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CHAPTER TWO: *FOUNDATIONS*

This chapter includes information on the inspection of bridge foundations. The two activities most associated with the construction of bridge foundations are structure excavation and, when necessary, pile driving. Both activities are conducted to construct a foundation of adequate bearing that does not shift or sink under the loads that are supported. The soils at natural ground level rarely have sufficient bearing to provide this support. Through structure excavation, the unsuitable material at ground level is removed to expose the denser, more compact material below.

In some cases, the foundation material exposed through excavation has adequate bearing. The footings for the bridge substructure units may be constructed and poured directly on the floor of the excavation. In many locations, however, there is not material of sufficient bearing for the footings. In those cases, foundation piling may be driven to provide the necessary support.

Section **206** outlines the requirements for structure excavation and Section **701** describes the requirements for piling.

STRUCTURE EXCAVATION

Unless otherwise specified, structure excavation as a pay item includes all associated activities necessary to complete the work, including providing drainage, bracing, sheeting, and other incidental items. Backfilling the footings and disposing unsuitable material are also activities commonly conducted and paid for under the general work item of structure excavation.

SOIL BORINGS

Before excavation for the footings begins, INDOT personnel investigate the underlying soils at the footing locations through soil borings. The soil borings indicate the types of materials below the surface and the elevations at which they occur.

The type of material at the footing locations determines, to a large degree, the bottom-of-footing (BOF) elevation and whether or not piling is required.

The contract plans include a boring data sheet that illustrates where the borings were taken in relation to the structure (Figure 2-1). In addition, a boring profile of each site indicates the types of materials encountered and the elevations at which they occurred. Technicians are required to note the type of material found at the planned BOF elevation. If the actual excavation contains material that differs greatly from what is shown in the profiles, the excavation limits and the footing design may have to be revised. The BOF elevation on the profiles is required to be marked, if not already noted.

CROSS SECTIONS

Following the initial staking of the site, contract personnel are required to take cross-sections of the footing locations to determine the volume of material that is required to be removed during the excavation operation. Once the excavation is complete, additional cross-sections are taken to measure the volume of material actually removed. Technicians are required to assure that enough cross-sections are taken to insure accuracy. The Contractor is paid according to the volume of material removed and the class of excavation required.

CLIENT	Indiana Department of Transportation	BORING #	TB-2
PROJECT NAME	State Road 18 Bridge over Salmon Ditch	JOB #	86.70860.0305
PROJECT LOCATION	Benton County, Indiana	STATION	71+26 Line A
		OFFSET	12 ft Right

DRILLING and SAMPLING INFORMATION

Date Started	8/13/03	Hammer Wt.	140 lbs.
Date Completed	8/14/03	Hammer Drop	30 in.
Drill Foreman	R. Wilkins	Spoon Sampler OD	2.0 in.
Inspector	S. Marcum	Rock Core Dia.	-- in.
Boring Method	HSA - Truck	Shelby Tube OD	-- in.

SOIL CLASSIFICATION

SURFACE ELEVATION 711

Soil Classification	Stratum Depth, ft
0.5 ft Asphalt, 0.5 ft Base (Visual)	1.0
Black, moist, medium stiff, clay with cinders (FILL) (Lab No. 4) A-7-6	5.5
Brown and gray, moist, very loose to loose SANDY LOAM (Lab No. 1) A-6 (3)	12.5
Gray, very moist, very stiff to hard SILTY LOAM (Lab No. 2) A-4 (3)	33.0
Gray, severely weathered SHALE	33.5
Bottom of Test Boring at 33.5 ft	

TEST DATA

Sample No.	Sample Type	Standard Penetration Test, Blows per 6 in. Increments	Moisture Content, %	Pocket Penetrometer PP-tsf
1	SS	4/4/5		
2	SS	4/3/4		
3	SS	2/2/2		
4	SS	4/5/5		
5	SS	4/9/9		2.0
6	SS	10/10/14		4.5+
7	SS	10/14/17		4.5+
8	SS	11/16/19		4.5+
9	SS	50/0.1'		

Remarks

Ground surface elevation estimated from plans prepared by H. Stewart Kline & Associates

Borehole backfilled in accordance with INDOT "Aquifer Protection Guidelines"

Borehole plugged with concrete

Traffic control required. Set-up No. 4

Auger refusal at 33.5 ft

Sample Type

- SS - Driven Split Spoon
- ST - Pressed Shelby Tube
- CA - Continuous Flight Auger
- RC - Rock Core
- CU - Cuttings
- CT - Continuous Tube

Depth to Groundwater

- Noted on Drilling Tools 12.5 ft.
- At Completion 11.0 ft.
- After 24 hours 8.0 ft.
- Cave Depth 27.0 ft.

Boring Method

- HSA - Hollow Stem Augers
- CFA - Continuous Flight Augers
- DC - Driving Casing
- MD - Mud Drilling
- HA - Hand Auger

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Figure 2-1. Test Boring Log

CLASSES OF STRUCTURE EXCAVATION

The class of excavation required is determined by the nature of the material to be removed and the elevation at which the material is found. Sections **206.01-206.05** describe four classes of excavation.

Class X Excavation

Class excavation requires one or more of the following conditions:

1) The presence of solid rock that requires blasting or the use of pneumatic tools or their equivalent to remove the rock

2) The presence of loose stones or boulders that are more than 1/2 yd^3 in volume

3) The presence of concrete, masonry, or similar materials that are part of an old structure that was not indicated on the plans

4) The presence of timber grillages, old piling, buried logs, stumps or other similar materials that extend beyond the limits of excavation and are required to be cut off

Wet Excavation

The plans usually indicate the upper limit of wet excavation with a horizontal line that represents the water line. Wet excavation requires the removal of material from that line down to the planned bottom-of-footing elevation. If the upper limit of wet excavation is not shown on the plans, an elevation of one foot above the low water level indicated on the plans may be used instead.

Dry Excavation

Dry excavation involves removal of material above the upper limit of wet excavation.

Foundation Excavation (Unclassified)

Foundation excavation includes all required excavation that is not classified in the proposal as either wet excavation or dry excavation. Foundation excavation does not include Class X excavation.

Structure excavation often includes a combination of the different classes. When there are overlapping classes of excavation, each class is required to be measured and paid for separately and in conformance with the Specifications.

Except for wet excavation, all classes of structure excavation are measured and paid for according to the number of cubic yards of material that is removed from the original position and that is below the limits of roadway excavation. Wet excavation is measured and paid for in terms of the theoretical amount of material bounded by the planned bottom-of-footing elevation, the upper limit of wet excavation, and the vertical planes 18 in. outside of the neat lines of the footing dimensions indicated on the plans.

LIMITS OF EXCAVATION

Structure excavation for footings is required to conform closely to the dimensions indicated on the plans and allow enough room for the construction of any necessary forms, bracing, or shoring. In most cases, the amount the Contractor may actually be paid for is 18 in. outside the neat lines of the planned dimensions. The Contractor may remove more than that; however, in most cases this material is not paid for.

If the excavation is material that is markedly different from what is shown on the soil borings data sheet, the Technician is required to immediately notify the PE/PS of the discrepancy. The footing may require redesign. This is especially important as the excavation gets closer to the planned bottom-of-footing elevation.

To guard against unexpected problems with a foundation, Section **206.11** contains provisions to pay the Contractor if lowering the footings is required. This section describes the procedures to pay for the additional excavation for up to 4 ft below the planned bottom-of-footing elevation. Excavation exceeding 4 ft below the planned bottom-of-footing elevation is paid for as additional work. (Sections **104.03** and **109.05**). Where a footing or a portion of a footing is required deeper than the elevation indicated on the plans, such additional excavation (except for class X) that is carried down to a plane which is 4 ft or less below the bottom of footing or as indicated on the plans, is paid for as extended dry excavation, extended wet excavation, or extended foundation excavation unclassified. The price is determined by multiplying the contract unit price for dry excavation, wet excavation, or foundation excavation unclassified, respectively, by the following factors:

1) For footings or portions lowered not more than 1 ft, the factor is 2.0

2) For footings or portions lowered more than 1 ft and not more than 2 ft, the factor is 2.5

3) For footings or portions lowered more than 2 ft and not more than 3 ft, the factor is 3.5

4) For footings or portions lowered more than 3 ft and not more than 4 ft, the factor is 5.0.

DISPOSAL OF EXCAVATED MATERIAL

Excavated material is required to be kept away from the edge of the excavated area to guard against cave-ins. A good rule of thumb is to store the spoil pile no closer than a distance equal to the depth of the excavation. For example, the spoil pile is kept at least 5 ft away from the edge for an excavation that is 5 ft deep.

The Contractor is required to also guard against runoff and erosion, especially in areas near rivers or streams. Erosion and pollution controls indicated on the plans are required to be implemented and maintained. Requirements for Temporary Erosion and Sediment Controls are discussed in Section **205**. The plans, special provisions, and standards are good resources for any special erosion control measures that are required. The Technician is required to be familiar with the requirements of the Erosion and Sediment Control Plan. The Department of Natural Resources (DNR) permit also has additional erosion control requirements that are required to be followed. These requirements are required to be reviewed prior to any foundation excavation. The Erosion and Sediment Control Plan and the DNR Permit are usually located in the Special Provisions of the contract documents.

Excavated material, if suitable, is used as backfill once the footings have been built, or to construct required embankments. Suitable material is required to meet the gradation requirements in Section **211.02**. Material that meets these requirements is classified as B borrow. Unless otherwise specified, B borrow is required in backfilling excavations for abutments, wingwalls, and piers up to the original ground line. Compaction requirements and methods of measurement for structure backfill are included in Sections **211.04-211.09**.

Excavated material that is unsuitable for backfill or embankment purposes is required to be kept separate from suitable material and disposed of carefully to avoid polluting nearby streams. If unsuitable material is removed from the right-of-way, this material is required to be placed in a location out of view from the traveled way. Written permission of property owners is required before placing or storing material on private property.

PREPARATION OF FOUNDATION SURFACES

If the bottom of the excavation consists of rock or other hard material, the bottom of the excavation is prepared by first removing all loose material, then cleaning and cutting the floor of the excavation down to a firm surface. Any seams or voids in the bottom of the excavation are required to be cleaned and filled with concrete, cement mortar, or grout. Ideally, the surface is level. In some cases, the bottom of excavation surface is stepped or notched so that the concrete footing keys into the rock foundation. This procedure guards against horizontal movement by the footing.

When the bottom of the excavation does not consist of rock or other hard material, and when foundation piling is not used, bottom of the excavation preparation is done somewhat differently. The excavation is required to stop just short of the planned bottom-of-footing elevation. Final excavation is not completed until the Contractor is ready to pour the footing. At that time, the Contractor is required to complete the excavation, leaving the floor smooth and level and taking care not to disturb the foundation surface. The Technician is required to assure that the prepared foundation is exposed to the weather no longer than necessary.

For footings that are supported on piling, excavation is required to be completed to the planned bottom-of-footing elevation before pile driving begins.

DE-WATERING EXCAVATIONS

Concrete for footings is ideally placed dry. Water in the foundation alters and weakens the concrete. The Contractor may de-water an excavation by pumping or by constructing a sump to collect water outside the footing location. When a sump is constructed outside the pay limits of an excavation, the limits are extended to include the actual lines of the sump. The additional pay limits, however, may not exceed 4 % of the area of the footing involved. If they do, the Contractor is not paid for the excess excavation.

When groundwater continually enters the excavation from below, a layer of concrete known as a foundation seal may be required to seal the water.

Cofferdams (Figure 2-2) or temporary dikes are often required when excavation work is done in stream channels, in unstable soils that may cave in without proper support, or near existing structures that may be disturbed by the excavation operation. Section **206.09** outlines the construction requirements for the use and design of cofferdams and of temporary dikes. Cofferdams and temporary dikes are paid for either as a part of the structure excavation pay item or as a separate pay item.

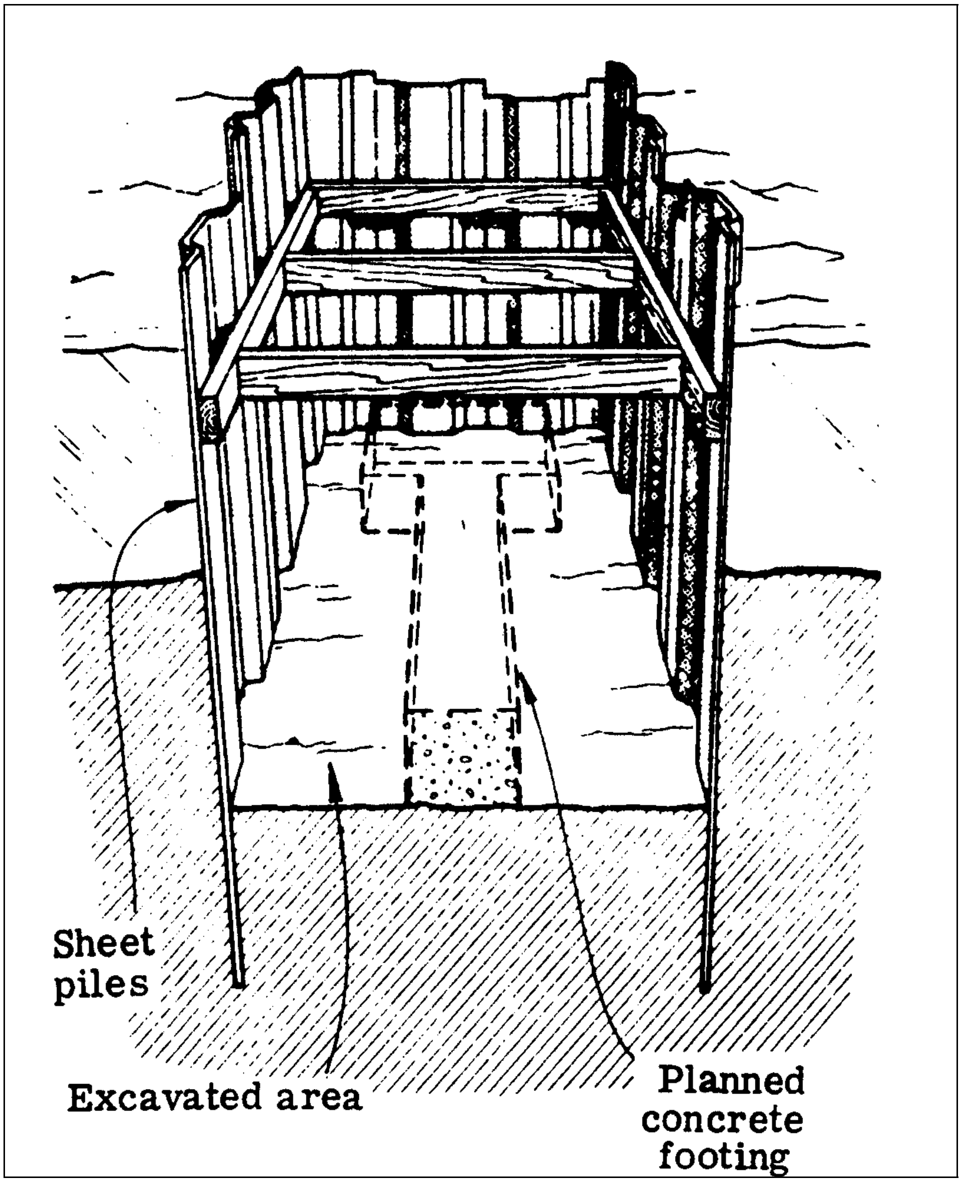

Figure 2-2. Cofferdam

Plans for the construction of cofferdams and temporary dikes are required to be submitted by the Contractor to the PE/PS. The PE/PS reviews the drawings only for compliance with the Specifications and the specific contract conditions. If the Contractor begins construction before the plans are approved, the Contractor takes the risk of not being paid for that work in the event the plans are rejected or revised.

A typical cofferdam consists of sheet piling that has been driven deep enough to prevent scour and sufficiently braced to keep water and soil out of the excavation. Cofferdams are required to also be large enough to permit pile driving and the construction of forms when these two items are required.

Cofferdams are required to be as watertight as possible so the water that is pumped out stays out. The Contractor is required to be careful not to pump out any concrete once the concrete placement begins. No pumping is permitted for 24 hours after the concrete placement unless approved by the PE/PS.

When water continually infiltrates the cofferdam from the bottom and pumping is not a feasible method of de-watering, a foundation seal may be required. A foundation seal is a layer of Class A concrete that is placed underwater inside a cofferdam through a tremie, which is a flexible tube made up of interlocking sections. Once the concrete hardens sufficiently, the water in the cofferdam may be pumped out, allowing the footing to be constructed in a dry condition. Foundation seals may be constructed by the Contractor only when they are required by the plans or requested and approved by the PE/PS. These seals are never constructed simply to provide a convenient working platform on which to construct the footing.

Once the footing and stem have been constructed, the cofferdams may be removed. The Contractor usually has the option of either pulling out the sheet piling entirely or cutting the sheet piling off two feet below the finished ground level. In any case, the Contractor is required to be careful not to disturb or damage the newly poured footing and stem during the removal operation.

SUBSOIL INVESTIGATIONS

Once the foundation excavation is complete, the PE/PS is contacted to approve the depth of the excavation and the character of the foundation material. Test Borings are required for foundations that do not require piling. The borings are required to be at least 5 ft below the footing. If the foundation is a spread footing placed on rock, then the rock is required to be proof tested. Three 2 in. diameter holes per footing are drilled into the rock for a depth of 5 ft. The following observations are made and recorded:

1) Speed of drilling

2) Drill pressure

3) Dropping or clogging of drill bit

4) Loss of drill water (if used)

5) Probing of the sides of the holes with a right angled chisel point. The chisel is required to be formed from a rod of 3/8 in. or 1/2 in. diameter.

6) Continuity of bearing material

A Professional Engineer is required to supervise the proof testing work. A report for each hole is prepared and submitted for review and approval.

Before pilings are driven, soundings are made for a depth of 10 ft below the bottom of the footing.

The Contractor may begin pile driving or constructing the footing only after the foundations have been approved by the PE/PS.

If the findings of the foundation investigation are significantly different from what was described in the original boring data for the site, the results are required to be given to the District Area Engineer or to Central Office for evaluation.

FOUNDATION PILING

Foundation piles (Figure 2-3) are load-bearing members made of steel, concrete, timber, or a combination of these materials. They are typically used where the foundation soils are too unstable or compressible to provide adequate support for the structure. Once in place, the foundation piling transfers the loads from the substructure to the firmer underlying layers of soil or rock.

To support the structure above them, piles are required to be driven to bearing, the point at which they do not sink or shift under the load. The minimum required bearing and the minimum tip elevation to which piling is required to be driven is indicated in a Pile Driving Data Table on the elevation view of the General Plan sheet.

TYPES OF PILING

INDOT uses three types of foundation piling:

1) Timber piles (treated and untreated)

2) Steel H-beam piles

3) Steel, shell-encased concrete piles or pile shells (Figure 2-3)

Figure 2-3. Foundation Piles

DELIVERY AND ACCEPTANCE

When piling is delivered to the job-site, the piling is checked to verify that the type of piling is as indicated on the plans. The General Notes section of the General Plan sheet usually specifies the type of piling to be used.

The second item to do is to ensure that the piling has been inspected and is acceptable for use. Steel H-piles and steel shell-encased piles are accepted on the basis of a mill test report that accompanies the piles. The report contains heat numbers that identify individual piles. The Technician is required to compare the heat numbers in the reports to the heat numbers stenciled on the individual piles to assure that the correct piles have been delivered and that the piles have been tested and approved. Steel shell-encased piles are required to have the steel gauge verified. The District Testing Engineer is notified to verify the steel thickness.

Timber piles have a stamp in the shape of the State of Indiana hammered on the ends to indicate that they have been inspected. Untreated timber piles are stamped on one end and treated piles have stamps on both ends.

While checking for proof of inspection, the Technician is required to also check the piling for significant damage and flaws. For example, treated timber piles are coated with a preservative to prevent or slow decay and to protect the piling from insects. Because the preservative treatment may not penetrate deep inside the wood, the outside surface of the pile is required to be completely covered. Also, timber piles that have been bent, twisted or split during transport or storage may have to be rejected.

Steel H-piles and pile shells are required to also be inspected for bends, kinks, rust, etc. Any major damage is required to be reported to the PE/PS. All piling is required to be stored off the ground and supported in such a way as to minimize bending stresses.

PILE-DRIVING HAMMERS

Contractors use large cranes equipped with pile driving hammers to drive piling to the required depth and bearing. The most common types of pile hammers are:

1) Gravity or drop hammers (used only when approved)

2) Diesel driven hammers

3) Steam driven hammers

4) Air driven hammers

All pile hammers to be used on a contract are required to be inspected and approved. The Contractor is required to furnish to the PE/PS copies of all of the manufacturer's tables, charts, and similar data necessary for determining the bearing values of piles driven with a particular hammer. The pile driving equipment may not be used until the Office of Geotechnical Engineering has approved the equipment in writing. Typically there are Recurring Special Provisions that provide additional information (Pile Driving Equipment Data Form). The Contractor is required to submit, for approval, the equipment at least 15 days before starting. The equipment is required to also perform satisfactorily during the installation of the piling.

GRAVITY HAMMERS

Gravity pile hammers (Figure 2-4) are the simplest type. Their major parts include a hammer, a large, heavy weight of approximately 3,000 lb to 3,500 lb that is raised no more than 15 ft by a crane and dropped repeatedly onto the head of a pile. The hammer and pile are kept in line by the leads and guides. The top of the pile is protected by a pad and by a cap that is shaped to fit the pile.

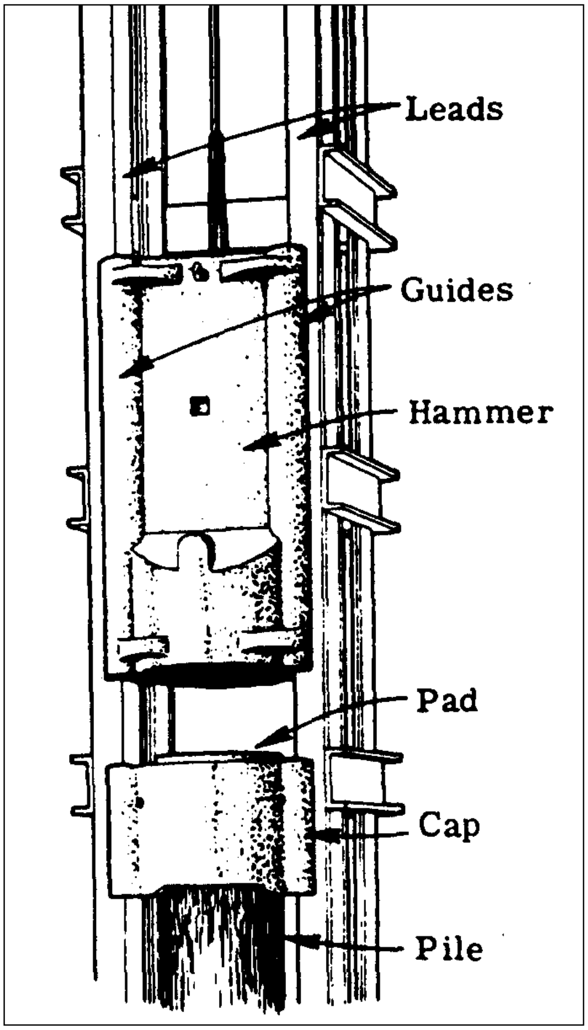

Figure 2-4. Gravity Hammer

Gravity hammers may only be used if the contract documents allow their use or if approved in writing.

DIESEL HAMMERS

Diesel powered hammers (Figure 2-5) are the most common type of pile drivers. There are open top and closed top hammers. Open top hammers deliver their blows through free fall, just like gravity hammers. The difference from the gravity hammer is in the return trip. On a gravity hammer, the hammer is raised back up with a cable. On a diesel hammer, the hammer or piston is raised by the force of a small explosion that takes place in a chamber located at the bottom of the cylinder.

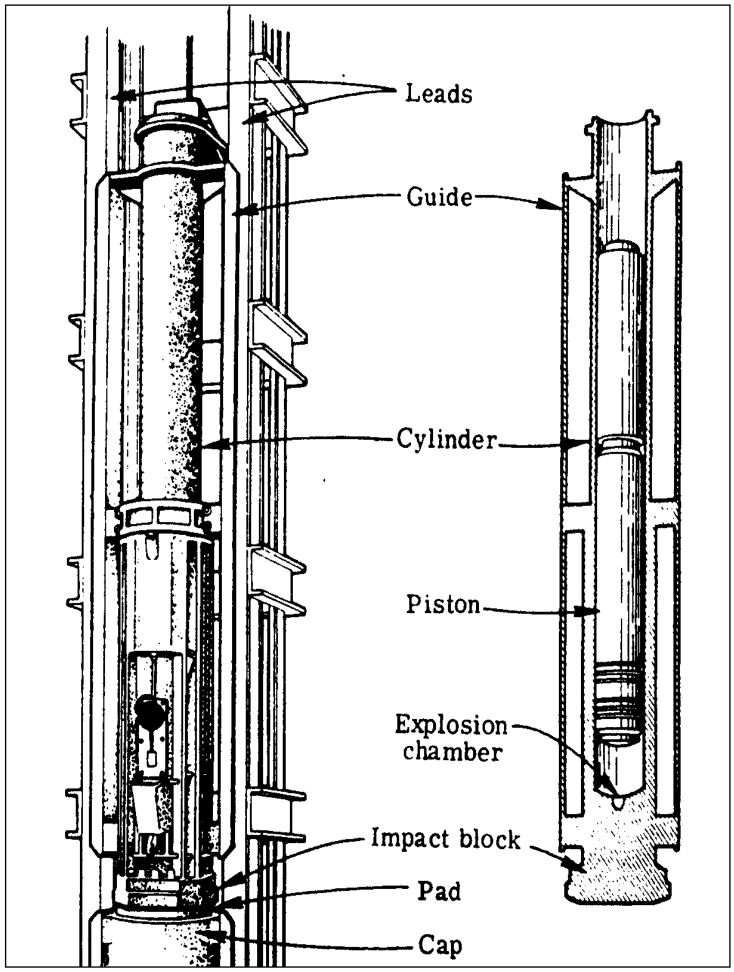

Figure 2-5. Diesel Pile Hammer

Closed top diesel hammers have one major difference from the open tops hammers. That is the presence of a second chamber at the top of the cylinder. The upper chamber may be a second explosion chamber or may function as a simple bounce chamber. Both procedures increase total energy output of the hammer.

STEAM AND AIR HAMMERS

Steam and air hammers operate like diesel hammers except that they are powered by steam or air. Steam and air hammers that have one explosion chamber are called single-acting hammers and those with two explosion chambers are called double-acting hammers. The plant and equipment furnished for steam and air hammers is required to have sufficient capacity to maintain, under working conditions, the volume and pressure specified by the manufacturer of the hammer. The plant and equipment is equipped with accurate chamber pressure gauges which are accessible to the PE/PS. The Technician is required to monitor the pressure gauges to know the energy that is being supplied.

ENERGY OUTPUT

Pile hammers are rated according to their energy output which is the force of the blows they deliver to the top of the pile measured in foot-pounds. INDOT maintains lists that contain the energy ratings for hammers of various types and manufacturers. The PE/PS is required to obtain the energy ratings lists for all hammers that are to be used on the contract.

The energy output for gravity hammers is measured by multiplying the weight of the hammer by the height of the fall. A hammer that weighs 4000 lb and drops 10 ft through the leads and onto a pile develops 40,000 ft-lb of energy per blow.

For Open-Top Diesel Hammers, the energy output is calculated as 80 % of the weight of the hammer times the height of the fall or .80 WH. The energy output for closed top hammers is calculated as 80 % of the manufacturer's rating.

When wave equation analysis is not used for pre-approval, the weight of the striking parts of air and steam hammers is required to not be less than one third the weight of the drive head and the pile being driven. The striking parts are required to not weigh less than 2,750 lb.

BEARING AND REFUSAL

Piles obtain bearing through friction, end bearing, or a combination of friction and end bearing.

A pile obtains bearing through friction as the pile is driven into the ground and displaces the soil surrounding it. The soil tightens around the pile, causing surface friction. As a result, progressively more force is required to drive the pile deeper. The point where-the amount of force needed to drive the pile deeper equals the estimated load the pile is required to support is the point at which the pile obtains bearing.

The second procedure that piles reach bearing is through tip or end bearing. The piles are driven until their tips come to rest on rock or some other material firm enough to support the structure. Steel H-piles are typically used as end bearing piles.

The third procedure piles may obtain bearing is through a combination of friction and end bearing. Again, steel H-piles and steel shell-encased concrete piles are typical examples of piling that may obtain bearing this way.

Bearing

The formulae used to determine the safe bearing value for piling are listed in Section **701.06**. They are also listed on the pile hammer manufacturer's rating sheets. Again, the minimum required bearing is shown on the plans. The proper method is required to be used to determine the bearing value for the piling as indicated in the contract documents. The options that are listed in the specifications include Wave Equation Analysis Program or WEAP, Dynamic Formula, Dynamic Pile Load Test, or the Static Load Test..

Wave Equation Analysis Program

With the wave equation analysis program, the pile capacity is determined based on the pile capacity versus blow count relationship obtained from the wave equation analysis.

Dynamic Formula

The ultimate pile capacity is determined by means of dynamic formula. Piles are required to be driven to the length necessary to obtain the ultimate pile capacity which is equal to the factor of safety times the design load. The ultimate pile capacity, as shown on the plans, may be calculated from the formula as follows:

English: $Ru = 0.5[1.75 \sqrt{E (\log 10N) - 100]}$

Metric: $Ru = 7 \sqrt{E (\log 10N) - 550}$

where:

Ru = The ultimate pile capacity in tons (kilonewtons)

E = The manufacturer's rated energy in joules (foot pounds) at the ram stroke observed in the field and not reduced for efficiency

log 10N = Logarithm to the base 10 of the quantity
10 multiplied by N, where N is the
number of hammer blows per 1 in. (25
mm) at final penetration.

There are also two Load Tests indicated in Section **701.04.** They are the Dynamic Pile Load Test and the Static Load Test.

Dynamic Pile Load Test

Dynamic measurements are used to evaluate hammer and driving system performance, pile driving stresses, pile structural integrity, and pile bearing capacity. Dynamic monitoring is conducted by the pile driving analysis (PDA) consultant in accordance with **ASTM D 4945**.

Static Load Test

The test pile capacity is verified by conducting actual loading tests of designated piles in the structure in accordance with **ASTM D 1143**, Quick Load Test Method, with loads applied by hydraulic jack. The load is applied in small amounts over a period of time. The safe allowable load is determined from the settlement versus load curve generated by the incremental loading in accordance with Section **701.06(d)1**.

To determine when a pile has obtained the required bearing, the Technician simply converts the rate of pile penetration to the corresponding bearing value shown on the ratings sheet. The rate of pile penetration is typically figured as the average penetration in inches over the last twenty hammer blows. Bearing conversion tables are provided by the Contractor but are required to be verified that they are accurate and that the proper piling formula is being used.

In some cases, the plans require that piling be driven to refusal rather than to a specific bearing value. Because the formula for determining refusal varies according to the size and type of piling and the type of hammer used to drive the pile, the Technician is required to contact the District Office for specific instructions for determining refusal.

Pile hammers are required to maintain and deliver consistent energy output throughout the pile driving operation. If a pile driver produces less than the required energy, the pile may appear to reach bearing or refusal before the required bearing has been achieved. The result is a foundation that, sooner or later, settles and shifts under the load of the bridge.

TEST PILING

INDOT requires the Contractor to drive test piles in each location that requires piling. Test piles are used to confirm the bearing values at the pile tip elevation shown on the plans and to determine or confirm the length of the foundation piling needed.

In small foundations, two test piles are required to be driven at opposite ends of the excavation. More test piles are necessary in large foundations to provide a better test of all the sections of the excavation. The PE/PS determines the exact number and location of the test piles.

After the test piles have been driven, they are typically included in the final structure as foundation piling. Because of this, test piles are required to be of the same type and meet the same requirements as the remainder of the piles to be used at that location.

All piles are required to be measured and marked at one foot intervals from the tip to the butt. Beginning 5 ft or so from the point where the pile would reach the minimum tip elevation indicated on the plans, the marks are required to be made at 1 in. intervals. The 1 in. marks help determine the rate of penetration at the time the pile reaches the specified bearing value or is driven to refusal.

As a general rule, test piles are required to be 10 ft longer than the length indicated on the plans. Then, if the piling does not reach bearing at the planned tip elevation, the Contractor is able to drive the pile an extra 10 ft to verify if bearing may be reached at a lower elevation. The Contractor may also splice test piles, with the permission of the PE/PS, if additional length is required to reach bearing. All splices are required to conform to the methods detailed in Standards **701-BPIL-04, 701-BPIL-05**, and **701-BPIL-06.**

To secure the most accurate bearing data possible, test piles are required to be driven to the final depth in one continuous operation. Stopping and restarting the driving operation may distort the results. If driving is discontinued for any reason, the Technician is required to record the tip elevation of the pile at the time of shutdown and the duration of the delay.

Final depth is determined in one of two ways:

1) The pile has been driven to refusal

2) The pile has obtained both the minimum tip elevation and the minimum bearing requirement indicated on the plans.

Once the necessary lengths are determined, the remaining foundation piling may be ordered. Timber piling is ordered by the PE/PS. Other types of piling are ordered by the Contractor.

DRIVING FOUNDATION PILES

The Contractor may begin pile driving after the following:

1) The excavation has been completed to the planned bottom-of-footing elevation

2) The excavation has been de-watered

3) Sub-soil investigations, where required, have been conducted

4) The foundation has been approved by the PE/PS

5) Test piles, where required, have been driven, and the results have been given to the PE/PS

6) The correct type of piling has been delivered to the site and has been inspected and approved

The location of each pile within a footing is shown on the substructure detail sheets of the plans. All piles are required to be driven within 6 in. of the planned location. Any pile driven outside this tolerance is required to be pulled back out and re-driven in the proper location.

The plans indicate which piles are to be driven plumb (straight up and down) and which are to be battered (driven at an angle). Battered piles help to resist lateral movement of the substructure.

The Contractor is required to check battered piles with a level and a template cut to match the required angle (Figure 2-6). To ensure accuracy, the template is required to be placed against the pile, not the leads.

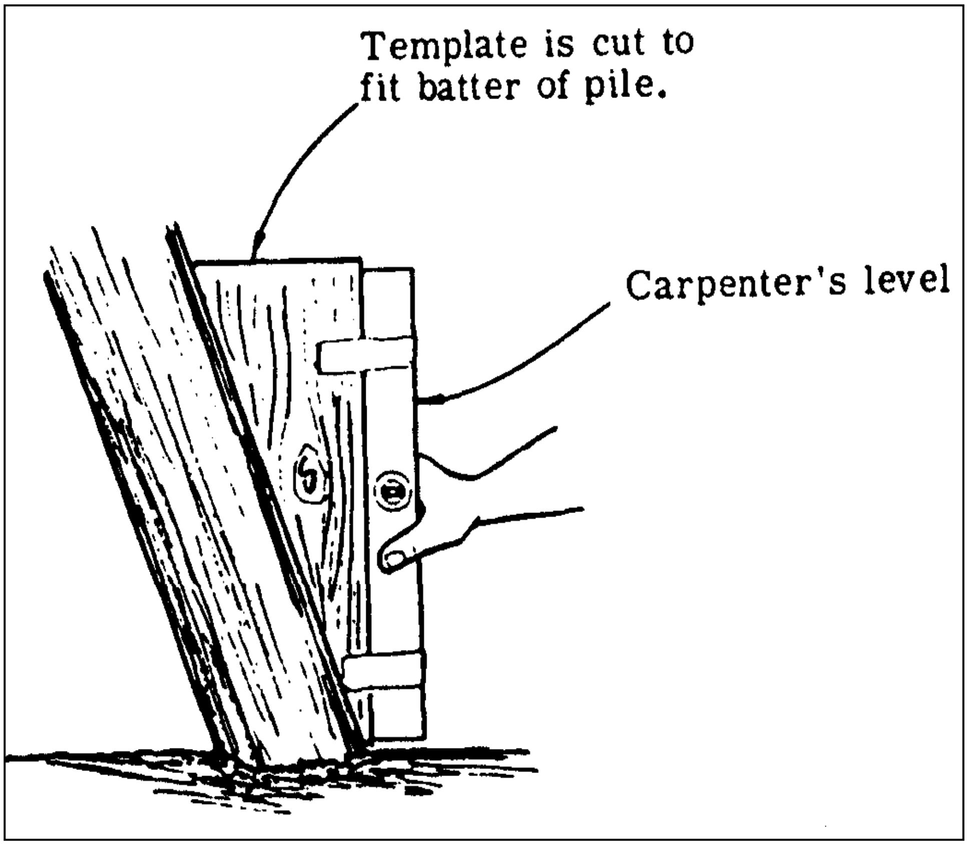

Figure 2-6. Battered Pile

The pile driving hammer is required to maintain a consistent speed (blows per minute) and energy output (ft-lb per blow) during the driving operation. Fluctuations in either speed or energy output causes unreliable bearing data. The Technician is required to observe the penetration rate of the pile and count the blows per minute. Abrupt changes in either rate may indicate inconsistent hammer operation.

Open top diesel hammers and single acting steam or air driven hammers may be checked for consistent operation by observing how far the ram projects from the cylinder on the upstroke of the cycle. If the ram projects the same amount over a period of time, the Technician may assume the hammer is maintaining a consistent energy output.

Closed end double acting diesel hammers may be checked for consistent operation by monitoring the bounce chamber pressure gauge that is mounted near ground level.

Closed end or double acting steam or air driven hammers may be checked for consistent operation by monitoring the plant (the equipment that supplies the air or steam) and hammer for consistent pressure readings from the chamber pressure gauges. The readings are based on the manufacturer's requirements.

All piling is required to be driven until the piling reaches the minimum tip elevation and achieves the required bearing value shown on the plans, unless conditions at the job-site prevent this procedure. Each pile is required to penetrate at least 10 ft below the planned pile cut-off elevation. The use of water jets may occasionally be required as an aid to penetration; however, water jets may only be used with permission. Jetting procedures and requirements are detailed in Section **701.04(c) 6**.

In the event adequate bearing is not achieved, even after the piles have been driven as planned or directed, the Contractor may use longer piles, use spliced piles, or drive more piles than called for on the plans with the permission of the PE/PS. The total planned bearing value for each portion of the foundation is required.

Four conditions that are required to be met during pile driving for proper bearing to be obtained are:

1) The hammer has free fall

2) The head of the pile is not broomed or crushed

3) The penetration is at a reasonably quick and uniform rate

4) There is no sensible bounce after the blow

These conditions, along with the proper and consistent operation of the hammer, help insure that piling is driven to safe bearing.

After driving, all piles are required to be cut off to a true plane and at the specified cut-off elevation. The Contractor is required to also remove all heaved material between the piles and restore the excavation to the planned bottom-of-footing elevation.

The Technician is required to document all important aspects of the pile driving operation on Form IC 225, the Pile Driving Record. On the reverse side of the form, the Technician is required to provide a drawing of the pile layout. The locations of all test piles and battered piles is required to be noted as well. Accurate documentation is important when the widening the bridge or replacing the bridge. Knowing what bearing the piling has for structural capacity analysis is also important.

DRIVING TIMBER PILES

The Contractor is required to take precautions to avoid damaging timber piles during driving. The head of the pile is required to be squared to insure full contact with the hammer and even distribution of the hammer blows. Most Contractors use caps and pads to protect the head of the pile. Piling with pointed tips may be used when required by the soil conditions as an aid in penetration.

Once begun, driving is required to continue until the pile reaches the required tip elevation and bearing. Driving may not be interrupted then resumed to obtain an increased bearing value.

DRIVING PILE SHELLS

The Contractor may drive pile shells with or without a removable core. Again steps are required to be taken to avoid damaging piles during the driving operation. Caps made to fit the head of the pile shells are required.

If the piling is to be driven through new embankment material, the Contractor is required to core holes for the piling through the embankment down to the original ground elevation. This procedure ensures the piles are driven into more solid, stable ground. When the contract requires reconstructing or replacing older structures, the existing fill and embankments of the older structure are considered as the original ground.

On occasion, the Contractor may be required to drive piling before the construction of the embankment, especially in areas where the embankment material is so sandy or permeable that cored holes would not remain open.

Pile shells are required to be inspected for damage after they have been driven. The Contractor is required to provide a suitable light for illuminating the interior of the shells for inspection. Reflecting sunlight down into the shell with a mirror works just as well. Any shell that has been damaged significantly (major bends, breaks, or kinks) may have to be pulled out and replaced.

The Contractor is required to remove water and debris from the pile shells before filling the shells with concrete. If the shells are not filled in a timely manner, they are required to be covered in some way to keep water out.

Pile shells require Class A concrete. The concrete is required to be vibrated in the upper 25-30 ft of the piles.

DRIVING STEEL H-PILES

H-piles are required to be protected during driving by a suitable cap that has been grooved or in some other way shaped to fit the pile head firmly.

As with pile shells, H-piles used for end bents may require pre-bored holes, but only when the embankment is 20 ft high or more.

Standard **701-BPIL-02** includes the requirements for Epoxy Coated Steel Shell Encased Reinforced Concrete piles and Steel H Reinforced Concrete Encased piles. Care is required to be taken to not damage the epoxy coating when driving epoxy coated piles and placing riprap.

MEASUREMENT AND PAYMENT

All piling is measured and paid for by the linear foot and at the contract unit price.

Timber piling may be paid for on an "as furnished" and an "as driven" basis. Timber piles "furnished" is a separate pay item and includes all accepted piles that are actually placed in the leads. All timber piles delivered to the site, but not placed in the leads because of unforeseen foundation conditions, are paid for at 50 % of the contract price for timber piles furnished (Section **701.15(a)**). These pilings remain the property of the Contractor, and are required to be removed from the job-site.

Timber piles driven are paid for as a separate item and include all costs for the labor, equipment, and tools required to complete the operation. Costs associated with furnishing the piling are not included.

Steel pile shells and steel H-piles are paid for on the basis of the linear feet actually used in the structure. Cut-off sections, piles that were driven but rejected, and unused piling are not included.

Epoxy coated piles may be furnished and driven at lengths greater than those shown on the plans. Additional lengths of such epoxy coated piles left in place and accepted are paid for as steel shell encased piles or steel H piles.

The costs of reinforcing steel which extends beyond the limits of the epoxy coating as shown on the plans and the repair to damaged epoxy coating is included in the cost of the epoxy coated steel shell encased reinforced concrete pile.