452×10^{-4}	1.550×10^{3}
acre	hectare (ha)	0.4050	2.469
square mile (sq.mi)	kilometer^2 (km^2)	0.3861	2.590
	VOLUME CONVERSIONS		
cubic foot (cu.ft.)	meter^3 (m^3)	2.832×10^{-2}	35.31
cubic yard (cu.yd.)	meter^3 (m^3)	0.7646	1.308
inch^3 (in.^{3})	meter^3 (m^3)	1.639×10^{-5}	6.102×10^{4}
inch^3 (in.^{3})	millimeter^3 (mm^3)	1.639×10^{4}	6.102×10^{-5}
gallon (U.S. liquid)	meter^3 (m^3)	3.785×10^{-3}	264.2
gallon (U.S. liquid)	liter (l)	3.785	0.2642
gallon (Imp. liquid)	liter (l)	4.546	0.2200
	MASS CONVERSIONS		
pound (lb.)	kilogram (kg)	2.205	0.4536
ton	tonne (t)	0.9072	1.102
	FORCE (OR WEIGHT) CONVERSIONS		
pound-force (lb.)	newton (N)	4.448	0.2248
kip	kilonewton (kN)	4.448	0.2248
ton	kilonewton (kN)	8.896	0.1124
	PRESSURE OR STRESS (FORCE/AREA) CONVERSIONS		
atmosphere (normal)	pascal (Pa) or newton/meter^2	1.013×10^{5}	9.871×10^{-6}
foot of water	pascal (Pa)	2.988×10^{3}	3.346×10^{-4}
pound-force/foot^2 (psf)	pascal (Pa)	47.88	2.090×10^{-2}
pound-force/inch^2 (psi)	pascal (Pa)	6.895×10^{3}	1.450×10^{-4}
pound-force/inch^2 (psi)	kilopascal (kPa)	6.895	0.1450
pound-force/inch^2 (psi)	megapascal (MPa)	6.895×10^{-3}	145.0
pound-force/inch^2 (psi)	bar (Pa x 10^5)	6.895×10^{-2}	14.50
kip/ft^2 (ksf)	pascal (Pa)	4.788×10^{4}	2.089×10^{-5}
ton/ft^2 (ksf)	pascal (Pa)	9.576×10^{4}	1.044×10^{-4}
	ENERGY CONVERSION		
foot-pound (ft.lb.)	joule (J)	1.356	0.7375
	MOMENT OR TORQUE CONVERSION		
foot-pound (ft.lb.)	newtonmetre (N.m)	1.356	0.7375

INTRODUCTION

This manual provides basic practical instruction on the inspection of driven piles. It covers the essential components of pile driving, such as the pile driving hammer, hammer accessories, the pile and soil, and frequently encountered test methods in an uncomplicated, yet knowledgeable, and practical manner. Insight is given into the methods of installing the foundation, dealing with the cranes which do the lifting, the hammers which do the driving, the leads that guide the hammer and pile, the compressors which provide the external power when required, and finally prevalent analysis tools and testing instrumentation and procedures which enable you, the Inspector, to do your job.

This DFI ***Inspector's Manual for Pile Foundations*** will help the Pile Inspector who has limited knowledge of pile foundations. Perhaps this Inspector has been pressed into service at a moments notice; a few helpful hints and suggestions to him are desperately needed and he can look here for the basics. It is also useful for the experienced Pile Inspector as a reference guide. However, this manual is not a detailed check list of every possible scenario and detail which could ever be encountered. There are other sources available which give more detailed descriptions (and should be consulted by the Inspector when appropriate; a list of this additional reference material is provided and suggestions made in appropriate chapters of this text). The current manual is more a brief "textbook overview" with some of the more important aspects given at least some emphasis so that the Inspector has some direction and hopefully helps to produce a safe, yet economical, foundation.

Piles are required when the surface soil strength is not sufficient to support a structure to be built upon it. Piles then transfer these loads to soil layers below the surface which are capable of supporting the loads. If the piles are not installed correctly, then they will not support the structure and costly corrective actions will be required, and in some cases complete failure could occur requiring demolition of the structure. Proper installation of driven piles is therefore critical to the success of the foundation and the structure to be placed upon it.

Pile driving inspection is often considered insignificant or underrated. Nothing could be farther from the truth since good inspection is absolutely critical to a good foundation. The Pile Inspector is the key element in the installation process and this role should never be minimized. The qualifications and experience of Inspectors varies greatly. The project specifications may dictate the experience level required for the Inspector. The industry sometimes simply demands that a "blow-counter" be hired to follow the rules provided by the Design Engineer or the local building code; the Inspector may be a high school graduate, or a person with a two year technical degree, or someone with a full engineering degree. Obviously, he must as a minimum have good concentration to count the blows and make other observations and record all information for every unit penetration on a data form. The Inspector should also be observant to note deviations which might be important. In many cases, a licensed Engineer may be performing the Inspector role; this Engineer will be better qualified but also has more professional liability and thus should take this role very seriously and seek additional information above and beyond that which is presented here.

Usually the Inspector is retained directly by the Owner or the Owner's engineering representative (referred herein as the Engineer or Design Engineer). In some cases the Contractor will provide personnel for inspection. The Owner, the Engineer, and the Contractor are all part of the project team. This team ideally will work together to install a quality foundation at a fair cost so as to best serve the public good. All team members may or may not have their representatives on site together, but a spirit of cooperation with all working to achieve a good foundation is preferred to a spirit of adversity.

Regardless of employer, you, the Inspector, have legal and ethical responsibilities to be completely honest in the performance of your duties; violations could cause the unscrupulous Inspector very serious trouble with his employer and the Law. Generally, the Engineer-of-Record is responsible for the final acceptance of the piles. Thus either directly or indirectly he must receive information from the Inspector on which decisions are based. The Engineer-of-Record should be on site for the first few piles driven and should instruct the Inspector on any specific items which are important to evaluate. The Engineer may visit the site from time to time, but the day by day assignment of inspection is the Inspector's job. During production pile installation, the Inspector needs sufficient two-way communication with the Engineer to report all field observations and receive new guidance from the Engineer in case conditions change. Although the Inspector generally does not have any interpretation responsibility or final authority in the acceptance of the foundation, the Inspector is a vital link as the "eyes and ears" for others because the information collected will be evaluated by those in approval authority.

The Inspector must be able to identify situations which could be a deviation from what is anticipated and thus a potential problem. For the answer to any deviation or problem, the Inspector must relay all observations eventually to the Engineer to obtain a solution. The communication must be prompt since delays generally result in expensive lost time, potential compounding of the problem, and extra expense to correct the problem. As the Pile Driving Inspector, the better and sooner that a description of real "on-the-site" observations of the situation is given, the better or more realistic a solution the Engineer will be able to provide.

Assuming the pile type selection, estimated length, designated load carrying capacity, and the pile arrangement have been determined by the Design Engineer, the job of assuring conformance in the installation becomes a group effort. Other participants in the group consist of the Surveyor, the Pile Supplier, the Pile Contractor, the pile driving work crew, and you . . . the Pile Inspector. It is helpful to have knowledge of pile driving procedures and prior experience in pile driving, but the Inspector should not hesitate to ask questions about any aspect of the installation and seek assistance from others; advice from some sources is potentially dangerous and if used should be discussed with the Design Engineer.

The first step for the Inspector on any project is to obtain and become familiar with the specifications, contract plans and drawings, soil borings, and site conditions. The Design Engineer is asking the foundation to transfer the super-structure weight through unacceptably weak upper soil layers by way of the piles to a lower more competent bearing layer; therefore, the Inspector's understanding of the Engineer's needs as communicated directly by him or through the contract documents is of prime importance and the Inspector's observational help will be needed to confirm that piles are driven undamaged to the bearing layer.

The next step of pile installation belongs to the crew. Piles are generally delivered to the site and unloaded by the crew. They should be stored and handled properly to avoid damage. Dents in steel piles should be avoided, and may be reason to reject that pile from being driven. Concrete piles generally must be supported or lifted at specific locations along their length; often the plans may specify procedures or the pile supplier may provide specific instructions to the Contractor. Blocking material (often timber) required to support the pile must be placed at the appropriate locations and intervals and keep the pile straight during storage. The lifting points and number of pick up points can be crucial to avoiding damage during handling.

It should also be noted that plans may include special coatings such as bitumen to be applied along the upper pile shaft, or special fittings called "shoes" or "pile points" to be attached to the pile toe. Piles may be equipped for mechanical splices, or require welding, or some other splice mechanism which have special requirements. The Inspector usually has responsibility for inspection and reporting of these specialty items. If in doubt on any item, contact the Engineer for clarification.

Prior to lifting and driving, the crew should mark each pile at uniform intervals (e.g. every 250 mm or every foot) along its length. As the pile is driven it is the Inspector's prime responsibility to record the number of blows required for each penetration interval. The Inspector should confirm that the crew drives the piles with good workmanship and in accordance with the plans and specifications of the termination criteria established by the Engineer.

Piles will be numbered according to the general site plan. The next step toward proper installation belongs to the Surveyor. He is responsible for staking out the pile locations according to the plan. Generally, the Surveyor will take the site plan and review the layout to make sure no errors are made. Often, however, the Surveyor is forced to work under pressure and perhaps may not have time for checking when the pile driving rig is waiting. The Inspector should have a site plan drawing at all times which shows pile layout and numbers. The Inspector should walk the job, check by eye and tape rule the location of the pile markers, and advise if anything appears to be wrong. At this stage, often a costly error can be eliminated because of an alert Pile Inspector.

The Contractor is responsible for the location of piles driven and should drive the piles as close to this Surveyor's stake as is practically possible. The Engineer may have indicated an allowable "tolerance" for deviation from the exact location; the Inspector should note piles which are driven outside the specified tolerance. The orientation of some piles (e.g. square sections, H-piles, etc) is also important and the plans must be followed by the Contractor to obtain the desired alignment. The Inspector is responsible to note deviations in location or orientation from the project plans.

While most piles are driven vertically, some piles are driven on an incline. The direction of inclination is shown on the plans and is important. Deviations from the prescribed direction and angle of inclination should also be noted in the Inspector's report to the Engineer.

The piles are then driven in a sequence usually starting at the center of the foundation and working outward whenever possible, or from one side of the site and working progressively across the site. This minimizes densification effects on the driveability of the adjacent piles, and may reduce the possibility of pipe pile collapse due to soil pressures.

The Pile Contractor should not be interested in seeking production at the expense of quality as he knows the cost of replacing or repairing defective workmanship is far more expensive than installing the piles properly the first time. The crew should have the same objective. However, they may be motivated to seek production rather than accuracy. The Inspector's job is to establish a productive working relationship with the Pile Contractor and crew so as to not to impede daily production but to firmly insist on conformance and a successful completion of the project. A blend of cooperation and conformance at the start of the job will eventually keep the harmony and, more often than not, produce maximum satisfactory production. No one wants to be involved in a foundation that fails as it can result in severe financial risk to everyone involved.

The plans have a specific elevation (relative to sea level or some other local reference) for the pile cap (usually a formed concrete block which transfers the structure load into a group of piles). The piles are designed to extend a certain distance into the cap, and thus each pile must be "cut off" at a certain elevation also. After each pile is driven, the surveyor should mark the elevation on each pile where it should be cut off. After any pile is driven and meets the termination criteria, the foreman may cut the pile at or just above cut-off elevation. It is the Contractor's responsibility to cut the pile at the proper elevation.

In some cases the elevation of a previously driven pile can be affected by the driving of another adjacent pile. This is generally not desirable. If the previous pile subsides, it could be that it is being pulled down as the adjacent pile intersects it and damage could be present on either or both piles. If the previous pile rises or "heaves" relative to its initial final elevation, it may lose toe capacity and need to be reseated. Pile heave is most likely for displacement piles which are driven in close proximity to each other. Project specifications may require that elevations of piles be checked at end of drive and also at the end of drive of adjacent piles to investigate for pile heave. It is good practice to know if heave is occurring and reseat piles if necessary.

While observing the driving, try to stand upwind of the rig -- obviously to avoid the exhaust spray of the hammer from ruining a good shirt. Also, never stand directly in front of the rig while driving a pile. If the pile breaks, no one should be directly in line. Hard hats are a must as things occasionally fall from the upper levels of the crane; e.g., a wrench from a crew members pocket, a spalled piece of a concrete pile head, part of a shackle from the pile line, a piece of ice (caused by freezing of the water vapor in the compressed air powering the hammer), a piece of hose, or even a part of the hammer or leads. Ear, eye, and toe protection should be used at all times; life vests are required for over-water applications. Stand as far away from the pile driving hammer as is practically possible to reduce danger from loud sounds. Stay as far away as possible during lifting of the piles and positioning the leads; the weights involved are substantial and if something fails or breaks that weight could cause serious injury or even kill people. Never stand near the pile for any reason at any time during driving since a falling object could cause serious injury. Don't stand behind the crane and take special care when the crane is moving or swinging. These are but a few of the precautions that will be required on site and that may help prevent serious injury to anyone. **Safety for yourself and others should always be anyone's first concern.**

A final item not directly related to the pile driving but which can affect the pile performance is the post excavation of the pile. If the pile is driven from existing ground elevation and later an excavation is made around the pile, the excavator machine may inadvertently pull the pile or displace it laterally and thus cause pile damage. It also happens that excavations sometimes experience slope failures; these lateral earth pressures can cause substantial lateral movement of the piles and possible damage. The Inspector should record and report any and all instances such as these which can adversely affect the pile strength.

This manual will help the Inspector be better equipped to lend an intelligent, practical, logical hand to the art and science of pile driving and may help the crew get that extra pile driven by the end of the day. While this manual should aid the Pile Inspector, the Deep Foundations Institute does not guarantee or intend to imply that the pile foundation will meet the design criteria. The Engineer must review the soil information, the field observations, and his own analysis and is ultimately responsible for the foundation design.

SITE INVESTIGATION

This chapter will help the Inspector to understand the importance of having a knowledge of the soil boring information. It is not intended that the Pile Inspector be capable of running a soil boring rig; but it is important that to be able to read and interpret important information on a soil boring log as it pertains to pile installation. It would be beneficial for the Inspector to have a working knowledge of the Unified Soil Classification System (ASTM D2487); the Engineer could provide this basic information chart, or the Inspector may refer to the ASTM D 2488 "Standard Practice for Description and Identification of Soils".

Subsequent to site selection and prior to facility design, some means of site investigation is undertaken which will aid the Owner in determining the cost of this project and the designer in making a foundation selection both from an economic and installation point of view. Investigations of the subsurface strata are required to estimate the pile length and size. Other than the obvious review of land conditions and contour considerations, the underground situation of a site is revealed by test pits for shallow foundations or deeper soil boring investigations which are more common for pile driving installations. Whatever the choice, either or both should be observed by someone who can make instant adjustments in the procedures, depending on the information encountered. However, the Inspector should have some familiarity with these methods. An understanding of the data obtained by the investigation is essential to a Pile Driving Inspector.

Test pits indicate the thicknesses of the upper layers, the elevation of ground water and existence of rock when it is within 4 meters (13 ft) of the surface. They also confirm the near surface soil situation, both as to type and consistency. In addition, the ground surface can be evaluated for its ability to support the future construction and pile driving equipment required for the project. Obstructions near the surface can be removed. One drawback of the test pit method is its depth limitation. Another concern of test pits relates to potential dangers due to possible collapse of any unbraced excavation; the Inspector should be cautious of any test pit or excavation with depth greater than one meter (3 ft).

Test borings are more common at sites requiring pile foundations since pile bearing strata are generally at depths greater than the practical limits of test pits. Essentially, a boring is a small diameter hole drilled into the ground through use of hollow stem augers, or with cuttings flushed out with wash water. Soil samples are recovered at intervals of 1.5 m (5 ft) or less by driving a spilt-barrel sampler of standard dimensions at the bottom of a string of standard drill +rod (such as AW or NW rod) with a 64 kg (140 lb) drop hammer falling 762 mm (30 in). The hammer mass is usually raised either by a rope-cathead system or by an automatic trip mechanism. The number of blows of the hammer required to drive the sampler 300 mm (one foot), the "N-value", is the Standard Penetration Test (SPT). The N-values are a measure of the soil strength and give an indication of the density of cohesionless soils (sands) and the consistency of cohesive soils (silts and clays). Even though the SPT yields a disturbed sample, which means the soil has experienced large structural disturbances during the sampling process, the soil sample can still be used for visual identification and laboratory classification. Bedrock encountered in a boring is generally sampled with a core drill. Special soil sampling devices may be used to recover soils not easily sampled with a split-barrel sampler or to recover undisturbed samples for laboratory testing.

The purpose here is to emphasize the need for a thorough subsurface investigation, properly inspected, so that all of the necessary data is available for design and construction. It is important to note, however, that the quality of the crew and equipment can affect the integrity of the data. For optimum results, only reliable, qualified drillers and adequately maintained equipment should be used. The following data should be recorded while inspecting a SPT boring operation:

1. Site location, hole number, and both ground and water elevation (note if water table is stable or is artesian).

2. Type of rig, size and length of sample rods (e.g. AW or NW), hammer mass and drop height (stroke), description of mechanism for raising and dropping the hammer mass (e.g. cathead-and-rope or automatic trip), and length and size of auger flights.

3. N-value blows, length of recovery in the soil sampler, casing blows, size and length of undisturbed sampling tubes and rock core barrels.

4. Visual classification of all samples including rock quality -- e.g. sand, silt, or clay, loose or dense, soft, hard, or fractured, existence of gravel, cobbles, boulders or other "obstructions".

5. Method of cleaning casing, depth to which casing was cleaned and if there is a loss of water while cleaning out the casing.

Note that a boring location plan compatible with the pile location plan is necessary for interpretation and application of boring data to the pile driving process. Items on a boring log of particular interest to a Pile Driving Inspector are:

- Elevation of grade during testing relative to excavation grade during pile driving.

- Depth, thickness, character and consistency of soil strata penetrated.

- Standard Penetration Test results, the N-value for each sample.

- Depth to the ground water table.

In general, boring log descriptions will differentiate coarse grained soils such as sands and gravels from fine grained soils such as silts and clays. Visually, gravels are particles between 5 mm (1/4 in) and 80 mm (3 in) in size. The division between medium and fine sand is about 0.4 mm (1/64 in). The division between sands and silts is defined by the No. 200 sieve (0.074 mm), which is about the size of the smallest soil particle that can be identified as an individual grain with the naked eye. Soils with smaller particles are termed fine grained soils. Rocks between 80 mm (3 in) and 300 mm (1 ft) are called cobbles, larger stones are called boulders. The consistency of coarse grained soils referenced to N-values (in blows per 300 mm; blows per foot) is generally given as:

Consistency	N-Value
Very Loose	<4
Loose	4 to 10
Medium Dense	10 to 30
Dense	30 to 50
Very Dense	>50

Fine grained soils are characterized as having "low" or "high" plasticity. Plasticity is defined by Atterberg limit tests in the laboratory; but, roughly, soil of low plasticity has the somewhat spongy feel of a flour and water mixture; soil of high plasticity feel like plasticine modeling clay. Organic silts and clays contain fine vegetation particles and are generally characterized by dark grey to black color and a "marshy" odor. Soils containing matted vegetation are referred to as peat. The consistency of fine grained soils referenced to N-value (in blows per 300 mm; blows per foot) is generally given as:

Consistency	N-Value
Very Soft	<2
Soft	2 to 4
Medium stiff	4 to 8
Stiff	8 to 15
Very stiff	15 to 30
Hard	>30

The soil stratum that has been selected as the pile bearing stratum should be identified in the specifications. The depth to that stratum at boring locations will be indicated by the boring logs. The Pile Driving Inspector may need to interpolate an estimated depth to the bearing stratum between boring locations to confirm that a pile has reached the bearing stratum. The Standard Penetration Test mimics pile driving; hence, piles will generally drive harder in strata with high N-value. For equal N-values, piles will generally drive harder in sand than in clays. In general, the driving resistance of piles driven into a stratum with a relatively uniform N-value will tend to increase with depth of penetration. As successive piles are driven, the Inspector should compare the pile installation logs and boring logs to evaluate and record the relationship between pile driving resistance and the character and density of the soils penetrated. This information may be of great assistance to the Project Engineer if he must be called on to evaluate and solve problems such as an insufficient pile capacity, damaged piles, or premature refusal.

Other useful information prepared during the subsurface investigation that may be available to a Pile Driving Inspector includes contour plans of the elevation or depth to the bearing stratum, or geologic sections that show soil stratification interpolated between borings. The subsurface investigation may also include a Cone Penetration Test (CPT). In this test, an instrumented cone-shaped point of specified dimensions (the "cone") is pushed into the ground at a constant rate using a hydraulic jacking system acting against the reaction weight of the vehicle. During the test the resistance to penetration of both the cone tip and a separate shaft sleeve is measured and provides a continuous record of the subsurface, an advantage of the CPT over the normal Standard Penetration Test. This resistance to penetration is also a relative measure of subsoil consistency and is empirically correlated to engineering parameters (shear strength, friction angle, correlated N-values, etc); the ratio of cone resistance to sleeve friction has been empirically correlated to soil type. Profiles of tip and shaft resistances and the friction ratio can be quite revealing. CPT testing can be performed relatively rapidly. A disadvantage of the CPT is that no soil sample is recovered; hence, CPT's are most useful when used to supplement soil borings and other site specific data.

When the toe of a pile reaches the bearing stratum, the final pile depth is usually defined in one of two ways:

- A specified pile penetration resistance (sometimes modified by a specified minimum depth of penetration into the bearing soil).

- A specified depth of penetration or toe elevation within the bearing stratum (most often used for piles in clay, where pile penetration resistance may be less indicative of pile capacity than in sands).

If a site is known or expected to contain hazardous waste or hazardous chemicals which can be potentially harmful, the requirements of the Occupational Safety and Health Administration (OSHA) Hazardous Communication Standard for the Construction Industry (29 CFR 1926.59) should already be implemented. This standard includes the designation of a Safety Coordinator responsible for following correct procedures for everyone's safety. OSHA Hazardous Waste Operations and Emergency Response (29 CFR 1910.120) provide additional important information. These regulations include: site evaluation and control, site-specific safety and health program, information and training program, personal protective equipment program, site monitoring program, medical surveillance program, decontamination procedures, emergency response program, engineering controls and work practices, and proper record-keeping procedures.

When hazardous wastes are involved, everyone's best efforts to fully comply with all safety training and special clothing or special procedures will be in their own best interest. Discovery of unknown potentially hazardous substances requires the Contractor and Inspector to report the condition in writing to the Owner as soon as possible. Work should be suspended immediately until a site assessment is made and perhaps special conditions provided so that work may continue safely.

It is good practice for the Inspector to review the borings prior to pile driving and have them available on site during driving. The soil classification and N-values may help the Inspector anticipate how the pile installation should proceed. The Inspector should compare the pile driving records with the soil borings. Changes in blow counts can often be explained by the pile toe encountering a different soil or rock layer. Sudden blow count decreases, if not in agreement with the soil boring N-value, may mean the pile is damaged or broken and further evaluation is then required. Pile lengths considerably in excess of the depth to rock or of neighboring piles founded in the expected bearing layer may also indicate damage. For economic reasons, soil sampling at every pile location is impractical, and thus some differences must be attributed to soil variations across the site; however, large variations in penetrations for adjacent piles should be questioned.

PILE TYPES

Although there are many pile types, the following list deals with the basic types of piles commonly used in the industry. DFI does not intend to exclude other possible types, but to present the commonly driven pile types and provide a basic understanding of some considerations which affect each type that can be critical to their installation and final acceptance. Because sheet piles are normally used to retain soil rather than as bearing piles, further discussion of this pile type is excluded from this manual.

TIMBER PILES

A. Timber piles should be treated per AWPA C3 when cut-off elevation is above groundwater elevation; untreated timber piles are acceptable only when the entire pile length will be permanently below the water table. All piles for permanent structures should be peeled. If the piles are treated, then the Inspector should check treatment certificates. Treatment is typically either:

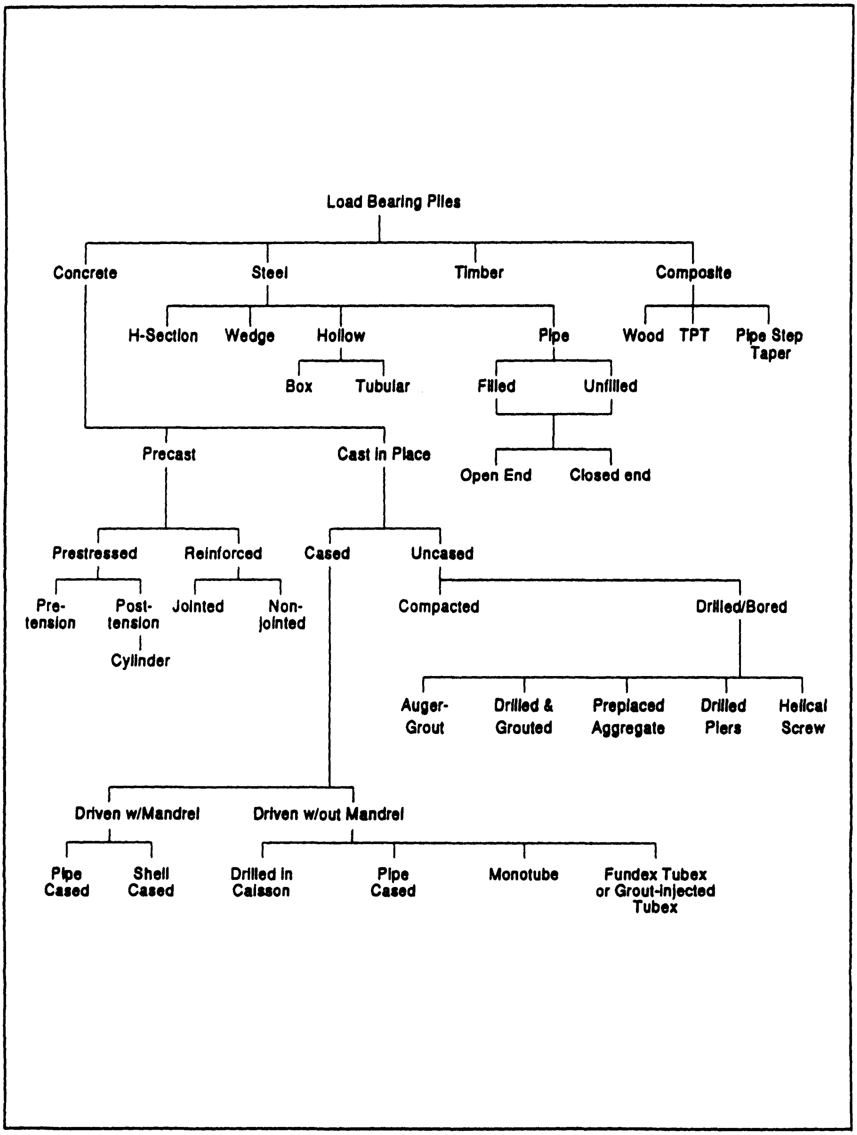
1. Waterborne
   (a) Ammoniacal Copper Zinc Arsenate (ACZA) -- a brown and green Douglas Fir pile.
   (b) Chromated Copper Arsenate (CCA) -- a green Southern Pine pile.
2. Creosoted -- a black pile (some specifications require "clear" creosote).

B. Piles should be reasonably straight. Since "Mother Nature" does not grow straight trees for piles, a guide is to stand at one end, sight the other end, and the line of sight (or a string line) should not depart from the pile; the deviation should be always less than half a diameter. Specific straightness criteria may be included in the specifications.

C. Timber piles are tapered throughout and generally driven toe down. Become familiar with the ASTM Standard D25 (Standard Specification for Round Timber Piles) as to diameter-circumference-length ratios, cracks, checks, knots, etc.

D. The ends of timber piles should be cut off perpendicular to the pile axis to minimize local contact stresses. The pile head may need trimming in order to fit into the helmet. Circumferential banding (particularly for creosoted marine piles) may be required by the specification to prevent splitting.

E. Generally, creosote treated wood piles up to 12 m (40 ft) long are unloaded simply by rolling them off the truck; longer creosoted and all ACZA or CCA treated



PILE TYPE CHART

This chart is from FHWA publication *Design and Construction of Driven Pile Foundations.*

Note: Drilled/Bored Piles are outside scope of this Manual.

piles must be lift unloaded to prevent damage. Suppliers and Contractors are aware of potential breakage involved in this act; the Inspector should be as well. Be sure to observe the unloading process from a safe location and "listen" for cracking. Any broken or cracked piles should be set aside and rejected.

F. There are approved splicing techniques for timber piles. However, all are costly and do little toward resisting lateral loads. The general rule is to avoid splices. Thus, the Contractor should be aware of the length of pile needed by (1) reviewing the borings, (2) knowing the cut-off elevation beforehand as it relates to the ground elevation, and (3) reviewing the contract specifications.

STEEL PILES

1. H-piles

Generally, H-piles are wide flange structural steel shapes having width and depth of similar dimension, and the same thicknesses for flange and web. Frequently, H-piles are driven to rock, into boulders, or when other obstructions are present, or where driving is very difficult and certain minimum penetration is a requirement. Unlike the timber pile, the steel H-pile is man-made and produced to established tolerances. The Inspector should look for the following:

A. Mill certificates should be requested with each delivery and are often required by specifications. Piles may have labels attached with information noting their size and strength; this should conform to the project specifications.

B. Unloading and stacking is usually done singularly and blocking is used between vertical layers to avoid permanent bending.

C. Square ends, straightness, constant widths between flanges throughout the length of the pile, to the manufacturer's tolerance.

D. Splicing is usually costly (compared with longer single section lengths) and so is avoided if possible. However, when required, splices are often made by full penetration welding (required in seismic zones), with or without patented prefabricated fittings which are available in varied sizes and shapes. Special splicing requirements may be contained in the job specifications. Welders should be certified.

E. Diligent observations should be made during driving. Excessive pile misalignment and twisting should be avoided or corrected.

F. The orientation of the section must be as shown on the plan, since the pile is stronger in one direction than the other.

G. As damage may occur to the pile toe when driven to rock or through obstructions, pile toe reinforcement ("shoes" or "points") are often specified; adhere to specifications or the manufacturer's recommendations for attachment.

2. Pipe Piles

Pipe piles may be driven as a bearing pile. In some cases, very high strength steel is used, such as in surplus oil pipeline stock. Pipe piles may be driven with or without a toe closure plate (e.g. "closed-end" or "open-end", respectively). While they are often filled with concrete (see Cast-in-place concrete piles) they may sometimes be designed to be left unconcreted. Since pipe piles, whether concrete filled or not, are generally installed by driving on the steel pipe alone and then often subsequently filled with concrete, they are treated here as a steel pile rather than as a cast-in-place concrete pile. Structurally, the concreted pipe pile is treated as a composite pile with the load shared between the steel and concrete.

A. Check outside diameter and wall thickness. Check delivery tickets and look for stencil markings on the pipe, particularly for size and steel grade information to check conformance with contract documents. A quick check for size would be to weigh a short section and then simply check the pipe weight charts for the measured outside diameter.

B. Check the pile toe closure if specified. Some specifications require that, if it is a round plate, the plate diameter be no larger than the outside dimension of the pile. Standard procedure, however, generally allows that the plate protrude 6 mm to 9 mm (1/4 to 3/8 in) beyond the O.D. of the pile to allow for the weld. In any case, examine the weld. When a non-welded end closure is used, be sure that it is perpendicular to the pile axis.

C. For closed-end pipe piles, check integrity, straightness and the driven pile length. Depth can be verified by dropping a tape rule down the inside. Straightness is generally limited to accepting the pile if any part of the bottom can be seen from the top. This can be accomplished by lowering a light down the inside of the pipe, or use a mirror if the sun is shining. The out-of-roundness (ovality) in a pipe pile is generally not considered to be critical, except if it affects the strength of the splice. Another means of checking straightness is to lower a long stiff pipe designed to go down the pipe if all is well, but to jam when the bending, or ovality, exceeds a certain value. It is fast and inexpensive. The Inspector does not have to wait for the fumes and dust in the pile to disappear, or empty the pile of water. In case of bowed piles, this "in advance" established limit criteria can clearly determine whether a pile is acceptable or not. Suggestions by the Contractor ultimately require the approval of the Engineer.

D. Splicing -- A pipe pile can be spliced by butt-welding or with an outside drive fit sleeve. If the original pipe section is spirally welded, the weldment can be ground off for a few inches back from the end of the pipe to permit accurate positioning of the sleeve. If the splice is of the butt-weld type, an interior backup ring is often used and at least one end should be beveled at 45° to insure a full penetration weld. The pipe section splices should be prepared and made according to the project specifications or as submitted by the Contractor and approved by the Engineer. Welders should be certified. Everyone will benefit from a properly fitted splice.

E. Concreting (if required - see also section on "cast-in-place" concrete piles) -- Ideally, the concrete will be poured into a dry pile (visual inspection or drop something attached by a string and listen for a metallic ring). If the pile is filled with water that cannot be removed, a tremie pour may be required. It is good practice to cover the pile head (with a cover, can, or plastic) immediately after driving to prevent introduction of water from the surface or other foreign objects from contaminating the pile.

PRECAST (PRESTRESSED) CONCRETE PILES

Precast piles are generally manufactured offsite, in predetermined lengths and shapes, and delivered to the job by conventional means (truck, rail, barge). Piles will be delivered which have been inspected at the plant and approved for the job with the cast date, length, and perhaps additional information. Piles may be square, hexagonal, octagonal or circular. Larger diameter piles may be hollow cylindrical shells. Piles are usually offloaded by crane one at a time, with handling at prepared or marked pick-up points only. In addition, piles must be stacked with supports at predetermined locations. Since internal inspection is usually impossible, diligent observations must be made during driving. The inspection process of precast (prestressed) piles begins at the plant.

Items which should be checked at the Plant (perhaps by the Inspector but likely by others):

A. That the geometry and other characteristics of the forms are as required.
B. That dimensions, form and quality of reinforcing are as specified.

C. That the quality of the concrete--mix, slump, strength, etc. -- is as required.
D. That there is a certificate indicating that the prestressing cables meet specifications.
E. That the prestressing procedure and forces are as specified.
F. That mechanical splice "joints" (if any) are properly installed square with the pile and centered.
G. That proper curing conditions are followed. Measure and document the strand slippage.
H. That proper handling and storage procedures are followed.

Items to be checked by the Inspector at the site are as follows:

A. That the age of delivered piles and corresponding strength of concrete, based on tests, are as specified.
B. That the geometry of the piles -- head perpendicular to longitudinal axis, length, straightness, etc. -- conforms to specifications.
C. That proper handling and storage procedures are followed (properly lifted and blocked).
D. That the condition of the piles is satisfactory (not fissured, spalled, strand slippage, etc.)
E. That splice "joints" cast with the pile segments, if any, conform to specifications.

Concrete is generally not able to withstand direct impacts from the pile hammer. To protect against local damaging contact stresses and to limit the amount of tension to acceptable levels, a pile cushion (usually of soft wood such as plywood) of 100 mm (4 inches) or more thickness is generally inserted between the helmet and the pile. Rarely will such cushions perform well after about 2000 blows and, therefore, require periodic replacement. Usually the old cushion is removed and discarded and a new cushion is inserted at the start of each pile. Changing the pile cushion is sometimes used as a quick way to raise the blow count and prematurely meet the termination driving criterion; the alert Inspector will reject this practice. If the cushion is changed during the driving of a pile, the blow count often temporarily increases as the fresh cushion absorbs additional energy; for this reason, the first 100 blows after a cushion change should be disregarded and the termination driving criteria and pile acceptance considered only after this break-in period.

While it is general practice to use full length one-piece piles whenever feasible, segmental piles are sometimes required. Splices may be mechanical or grouted. Usually, the splice must be capable to transmit all stresses across the pile splice.

Some concrete piles have an H-pile cast into and protruding from the pile bottom to allow extra penetration trough dense soils and provide extra embedment in hard soils where minimum depth restrictions are required such as in potential scour situations.

While most concrete piles driven in North America are prestressed, in other parts of the world regularly reinforced concrete piles are quite common. Such piles are made in relatively short sections (typically up to 12 m or 40 ft) with mechanical splices to extend their length. This allows more flexibility in the casting and also lighter cranes to accomplish the work.

CAST-IN-PLACE (C.I.P.) CONCRETE PILES

Piles in this category consist of any of the following types. All, however, are filled with concrete.

1. Pipe Piles

These closed end piles are identical with those described in the steel pipe pile section and the detailed discussion will not be repeated since pipe piles, whether concrete filled or not, are generally installed by driving on the steel pipe alone. Structurally, the concreted pipe pile is treated as a composite pile with the load shared between the steel and concrete.

A. Concreting -- Ideally, the concrete will be poured into a dry pile. After driving, inspect the pile for dryness (visual inspection or drop a metallic object attached to a string and listen for a metal-to-metal ring). Usually, if concrete is poured into a pipe containing water, the water will "bleed" through the concrete causing segregation and laitance to form, adversely affecting the concrete mix and concrete strength. Water may be removed by any one of several methods: airlift, electric pump, air pump, steam syphon, etc. If the water cannot be removed from the pile so that a dry pour can be made, a tremie pour may be required. (Concrete is placed through a pipe or pump hose to the bottom of the pile, the rising concrete then displaces the water without washing out the cement.) It is good practice to cover the pile head (with a cover, can, or plastic) immediately following installation to prevent introduction of water from the surface or other foreign objects from contaminating the pile.

B. Concrete -- Concrete should have a high enough slump to prevent arching (local void due to concrete spanning across the entire pile diameter). Generally little or no vibration is necessary, provided the slump recommended by the project specifications is followed.

2. Shell Piles

Shell piles are usually made of corrugated steel, have a light wall thickness, require the use of internal support (mandrel) during driving, and are always later filled with concrete. The distinction between C.I.P. pipe piles and shell piles is simply their wall thickness and strength differences prior to concreting. Whereas C.I.P. pipe piles derive their structural strength through a combination of the steel and concrete areas, the steel in a shell pile, because of its light gauge wall thickness and the corrugation, is basically considered only as a form and is assigned no strength contribution; the structural strength is derived from the concrete alone.

The mandrel is inserted into the shell prior to driving. It is the mandrel which is impacted by the hammer and, in essence, pulls the shell along as it penetrates the soil. The shell and mandrel may have either a constant diameter section or be step tapered.

The step taper pile is made of sections of preset lengths, with variation of about 25 mm (one inch) in the diameters in these sections. The sections are screwed together and have a casting at each joint for the mandrel to rest on. The mandrel is a solid core, often pinned together in sections, with section lengths and diameters matching the length and diameter of the shell. The mandrel is withdrawn after pile installation.

The constant diameter shell is driven with a mandrel that is first inserted then expanded either mechanically, hydraulically, or pneumatically. A system of cleats or helix bars on the mandrel's surface locks into the corresponding shell corrugation during driving. Upon completion of pile installation, the mandrel is deflated and extracted. To prevent damage to the mandrel, the Inspector may help keep driving stresses within acceptable limits by confirming proper hammer operation and use of appropriate cushion material.

Virtually all of the guidance regarding integrity, straightness, dryness and pile toe closures of pipe piles applies to shell piles as well. Those items which are peculiar to shell piles are as follows:

A. Splicing -- If the wall thickness is very thin (usually 18 to 12 gauge), then it generally requires gas welding rather than electric welding and as such tends to develop pin holes at the splice. Piles should be checked for dryness and welding procedures improved if needed to prevent excessive leakage since a dry pile helps everyone. Those piles where splicing consists in "screwing" one shell section into the other should be burlapped and swabbed with bitumastic before joining segments.

B. Collapse -- Although the shell is thin relative to its diameter, the corrugations strengthen the pile against collapse due to soil and water pressures on the outside of the shell. The wall thickness should be selected based upon the expected lateral pressures. Higher soil stresses are generated during driving adjacent piles in the group due to compaction of the soil during driving. Care should be taken in determining a driving sequence which minimizes these excess stresses. Many shell pile failures are caused by obstacles such as rocks or shards which can tear the shell during driving.

C. Mandrel - It is important to observe the mandrel during driving and as it is removed from the shell after driving is completed. Place a mark on the mandrel at a point equal to the pile shell length. By observing this mark relative to the shell for each pile, the Inspector can determine if:

(1) the mandrel punches through the pile bottom, indicated by a sudden change in position between the mark and the top of the shell,

(2) if the shell is stretching which indicates slippage between the mandrel and shell, or

(3) if the pile comes up with the mandrel. Sometimes the mandrel withdrawal will pull the pile with it. If the shell comes up, tell the foreman to reseat and redrive the last few inches.

Upon extraction of the mandrel from the shell, observe the mandrel surface for extreme wetness or evidence of debris or soil particles, taking into consideration dampness can be caused by condensation and dirt may have been present in the shell prior to driving.

D. Concreting - **Always check for collapse and that the pile is dry just prior to filling with concrete**. Other suggestions as for cast-in-place concrete piles should be followed when concreting.

When setting up, check to see that the mandrel is firmly seated into the shell before driving. If this is not done, the shell may crimp and result in "leaks", or a bottom-collapsed pile, or a "stuck mandrel".

3. Fluted Piles

The distinction between other cast-in-place piles and fluted piles is shape of the cross section. The lower sections are generally tapered and the extensions usually have a constant cross section. The splice is made by inserting the extension into the lower section and welding it. The strength of the splice is sometimes improved by a steel band attached to the top of the lower section. A conical point, preattached at the factory to the bottom of the section, closes the pile toe.

All recommended practices for other cast-in-place piles apply regarding straightness, integrity, dryness, etc. One benefit of this pile shape is that due to the fluting, the thinner walls are able to withstand the hammer impact without a mandrel.

4. Compacted Concrete Piles (Pressure Injected Footings)

The construction of compacted concrete piles requires the use of special equipment and a particular technique. Items to be checked and recorded include:

A. The alignment of the driving tube.

B. The resistance to driving the tube (blows per unit depth); hammer drop height and weight.

C. The elevation of the bottom of the driving tube before forming the base. Elevation of hammer bottom when forming the base (should be at least 75 mm {3 inch} above the bottom of the driving tube).

D. The concrete mix used for the base and its strength determined from the compacted samples.

E. The base formation; volume and number of buckets and number of blows per bucket; hammer weight and drop height (actual, specified); final volume of the base.

F. Placement of reinforcing, if any. Seating into the base of the permanent liner, if any.

G. Quality of concrete for the shaft: mix, slump, freshness; taking test cylinders at least once per day of pour, or for each 30 m^3 (40 yd^3), and of any suspect batch.

H. The relative position of the bottom of the driving tube and top of the concrete during compaction of the shaft.

I. The concrete volume in the compacted shaft compared to the length and diameter of the shaft.

J. The cut-off elevation.

K. The elevation of the top of the liner (if any) immediately after installation of its shaft is complete.

L. The elevation of each liner after all adjacent units are driven (to check for possible heave).

M. The backfilling of the annular space around the permanent liner.

5. Bottom Driven Cast-in-Place Concrete Piles

These piles are usually small diameter and are installed by driving with a special air tool. The tool is inserted into a slightly oversized, thin wall, sacrificial casing, usually containing a dry or damp concrete plug, and the tool must operate at the correct minimum air pressure. This short partial casing is then bottom driven to the appropriate depth or to a predetermined driving resistance. Depending on the soil conditions, as the pile is driven, the short casing may need to be extended to prevent collapse of the hole or water intrusion. Upon completion of the driving, the tool is extracted from the oversized hole. If the hole is uncased, the hole should be inspected for collapse or water intrusion; if problems are detected, the pile should be redriven with a full length casing. Center reinforcing steel is usually added to uncased holes. The cased or uncased hole is then filled with concrete.

6. Miscellaneous

There are many pile types, too numerous to describe in detail in this manual. Composite piles consisting of a lower section of one pile type extended by another pile type are utilized on some projects. This manual is not intended to provide an exhaustive list. The reader is referred to the ***DFI Catalog of Driven Foundation Piling*** for additional information. If the Inspector is familiar with those listed, the Inspector should understand most pile types likely to be encountered.

IMPACT PILE DRIVING

The energy expended by the hammer during driving does work on the pile as it overcomes the soil resistance while advancing the pile into the ground. The observation of final penetration per blow is important information in the capacity and quality control evaluation. This energy expended is the general principle behind the development in the late 1800's of so-called "dynamic formulas" or "energy formulas". These formulas contain many oversimplifying assumptions. They generally poorly model the hammer, usually overlooking the helmet and cushions, often make no allowance for the pile size and weight, neglect wave propagation, and have no provisions for soil dynamic effects. The hammer efficiency is only indirectly considered, and the diesel cycle is completely ignored. There are now hundreds of variations of these formulas, and it is now generally acknowledged by the engineering community that they are all unreliable and should no longer be used in modern practice, particularly for hammer selection. However, they are still encountered, primarily to control pile installation on smaller projects, or by the Contractor who may seek some guidance for hammer selection and not have easy access to or be comfortable with computers. The Engineering News and Hiley formulas are among the most often used, although the Gates formula apparently provides more consistent capacity prediction based on blow count. Some specifications still explicitly state which formula is to be applied.

With the advances in modern computers, a numerical procedure commonly referred to as the "wave equation" was developed by E.A.L. Smith of the then Raymond Pile Driving Company in the 1950's. The wave equation overcomes most shortcomings of the dynamic formulas in that it can accurately model all components of the process including the hammer, helmet and cushions, pile, and soil static and dynamic behavior. Basically, the computer translates physical parameters of driving system, pile, and soil which are input by the Engineer. Complete hammer models, including the thermodynamics required for diesel hammers, are stored in a file and can easily be recalled by identification number only. With today's computer availability and capability, a complete analysis takes only a few minutes. The ease of data entry means that both Contractors and Engineers usually run the program to check their submitted driving system and to define preliminary driving and termination criteria for the required pile capacity. These criteria are often expressed as a certain number of blows to advance the pile a specified distance (e.g. blows per foot, blows per inch, blows per 250 mm,...) or in other countries as a "permanent residual penetration per blow" (often measured as a penetration per 10 blows). This blow count is generally recorded during the entire driving of the pile by the Inspector in a "driving log", although some authorities only require records of the last part of driving such as the final 3 m (10 ft).

The preliminary driving criteria should be evaluated by the Engineer following an indicator or test pile program or after the first few piles are driven on the project.

While dynamic formula and wave equation analysis are used in the design stage to determine a preliminary driving or termination criteria, these methods contain many "assumptions". It is common to further investigate these assumptions and require actual measurements to confirm the adequacy of the resulting termination criteria and pile foundation. A method commonly used when driving and termination criteria are being established is dynamic pile testing. Measurements are made during the hammer impact of strain and acceleration of the pile. Computations then are made to determine estimated load carrying capacity, driving stresses and pile integrity, and hammer performance. Dynamic testing is commonly performed on several piles on site, for larger projects perhaps on several site visits, to maintain quality assurance or answer questions as problems may arise (long or short piles, high or low blow counts, etc., compared with normal or expected pile behavior). Results from these measurements and analyses may be used to provide additional information or confirm the assumptions made in the design phase or adjust the preliminary criteria. Alternatively, a static loading test may be performed to provide a definitive answer regarding the load carrying capacity of a single pile. Both dynamic and static testing are covered in more detail in other sections of this manual.

The following is a brief overview of details of the pile driving process, and the driving equipment which the Inspector should understand. A pile driving hammer imparts energy by virtue of a ram falling a certain distance (called the stroke or fall height). The pile and soil offer a resistance to this motion generated by the impact. Larger-sized displacement piles have more difficulty penetrating the soil than smaller ones, and for the same input, stiffer steel piles (larger cross sectional area) penetrate more easily than more flexible piles. Driveability is affected by the ram weight relative to the weight of the pile.

The Inspector should ask the crew foreman to have each pile marked at regular intervals (typically every foot or every 250 mm). Where it is expected that the pile will reach its final resistance, possibly finer markings (such as per 25 mm, per inch, per 100 mm, etc.) may also be desirable. One of the most important tasks of the Pile Inspector during pile installation is to record what is happening during the installation process. Commonly a form is used to record several requested items for each pile driven (see Pile Driving Report or "Log" in Appendix for a sample). This form will include as a minimum the pile name, date and time of pile start and end of driving or restrikes, specific observations about the hammer (such as stroke, fuel setting or energy readout), *interruptions* including reason and duration of stoppage, and cushion information. The prime information required, however, is a detailed count of the number of blows required to drive the pile each unit penetration increment. The Inspector should record all unusual events which occur such as hammer problems, hammer fuel settings or operating pressures, and strokes, inappropriate handling of the piles or variable driving procedures.

Usually, the blow count is taken per 250 mm (or per foot) and recorded by the Inspector for the entire length of the pile. When the pile approaches the blow count required by the specified termination criteria, the Inspector may be asked to start counting over a finer increment, such as per 25 mm (per inch). If recording over this finer increment, most specifications require that the Inspector observe and record the driving for at least three consecutive finer increments. If the resistance is at least the same for those three increments, it may be concluded that the termination criterion has been achieved and the pile is likely to have sufficient capacity. There may be an additional imposed upper limit for blow count for any single depth increment to prevent either hammer or pile damage. For example, in special cases, such as driving to toe-bearing on very competent soil or bedrock, driving must be watched very closely and stopped promptly before the pile is damaged. In case of driving to hard rock, it may be necessary to assure the pile reaches rock, but then apply only a set number of additional blows.

Some driving criteria state that both a minimum penetration and a minimum capacity be achieved. A minimum depth requirement may be given for reasons such as settlement, or scour. The Inspector must be aware of such possible additional requirements and insure that, if possible, they should be satisfied for each and every pile. If the pile encounters substantial resistance above the minimum penetration or intended bearing stratum, or if there is any doubt about the specification requirements, clarification by the Engineer is essential.

An important consideration when recording the number of blows per unit penetration is the reference elevation. The Inspector counts the blows by observing as the lines on the pile go past some fixed reference line. It is poor practice to use the hammer leads as a reference as it can change. Also, since the pile "gate" is often removed at the end of driving, it should also be avoided as the reference. The existing ground or water elevation is often used; there are potential problems with both. If the ground surface is not the elevation of the final bottom of footing elevation, then excavation could change the ground elevation. If the water surface is used, it may be affected by tides or waves. It is best to include in the report a description of the reference used so that adjustments and assessments of the final pile toe elevation are possible.

A final blow count should not be taken when the pile head is damaged as the defective pile head reduces the energy delivered into the pile which then gives a false indication of the blow count, driving resistance, and hence pile capacity. Sudden decreases in blow count during driving may indicate damaged or broken piles. The driving of piles should result in a relatively uniform blow count behavior from pile to pile. Neighboring piles should reach the termination criteria at about the same elevation. Large differences in blow counts or final elevations are generally of serious concern and should be immediately brought to the attention of the Engineer. While the Contractor may want to splice a pile and continue driving if it has not reached termination criteria, the pile may be damaged and therefore rejected so splicing and driving may be a waste of time and money. Piles which reach refusal far above neighboring piles or the minimum required elevation are equally cause for concern and the reason for the premature refusal should be investigated by the Inspector and the Engineer.

Regardless of the required driving or termination criteria, several basic rules should be followed during driving. It should be noted that many hammer manufacturers void their equipment warranties when hammers are subject to blow counts in excess of 100 blows per 250 mm (120 blows per foot). Thus, some Contractors and Engineers have suggested this practical upper limit for "refusal"; they further contend that instead of requiring higher blow counts, a larger hammer or a larger stroke (if possible) should be requested. Excessively hard driving with heavy or even medium weight hammers has the potential to cause considerable damage to piles. This is especially true for wood piles, where breaking the pile or brooming of either end is common with hard driving. Hard driving can induce breaking of concrete and bending of steel piles, causing these piles to spall or bend beyond their practical limit for use as a part of the foundation. In addition, the resulting damage does not always occur at the pile head. For example, the toe of the pile may be damaged, thus reducing bearing capacity below acceptable limits.

The driving stresses are primarily a function of the hammer's ram impact velocity which is a function of the stroke. The hammer stroke (or energy) should be monitored at all times for every hammer type. Air hammers are often equipped with dual stroke capability. In all cases they depend upon adequate air pressure for a full stroke. Thus, the stroke may vary which is easily observed if the Inspector occasionally observes the ram motion. Modern hydraulic hammers are designed to have strokes which are infinitely variable; many hydraulic hammers have built-in hammer monitors which the Inspector should observe and record the energy readings. While the stroke of open end diesel hammers is quite variable, the stroke (H) can generally be obtained from the blows per minute (BPM) rate of the hammer from the following equation:

$$H\,[m] = 4400/(BPM)^2 - 0.09$$

Given the broad range of pile types and sizes and hammers available, it is difficult to generalize what constitutes "hard driving". Limits should be established due to risk of damage and also reasonable productivity and therefore cost of the project. In some cases, piles experience sudden refusal, while in other cases the blow count gradually increases with depth and driving may be "hard" for a considerable distance. Some guidelines as to what will constitute "excessively hard driving of piles" should be agreed upon with the Owner, Engineer, Contractor, and Inspector before a project is started. This may be defined in the specifications as refusal. This agreement may need to be tempered during the progress of the job, for example, by the amount of pile damage occurring. If damage is frequently occurring, dynamic measurements should be made to investigate the cause and find an acceptable remedy (change in cushion, stroke, hammer setting, different hammer, etc.).

Low blow counts (large penetration per blow) can also pose danger by inducing potentially high tension stresses in concrete piles, and the risk of alignment difficulties for any pile type. When this condition is observed, it is often necessary to reduce the hammer energy to better control the pile installation process. Again dynamic measurements may help diagnose and correct the tension stress problem.

Hammer cushion material will be used in many hammers. Its purpose is to eliminate the possibility of the ram point hitting either the hammer base or the various driving head attachments to the hammer. The Inspector should observe and record all hammer cushion maintenance efforts and cushion changes. If the hammer cushion material is preassembled in the hammer, no additions will be made during the drive. If it is not, and insertions are made during the pile installation, do not allow these additions to be made indiscriminately. If this situation occurs, allow ten or more blows occur before counting the blows for establishing termination criteria. The practice of using wood chips as a hammer cushion can lead to very poor results and should not be permitted.

The Inspector should review the specifications, particularly regarding the driving criteria. The Inspector should be properly and thoroughly prepared to observe and document the pile driving operation. Blow count records per unit penetration increment need to be accurately maintained. Unusual conditions and occurrences should be noted and brought to the attention of the Engineer. Observations of the hammer performance, such as stroke or pressure, should be noted. Since the driving criteria is related to a certain hammer performance and was established by wave equation analyses or other means with an assumed hammer and driving system condition, both blow count and hammer performance requirements must be satisfied.

TEST PILES

At the outset of most jobs, or for large projects possibly in a separate contract, one or more "test piles" are driven for various reasons; the term "test pile" as used in this manual does not necessarily mean a pile which is to be subjected to a static loading test. A "test pile" may alternatively be called an "index pile", "indicator pile", "probe pile", or other descriptive term in the specifications. From an Owner's view, the use of test piles can be a major cost saving exercise by determining optimum pile lengths or pile types. Often test piles also are driven at various locations around the site to a safe and economical termination or driving criteria. In some instances, test piles are to confirm the boring results, assess site variability, and establish the necessary pile lengths to order. On many projects, test piles may be driven merely to blow count with no further testing. While, on other projects, they are subjected to dynamic testing. When required by specification or the Engineer's direction, one or more of the test piles may be statically load tested. If there is not sufficient knowledge about the site, or if refinements of the pile capacity could save substantial money, then both static and dynamic pile testing may be performed. Where the soil profile is uniform, a single static test may be sufficient. For large sites or variable soils, dynamic testing may be very helpful. Sometimes several different types of piles will be driven and some or all will be tested to choose the most economical foundation.

Sometimes the test pile is driven deeper or to higher blow counts than required for production, primarily to investigate the strength of a bearing layer; however, care has to be taken that the piles are not damaged. If a pile is to be statically tested, then overdriving is often undesirable as it may result in selection of higher than required pile length for all subsequent production piles and therefore cause extra unnecessary expense for the owner's foundation. Regardless of why a test pile is specified or driven, all parties involved in a project place their own particular emphasis on the information obtained.

1. **The Contractor** -- Regardless of how many dynamic or static tests the specifications require, the Contractor may want to drive a certain number of test piles to assess the entire site, particularly when the site is large and soil conditions appear variable. Ideally, the test piles will be driven in close proximity to the soil borings. As a result of these test piles, the Contractor will determine if problems are likely to exist and how they may be best overcome, and confirm the order lengths for the entire job and the driving time per pile. The test piles provide a learning experience for the pile crew. The Contractor can formulate a plan to maximize the production rate. Finally, static load test piles, if required, can be installed easily during the test time period so that production pile driving can begin with no delays.

2. **The Design Engineer** -- Test pile information will provide valuable information on the performance of the pile, the performance of the proposed hammer, the performance of the Contractor's personnel, the reliability of the borings, and verification of the static analysis design. Will the piles and the soils respond as anticipated? Are any changes in foundation design or preliminary driving criteria necessary? Are the Contractor's equipment and methods in accordance with the specifications and local building codes? Did the dynamic or static testing reveal any surprises or unusual results which could adversely affect the design or installation? Does it appear from the testing that the driving criteria could be relaxed for significant savings? What type of deviations from the anticipated might occur during the course of production driving?

3. **The Owner** -- The Owner shares many concerns with both Contractor and Design Engineer. The Owner will be interested in three things in particular. Is the pile the most economical choice both in cost and in installation time? Will the foundation costs be as anticipated, can any savings be made, and, if costs will be higher, is there anything that can be done to remedy the situation? And, finally, when will the production piles be completed so the construction of the structure can be started?

During driving of the test piles, the Inspector should attempt to complete the formulation of the final criteria for driving the production piles. In many types of soils, the so-called "soil set-up" ("soil freeze") will occur. This is simply a gain of capacity over time. Not all soils experience this gain; coarse sands for example have little capacity change. However, some soils, such as clays, silts, and even fine sands, can experience substantial capacity changes. It is important to measure or quantify this capacity change. One method is to perform static tests after a sufficient waiting period. Another possibility is to perform a restrike of the pile, preferably with dynamic testing. The pile may be left slightly above cutoff elevation and allowed to sit for a period of time; soil set-up is time dependent so a longer wait may result in a higher capacity. When the pile is redriven, make sure the hammer is "warmed up" and performing according to the manufacturer's specifications. The number of blows should be carefully recorded in 25 mm increments (one inch) because the pile may lose strength during the restrike and revert to blow counts experienced at the end of initial driving.

In some soils, such as very dense saturated fine sands, silts, or shale bedrock, the opposite of set-up may occur. The pile capacity may reduce rather than gain strength with time. This phenomenon is called "relaxation" and its occurrence or absence can be checked by comparing blow counts from end of drive to restrike blow counts on the same pile, or by comparing nearby piles driven under different conditions of hammer temperature (hot after extended driving, or cold after long wait or such as first pile driven each day).

The Inspector should assure that the crew will routinely keep the pile and hammer aligned since this minimizes potential damage due to local stress contact pressures, or bending of the pile, and maximizes energy transfer to the pile. Where obstructions to driving are present, the Inspector should observe and document how much difficulty was encountered to maintain proper location, orientation, and plumbness during the installation. Also the existence of "pile heave", that is, the rising of previously installed piles caused by the driving of adjacent piles should be measured, documented, and brought to the attention of the Engineer for review and direction.

Test piles are driven prior to production driving and it is the Inspector's job to monitor the driving properly, to understand the relationship of the piles to the borings, and to be alert for and document variations in driving. After initial dynamic and static tests are completed, the driving and termination criteria will be established for production pile driving. The Inspector is the eyes of everyone connected with the job. All deviations during production from the test program should be noted and promptly brought to the attention of the Engineer.

DYNAMIC PILE TESTING AND ANALYSIS

The driving process is simulated by a "wave equation" computer program. The hammer system and pile are represented as a series of springs and masses. Static and dynamic soil properties are also modeled. The response of the pile and soil to the hammer impact are analyzed to estimate the pile driving stresses and penetration resistance (number of blows per unit penetration) of the soil for a range of pile capacities. In this way, different hammer and pile combinations can be analyzed before mobilization to the site to confirm that the pile might be safely driven to the desired capacity. This analysis is the best way to determine preliminary driving criteria which may be your initial guideline.

The wave equation, however, contains several assumptions. Hammer efficiency, cushion properties, and soil response parameters are estimated. While the Engineer may choose these input values conservatively, it is quite common to confirm these assumptions by comparison of test pile driving with static analysis, followed by static loading tests, or dynamic pile testing on selected piles.

Dynamic pile testing measures force and velocity of the pile under the impact applied by the hammer, and is covered by ASTM D4945 "Test Method for High-Strain Dynamic Testing of Piles". The testing is usually performed by the Engineer or a specialty Consultant using dynamic pile testing equipment on test piles, indicator piles, or production piles. It is used to investigate wave equation assumptions, to supplement or replace static testing, as a quality control tool on large projects, or to diagnose unexpected problems and aid in their solution. The specifications will often state the number of piles to be tested, their location, and whether tests are to be performed during driving or restriking.

Dynamic testing is a specialized procedure beyond the Inspector's responsibility. While it is rare that the Inspector actually performs this test, cooperation with the Engineer or Consultant is important for a successful test. The Inspector should note on the pile records when and which piles were dynamically tested. The Engineer or Consultant performing the testing will request a copy of the driving record. For restrikes, the Inspector should carefully monitor the movement during restrike (total permanent movement for the applied number of blows, or the number of blows for each 25 mm or one inch).

Dynamic testing calculates the energy transfer to the pile from the force and velocity measurements. Since blow count depends on the hammer performance and is often used as a quality control tool for pile acceptance, it is important to assure that the hammer is performing as assumed. The Engineer or Consultant making the measurements can advise if the energy is lower than expected, the hammer is in need of maintenance, or the cushion material should be changed.

Dynamic testing results indicate pile bearing capacity at the time of testing. Testing during initial driving estimates the capacity of the remolded soil with often elevated pore pressures. Therefore, dynamic testing to estimate service loads usually requires restrike testing to include any time dependent soil strength changes such as set-up or relaxation. The specifications may state the wait period after installation for the restrike testing which is generally dependent upon the soil type and may vary from one day for clean sands to a week or more for piles in clay soils. High blow counts or low permanent displacement per blow is usually not desired for dynamic testing so the hammer energy applied should be sufficiently large during restrike to keep the blow count reasonable.

While the wave equation analysis estimates driving stresses, real conditions may vary due to actual hammer, cushion, and even soil behavior. If hammer performance and driving stresses are too low, then productivity will suffer, or the pile could be stopped prior to attaining sufficient capacity. If stresses are too high compared with pile strength, then the likelihood of pile damage is increased due to compressive stresses, bending or local contact stress concentrations, or tension stresses for concrete piles. Specifications may require dynamic testing to investigate stresses during driving, especially to determine tension stresses in concrete piles during easy driving. If needed, the driving system can be adjusted to change the driving stresses.

For solid section concrete piles or H piles, visual inspection for damage below grade is virtually impossible. However, dynamic pile force and velocity records provide information regarding serious pile imperfections or damage below grade. It should be mentioned that in some instances concrete piles, augered or driven or cast-in-place pipes, can be more quickly tested for integrity by the inspection technique described in ASTM D5882 where a small hand-held hammer is used to strike the pile and subsequent pile head velocity is measured and investigated for unusual reflections.

These ASTM D4945 dynamic testing methods are covered in more detail by the DFI Short Course Text ***Dynamic Monitoring and Analysis of Pile Foundation Installations*** (Hannigan, 1990). The Inspector is referred to that document for further details and examples.

Recently, a specialty Consultant developed a different dynamic test method as an alternative to static pile testing. In this test, a mass of about 5 to 10% of the desired test load is placed above a pressure cylinder attached to the pile head. A solid fuel burns to produce a high pressure, propelling the mass up and applying a downward force on the pile for a duration of about 0.1 seconds. Pile displacement monitored electronically and load measured by a load cell are collected by a computer. The applied force is opposed by the sum of all static and dynamic soil resistance forces. Data must be interpreted to account for dynamic effects and the pile must experience significant permanent penetration if the ultimate static load is to be estimated.

STATIC COMPRESSION LOAD TESTS

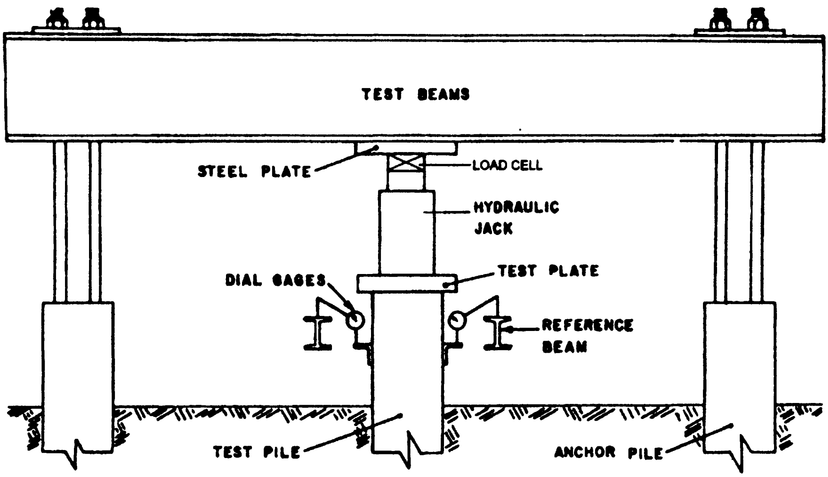
This section is provided as a brief overview of what to expect and what is important in a compression static loading test. It is not intended to be a complete instruction guide or specification. The reader is referred to the appropriate job specification for specific instructions or to the ASTM D1143 guidelines. DFI has also prepared a more extensive discussion on static compression load testing and its interpretation entitled ***Guidelines for the Interpretation and Analysis of the Static Loading Test***. For tension or uplift static loading tests, see ASTM D3689. For specific guidance in conducting lateral loading tests, see ASTM D3966.

Note: static load testing often involves large weights which can become unstable, or large energies may be locked into the reaction system. Constant care and concern for safety should therefore always be highest priority.

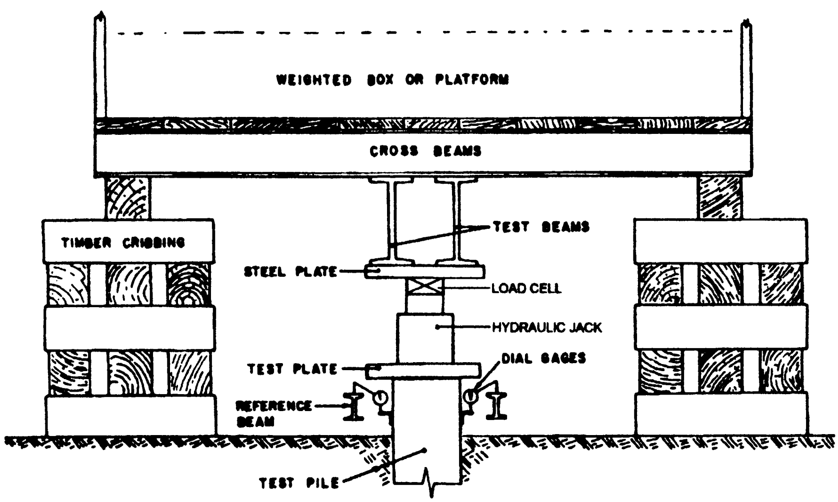
Often, in order to verify design pile capacity, a static load test is specified. A single static test is particularly appropriate when the soil conditions are uniform. When the site is highly variable, more than one static test or a combination of static and dynamic testing may be required. The requirement to statically test may come from the local or state codes, the Design Engineer or the Owner or local building authority, and is common for designs with higher pile loads. In most cases during a static test, the load is applied to the pile through a hydraulic jack in certain increments while pile head movement is observed. Occasionally movement below grade is also monitored.

Static load tests are expensive and therefore should be conducted with great care. The first step toward completing a static test is, of course, to install the pile. In fact, piles may be installed in several locations to check conformity with the borings, to determine driving conditions, and to allow for selection of a pile with representative yet weaker behavior (low blow count). It is generally recommended that the pile to be statically tested be driven to the anticipated production pile termination criterion. A complete, carefully collected driving record including blow counts, hammer type, stroke or hammer setting, cushion type and thickness should be recorded. Pipe piles are often filled with concrete for service conditions. Therefore, concreting may be required prior to the static test to provide sufficient structural strength for the anticipated maximum test load.

After the test pile is installed, the Contractor will assemble the reaction system. The Contractor may choose a platform of weights, a soil-filled box, the crane itself, or another piece of equipment. Alternatively, he may install a series of "reaction" piles or tie-down anchors properly braced and connected, to provide the reaction for the jack



TYPICAL SETUP FOR PILE STATIC LOADING TEST IN AXIAL COMPRESSION USING ANCHOR PILES



TYPICAL SETUP FOR PILE STATIC LOADING TEST IN AXIAL COMPRESSION USING LOADING PLATFORM

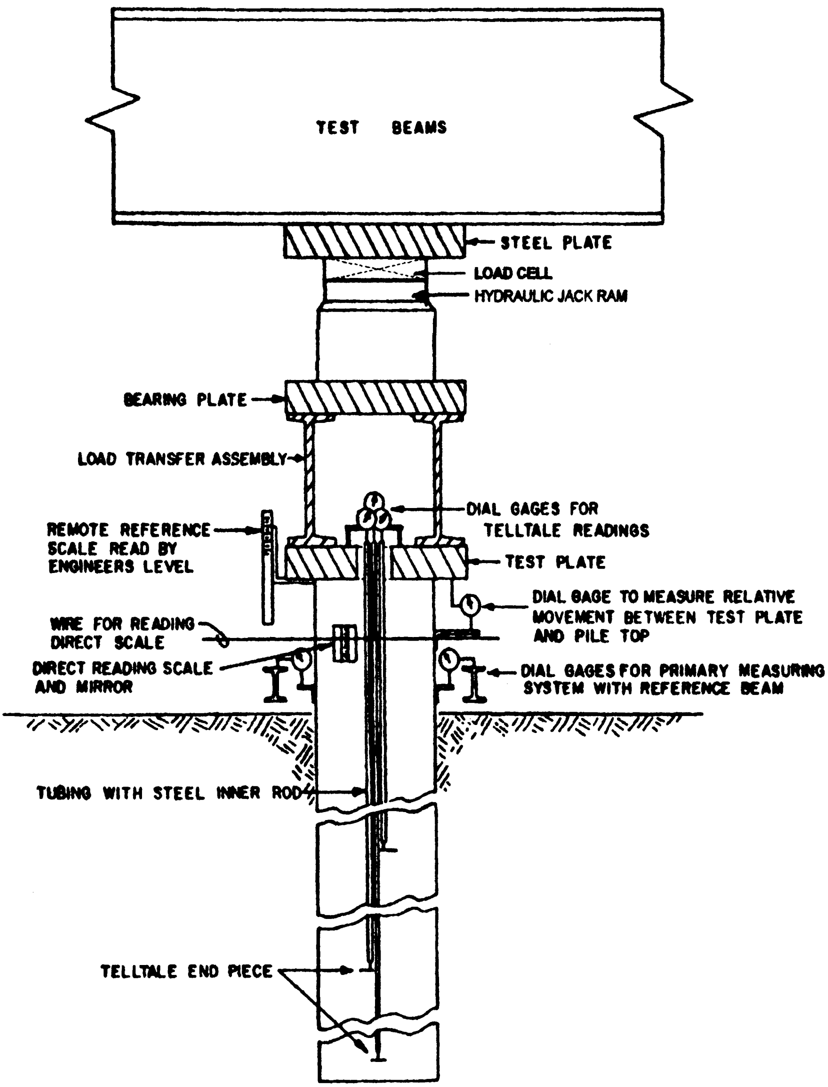
LOAD TEST SETUPS

to impart the load to the pile. If anchor piles are driven, they should be installed prior to the test pile.

The sensors for monitoring the pile movement are installed. At least two measurement methods are used, so if one becomes inoperative, the test is not lost. Dial gauges are always suspended from independently supported reaction beams, the pistons of the dials remain in constant contact with the pile or plate atop the pile, and extend as the pile moves under load. Precheck the dials to assure they move freely and are in good working order. The Inspector should be familiar with how to read the dials during the test. Usually, two or more dial gages (resolution to .001 inch or to 0.01 mm) are placed symmetrically around the pile. The reading of each dial gage must be recorded by the Inspector. The difference between the readings of the individual dial gages reflects the tilt of the pile head. If the tilt progressively increases during pile loading, the test may have to be stopped, the load taken off and system realigned prior to restarting the test. **This is extremely important to assure safety of all personnel on site.** In addition to the dial gages, other displacement monitoring of the pile head may include a surveyor's level referenced to a permanent bench mark, or a thin piano wire stretched independently and passing across a scale with a mirror behind it. If the wire and its image line up while reading the scale and establish the same frame of reference, then the reading will be accurate. Some piles may also have dial gages attached to free rods in tubes, called "tell-tales", to monitor pile displacements at locations along the pile shaft or at the toe to investigate load transfer.

The load should be read using both a calibrated load cell and jack pressure gauge to assure accuracy and redundancy. It is customary that the jack be calibrated and certified so that the gauge pressure reading corresponds with the load imparted. Because friction in the jack makes hydraulic pressures an inaccurate load indicator, the load cell is normally considered more accurate. The exact location of the piston at the start of the test should be marked so that horizontal movement of the pile head can be detected. Another indication of poor test alignment is to look at the bearing surface between the jack and the reaction system. If more "daylight" can be seen between bearing surfaces than was present at the start of the test, then the pile is moving laterally.

For safety, it is important to periodically step back and inspect the whole test. Is the platform still level? Are the pile and jack still aligned? Could the platform be tipped at the next or subsequent increments? If this is possible, then stop the test. Keep alert. Rather than crawling under an unsafe loading structure, request a surveyor's transit or a telescope and read the dial gauges remotely. If any dangerous situation occurs, stop the test. Observations of reaction pile movements should be made during loading.



TYPICAL SETUP FOR MEASUREMENT OF PILE AND LOAD DISPLACEMENTS

After all the equipment, specifications, and pile logs have been studied, the load test can be started. Loads and corresponding movements from each sensor during all "hold" periods must be recorded with time of application and any unusual observations for a permanent record. For the "Quick Load Test Method", increments of 10 to 15 percent of the design load are applied and held for a brief time period, typically 5 minutes each. Alternatively, for a "Maintained Load Test", loading increments of 25 percent of the design load are applied usually every one or two hours, but specifications may require holding the maximum test load even longer; practices vary across the country. Occasionally, specifications require the load to be removed after each increment before application of the next load increment. This process is called "cycling".

The Inspector is often requested to monitor the load test. The Inspector should obtain and understand full instructions for load increments and hold periods prior to starting the test. Specifications may require higher loading than twice the design load; be aware of the maximum loading requirement.

The applied load causes movement of the pile head because:

1. The pile will shorten due to elastic deformation of the pile and the pile toe may also move due to elastic deformation of the soil.
2. The pile will bend below grade due to pile curvature developed during installation and inadequate lateral restraint.
3. If the applied load is high enough, the soil stratum at the toe will fail and allow increased penetration with decreasing load increases. Then a large net residual displacement remains after removal of the test load.

Elastic shortening will always occur and its magnitude will relate to the pile stiffness and length. Pile bending may happen, but could be difficult to confirm. The third situation occurs when the soil reaches its ultimate load capability and thus the static test has reached a failure load. Ideally, static loading tests should all be carried to soil failure to obtain the maximum information, and allow for optimizing the pile design load and reduced foundation costs. However, the static test load should never exceed the design load of the reaction system (frame, dead load, or reaction piles).

Once soil failure has been achieved or the specified maximum load applied, this load is generally held one hour for a quick test procedure, or at least 24 hours for a maintained test. The load holding time may be extended if the movement rate exceeds a certain amount (usually 0.30 mm or 0.012 inch per hour). Depending on the percentage and distribution of pile shaft resistance, it may require a considerably longer period of time before the rate of movement diminishes enough to meet the "hold" period requirement. End bearing piles usually exhibit little extra movement during the hold time.

At the conclusion of the test, the load is removed (usually in 25 percent increments of the total test load) and rebound readings are taken. The final readings after release of all load to zero when compared with the initial readings before loading will enable computation of the net pile movement. Soil failure will be evident if a large net pile movement has occurred.

It is vital that the data recorded be clear, concise, and as such, reported to all interested parties. Aside from the pertinent data required in the specifications, it is important to record any and all out of the ordinary events that occurred throughout the test, including weather, depth to ground water, elevation of river or ocean level, breakdowns in equipment, names of firms and titles of the various visitors at the test, and anything else considered pertinent. Remember, a report lasts longer than the memories of the persons involved. It should be noted that it is not the responsibility of the Inspector to interpret the test results. Interpretation is the responsibility of the Engineer.

There is another recent alternative to traditional loading at the pile head. A high capacity, sacrificial jack is installed in the pile, usually at the pile toe. The jack simultaneously loads the end bearing downward and the shaft resistance upward and the test continues until reaching either the ultimate end bearing, the ultimate shaft resistance, or the maximum jack capacity. This arrangement eliminates the need for reaction frames or dead load. Displacements are monitored with tell-tales both at the top and bottom of the sacrificial jack. The sacrificial jack is installed on displacement piles prior to driving, or could be installed on open-end pipes after driving is completed. Usually this test is entirely performed by the specialty Consultant.

PILE HAMMERS

This publication is a companion to the ***Pile Inspector's Guide to Hammers***, compiled by the Equipment Applications Committee of the Deep Foundations Institute, which provides basic information about various commonly encountered pile driving hammers, contains check lists for the Inspector to verify operational conformance with the manufacturer's specifications, and makes suggestions for troubleshooting substandard hammer performance.

A century ago a Pile Inspector only needed to understand the operation of a gravity or a single-acting air-steam hammer, and some dynamic formula. With the advent of modern pile installation tools such as diesel or hydraulic hammers, and vibratory driver-extractors, the Inspector's job has become more complex. Add to this the present trend toward larger structures with more sophisticated designs with larger piles and higher design loads, seismic design requirements, and understanding of site variability, and the need for better control of the pile foundation installation becomes more critical. The Inspector must now have a good working knowledge of the type and operation of the pile hammer on the job in order to know if it is operating correctly and efficiently so that the observed blow count is meaningful and the pile attains sufficient penetration and capacity at the termination driving criterion.

Prior to the start of any pile driving operation, the Contractor should furnish a submittal to the Engineer regarding the specific equipment to be used on the job. This list would include the make, model and type of the intended pile hammer or hammers, the cushion materials and proposed thicknesses, and the helmet weight. Often the Engineer will then perform the wave equation analysis to determine the blow count (blows per unit penetration) to be observed at a specified pile bearing capacity and investigate the potential for overstressing the piles and ways to reduce the likelihood of potentially damaging situations. It should be noted that increasing the driven length of concrete piles will increase the potentially damaging tension forces. If some piles are to be driven on an inclination (a non-vertical pile), a proper correction factor should be applied to the blow count. The reason for this correction is to compensate for the energy losses resulting from the ram's non vertical fall. The maximum angle of inclination, often expressed as a ratio of horizontal to vertical slope, recommended by the individual hammer manufacturer should not be exceeded.

The Inspector should have an operating manual for the hammer and a manufacturer's specification sheet which gives the pertinent hammer data; i.e., ram weight, rated energy or actual stroke, operating speed, requirements for the air compressor or other outside power source if required by the hammer type, appropriate cushions and helmets, etc. It is the Inspector's job to confirm that the equipment used on the project matches the originally submitted equipment. The Inspector must become familiar with this information prior to the job start. All hammer manufacturers and their local representatives are ready to offer assistance. Once in the field, the Inspector should be alert to any variations from normal operation that can occur in any pile hammer due to continuing use, or differences in equipment being used from the original submittal which may affect the blow count criteria established by the Engineer. Such differences should be promptly communicated to the Engineer. The age (or serial number) and condition of the hammer should be noted as well as the date of the last overhaul.

The energy rating used by most hammer manufacturers is simply the hammer's potential energy. With gravity drop hammers, the potential energy is computed by basic arithmetic: multiplying the known ram weight by the distance it will fall. Actually this same computation applies to most single acting hammers regardless of their type such as air, diesel or hydraulic operation. "Single-acting" refers to gravity only as the source of downward acceleration of the ram. In an attempt to speed up the operating cycle and thus apply more blows per minute to improve productivity, some hammers are built "double-acting" in that an external power source is used to assist gravity during the shortened downstroke; it should be obvious that this assisting double acting power source must be working properly if the hammer is to provide the proper amount of energy and that part of the Inspector's job is to be sure it is working up to specification. The "rated energy" given in equipment specifications by most manufacturers of both single-acting and double-acting steam, air, hydraulic or diesel hammers is intended to be comparable to the simple "potential energy" of a gravity drop hammer.

Many specifications specify that the manufacturer's hammer energy rating be within some specified energy range. The potential energy is converted to kinetic energy (energy of motion) as the ram falls. Some manufacturers, particularly of hydraulic hammers, rate their hammers by the kinetic energy computed from measured ram velocity just prior to impact. This energy is also called net energy.

For all hammers, the energy delivered to the pile is always smaller than the rated or potential energy available at the top of the stroke due to a variety of energy losses in the mechanical equipment during the downward stroke. Losses include friction during the ram fall, the air supply which includes hose diameter and length for air hammers, preadmission of lifting pressure for air hammers, compression of gasses in a diesel hammer after the ram passes the exhaust ports, driving system masses and inelastic collision losses in the hammer cushion-helmet-pile cushion assembly, misalignment, and other loss sources. Many of these loss sources are accounted for by the wave equation analysis.

When the hammer is suspended by crane cable in the leads, always be aware of how much slack there is in that cable. During driving, the hammer should be fully supported by the pile and not the hoist cable. Sometimes when there is little length of pile left and the pile has not achieved the termination blow count, the crane operator might tighten up on that hoist cable, thus artificially decreasing the energy transfer per blow. If the Pile Inspector is looking at only the pile/ground interface and notes only the resulting increased blow count, the pile driving might be prematurely stopped. Driving while the hoist cable is not slack is also a potential safety hazard.

Various hammer cushions, helmets, and pile cushions placed between the hammer and the pile head affect the actual energy the hammer transfers into the pile. If losses are excessive and the energy delivered to the pile is much less than intended, then the pile capacity could be much lower than anticipated. Many specifications require the Contractor to submit the proposed driving system for approval by the Engineer; if the Contractor changes the driving system, the Engineer should be notified so he can evaluate the change and possibly adjust the termination driving criterion.

The cushion materials used and their thickness must conform to the Engineer's specifications. The Contractor may change the hammer cushion, or change or add pile cushions, prior to the conclusion of driving the pile but this is bad practice since during the next few blows following inserting new pile cushion material energy transfer will be poor and the untrained eye and ear may incorrectly think the pile is "good". Therefore, specifications usually prohibit the indiscriminate changing or adding of cushion material. Pile cushion exchanges for concrete piles should be done only at certain established intervals (e.g. at beginning of each pile, or after 1500 blows, etc.). Furthermore, the Inspector should ignore at least the first 100 more blows after cushion change before counting blows used to determine pile acceptance. The Inspector should include and clearly mark in the pile inspection report the time and depth of any such cushion changes.

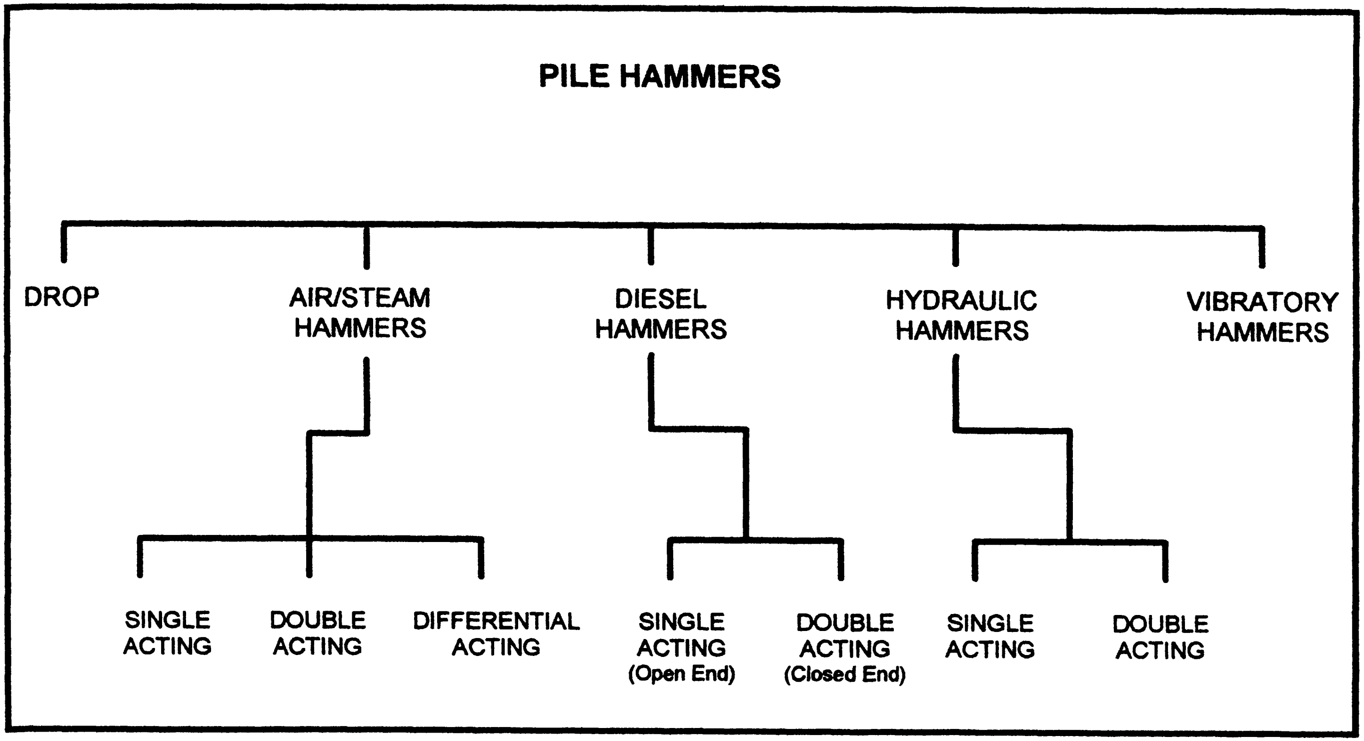
Remember, many hammer manufacturers void their warranty if the driving resistance exceeds 10 to 20 blows per 25 mm (10 to 20 blows per inch); some therefore suggest that if a higher blow count is needed, then a larger hammer should be considered.

Another potential energy loss concerns damaged pile heads. If the head of a steel pipe or H-pile is damaged, then its axial stiffness is reduced. In effect it becomes a "cushion" and will absorb energy which generally causes the local pile head damage to increase. This deformation causes an undesirable energy loss, causing the blow count to artificially increase. If pile head damage is observed, the damaged section must be removed prior to assuring that the pile has met the termination driving criteria. It is the Inspector's responsibility to record and report to the Engineer any pile head damage and its removal prior to final termination acceptance. Pile head damage is often due to either poor hammer-pile alignment, high driving stresses which could be verified by dynamic testing or estimated by wave equation analysis, or due to poorly fitting helmets.

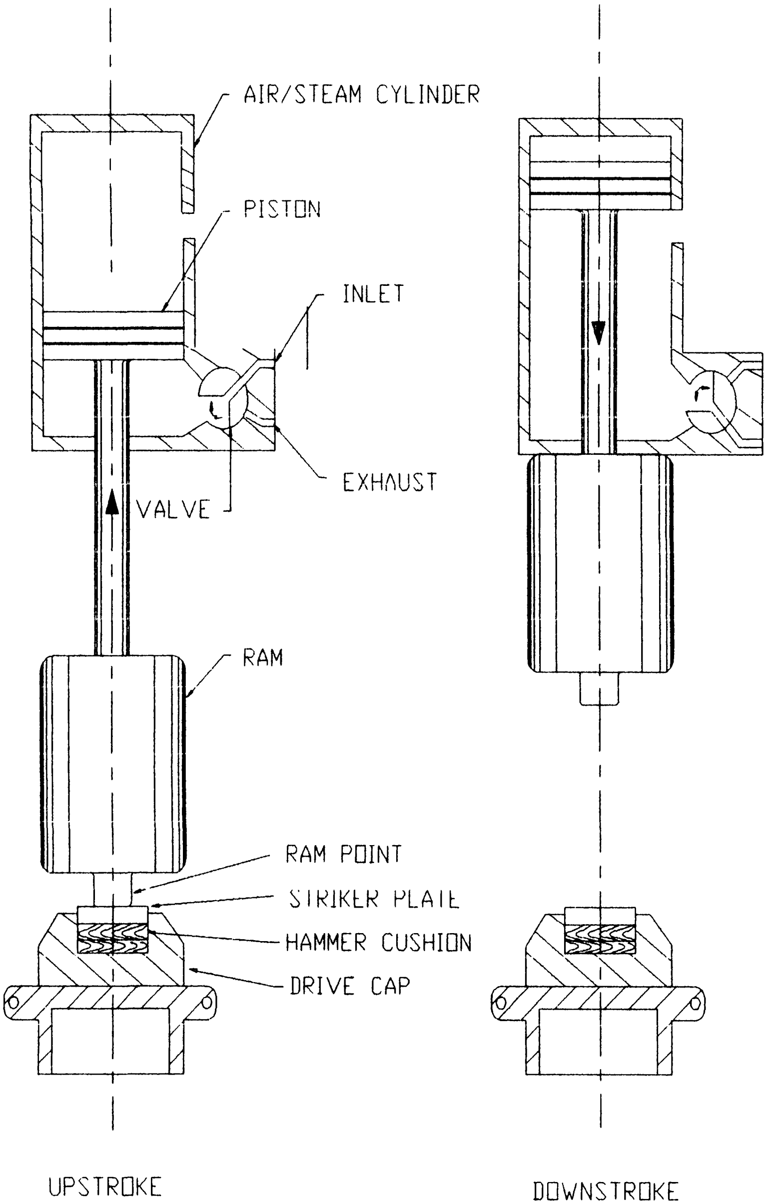
The hammer stroke is generally easily observed for any single acting air hammer. However, various air hammers do not always run at their full stroke rated energy. For example, air hammers may have different operating energy depending on the air supply during the power cycle and also due to the pile rebound (rebound is dependent upon the pile stiffness and the soil resistance). Preadmission of the air pressure lifting the ram becomes more critical if the hammer cushion is not the correct thickness as specified by the manufacturer (it is the Inspector's job to assure proper hammer cushion thickness), or if the slide bar is worn and causes premature admission of the air pressure. The slide bar also controls the length of the power input from the compressor. The power stroke is considerably less than the full rated stroke. At the end of the power stroke the motive pressure is removed, the ram has some upward velocity, and then coasts upward under the resistance of gravity before the fall cycle begins. Thus air hammers are not constant energy devices; the Inspector should try to observe and record the stroke height, and the operating rate in blows per minute. The compressor size and operating pressure, and the hose diameter, length, and condition also affect the ability of the hammer to attain the rated stroke (and rated blows per minute); these should be noted in the Inspector's report, particularly at the end of driving when the termination criteria is met.

The stroke and performance of diesel hammers will depend upon the pile stiffness, soil resistance, the compression ratio, and the fuel charge. The compression will be affected by maintenance of the piston rings and lubrication, while the fuel charge is controlled by the fuel pump setting and the maintenance of the fuel pump. If preignition of the gasses is suspected, the Inspector should compare piles driven when the hammer is "cold" to piles driven after continuous driving to look for large disparities in the driving records of neighboring piles. Diesel hammers do not always attain their full rated stroke; it is important that the Inspector record the actual stroke for each penetration increment in the pile inspection report. The stroke of an open end diesel hammer can be visually observed, or computed from the observed blows per minute. The observed stroke should be similar to the stroke established for the termination driving criterion, perhaps determined by a wave equation analysis or by comparison with the stroke observed for the test piles which were either dynamically or statically tested.

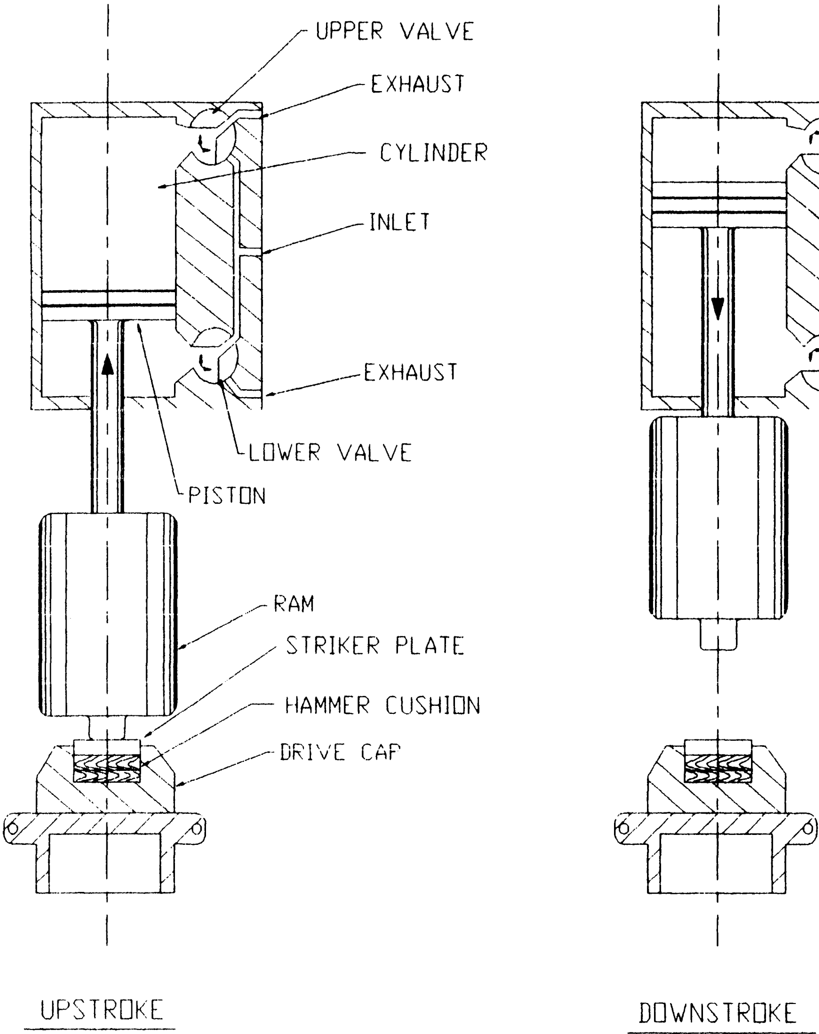
In the case of double acting hammers, the energy performance depends heavily upon pressure during the downward ram motion. For double acting air hammers, most *manufacturers* provide a chart which relates energy to speed of operation; thus the Inspector will need to observe and record the operating rate in blows per minute. For



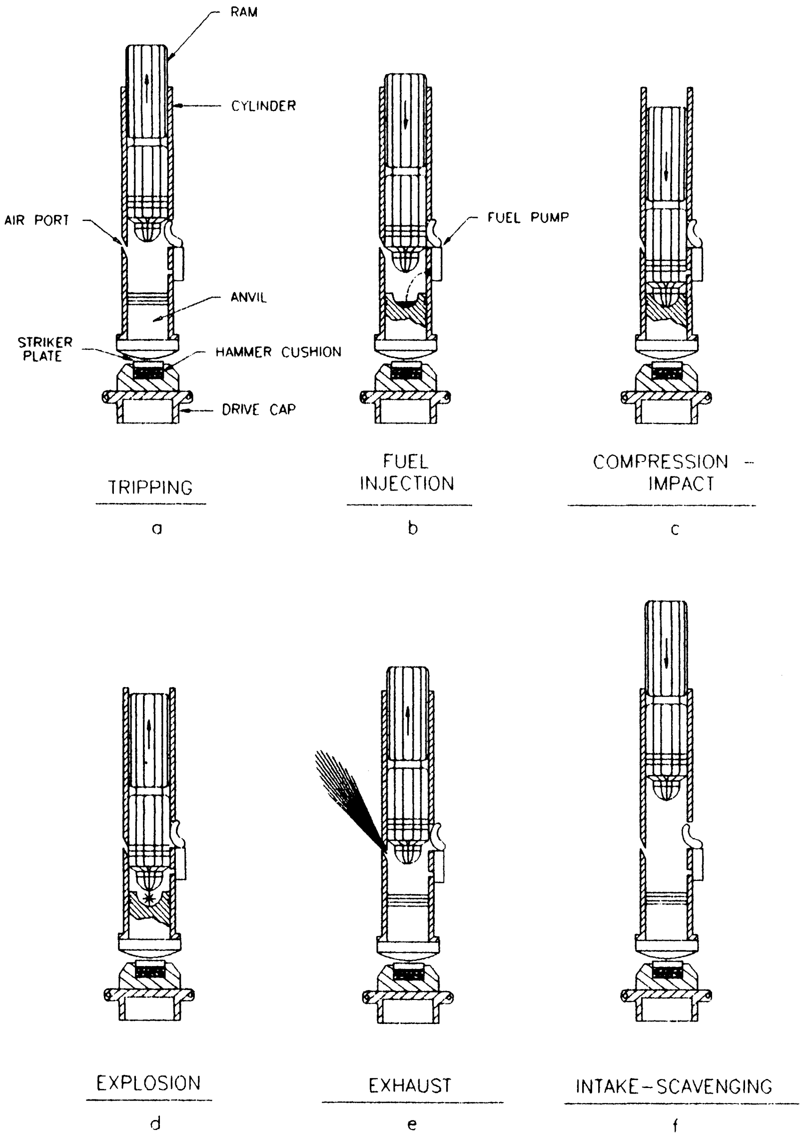
PILE HAMMER CLASSIFICATIONS



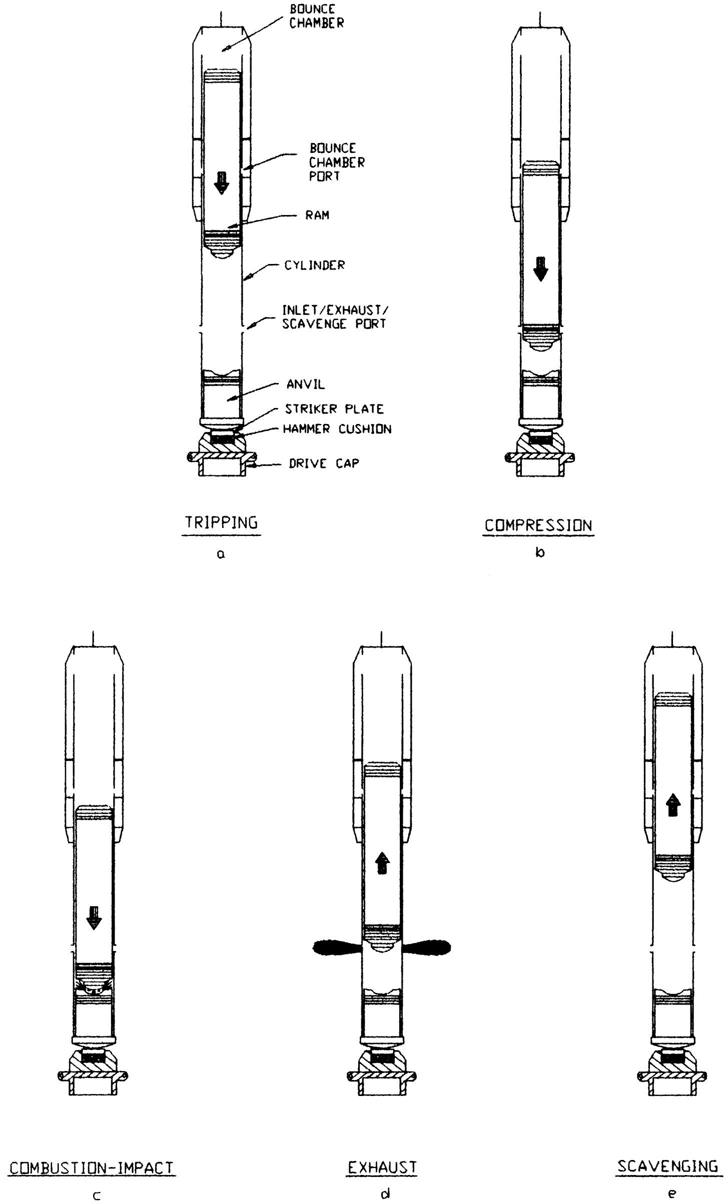
SINGLE-ACTING AIR/STEAM HAMMER



DOUBLE-ACTING AIR/STEAM HAMMER



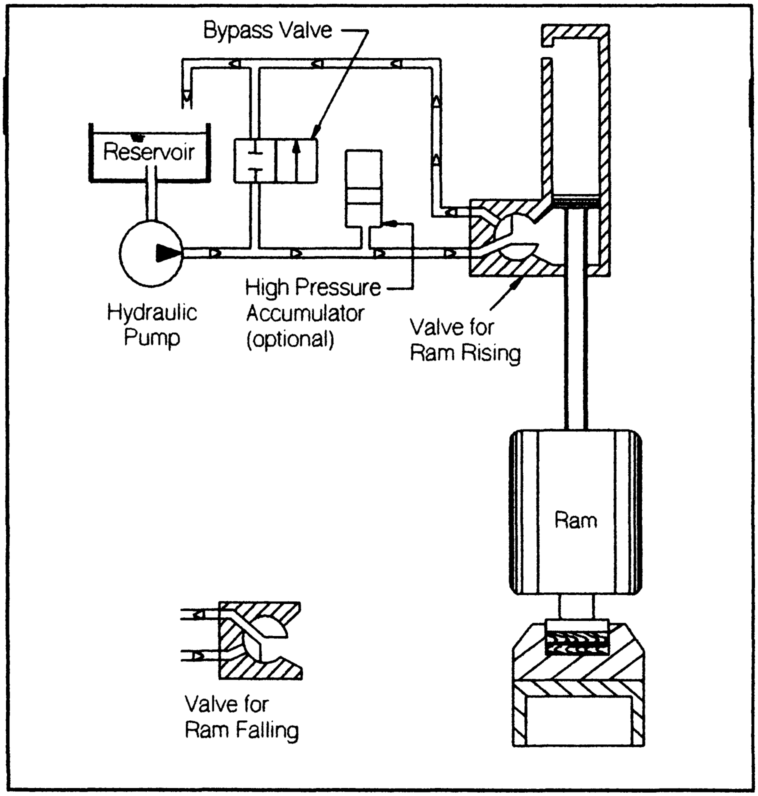
OPEN END DIESEL HAMMER (SINGLE-ACTING)



CLOSED END DIESEL HAMMER (DOUBLE-ACTING)

double acting diesels, all manufacturers provide a gauge which measures the maximum pressure in the air chamber above the ram (the "bounce chamber"). For a given hose diameter and length, this maximum pressure corresponds to the hammer energy which can be read off a chart; it is important to record this maximum bounce chamber pressure and realize that the specified termination criteria will probably also be given based upon a specified bounce chamber pressure for a given hose diameter and length.

For the newer hydraulic hammers, they may be easily adjusted to operate at continuously variable ram strokes. In most hydraulic hammers, the ram is visible and stroke height can be estimated; however, some models are double-acting. After the hammer senses the ram impact, power is applied for a user selected time which, if adjusted, can alter the stroke height.



HYDRAULIC HAMMER SCHEMATIC

Many of these hammers have a built-in readout device which displays the kinetic energy just prior to impact, and thus provides the Contractor and Engineer a means for inspection and control. The energy readout device is a definite advantage which provides very valuable information for the Engineer. It is essential to record the stroke or energy readout with the observed blow count, or to visually observe and record the stroke. Occasionally the readout device may malfunction; any additional observation of stroke and blows per minute should be noted when possible.

The term "efficiency" can cause some confusion as it means different things in different contexts. For wave equation analysis, the "hammer efficiency" represents effectiveness during the fall in converting potential energy to kinetic energy with losses generally due to friction; this wave equation hammer efficiency is a computer input and is generally a rather high value (typically .67 for air hammers and .80 for diesels). The term "transfer efficiency" is sometimes mistakenly used instead of the more correct term "energy transfer ratio" which is the ratio of energy transferred to the pile divided by the manufacturer's energy rating for the hammer. (The energy transferred to the pile may be measured by dynamic pile testing or approximately estimated by a wave equation analysis.) If there is any doubt about hammer performance and energy transfer ratio, then suggesting that dynamic testing be performed is probably the best solution. The measuring and recording of as many definite observations as possible may result in a smoother and more productive pile installation, and is less likely to result in a confrontation or dispute headed for a costly court room resolution.

There is also a wide variety of vibratory pile drivers; they may have different operational characteristics, have different sizes and operating frequencies, and be powered by either hydraulics or electricity. Specific formulas to determine bearing capacity have been developed for specific vibratory pile drivers on a specific job site, but none of the formulas has been generally accepted by the foundation industry. While the primary use of vibratory pile drivers at this time is restricted to installing H-beams or sheet piles for soil retention, there is expanding use for installing H-beam or open end steel pipe bearing piles. Displacement or open profile piles may be only partially installed by the vibratory pile driver followed by final driving with a conventional impact hammer to the established driving criteria for the impact hammer. Piles may be fully installed by the vibratory pile driver when driven to a specified toe elevation in a well defined soil strata; at least one vibrated pile should then be statically tested to the desired capacity to confirm the design embedment. The Inspector should record the time required to install each pile, preferably with the same penetration rate as a function of length, and particularly at the end of installation, as the statically tested pile. Vibratory pile drivers are frequently used for pile extraction purposes when the pile was driven in the wrong location; if pile damage is suspected, the vibrator may extract the pile for visual inspection.

The Inspector must verify that the hammer is performing properly. While this guide has offered a few ideas and suggestions and items which should be recorded, it is not intended as a complete inspection manual for the hammer. Since the hammer is such a critical tool for the installation and inspection of the pile driving process, a more thorough understanding is beneficial. The Inspector should obtain as much information from the manufacturer as possible and further obtain and review a copy of the ***Pile Inspector's Guide to Hammers*** for a more complete discussion of the operating characteristics of the hammer on the job.

PILE DRIVING MACHINERY AND EQUIPMENT

This section basic descriptions of the equipment the Inspector will encounter on typical pile projects. Since rigging practices vary all over the country, there are considerable differences in the equipment used by various Contractors.

Crane

Most pile driving Contractors use a crane with 400 to 1500 kN (40-150 ton) lifting capacity depending on the size and length of piles being installed and weight of the hammer and pile. The boom consists of a head section where the boom tip is located, a heel section which is attached to the base of the crane, and the inserts of varying length between. Some Contractors relace or double lace the boom sections when torsion or twist is expected to be exerted on the boom, such as when augering is required. With fixed leads, the boom length is usually about equal to the pile length and shorter than the lead length by the length of the hammer. There are usually at least two lifting drums on each crane. The cable diameter on each drum varies depending on the lift to be made in accordance with the crane manufacturer's recommendations. Some cranes have a third drum which is used for a variety of tasks such as to pick up the pile, an auger or a jet pipe. There are dedicated pile driving machines built around large excavator type base machines; this type equipment is more likely to be encountered outside North America.

Leads

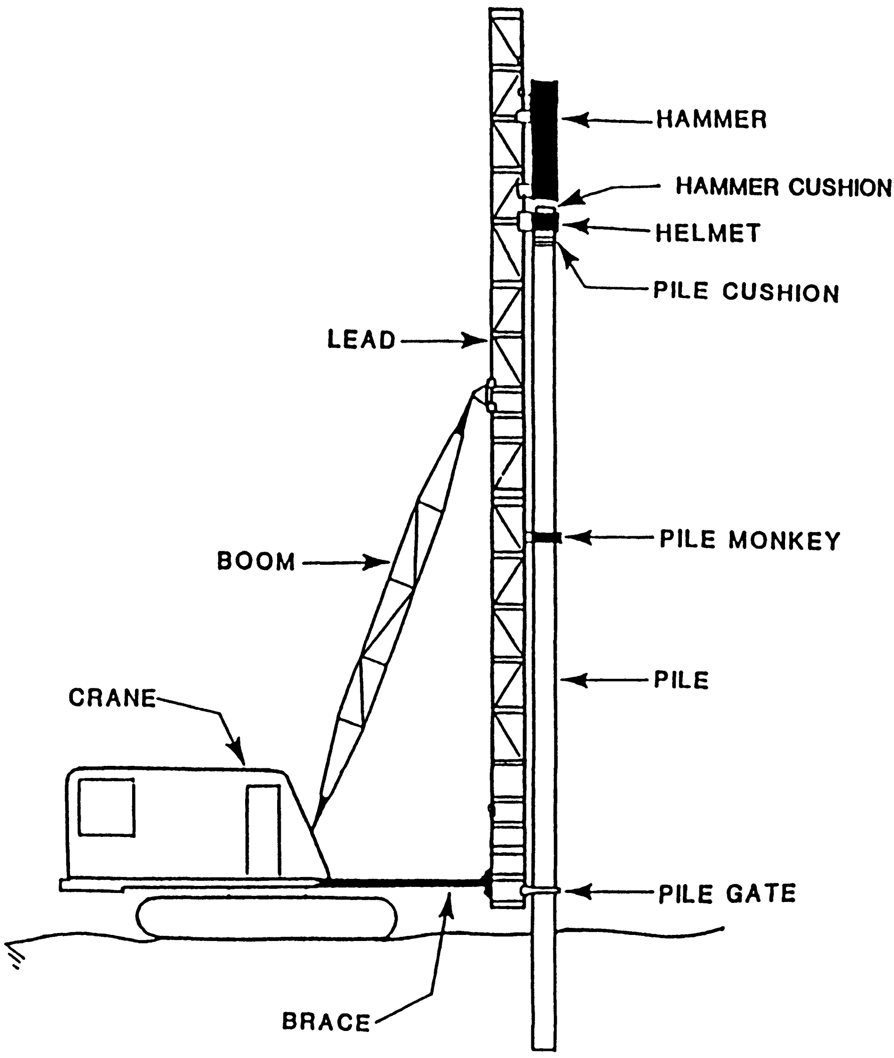
Sometimes called "leaders" or simply "guides," all leads guide the hammer and pile during the full length of driving, concentrically align the pile and hammer, and control the plan location and inclination of installation of each pile. To maximize energy transfer, the cable to the hammer is slack during driving and the pile supports the axial component of the hammer weight during driving, while the leads support the horizontal component during inclined driving. Great care is usually taken to align the pile to the desired inclination prior to and at the very early stages of driving. However, if the pile wanders from the desired inclination during driving, it may be best to allow this deviation rather than forcing the pile back which could result in damage.

Leads are straight, often consisting of two beams held parallel by angle-iron bracing, forming a "box" or "U" shaped arrangement. Between these beams located in the front of the box rides the hammer which is suspended by cable. Leads should be at least as long as the sum of the hammer length and length of the longest pile segment to be driven. Most box leads are approximately 1.2 m (4 ft) deep and about the same width with the space between the main parallel beams ("hammer rails") being as much as from 500 to 800 mm (20 to 30 inch), depending on the hammer and pile diameters to be used.

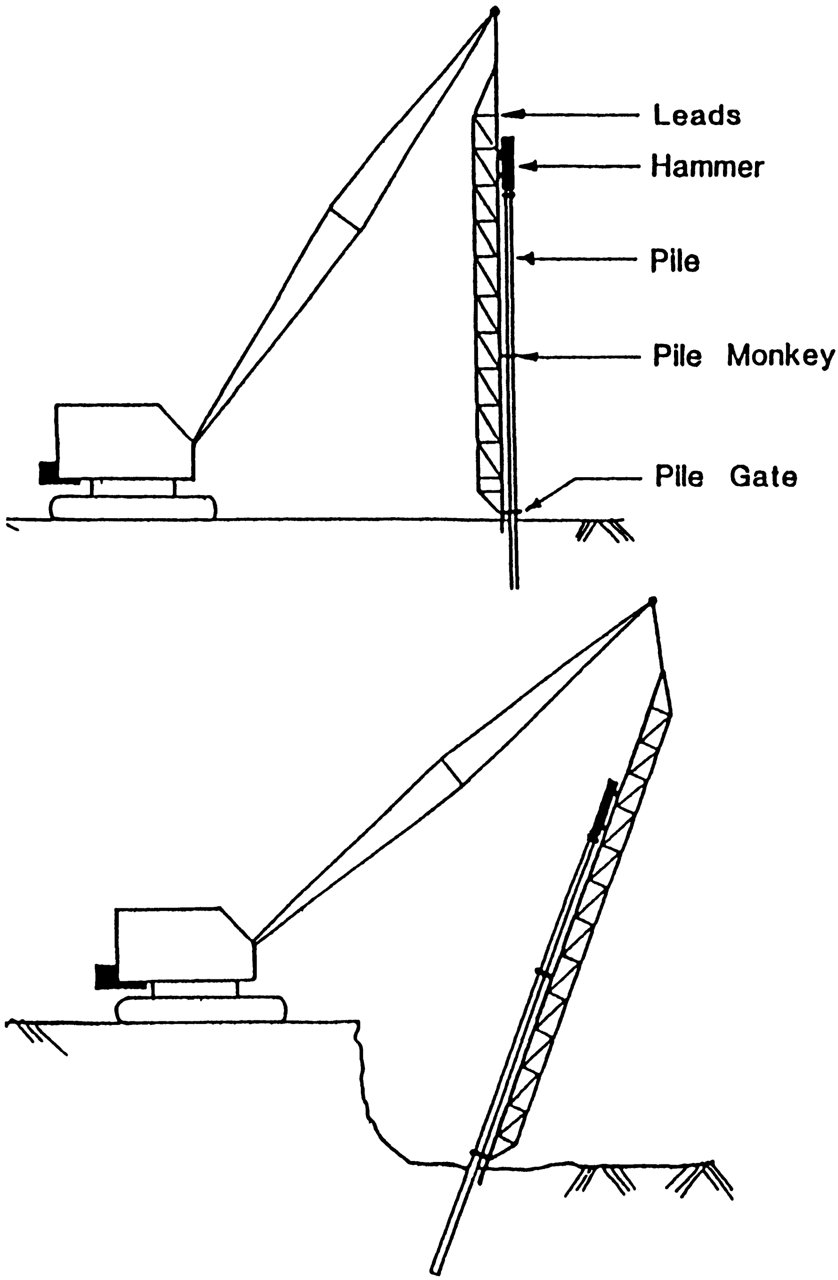
Other types of leads, particularly in use with diesel or hydraulic hammers, are not of the "box" type; they may consist of a pipe section, a heavy H section, or a compact laced spacial truss system. On these alternate lead designs, the hammer rides on the front face of the leads rather than between the rails. These leads are smaller and therefore have the advantage of being lighter weight than the box leads.

If leads are of the "Fixed" type, at some point approximately 2/3 above the bottom, the leads are "pinned" to the boom tip so that about 1/3 of the leads is freely extending above the boom tip. They may also be connected to the base of the crane at the bottom of the leads by a member called the "brace". Other names for this member are the "A" frame, the "spotter", the "spreader", the "apron", the "spider," the "kicker brace", the "strong back", or the "bottom brace". In a fixed lead situation this "brace" plays an important role, in that it stabilizes the leads from twisting and makes the crane and leads act better as a unit. It can be made up of several sections which telescope into each other so that the bottom of the leads can be pushed out or pulled in for proper pile inclination. These telescoping sections can be extended or retracted by hydraulics or with cables and a tugger hoist; the brace can be maneuvered without changing the position of the boom. The brace may also be equipped with a member horizontally perpendicular to the brace which will allow for a side inclination; this member is usually referred to as a "moonbeam".

Fixed leads generally result in a heaver total weight, and provide a more stable operation. The inclination of a pile can often be better controlled and the use of a template is generally not necessary with this type system. The hammer is suspended by a cable which comes from the drums up the back of the boom, through a sheave on the back of the boom, then up the leads above to another sheave on near the top of the leads, to another sheave directly above the space between the parallel beams or hammer guides, then immediately down to the top of the hammer. If the hammer is heavy, that cable may go through a sheave on the top of the hammer and then back up to the top of the leads where it is dead-ended. The latter is called a "two-part line". A second crane line is used to pick up the pile. A variation on "fixed leads" is the "semi-fixed leads" or "vertical travel leads" where the attachment point for the leads to the boom tip is free to move; this system requires an extra crane line to control the elevation of the leads.



FIXED EXTENDED LEAD SYSTEM
Sketch from Pile Dynamics Inc. Publication
Note: Semi-Fixed Leads have added ability to move in the up-down direction



SWINGING LEADS
Sketch from Pile Dynamics Inc. Publication

As an alternative to fixed leads, the so-called "swinging leads" have the whole lead assembly supported by a cable from one drum and the hammer simply suspended from the boom tip by different cable from another drum. In this instance there usually is a third drum on the crane to pick the pile. Alternatively, the pile can be lifted by a short choker cable attached to the bottom of the hammer. Occasionally, the leads are suspended by a length of heavy cable simply connected to the boom tip and to the top of the leads by use of shackles. The main advantage of swinging leads is their relatively light weight and flexibility in use; the crane may often be considerably smaller and the reach is generally increased. They may be more difficult to control, are more labor intensive, and may take longer to position than fixed leads. Swinging leads have "points" at the bottom of the leads which are lowered (dropped) into the ground to provide a point of fixity.

Generally for larger piles driven over water by a crane on a barge, "offshore" leads may be used. These leads are relatively short and primarily are used to align the hammer with the pile head. The hammer is suspended from these leads by a short cable attached to the leads; the leads are supported by a single line from the crane. The bottom of offshore leads has a circular conical collar to facilitate mating of the hammer with the pile head. They must be lowered as the pile is driven to follow the pile so that the hammer weight is supported by the pile rather than by the leads. These leads do not provide any fixity since they do not touch the ground. The pile location and alignment are controlled generally by having a "template" through which the pile is inserted and which provides the lateral support.

External Power Source

The ultimate power source of most cranes is a diesel engine mounted inside the crane; hydraulic hammers require a hydraulic power pack, consisting of a hydraulic pump powered by a diesel engine. In the case of dedicated pile rigs, common outside North America, the crane power source also may provide power for the hydraulic hammer. Diesel hammers are self contained in that they are an internal combustion engine and burn fuel stored in a tank attached to the hammer. The power source for air or steam hammers is either an air compressor or an external steam generator. Compressors are today far more common; boilers are generally restricted to large offshore barge mounted rigs and are in declining usage at the present. In either case, the compressor or boiler is either on the ground nearby the crane, or often mounted on the rear of the crane to serve as the counterweight as well as to increase the mobility of the crane.

Most land pile driving operations using air-steam hammers use air compressors as the power source because of their convenience. They can be towed to and around the site. They are diesel powered and can be fueled with or from the same supplier as the crane. Compressors range in size and must be of sufficient capacity to supply the hammer.

Different hammers require different capacity compressors, although using a larger than required compressor is always acceptable. Some Contractors have an "accumulating storage tank" in line between the compressor and hammer; this generally improves the hammer performance. The size and length of hoses may affect the hammer performance. The air volume or pressure supplied to the hammer should usually be adjusted so that the hammer operates at its full stroke at the end of driving when the termination criteria is achieved. The compressor also supplies a lubricant to the hammer through the air hoses.

Boilers vary in physical size and capacity, but must be of sufficient size when used to power the hammer. One drawback of using a boiler is that the water supply may be quite a distance from the boiler and if a hose is stretched to the source, the filling operation impedes the mobility of the rig. Boilers require a longer preparation time before they can reliably provide power as the system must be brought up to a stable operating temperature. Another drawback is that the height, weight and size of the boiler.

Followers

When it is necessary and allowed to drive the pile head a short distance below grade or under the water surface, a follower is employed. Followers are usually made of a steel pipe or H section and are inserted between the hammer and pile head. Lengths may vary from 1 to 10 m (3 to 30 ft) or more depending on the specific requirements of the site. When used to drive concrete piles, the pile cushion is generally placed between the follower and the pile. Followers should be designed with a basic stiffness which is similar to or in excess of the stiffness of the pile to be driven for best energy transfer and so that stresses in the follower are not excessive. The adequacy of follower design can be checked by a wave equation analysis. Only follower designs approved by the Engineer should be used. Since the follower often affects the driveability, the driving or termination blow count criteria may need modification. Many specifications prohibit the use of followers.

Augering, Jetting, and Spudding

These methods may be required when driving is difficult and a minimum penetration is required, where obstructions are present, to reduce vibrations, or to avoid densification and thus extremely hard driving when many closely spaced piles must be installed, or where the soil will not accommodate displacement piles without causing heave or lateral pressure problems. It should be noted that the specifications may require or prohibit these tools on the project site; when allowed, there may be specific limitations imposed such as maximum size or depth which must be followed by the Contractor. The Inspector must know the restrictions or limitations and should record observations of their use in the installation record of each pile.

Augers are drills which can remove a soil column prior to pile installation. Usually the auger diameter is less than the pile diameter, and the auger depth is less than the final pile depth. Many Contractors mount permanent brackets on the side of the leads to accommodate augers. The augers are powered by air, hydraulics, or electricity. Augers are usually suspended from either a third drum, or from a separate winch located on the crane. Some Contractors suspend the auger directly in the leads in place of the hammer, particularly on a large multiple crane job sites where augering for many or all piles is either required by specification or desirable for production. The Inspector must document the auger diameter and depth for each pile.

Jetting will often be used when the soil is a dense granular material and often is performed on barges or other operations in near-shore environments. Jetting is generally more difficult to control than is augering. The water jet under great pressure washes out the soil in advance of or along side the pile. Preferably jetting should be done through tubes installed in the pile center using specially designed nozzles at their bottom. Jetting via separate pipes placed alongside the pile can cause the pile to drift laterally or bend excessively. A pump at the water source pumps water to and through the jet pipe, which is suspended like the auger. As jetting is generally more difficult to control than augering, care must be taken to not jet to excess as the removal of too much material may adversely affect the pile capacity; the Inspector must observe and record the jetting process. There may be restrictions imposed by local authorities or the contract documents due to jetting spoils polluting the water.

Another technique is wet drilling, which combines the augering and jetting methods. A bladed bit with water nozzles is mounted on the end of a hollow Kelly bar through which water is circulated by a jet pump. The bit is advanced by drilling and the jet washing through soil or obstructions.

Where the upper soils consist of miscellaneous fill, instead of augering or jetting, the Contractor may resort to spudding, particularly if the depth of required hole is modest. A "spud" can be a short section of concrete-filled pipe, a short length of timber pile, or a section of H-beam which is raised by a crane line and dropped. The impact of the spud with the soil creates a hole. The difficult part of spudding is that a spud may not be able to be pulled when installed too deep.

With any of these driving aids, the Inspector should record the time and type of assistance method and any unusual observations. The record should include as a minimum the depth of the preformed hole, the depth the pile penetrates under its own weight and the weight of the hammer, and the number of blows per unit penetration during the subsequent driving. The pile should be driven past the bottom of the disturbed soils.

REFERENCES

The following publications by DFI will be of specific help to the Inspector. It is definitely recommended that the Inspector obtain these publications for reference.

Glossary of Foundation Terms
(DFI Equipment Applications Committee, 1981) Listing of many terms and explanation of these terms which Inspector may find in use on a pile driving site.

Pile Inspector's Guide to Hammers
(DFI Equipment Applications Committee, Second Edition 1995) Excellent recourse for Inspector for the operation of common pile driving hammers, and corresponding checklists to assure their conformance to manufacturer's specifications, or troubleshooting sub-standard performance..

Other publications by DFI which may provide further insight or be of benefit to the Inspector:

Driven Foundation Piling and Accessories Catalog
(DFI Driven Pile Committee, 1995) A compilation of information and specifications.

Dynamic Monitoring and Analysis of Pile Foundation Installations
(DFI Short Course text by P. Hannigan, 1990) A summary of dynamic pile testing with examples and explanations to guide basic understanding of these methods and results.

Guidlines for Interpretation and Analysis of the Static Loading Test
(DFI Short Course text by B. Fellenius, 1990) A good review of static tests and results.

Guidelines for Static Pile Design
(DFI Short Course text by B. Fellenius, 1991) Discussions for designer on load transfer, capacity estimation, capacity change with time, settlement computations, and allowable stresses.

Guidelines for Writing Construction Specifications for Piling
(DFI Short Course text by B. Fellenius, 1990) Follows Public Works Canada and Canadian National Master Specification with explanation and advice to designer, to reduce disputes.

Reference is further made to the following ASTM Standards which the project may specify and the Inspector may therefore need to follow or observe.

ASTM D25	Standard Specification for Round Timber Piles
ASTM D1143	Standard Test Method for Piles Under Static Axial Compressive Load
ASTM D1586	Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils
ASTM D2487	Standard Classification of Soils for Engineering Purposes
ASTM D2488	Standard Practice for Description and Identification of Soils
ASTM D2555	Standard Method for Establishing Clear Wood Strength Values
ASTM D2899	Standard Method for Establishing Design Stresses for Round Timber Piles
ASTM D3689	Standard Test Method for Individual Piles Under Static Axial Tensile Load
ASTM D3966	Standard Test Method for Piles Under Lateral Loads
ASTM D4945	Standard Test Method for High-Strain Dynamic Testing of Piles
ASTM D5882	Standard Test Method for Low-Strain Integrity Testing of Piles

Finally, further additional reference material on pile driving can be obtained from numerous standard textbooks on soil mechanics or foundation engineering and manuals. The following are considered as particularly good reference materials:

Design and Construction of Driven Pile Foundations
Manual prepared for US DOT Federal Highway Administration, FHWA-HI-96-033 by Goble Rausche Likins and Associates (1996). The first volume reviews design; the second volume reviews field construction and is particularly relevant to the Inspector. This publication is among the most complete texts anywhere.

Design of Pile Foundations
Technical Engineering and Design Guides as adapted (by ASCE) from the US Army Corps of Engineers (1993). EM 1110-2-2906.

Inspector's Qualification Program for Pile Driving Inspection
Manual for Florida Department of Transportation by Williams Earth Sciences, Inc. (1995)

Recommendations for Design, Manufacture and Installation of Concrete Piles
American Concrete Institute ACI 543R (1986)

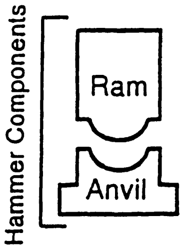
Contract No.: ____________________ Structure Name and/or No.: ____________________

Project: ____________________ ____________________

____________________ Pile Driving Contractor or Subcontractor: ____________________

County: ____________________ ____________________

(Piles driven by)



Hammer

Manufacturer: ____________ Model No.: ____________

Hammer Type: ____________ Serial No.: ____________

Manufacturers Maximum Rated Energy: ____________ (Joules)

Stroke at Maximum Rated Energy: ____________ (meters)

Range in Operating Energy: ________ to ________ (Joules)

Range in Operating Stroke: ________ to ________ (meters)

Ram Weight: ____________ (kg)

Modifications: ____________________

____

____

Striker Plate

Weight: ____________ (N) Diameter: ____________ (mm)

Thickness: ____________ (mm)

Hammer Cushion

Material #1	Material #2 (for Composite Cushion)
Name: ____________	Name: ____________
Area: ____________ (cm²)	Area: ____________ (cm²)
Thickness/Plate: ____________ (mm)	Thickness/Plate: ____________ (mm)
No. of Plates: ____________	No. of Plates: ____________

Total Thickness of Hammer Cushion: ____________

Helmet (Drive Head)

Weight: ____________ (kN)

Pile Cushion

Material: ____________________

Area: ____________ (cm²) Thickness/Sheet: ____________ (mm)

No. of Sheets: ____________

Total Thickness of Pile Cushion: ____________ (mm)

Pile

Pile Type: ____________________

Wall Thickness: ____________ (mm) Taper: ____________

Cross Sectional Area: ____________ (cm²) Weight/Meter: ____________

Ordered Length: ____________ (m)

Design Load: ____________ (kN)

Ultimate Pile Capacity: ____________ (kN)

Description of Splice: ____________________

____

Driving Shoe/Closure Plate Description: ____________________

____

Submitted By: ____________ Date: ____________

Telephone No.: ____________ Fax No.: ____________

PILE AND DRIVING EQUIPMENT DATA FORM

From FHWA Publication "Design and Construction of Driven Pile Foundations"

DAILY INSPECTION REPORT

Project No.: ____________________

Date: ____________________

Project: ____

Weather Conditions: ____

Contractor: ____

Contractor's Personnel Present: ____

____

____

Equipment Working:____

____

Description of Work Accomplished: ______________________________________

____

____

____

Special Persons Visiting Job: ____

____

Test Performed: ____

____

Special Comments: ____

____

____

TYPICAL DAILY INSPECTION REPORT

PILE LOAD TEST

Sheet ______
of ______

DATE ______ PROJECT: ______

PILE NO. ______ ______

DESIGN LOAD ______ CONTRACTOR: ______

TYPE OF PILE ______ JOB NO: ______

INCREMENT NO: ______ LOAD ______ PRESSURE: ______ H. I. ______

TIME:	GAUGE 1	GAUGE 2	GAUGE 3	WIRE INCHES	ROD ft	▲ GAUGE (INCHES) 1	▲ GAUGE (INCHES) 2	▲ GAUGE (INCHES) 3	▲ WIRE INCHES	▲ ROD ft	▲ ROD in.
1/2 min.											
1											
2											
4											
8											
12											
16											
20											
24											
28											
32											
36											
40											
44											
48											
52											
56											
60 1 hr.											
64 1 hr - 4 min.											
68											
72											
76											
80											
84											
88											
92											
96											
100											
104											
108											
112											
116											
120 2 hrs.											

TYPICAL PILE LOAD TEST REPORT

PILE DRIVING LOG

STATE PROJECT NO.: ______________________ DATE: ____________

JOB LOCATION: ______________________

PILE TYPE: ________ LENGTH: ________ BENT/PIER NO.: ________ PILE NO.: ________

HAMMER: ________ ENERGY/BLOW: ________ OPERATING RATE: ________ HELMET WEIGHT: ________

REF. ELEV.: ________ PILE TOE ELEV.: ________ PILE CUTOFF ELEV.: ________

PILE CUSHION THICKNESS AND MATERIAL: ______________________

WEATHER: ________ TEMP.: ________ START TIME: ________ STOP TIME: ________

METERS	BLOWS	STROKE / PRESSURE	REMARKS	METERS	BLOWS	STROKE / PRESSURE	REMARKS
0 - 0.25				8.00 - 8.25			
0.25 - 0.50				8.25 - 8.50			
0 50 - 0.75				8.50 - 8.75			
0.75 - 1.00				8.75 - 9.00			
1.00 - 1.25				9.00 - 9.25			
1.25 - 1.50				9.25 - 9.50			
1.50 - 1.75				9.50 - 9.75			
1.75 - 2.00				9.75 - 10.00			
2.00 - 2.25				10.00 - 10.25			
2.25 - 2.50				10.25 - 10.50			
2.50 - 2.75				10.50 - 10.75			
2.75 - 3.00				10.75 - 11.00			
3.00 - 3.25				11.00 - 11.25			
3.25 - 3.50				11.25 - 11.50			
3.50 - 3.75				11.50 - 11.75			
3.75 - 4.00				11.75 - 12.00			
4.00 - 4.25				12.00 - 12.25			
4.25 - 4.50				12.25 - 12.50			
4.50 - 4.75				12.50 - 12.75			
4.75 - 5.00				12.75 - 13.00			
5.00 - 5.25				13.00 - 13.25			
5.25 - 5.50				13.25 - 13.50			
5.50 - 5.75				13.50 - 13.75			
5.75 - 6.00				13.75 - 14.00			
6.00 - 6.25				14.00 - 14.25			
6.25 - 6.50				14.25 - 14.50			
6.50 - 6.75				14.50 - 14.75			
6.75 - 7.00				14.75 - 15.00			
7.00 - 7.25				15.00 - 15.25			
7.25 - 7.50				15.25 - 15.50			
7.50 - 7.75				15.50 - 15.75			
7.75 - 8.00				15.75 - 16.00			

PILE INFORMATION: ______________ MANUFACTURED BY: ______________

WORK ORDER NO.: ______________ DATE CAST: ______________

MANUFACTURER'S PILE NO.: ______________ PILE HEAD CHAMFER: ______________

PILE TOE CHAMFER: ______________ SIGNATURE: ______________

TYPICAL PILE DRIVING LOG (Metric Units)