CONSTRUCTION

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DRILLED SHAFT MANUAL

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

BRIDGE DIVISION

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F O R E W O R D

Drilled shaft foundation design and construction must be based on the supporting capacity of the existing soil and/or rock formations at the site. The foundation of each structure will have certain distinctive problems during construction, some simple and others more complex.

It is the duty of the inspector to see that a foundation is constructed to fulfill the design requirements. He must be able to anticipate problems associated with given conditions, be familiar with the work and technique involved, the plans and specifications, the design requirements and the existing soil conditions as evidenced by test hole data.

This manual attempts to provide sufficient information about drilled shafts to help recognize, understand and solve some of the problems that may arise during construction and help interpret the specifications. In case of conflict, the plans and specifications will always take priority.

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CHAPTER 1

INTRODUCTION

101.1. DRILLED SHAFT FOUNDATIONS

The purpose of a drilled shaft foundation is to transmit load from a structure to the soil without settlement.

Originally, drilled shafts were designed to support a load by point bearing in hard material such as rock or shale. A design then evolved using smaller diameter shafts with bell footings. This provided a means of using smaller sized shafts at shallower depths in somewhat weaker soils such as stiff clay.

Through research, involving the use of test loads on instrumented drilled shafts, a design procedure utilizing skin friction has been developed which provides additional economy in foundation construction. It utilizes skin friction along the sides of the shaft to support part of the load with the remainder being carried in point bearing at the tip. It has also made drilled shafts extremely versatile as to the material in which they can be used.

Drilled shaft design has progressed to the point where shafts can be founded in rocks, shales, clays, sands and gravel, and can be constructed in dry or wet conditions.

As in any foundation, drilled shafts must be designed to carry dead and live load, and be stable enough to resist the forces of wind, water current and the effects of scour and moisture changes in the soil.

101.2. LOAD CARRYING CAPACITY OF DRILLED SHAFTS

A drilled shaft transfers load by friction and point bearing into the underlying strata. Shafts with or without bells are indicated on the plans and are designed to transmit all the load in point bearing, or friction and point bearing. Before construction of the shafts begins, the design intent should be understood by inspection personnel. Pertinent notes on the plans and the specifications should be referred to and followed.

The depth of effective penetration required to develop the design bearing capacity has been determined from test hole data and laboratory test data. The penetrations shown on the plans are approximate values and may be adjusted upward or downward to conform with the design intent to provide a safe and economical foundation. As drilling progresses, a comparison of the materials encountered with the descriptions and penetrometer test values shown on the boring logs will assist greatly in this judgment. The Contractor may be required to make soundings or obtain cores at the founding elevation shown on the plans to verify the adequacy of the supporting materials.

For small structures where soil data indicates uniform soil conditions, it is usually more economical and logical to rely on penetrometer data and judgment than to test load a shaft to verify required penetration.

On large structures where soil conditions indicate variable sizes and lengths of shafts, more accurate information with resultant cost savings may justify a shaft test load. The use of a test loaded shaft is an added cost and might delay completion of the work. When a test load is used, the test shafts should be founded at plan tip elevation. Upon completion of the test load, the design may be modified and lengths adjusted as covered in Chapter 6.

CHAPTER 2

EQUIPMENT

102. GENERAL

The rigs used in drilled shaft construction vary in size and mobility. Some rigs are mounted on crawler type cranes and others are mounted on specially designed rubber tired vehicles.

Those mounted on crawler type cranes are especially suited for deep, large diameter shafts but can be used for any size shaft. They are generally capable of accomplishing all the required operations of drilling, setting and pulling casing, setting reinforcing steel and placing concrete.

Rubber tired rigs have greater mobility than crawler type rigs. They are usually lighter and can be used on most drilled shaft projects but they must often be supplemented with a crane or other type equipment which can furnish adequate boom length and/or lifting capacity for handling casing, setting reinforcing steel and for placing concrete. Either type of rig is acceptable if it has adequate drilling capacity for the size and depth of shaft to be drilled.

Some rigs are equipped with hydraulic leveling devices (outriggers) but others are not. Hydraulic leveling devices make alignment of the rig a much easier task.

The drilling mechanism is powered by a gasoline or diesel engine. Some rigs employ a single engine from which a power take-off device is used to operate the drilling mechanism consisting of a turn table that transfers energy to an auger, core barrel or other tools by means of a square bar (Kelly bar). Kelly bars may be of one piece and size, or of the telescoping kind which has a hollow outer bar and a solid or hollow inner bar. The telescoping kind is helpful for drilling various length shafts without having to change the rig boom height to accommodate a longer Kelly bar.

The majority of shafts are drilled with augers. An auger has one or two helically curved plates attached around a central axis to form a screw-like boring device. The cutting edges are located at the lower edge of the spiral plates. The cutting edge usually consists of hard surfaced cutting teeth which are useful for loosening tight material and for cutting into moderately hard material such as soft limestone or shale.

A single flight auger has one cutting edge projecting from the central axis. This causes an unbalanced cutting force which may cause the auger to wobble and drift, but all augers have a central point, projecting below the cutting edge, which penetrates the soil ahead of the cutting edge and minimizes the tendency for the auger to drift. This type of auger has been used in most soil materials. It is especially suited for drilling into material such as gravel, which may contain small boulders, because it has a greater clearance in the spiraled plate to accommodate and pick up such boulders.

A double flight auger has two balanced cutting edges with two spiraled plates attached around the central axis. This type is better than the single flight auger for holding correct alignment while drilling is in progress. It can also be used in most kinds of material. Because there is less space between the spiraled plates, it tends to hold material a little better than the single flight auger. It is especially suited to drilling in fine material, such as water bearing sand, which might not be easily retained on a single flight auger for extraction from the bore hole.

A continuous flight auger is designed to bring the cuttings directly to the surface without extracting it from the bore hole. It may be either of the single or double flight type. It is constructed so that, as drilling progresses, segments are added until the desired depth of shaft is reached. With this type of auger, it is sometimes difficult to produce a shaft of correct alignment because the auger is not normally extracted so that vertical alignment can be checked as drilling progresses. Sometimes, loose fitting connections may cause the tip of the auger to drift thereby causing incorrect alignment. This type of auger requires greater care in the initial alignment in order to stay within reasonable shaft alignment tolerances. This type of auger tends to 'gum-up' in some clays and will not convey the material out of the bore hole, thus requiring extraction and cleaning of the auger quite often.

A core barrel is sometimes used for drilling through very hard material. A core barrel is a cylinder of the required diameter with hard surfaced, saw-like teeth along the cutting edge. Specially designed rock augers with special cutting teeth are sometimes used in very hard material. Occasionally a drop bit is used to break hard material, but this requires additional equipment. After breaking hard material with a drop bit, a core barrel is used to trim the sides of the shaft to proper dimensions and alignment.

Belling tools operate by pressure from the Kelly bar, causing the cutting edges to flare outward. As the tool rotates, the bell is cut and shaped at the bottom of the shaft. When the Kelly bar is raised, the belling mechanism retracts, holding the cuttings for removal.

A bail bucket is a cylindrical bucket equipped with a foot valve designed to pick up and remove mud, slurry and cuttings from the bottom of a shaft. The bucket should have a diameter slightly smaller than the shaft.

The "rodless drill" is a unique piece of drilling equipment. Three rotary drill bits are mounted on a counter-rotating unit and so geared to balance out the torque reaction of the rotating drill bits. It has an electric motor within the drill and operates submerged in slurry while it is suspended from cables. Guide plates on the sides of the drill keep it in good alignment. It does not need to be removed from the bore hole periodically because it uses a reverse-circulation system which removes cuttings as they are made. The slurry is used to control caving and ground water and to remove cuttings. The cuttings are moved toward the center of the drill by the bits and are subsequently pumped from under the drill through a relatively small inlet running up through the center of the drill and through a pipe or hose to a discharge tank at the top. The reverse circulation of the slurry brings the cuttings to the surface in a suspended form, where they are screened from the slurry.

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CHAPTER 3

ALIGNMENT CONTROL

103. GENERAL

Prior to starting any foundation work, previous staking should be checked by the inspector to satisfy himself that the staking is correct.

During drilling, the alignment of the shaft must be checked periodically both horizontally and vertically.

It is customary to set one stake locating the center of the shaft and two reference stakes on opposite sides. The reference stakes should be placed equal distance from, and near enough to the center of the shaft, to be used by construction forces to locate its center, align the reinforcing steel, and place any other temporary stakes that may be desirable. At least one reference stake should be graded for convenience in establishing the finished grade of the shaft.

Drilling crews often set additional working stakes for alignment control. These are generally located before drilling is started, with the original reference stakes being kept undisturbed for a periodic check on the working stakes.

One method employs two 2"x4" stakes driven on opposite sides of the shaft and equal distance from the center thereof. These usually project above the ground and are set to the same elevation. The alignment is checked with a plumb bob and a straightedge notched at the center and each end to match points on the reference stakes. The center notch should fall directly over the center of shaft. By suspending a plumb bob from this notch, a rule may be used to check the horizontal alignment at the surface of the ground.

Another method employs four 2"x4" working stakes, with string lines stretched to opposite points and intersecting directly over the center of shaft. The horizontal alignment is checked in the same manner as for the previous method.

The use of transits is recommended for locations where surface conditions are unstable and do not permit the use of working stakes or nearby reference stakes.

The vertical alignment may be checked by lowering a plumb bob from the point above the center of the shaft. If an auger is being used, the plumb bob should fall inside the small hole made by the auger at the bottom and center of the shaft. This method gives good results when the shaft is dry and the bottom can be seen.

Another method of checking the vertical alignment in dry shafts is to suspend a plumb bob along the wall at two points approximately 90° from each other and measuring to the plumb bob string from the point over the center of the shaft indicated by the notch in the straight-edge or the point of intersection of two string lines.

These two methods work well for dry shafts, either cased or uncased, but it is also necessary to check the vertical alignment of a shaft that is full of water or slurry.

When the slurry method or underwater construction is used, vertical alignment is best checked by lowering the auger (or other tool) to a point just above the bottom of the shaft, plumb the Kelly bar and use it to check alignment at the top of the shaft. This should give an indication of any drift of the auger. This method can be used with the rodless drill by plumbing the support cable.

The Contractor should be informed immediately when excessive deviations are found so that corrective measures may be taken.

The tip elevation of the shaft is controlled by measuring the depth of the bore hole from the top of the working stakes. Since the working stakes have been set to a known elevation, the tip elevation is easily determined. The top of the shaft is controlled in a similar manner, however sometimes a level is required for this purpose when working stakes cannot be set and maintained near the shaft location.

CHAPTER 4

DEPTH OF PENETRATION

104. GENERAL

The tip elevations shown on the plans indicate the elevation at which satisfactory bearing material should be encountered. These tip elevations are approximate and are for estimating purposes, but are generally correct for construction. In some cases however, the tip elevation must be varied to achieve design requirements. Sometimes the nature of the material will dictate extra depth, or that the shaft be shortened, if the founding material is at a lower or higher elevation than indicated on the plans.

During drilling of the first few shafts, the inspector should examine the cuttings carefully and become familiar with the various materials encountered, especially at the elevations where penetrometer tests are indicated on borings. This will help him visually evaluate the soundness of the founding material and also detect changes in the material. The drilling technique and acceptable control procedure should be worked out on the first few shafts drilled. Each shaft should be evaluated individually, based on the material encountered at the proposed tip elevation.

Extra depth drilling may be required if the shafts are designed with bells tipped in a sandy material below a water bearing strata. Here the shaft must be cased to seal out the water. If the seal breaks before or after the bell is formed, the casing must be lowered to develop a new seal and a new bell formed before concrete is placed.

An example of underrun would be a specified "minimum penetration" into a very hard material which is encountered above the anticipated elevation. Then it is desirable to stop short of plan depth when the required penetration into the hard material is achieved.

Alterations in plan length may be made by the Engineer, as judged proper to satisfactorily comply with the design requirements. Where bells are shown on the plans, but conditions do not permit their construction, the Bridge Division should be consulted immediately for recommended procedures for an alternate design. The specifications provide a method of payment for extra depth shafts, however when bells are eliminated, a field change is required.

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CHAPTER 5

CONSTRUCTION METHODS

105.1. GENERAL

The procedure and techniques used to successfully construct drilled shafts will usually vary from one location to the next. Sometimes different techniques must be used within the limits of a single structure. The general procedure will be governed by the specifications, the subsurface soil structure, the requirements imposed by the design of the shaft and by special provisions or specifications when a particular procedure is specified. The procedure must accomplish two things, control caving and control free flowing ground water; these are the primary objectives toward the successful construction of drilled shafts.

105.11. INFLUENCE OF SUBSURFACE SOIL STRUCTURE

The test hole data in the plans show the anticipated soil structure and usually the ground water conditions in which shafts must be constructed. The test hole data is used primarily for the preparation of plans and is generally accurate enough to be used for the determination of construction methods. However, everyone involved with shaft construction must be aware that it is difficult to accurately classify all materials when making foundation investigations and that actual conditions may be somewhat different than indicated. There may also exist undetected variations in the soil and in the elevation of soil layers which may not have been accurately detected due to the distance between test holes.

The test hole data shown on the plans will indicate a general procedure to be used, which is verified when drilling the first few shafts. Usually some adjustments in procedure must be made to compensate for unanticipated conditions.

Materials which are subject to caving are cohesionless materials such as sand and gravel, and some slickensided clays. The tendency of a material to cave depends on its binder content and ground water conditions. Soft mucky clays may also be subject to caving but usually they have a tendency to gradually flow in toward the center of the shaft unless this is controlled by the construction procedure.

In cohesionless materials and slickensided clays, the tendency to cave is much greater if an attempt is made to dewater the shaft when free flowing ground water is present. For these conditions, casing, slurry or a combination of both may be required to control caving and the effects of ground water.

Occasionally a slickensided clay is not identified as such in the test hole data. When encountered it can cause serious caving problems particularly if bells are to be constructed.

If any caving problems develop with bell footings, construction should be stopped and consideration given to redesign of the shaft foundation.

The presence of free flowing ground water can be a problem if not properly controlled. It can cause caving, and sometimes the pressure can be great enough to cause the seal to fail, especially if the casing does not penetrate sufficiently into a layer of cohesive soil. This is more frequent where bell footings are required.

Where free flowing ground water cannot be sealed out by casing, the flow must be controlled by allowing the water to seek a static head and proceed to construct the shaft using underwater procedures. The construction of a shaft under water should be the last alternative since it is preferable to place concrete in a dry condition.

105.12. INFLUENCE OF DRILLED SHAFT DESIGN

In some soils, bell footings may be required by the design to carry the load in point bearing. The use of bells allows shafts to be founded in material of lower bearing capacity. They contribute greatly toward economical foundations by allowing large bearing areas with a relatively small diameter shaft.

Shafts that are designed for point bearing only, usually have the least effect on the construction procedure. In this case, the main concern is to use a construction procedure which does not disturb or loosen the material on which the shaft tip must bear. A shaft which bears on disturbed or loosened material may subsequently settle and cause damage to the structure it must support.

For shafts designed so that part of the load is carried in skin friction along the vertical surface of the shaft, the construction procedure is somewhat more difficult. Not only must the construction procedure assure good point bearing at the tip of the shaft, but it must also assure good contact between the soil and concrete throughout that portion of the shaft designed for skin friction. A casing, left in place, may not develop the required skin friction, therefore when the plans indicate skin friction design, the casing should not be left in place.

Occasionally a casing will develop sufficient resistance so that it cannot be pulled with available equipment. The inspector must decide whether to leave the casing in place or insist on other alternatives. To help make this decision, the inspector should know if the shaft design is based on point bearing only or if it is based on point bearing plus skin friction.

Where the shafts are designed for point bearing only, no adverse effect will result from leaving the casing in place. When the plans indicate that skin friction is used in the design of the shafts, it becomes important that the casing not be left in place. For skin friction design, there are several alternatives when the casing cannot be removed with equipment present at the jobsite. As soon as it becomes apparent that the casing cannot be removed, some alternatives are:

1. Remove the steel and concrete from the bore hole while the concrete is still fresh. Replace the steel and concrete when equipment with sufficient pulling capacity has been brought in to pull the casing at the proper time.

2. Check the founding material at and below shaft tip elevation. The shaft may still be acceptable with a casing left in place, even with the loss of skin friction, if the founding material is adequate for supporting the entire load in point bearing.

3. Remove the steel and concrete from the bore hole while the concrete is still fresh, and if possible, drill below the casing to a depth which develops the required point bearing and skin friction, replace the steel and concrete and leave the casing in place. Depending on the material below the casing, drilling deeper without lowering the casing may require underwater placement of concrete.

4. If the concrete has set beyond being easily removed, two smaller shafts may be designed and placed to supplement the main shaft for the loss of skin friction and a footing cap placed across the shafts.

In those instances where the casing cannot be removed, the Bridge Division should be consulted regarding an acceptable solution.

105.13. INFLUENCE OF SPECIFIED METHODS

When a particular method or procedure is required or permitted, such as the Slurry Displacement Method, the work must be performed in accordance with special provisions or special specifications. The inspector must be aware of these specification requirements and how they may affect or relate to the procedure for drilled shaft construction.

105.2. CASING

The specifications permit the use of casing having an outside diameter not less than the specified diameter of shaft; otherwise the size of casing and the size of drilled excavation will be left to the discretion of the Contractor. Extra compensation is not allowed for concrete required to fill an oversize casing or oversize excavation.

Casing is manufactured with the outside diameter as the standard and is readily available. Casing which must be manufactured to a specified inside diameter is not readily available, usually requires a special order, and is considerably more expensive than outside diameter casing. The additional cost of inside diameter casing cannot be justified.

For the shaft diameter required, the use of outside diameter casing will require a smaller auger or bit to be used below the casing; this is acceptable from a structural standpoint and is the intent of the specifications. The shaft size below the casing should be the maximum size possible when drilling through an O.D. casing of the specified size.

Dirty casing, casing coated with concrete, or that which is out of shape make extraction difficult and may cause the steel and concrete to rise when the casing is extracted. Casing which is out of round is sometimes difficult to turn (or spin) into the bore hole to develop a seal.

105.21. SURFACE CASING

A surface casing is a short length of casing which is used to prevent caving of the ground surface or control water at the top of the bore hole. It also limits the size of shaft at the surface and provides a positive opening for escape of drilling slurry or water trapped outside the regular casing.

When used, it should project a short distance (one to two feet) above the ground surface to a point several feet below the top of shaft elevation. It should extend downward a sufficient length to control shallow caving or ground water and should be a minimum of 12" larger than the diameter of shaft or regular casing, when multiple casing is used.

105.22. REGULAR CASING

Casing is generally used to control caving and ground water down to an elevation where the material will permit a seal to be established. When shafts are constructed in cohesionless water bearing material, a seal usually cannot be made. Here the casing is used to control caving with placement of concrete being done under water.

Due to the lengths of regular casing, the soil must be excavated from the shaft or worked into a slurry inside the shaft (processing the bore hole) so that the casing may be installed freely.

Sometimes, when shafts are to be constructed in a deep layer of granular material, the regular casing may be driven to grade with a vibratory hammer and the material subsequently drilled out from within the casing. This method cannot be used where the casing must pass through layers of clay, rock or shale.

105.3. DRILLING SHAFTS

The three general methods of shaft construction are:

1. The dry method (uncased).

2. The cased method.

3. The slurry displacement method.

The method(s) to be used on a specific project will depend on the subsurface conditions and the requirements of the plans and specifications.

105.31. THE DRY METHOD (UNCASED)

When shafts are drilled without the use of casing or slurry, the procedure is called the dry method, and is applicable to soils such as stiff clays, rock, shale and some sandy clays where caving will not occur.

Sometimes minor water seeps will be encountered and water may accumulate in the bottom of the shaft. Minor seeps are of little concern as long as they do not produce caving. Small accumulations of water can be removed by drilling the last foot or so just prior to setting steel and placing concrete. Sometimes water accumulations can be removed by placing dry material in the shaft to blot or soak up the water, subsequently removing it with an auger or a clean out bucket, making certain to return to original depth.

Where seepage is so great that it cannot be controlled, casing and/or underwater procedures may be required.

After the rig is centered over the shaft, the excavation is carried to its full depth using an auger or core bit. The size of the drilling tool should be the same size as the shaft. If bell footings are required by the plans, they are formed with a belling tool when the shaft has been drilled to its full depth. See Section on "Bell Footings".

Figure 1 illustrates the general procedure for constructing a drilled shaft by the dry method.

105.32. CASED METHOD

Casing is <u>generally</u> used when soil or ground water conditions indicate that caving will occur, and to seal free flowing ground water out of the bore hole, so that drilling and belling can be done in the dry at lower elevations.

A good example would be where a shaft must be drilled through a layer of water bearing sand into a layer of stiff clay. Sometimes, when long shafts are required, more than one layer of water bearing or caving type material may be encountered. In this case multiple casings or processing with drilling mud, may be required for successful completion of the shaft.

For cased shafts, the material is either removed, loosened or converted into slurry in the bore hole in a manner which controls caving and ground water until casing is set. Usually, caving is controlled by the use of slurry, but in some cases where the caving layer of soil is not very thick, the driller will begin, a few feet above the caving layer, to loosen the soil, leaving it in the bore hole until he has penetrated through the caving layer into the layer in which the seal is to be made. The casing is then spun down through the loosened material and the seal made. Drilling then continues in the dry to the required shaft tip elevation.

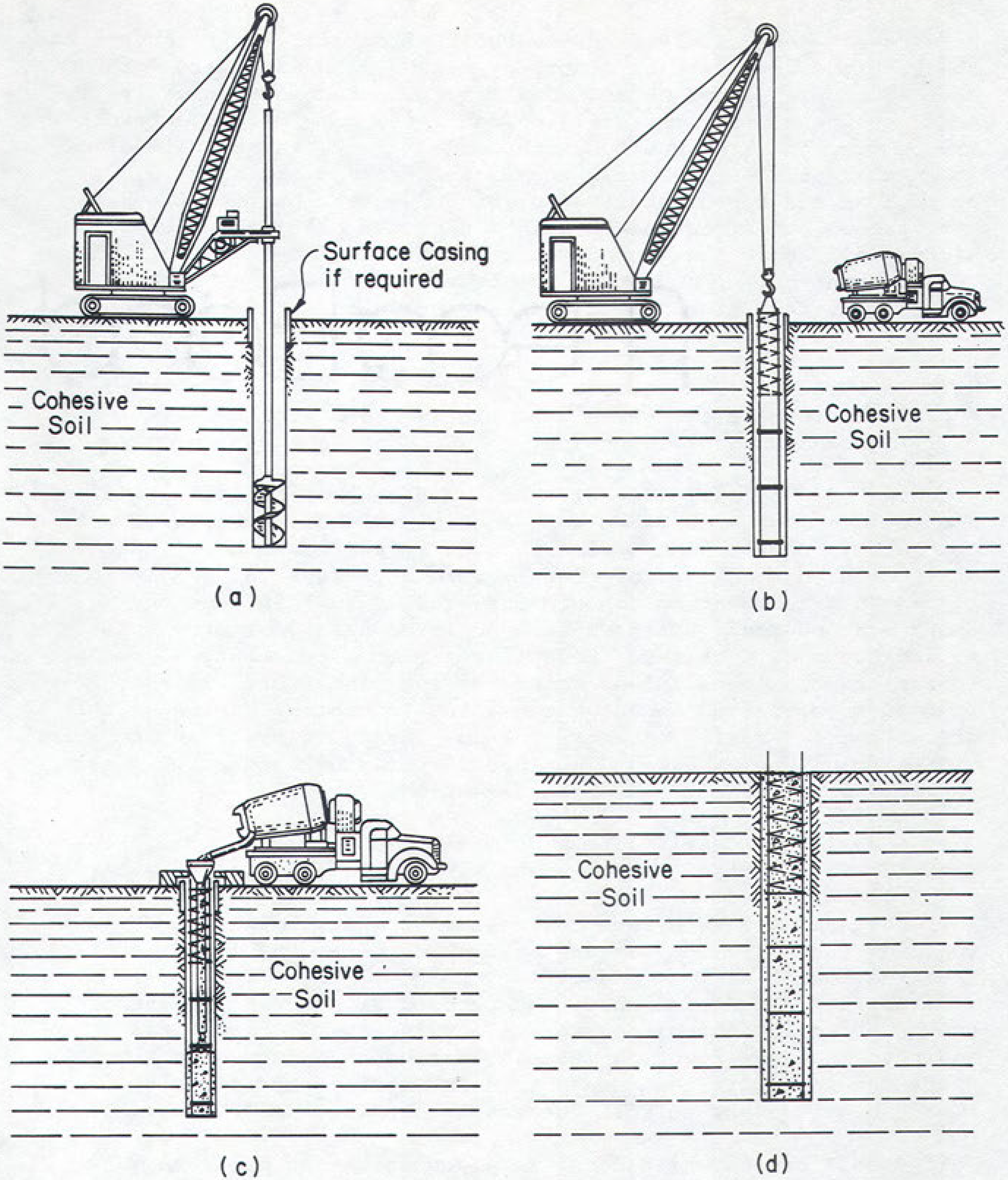

Figure 1
DRY METHOD

(a) Initiating drilling; (b) Placing rebar cage; (c) Starting concrete pour; (d) Completed shaft.

In cases where slurry is used, the driller will start converting the cuttings into a thick slurry by mixing with water from ground sources or with added water. Drilling mud can be, and usually is, added to the slurry. As drilling continues, some of the cuttings are removed from the shaft, but the mixed slurry is maintained at an elevation well above the caving layer and may have to be as high as the top of shaft. Any ground water that is present can be kept under control by maintaining the elevation of the slurry well above the ground water elevation. An auger full of cuttings and/or a bail bucket must be extracted slowly so that they do not form high negative pressures which would cause the water to flow from the ground into the bore hole. This kind of flow usually contributes to caving and often causes the seal to fail. When drilling reaches the sealing layer, the casing is set and a seal developed, after which the slurry can be removed and drilling can continue in the dry.

Casing is generally very effective for control of caving and ground water, but there are some conditions when casing will not completely control ground water. Such a case would be a shaft drilled through a layer of gravel, through a layer of clay then tipped in water bearing cohesionless sand. In this case the shaft must be constructed under a positive head of slurry and no attempt should be made to dewater the bore hole once it has penetrated the cohesionless water bearing sand. Drilling should proceed as discussed above using slurry to control caving of the gravel until a casing is set. In some cases, in order to properly control caving of the founding layer, it may be necessary to set the casing at or near shaft tip elevation.

If a seal should fail after the casing is set, there is an inflow of water and soil which usually requires a change in procedure.

If the seal breaks before concrete placement begins, it is best to allow the water to seek a static head, clean the loose material from the bottom of bore hole making sure the founding material remains firm and undisturbed, and proceed with the remainder of the construction using underwater techniques. If conditions indicate that the founding material has been disturbed, the shaft should be drilled deeper to sound undisturbed material. It may be necessary to pull the casing and use a longer one.

If a seal breaks while concrete placement is in progress, the work should be stopped, the steel pulled and the concrete removed. A new seal should be made before proceeding with steel and concrete placement. If a seal cannot be made, then underwater procedures should be used to construct the shaft.

If construction of a bell is involved, it may be necessary to extend the length of shaft so that a seal is developed at a lower elevation and thus allow construction of the bell. The other alternative would be a design change which deletes the bell and incorporates a skin friction design with longer straight shafts.

Figures 2 and 2A illustrate the general procedure for construction of a drilled shaft by the cased method.

105.321. DRILLING SHAFTS THROUGH WATER

The procedure for drilling shafts through water will largely be determined by the nature of the material to be drilled, and to some extent by the plan details. The former will dictate whether or not an effective seal can be made and whether a wet or dry procedure will be used. In these cases, the Contractor and the Engineer should agree on a procedure that is appropriate for the conditions.

The procedure for constructing shafts through water will require at least one casing. Sometimes the plans may require a particular method or that a casing or a metal form be left in place. If no particular method is specified in the plans or specifications, the Contractor then is free to select a method acceptable to the Engineer.

Any casing or metal form used must extend above the surface of the water for proper concrete placement.

When using a single casing, it is usually left in place to form the concrete through the water and become a permanent part of the structure. It should be properly aligned and extend down into the soil far enough to develop a seal if possible. The shaft is then drilled to the proper depth, dewatered if possible, the reinforcement set, and concrete placed in the dry. When the water cannot be sealed out, underwater procedures must be used.

Sometimes double casing is used with an oversize casing being set with a lighter gage form or second casing being set inside. Reinforcement and concrete is placed for the shaft to the required elevation. The lighter gage form or inside casing is left in place and the outer casing is removed.

Another method using double casing allows removal of both casings. Pea gravel is used between the two casings to confine the plastic concrete as the inner casing is pulled. The pea

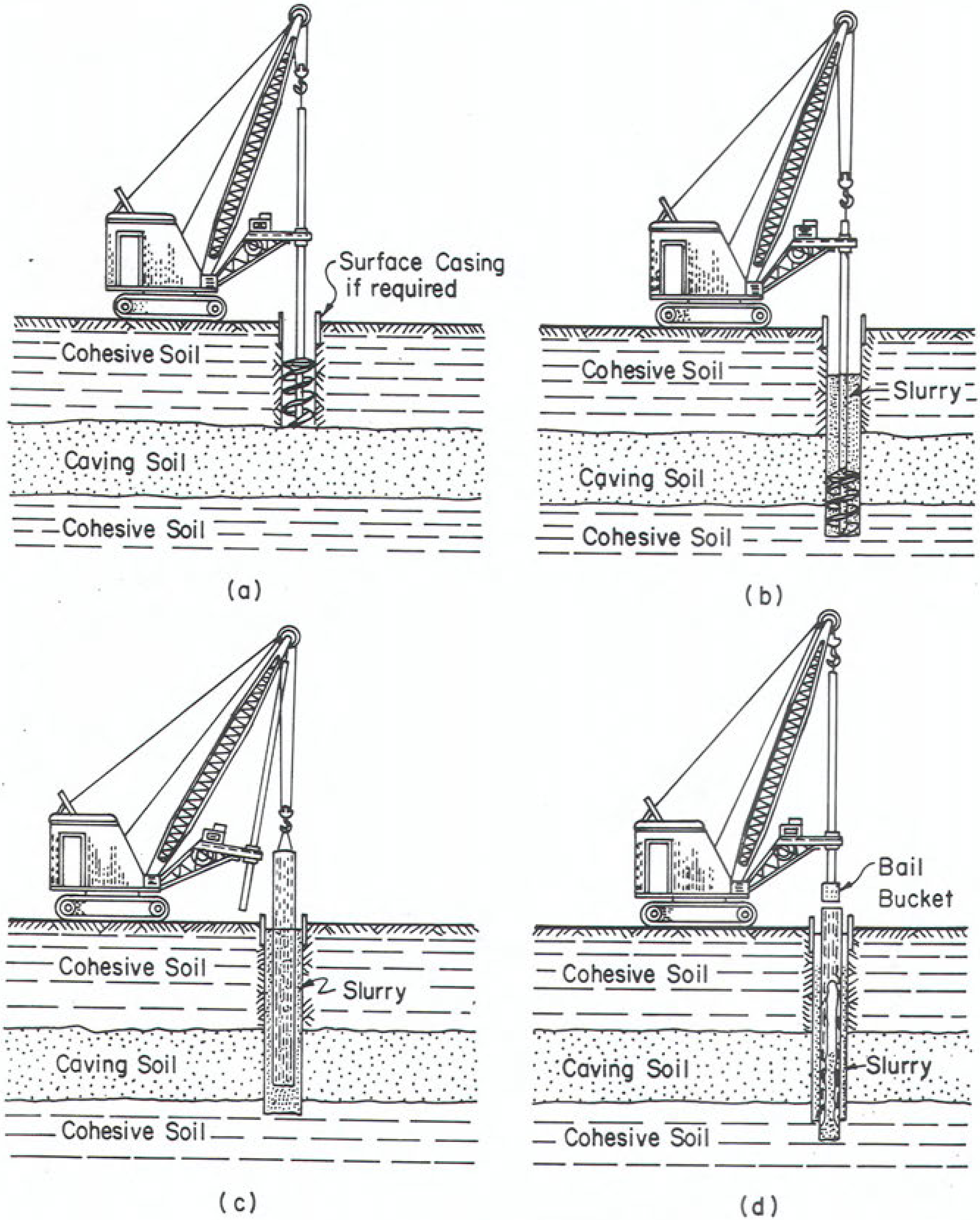

Figure 2

CASING METHOD

(a) Initiating drilling; (b) Drilling with slurry; (c) Introducing casing; (d) Casing is sealed and slurry is being removed from interior of casing.

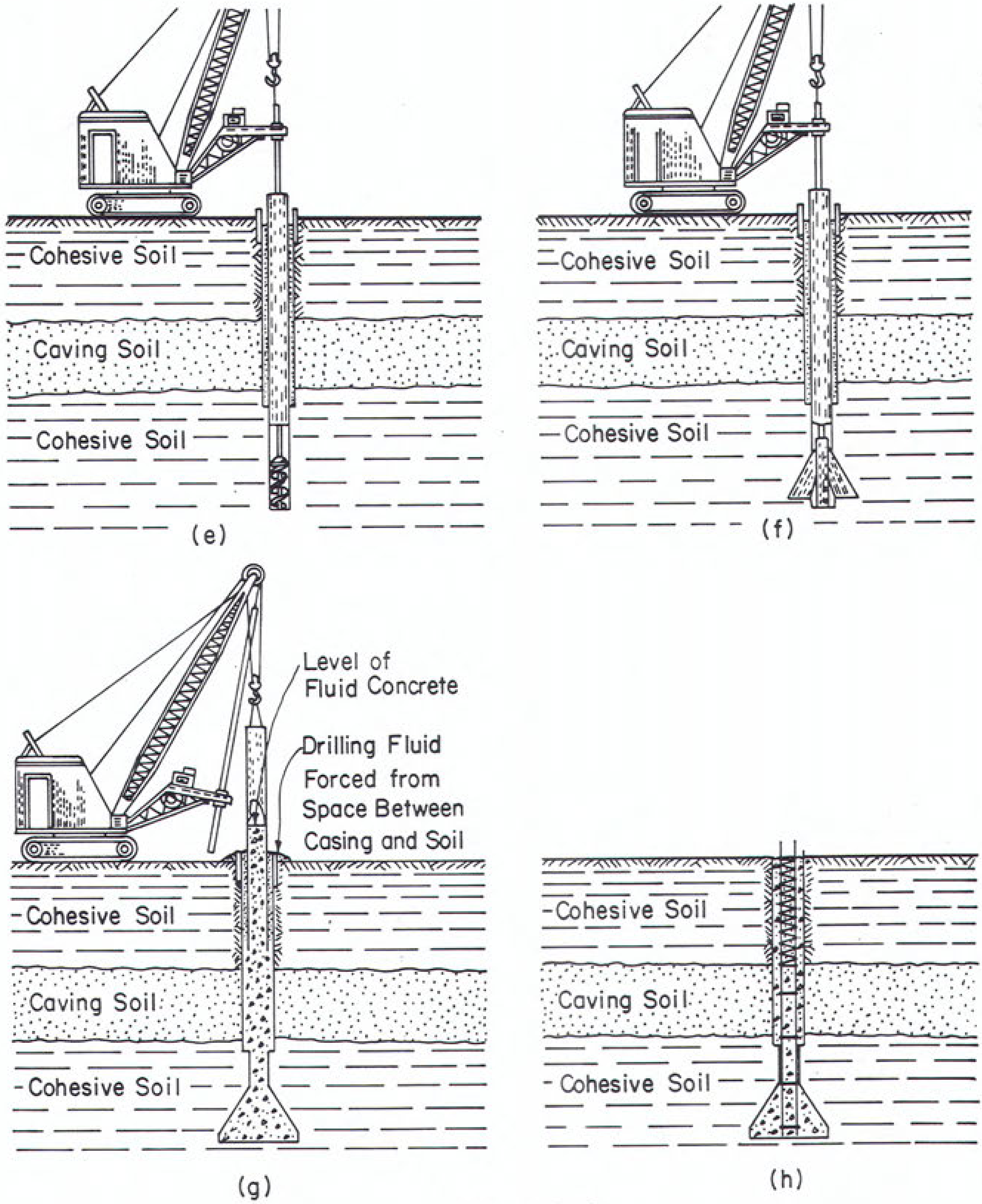

Figure 2-A
CASING METHOD
(e) Drilling below casing; (f) Underreaming; (g) Removing casing; (h) Completed shaft. Placing reinforcing and concrete not shown.

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gravel should be rounded particles to minimize interlocking of the aggregate. It acts as a reservoir to absorb water or mud slurry which is displaced upward as the inner casing is pulled, and also acts as a buffer to prevent the concrete from bridging across to the outer casing. The thickness of pea gravel (distance between the two casings) should be sufficient to prevent interlocking of the aggregate against the outer casing. The inner casing is pulled while the concrete is still plastic. The outer casing may be pulled when the concrete has gained sufficient strength to resist tension and bending stresses (500 psi flexure). Sometimes, for long shafts, a third casing may be necessary to control caving and ground water below the tip of the second casing.

Sometimes shafts must be drilled through water into hard rock that has little or no overburden. This presents problems in obtaining correct alignment and a good seal at the bottom of the casing. In order to start the bore hole with correct alignment, a casing must be set and held as rigidly as possible by means of guy cables, to provide lateral support for the drill, otherwise the drilling tool will tend to drift from correct alignment. Under these conditions, concrete is usually placed using underwater procedures.

105.322. DRILLING SHAFTS IN COHESIONLESS MATERIAL

Dry pack sands usually furnish adequate support for drilled shafts. Some pack sands contain enough clay particles to develop a seal and in some cases they may even permit belling. With such conditions, no major problems exist.

Cohesionless water-bearing sands and gravels may also furnish adequate support for drilled shafts, but present certain problems during drilling and concrete placement. It is difficult to dewater the shaft without causing the sand at the tip of the shaft to be lifted into the casing by hydrostatic pressure from outside the casing. In such material, shafts must be drilled to grade in a manner that insures that the founding sand or gravel will not be disturbed by water pressure.

To keep the founding material from becoming disturbed by ground water pressure, the shaft should be constructed under an adequate head of water or slurry maintained well above the ground water elevation and any anticipated caving layer. As drilling progresses, the water or slurry will generally control ground water pressure and caving of sand and fine gravel, until the casing is set.

When founding in cohesionless materials, it is preferable to set the casing at or near the bottom of shaft elevation.

No attempt should be made to dewater the shaft so that the founding material will not be disturbed.

When the bore hole has been drilled to grade, the slurry should be diluted with water to allow as many cuttings as possible to settle out. The bottom of the bore hole should be cleaned with a clean-out bucket. When the bottom of the bore hole is clean, the reinforcing steel may be set and concrete placed by underwater methods.

This procedure works well for founding in any cohesionless, water-bearing material as long as a sufficient head of water or slurry is maintained.

105.33. BELL FOOTINGS

Because of the limitations of the belling tools, bell footings are most suited for use in stiff clays, shales, and combinations of sand and clay with sufficient binder to support a bell. They are not suited for use in hard rock, hard sandstone, material containing large boulders or in soils subject to caving.

Bells should be constructed in the dry if at all possible. Some minor water seepage into the bell is permissible if it does not induce caving. Belling and final clean-out should be coordinated with placing of reinforcing steel and concrete to minimize the time that the bell remains unsupported and subject to caving.

When conditions are encountered that are not suitable for belling, the work should be stopped, and agreement reached on an alternate design. Alternate designs are usually straight shafts without bells, designed for point bearing and skin friction. In most cases, the alternate design should be used just for those shafts which cannot be belled. Just prior to belling, the inspector should check the soil material where the bell is to be founded and if possible determine whether or not a bell can be constructed. If there is any doubt about the ability of the soil to support the bell, then the alternate design should be used.

105.34. SLURRY DISPLACEMENT METHOD

The "Slurry Displacement Method" is defined as a procedure whereby the sides of the excavation are supported by a processed bentonite slurry, then the slurry displaced by concrete to form a continuous concrete shaft. Casing, other than surface casing, is not used.

The slurry displacement method is to be used only when required or permitted by the plans, specifications and/or special provisions.

The primary functions of the slurry are to prevent caving and ingress of ground water. The slurry provides lateral support to the walls of the excavation to counteract the earth pressure, and it serves to prevent sedimentation for a period of time by holding particles of clay, silt and sand in suspension after the excavation has been completed.

The physical properties of a slurry that influence its performance and its ability to form an impervious membrane, are its viscosity and specific gravity.

The viscosity of the slurry depends on the ratio of bentonite to water. For a given ratio, the viscosity will vary with the source of bentonite. A good quality slurry is one which has enough bentonite with sufficient viscosity so that settlement of the suspended particles does not occur. Existing soil conditions in the excavation generally determine the appropriate viscosity to use. In general, as the soil becomes coarser and more cohesionless, the greater the viscosity must be to form a suitable membrane.

The specific gravity of the slurry is also dependent on the ratio of bentonite to water. The specific gravity of the slurry, when properly controlled, can be used to adjust the amount of pressure acting on the membrane or to adjust the amount of liquid head required to maintain a given pressure on the membrane. As for viscosity, different sources of bentonite produce slurries of different specific gravities.

If the specific gravity becomes too great, the slurry will become too heavy in relation to the concrete and placement of good sound concrete may become difficult. The concrete must clean the sides of the bore hole of slurry, displace all slurry, and clean the reinforcing steel as the slurry is displaced. This is difficult to accomplish if the slurry becomes too viscous from contamination.

No hard and fast rules can be made relative to the properties of the slurry. Some guide lines are given herein, but different values for each property may be needed depending on the soil structure encountered and the source of the bentonite to be used. The following table indicates approximate values for specific gravity and viscosity for various soil materials.

Material Type	Specific Gravity	Funnel Viscosity 500/500 cc Sec.
Clay	1.02-1.05	20-22
Sandy-Clay	1.05-1.07	22-25
Sand-Silt	1.08-1.12	28-34
Sand	1.10-1.15	33-38
Sand & Gravel	1.15-1.20	36-43

Funnel viscosity is measured by placing 500 cc of slurry in a Marsh funnel, then measuring the time in seconds for the material to completely flow out. This test is simple and easily performed. Specific gravity can be checked with a scale or mud balance.

The funnel viscosity of water is about 19, and the specific gravity is 1.0, therefore the viscosity must be greater than 19, and the specific gravity greater than 1.0.

As a starting point, a slurry with a specific gravity of 1.05 to 1.07 and a viscosity of 22 to 25 should be used, then the values varied as drilling requirements indicate.

The slurry may be mixed in the bore hole, as drilling progresses by adding water and bentonite in the proper proportions, or it may be premixed in a tank of sufficient size to fill the bore hole, and for recovery of the slurry after concrete placement, for use in additional shafts. The slurry is made by thoroughly mixing bentonite with fresh water. Two to eight percent of bentonite, by weight, is usually required to produce a specific gravity of 1.02 to 1.15. Seawater should not be used with bentonite, but may be used with a saltwater gel which is not affected by the salt content of the water. A saltwater gel is not as effective as a bentonite gel and its use is discouraged.

The slurry should be maintained well above the ground water elevation and should be at or as near to the surface as possible. There should be enough head of slurry to cause some flow of slurry into the surrounding soil. As the flow continues into the voids of the soil, bentonite particles in the slurry are filtered out along the surface of the shaft and a membrane is formed. It is necessary for the membrane to have sufficient strength to prevent caving and inflow of water, and it will have, if there is adequate positive pressure (head) on the membrane. If the level of slurry is allowed to fall, the pressure is reduced and the membrane may be overcome by the ground water pressure or the weight of the soil.

If the viscosity and specific gravity decrease while in use, it is usually because of ground water diluting the slurry. In this case the height of the slurry in the shaft should be increased to counteract the ground water pressure, or additional bentonite used to increase the specific gravity of the slurry where the head of slurry in the shaft cannot be raised.

If the viscosity and specific gravity increase while in use, it is usually the result of contamination of the slurry by clay particles. This can usually be corrected by diluting the slurry with water, but if the viscosity cannot be corrected in this manner, the slurry should be discarded.

If the viscosity decreases and the specific gravity increases while in use, it is usually the result of sand particles held in suspension by the slurry. In this case it becomes a problem trying to bring both properties back within desired limits by trying to correct one or the other by the addition of water or bentonite. If these properties cannot be successfully corrected, the slurry should be discarded.

The following steps should be taken tc insure an acceptable shaft when using conventional drilling equipment.

First drill in and set a surface casing, if needed. As drilling progresses, fill the bore hole with slurry, so that a static head of slurry is maintained preferably near the ground surface, but well above ground water elevation or any caving soil layer, during the entire drilling operation.

Try to maintain the specific gravity and viscosity fairly close to that of uncontaminated slurry unless an adjustment is necessary to control caving and/or ground water.

To minimize contamination, drilling should proceed with minimum agitation or mixing of the cuttings with the slurry. The auger should be moved slowly while drilling, then extracted in a manner which allows the slurry to flow around it when filled with cuttings. Extraction of the auger must be done very slowly, to avoid a suction or negative pressure below the auger which could fail the membrane and cause caving or inflow of ground water.

The slurry in the bore hole should be of uniform consistency throughout. A clean out or bail bucket can be used to remove the thicker slurry from the bottom of the hole. Extraction of the bail bucket should be very slow for the reasons mentioned above.

When the hole is clean and the slurry in the bore hole is in satisfactory condition, the cage of reinforcing steel should be set and the slurry displaced by underwater concrete placement methods as soon as possible.

If there is a delay of more than one hour between hole completion and placing of reinforcement and concrete, the slurry should be agitated to return it to a uniform fluid state, and the bottom of the bore hole rechecked for material settlement and recleaned if necessary.

Concrete must be placed by the closed tremie method. (See Placing Concrete Underwater.) The concrete should be a properly retarded seven sack design with good workability, having a slump of approximately 6 inches. A mix using a Grade 3 coarse aggregate and having good flow characteristics is recommended.

The displaced slurry may be collected for reuse in processing other shafts, provided its specific gravity and viscosity is satisfactory. During concrete placement, some cement will mix with the slurry at the interface of the concrete and slurry, and cause an increase in viscosity. If the slurry is to be salvaged for reuse, the slurry should be observed as it is being displaced to detect the zone of increased viscosity just above the concrete. The slurry in this zone should be discarded.

After the slurry has been completely displaced and contaminated concrete removed from the top of the bore hole, leaving clean concrete exposed, the surface casing is pulled. The amount of slurry contamination of the concrete depends on the condition of the slurry, depth of hole, speed of concrete placement, size of shaft and configuration of the reinforcement cage. A three foot depth of contaminated concrete is not uncommon. Enough concrete must be placed to displace the contaminated concrete and to insure cleanliness of the steel.

The general procedure for the slurry displacement method is illustrated in Figure 3.

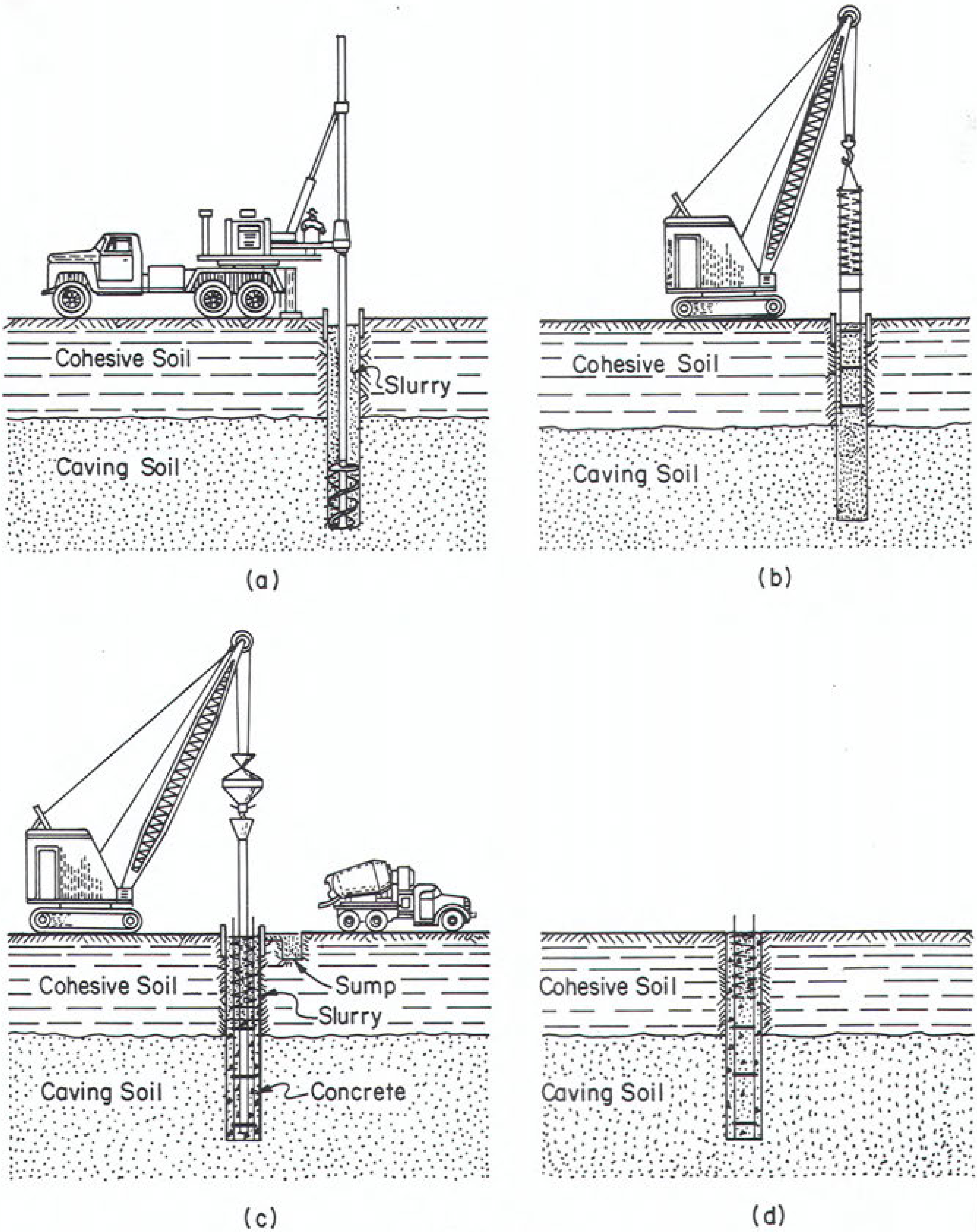

Figure 3
SLURRY METHOD
(a) Drilling to full depth with slurry; (b) Placing rebar cage; (c) Placing concrete; (d) Completed shaft.

105.4. INSPECTION OF SHAFT EXCAVATION

It is of utmost importance that the material in which the shaft or bell footing is to be placed is the same material considered for the shaft design. Elevations of strata will vary from one location to the next, so that penetration into or bearing on, a particular material must be verified. It is better to lower a shaft or bell footing a few feet to insure a sound foundation than to risk settlement if the material encountered at a particular elevation is not as anticipated.

Specifications provide that the Contractor core the material below the founding elevation up to a maximum of five feet, when requested by the Engineer. A four inch diameter core should be the minimum size used. If there is doubt about the material encountered, it is recommended that the coring be done.

All shafts must be inspected for proper horizontal and vertical alignment.

The shaft and bell dimensions must be checked for compliance with the plans.

The bottom of the shafts or bells must be inspected either visually, by probe or other method, to make certain all loose material has been removed from the bottom of the bore hole and to make certain that the material in which the shaft is to be founded is adequate.

A protective shield and an adequate fresh air supply should be provided for personnel entering a shaft for inspection or other purposes.

The casing should be inspected for cleanliness, water tightness and size. The outside diameter of casing must not be less than the nominal diameter of the shaft. Alignment of the casing should be checked as it is being set.

Adequate measures must be taken to assure that any static head of water or slurry required by the construction procedure is held at a relatively constant level. Failure to maintain the static head at a sufficient height can result in caving, and damage to the footing area and/or to the concrete during placement. Inspection of the bottom of shaft for cleanliness is a problem for underwater or slurry conditions. For this purpose a weight (such as a window sash weight) attached to the end of a metallic tape can be used as a sounding device to inspect the shafts. The weight should be attached to a line that does not stretch easily. A metallic tape works well for this purpose as well as for measuring the depth of the shaft. By lowering the weight and gently sounding the bottom, the general condition of the bottom of the shaft may be determined. Tight undisturbed material will produce a solid feel through the tape; loose material will feel soft or spongy. For shafts drilled by conventional methods, a clean-out bucket of the proper size should be used to pick up any loose material at the bottom of the bore hole when constructed under water or slurry.

If an airlift is used to clean the bottom of a shaft which requires a static head, water or slurry must be pumped into the top at the same rate that it is removed from the bottom, in order to maintain the required static head. If the shaft is founded in cohesionless material, airlifts should not be used.

105.5. INSPECTION OF STEEL PLACEMENT

The reinforcing cage must be carefully placed in uncased shafts to prevent gouging of the sides, which may cause loose material to fall into the shaft. Spacer blocks, spaced at intervals along the reinforcing cage, must be used to insure concentric spacing for the entire length of shaft.

Metal spacers should be used in cased shafts to insure concentric spacing of the steel. They also provide less drag between the casing and steel during casing removal. Small size bent pieces of reinforcing steel tied or welded (where permitted) to the vertical bars at intervals make excellent spacers.

The cage of reinforcing steel should be placed on the bottom of the shaft, or to the depth required by the plans, and adequately supported at the top to prevent the steel from slumping downward.

The tendency for the steel to slump is much greater in deep cased shafts. The top of the steel cage should be held and not released at any time during casing extraction. The tendency for the cage to slump downward is caused by the drag and torque placed on it by the concrete as it flows downward past the spiral reinforcement during casing extraction. This tendency can be virtually eliminated by the use of horizontal steel bands in lieu of the spiral reinforcement. The bands are welded to the vertical steel starting at a point approximately 15 feet below the top of shaft and spaced uniformly downward. In the top 15 feet of shaft, spiral is required and <u>no</u> welding is permitted.

Details for the use of bands are given in the plans. Generally, bands are more beneficial for shafts greater than 50 ft. in depth. This method provides a very rigid cage that is easy to handle.

The reinforcing steel must be carefully aligned horizontally with enough projection at the top of the shaft to properly make a splice of the column steel or for projection into the footing as required by the plans.

105.6. CONCRETE PLACEMENT IN DRILLED SHAFTS

105.61. GENERAL

Concrete placement should begin as soon as possible after the shaft has been excavated. Occasionally seep water may present a problem if concreting is not completed quickly. Delivery of concrete to the job site should be coordinated with the final drilling, belling, and clean out being done just prior to arrival at the job site, to keep seepage to a minimum and to reduce the chances of caving. Sometimes pumping may be used successfully to rid a shaft of excess seep water. For the cased method or the slurry displacement method, the operation should be as nearly continuous as practical from the start of drilling to completion of concrete placement.

For shafts placed in the dry, the concrete must be placed through a suitable tremie to prevent segregation and unnecessary splashing on the reinforcing steel. The concrete should be directed toward the center of the shaft, not eccentrically, to prevent unequal pressures that may affect the steel alignment. The tremie may be constructed in sections which are removed as placement progresses. Free fall of concrete should not exceed three feet. This type of tremie is fed by placing concrete into a hopper at its top. A non-jointed pipe tremie may be used if sufficient openings of the proper size are provided to allow for the flow of the concrete into the shaft. The concrete should be fed into the pipe through a hopper at the top, or may be fed in at side openings. The pipe should be raised as placement progresses so the discharge of the concrete is always directed downward toward the center of the shaft.

The slump value of concrete for drilled shafts should be near the maximum allowable to obtain satisfactory consolidation without vibration, to facilitate filling of all voids outside the casing.

105.62. CASED DRILLED SHAFTS

To reduce the friction encountered during extraction, the concrete mix should be well designed, with a slump near the maximum permitted, to provide the maximum lubrication possible between the casing and the concrete. The mix may be designed with entrained air to provide additional lubrication and greater workability. The percentage of entrained air in the mix design should be as specified for the grade of coarse aggregate used in the mix. Retardation of the concrete is required in all cased shafts. When the concrete placing and casing extraction operation progresses slowly, a retarder will aid in keeping the concrete plastic for a greater length of time to allow the satisfactory completion of the work.

As has been discussed previously, the use of a drilling mud will help reduce the friction on the outside of the casing.

During casing extraction, the concrete may become contaminated by the drilling slurry or water trapped in voids outside the casing. This can occur when the bottom of the casing passes a void and the concrete hangs inside the casing and does not flow into the void or displace the slurry outside the casing. The result may be a separation of the concrete with an inflow of slurry or water into the shaft at the bottom of the casing. With such separation of the concrete, the reinforcing steel cage may be displaced upward due to excessive friction between the steel, concrete and casing. This can generally be prevented by using workable concrete, speeding up concrete placement, uniform casing extraction and keeping an adequate head of concrete inside the casing.

Contamination of the concrete may also occur if the seal is broken before sufficient concrete has been placed inside the casing. In this case the hydrostatic pressure on the outside is greater than that of the concrete inside the casing. The result is an inward flow of slurry or water through the concrete. After a shaft has been sealed and de-watered prior to concrete placement, it is difficult to determine the static water level outside the casing. As the casing is extracted, any slurry or water outside the casing must be displaced upward. This displacement will raise the outside water or slurry level causing it to flow out at ground level. Sufficient openings should be left around the casing at ground level to permit slurry or water to escape without contaminating the concrete. To prevent an inflow of water during casing extraction, a sufficient head of concrete must be maintained in the casing to counteract the outside water pressure before the seal is broken. As the casing is being extracted, a sufficient head of concrete must be maintained therein for any anticipated overrun due to filling voids and to maintain the level of the concrete above the top of shaft elevation. The casing should be extracted slowly and smoothly with the pull in the direction of the center line of the shaft, in increments if necessary, so that voids outside the casing will be properly filled with concrete. When the casing is completely extracted, the top of the concrete should be somewhat above the top of shaft elevation. The excess concrete together with any mud must be cleaned off to sound concrete, and the top of the shaft properly cured.

During the extraction of the casing, several observations should be made:

1. The level of concrete inside the casing during extraction should be constantly monitored. The concrete should not be lifted with the casing but must flow downward. The rate of downward flow will vary and depends on the condition of the shaft outside the casing.

2. Observe the flow of slurry or water around the outside of the casing as it is displaced by the concrete. A sudden reversal of flow may indicate concrete separation or a blow-in due to insufficient concrete in the casing.

3. Observe the cage and concrete for any upward movement during casing extraction. Generally, any upward movement of the steel not exceeding 2 inches or any downward movement not exceeding 6 inches per 20 feet of shaft length will be acceptable. Any upward or downward movement of the steel beyond the above limits is cause for rejection.

The normal tendency during the downward flow of the concrete as it fills the voids outside the casing is to produce a drag on the reinforcing steel causing it to slump downward. A positive means of holding the reinforcing cage at the top must be provided to prevent slumping of the steel.

The inspector must have sufficient first hand knowledge of the placement to accept or reject the shaft soon after the casing is pulled. This decision should be made immediately.

Where skin friction design is used, it is imperative that the casing be removed. If for any reason the casing cannot be removed from the shaft, the Bridge Division should be consulted for alternative design requirements.

105.612. PLACING CONCRETE UNDER WATER

After the casing has been set and the shaft properly inspected, the water in the casing must be brought to a static head and the concrete placed by the closed tremie method as follows:

> The tremie consists of a watertight pipe not larger than 14 inches in diameter and long enough to reach the bottom of the shaft, and with a receiving hopper at the top.
>
> When placing concrete with a tremie, the concrete should be plastic and cohesive and should have good flow characteristics. This requires a higher slump and a richer mix than is generally used for placing under dry conditions. The mix should be designed in accordance with the requirements for placing concrete under water as provided in the specifications.

The lower end of the closed tremie should be equipped with a hinged foot valve controlled with a line from the top, by a combination of heavy plastic sheeting over a wooden plug, a foam rubber plug (rabbit) or other suitable means that will keep water out until the tremie has been placed in position at the bottom of the shaft and fully charged with concrete. The plug is forced out, or the valve opened by lifting the tremie a short distance. Plugs or valves at the bottom of a tremie cause the tremie to displace more water and have greater bouyancy. Sometimes this makes it difficult to force a light weight tremie to the bottom of the shaft. Sometimes it is desirable to set the pipe at the bottom of the shaft and insert a snug fitting foam rubber plug at the top of the tremie. The plug will be forced downward by the weight of the concrete and will keep the concrete from free flowing through the water inside the tremie. As the concrete begins to flow, additional concrete must be added to the hopper to maintain the head of concrete near the top of the tremie. After concreting has started, the lower end of the tremie should be kept submerged in the concrete as deep as conditions will permit. This will depend largely on the depth and flowability of concrete to be placed and the head of concrete that can be maintained in the tremie. The tremie should be lifted slowly to permit the concrete to flow out. Care must be taken not to lose the charge in the tremie by lifting it too high. If the charge is lost, it is necessary to raise the tremie to void it of water, plug the lower end, lower the tremie into the previously placed concrete, and recharge it again before concreting continues. Jerking the tremie up and down to make the concrete flow should be avoided, as it produces a washing and agitating action at the top surface of concrete. A rapid continuous flow of concrete through the tremie assures good distribution by taking advantage of the energy of flowing concrete.

Concrete is placed to the top of the casing, with concrete replacing all water inside the casing before it is pulled. It is permissible to loosen the casing and pull it intermittently, if a sufficient head of concrete is maintained therein.

105.613. PLACING CONCRETE UNDER SLURRY

After the shaft has been completed using the slurry method, concrete placement should generally follow the same procedure specified in the preceding section. The slurry must be displaced by the flow of concrete from the bottom and in addition, flowing concrete must clean the reinforcing steel of slurry as it rises upward. For this reason the slurry should have as uniform a consistency as possible without slurry settlement at the bottom. Overly thick or contaminated slurry will interfere with the quality of the shaft. Uniform placement of the concrete without delay is even more important in this operation than when placing concrete underwater.

The inspector should note the flow of slurry at the top and attempt to maintain a uniform flow by regulating both the placement of concrete in the tremie, and the rate of upward movement of the tremie. Some contamination usually occurs at the interface of the concrete and slurry. The placement should be observed at this point to see if there is contamination of the concrete. When contamination is observed, continue placing concrete until all contaminated concrete has been displaced from the shaft.

When the slurry displacement method is used, the volume of concrete placed in a shaft is an important factor in determining the adequacy of the shaft. If there is an appreciable difference in the theoretical amount of concrete required and that actually placed, construction procedures should be reevaluated and changes made where necessary.

If there is an underrun of concrete placed from the theoretical amount required, the shaft is questionable and an investigation should be made of its adequacy prior to acceptance.

105.7. BATTERED SHAFTS

Frequently, battered shafts are used and present special problems during construction. Since the walls of a battered shaft are not in a vertical position, they are more prone to caving. The shaft alignment may be difficult to hold as the weight of the drilling equipment produces a tendency to drift toward the vertical position.

To counter these problems, the use of casing generally provides an adequate solution. Depending on the location of caving and ground water, if any, multiple casings may have to be used. Caving and alignment can be controlled by having the casing tip follow closely behind the drilling. If the casing is carried down in correct alignment, it will provide a solid base for the side of the drilling tool to rest against and thereby help maintain alignment.

Concrete placement for battered shafts is conducted similarly to that used in vertical shafts. A special effort should be made to place the spacer blocks on the lower side of the reinforcing steel in order to properly align the cage and support it off the casing.

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CHAPTER 6

TEST LOADING DRILLED SHAFTS

106.1. GENERAL

A test load is performed on a drilled shaft to determine its static bearing capacity. This value is correlated with the bearing capacity obtained from field and laboratory soil tests. From this information, shafts may be shortened or lengthened as indicated by the test load.

Test loading is applied in accordance with the Item, "Foundation Test Load", of the Standard Specifications and Special Provisions thereto.

Shafts to be test loaded are designated on the plans or by the Engineer, and must be constructed by the same procedures as anticipated for the regular shafts, i.e., dry method, cased method or slurry displacement method. A complete drilling log and record of the test shaft and anchor shafts must be kept. The loading of the test shaft will be as prescribed by the "Quick Test Load Method".

For the "Quick Test Load Method", the load is applied by means of hydraulic jacks reacting against suitable beams held down by anchor shafts. The drilled shaft test load details are usually provided in the plans but may be as approved by the Engineer in special cases.

The Resident Engineer should arrange well in advance of test loading for certain equipment furnished by the Department and the Contractor.

The Department has reaction beams, hydraulic jacks, pumps, extensometers (Ames dials) and necessary accessories. All other equipment, labor and incidentals are furnished by the Contractor.

When a shaft test load is not required by the plans but deemed advisable by agreement between the field and D-5, the Bridge Division will aid in designing, checking the test load details, locating equipment, setting up the work and performing the test.

The anchor shafts, sometimes with bells, which are used in the test load setup, are founded deeper than the test shaft to provide adequate holddown capacity, and eliminate any influence which they might have on the test. Enough projection above ground to accommodate the anchor posts, reaction beams and jacks is provided (as shown on plans). The anchor shafts and size of bells have been determined in the planning stage and are dependent on the anticipated ultimate load. The anchor shafts should be located as specified in the shaft test load details, but if no details are furnished, they should be located not less than 7 feet clear distance from the anchors to the test shaft to minimize disturbing the soil surrounding it. Preferably, anchor shafts should be drilled and concrete placed before the test shaft is constructed. The concrete must have reached its design strength and the surrounding soil given sufficient time to adjust to the changes brought about by the migration of water and cement particles from the fresh concrete. The frictional resistance of a shaft generally increases with time. The specifications require a waiting period of seven days between concrete placement in the test shaft and load testing.

The test load setup is designed to carry the test shaft to plunging failure or to the capacity of the jacking equipment whichever is reached first.

Provisions must be made for measuring accurately the gross settlement and load on the test load shaft at regular intervals as it is gradually loaded. Gross settlement measurements should be made to the nearest thousandth of an inch by means of four extensometers (Ames dials). These should be supported independently of the test load shaft on two beams rigidly supported from the ground (Figure 12). Rigid projections attached to the test load shaft should be in contact with the extensometers to actuate the dials. Since the ground surface around the test loaded shaft is likely to settle during loading, all supports for settlement measuring devices should be located a clear distance from the supports to the test shaft of not less than 7 feet to avoid being influenced by such settlement.

106.2. METHOD OF LOADING

The loading is applied in increments of 25 or 50 tons (specified by the Engineer) at 2½ minute intervals (Figure 6). The following procedure is used:

1. Take initial extensometer readings with no load.

2. Apply the specified increment of load at 2½ minute intervals. Keep the load constant between each application.

3. Record extensometer readings, total load and time immediately before and after the application of each load increment.

4. Concurrently, plot a Load-Settlement Graph (Figure 7). When it is apparent that the curve is beginning to bend downward and plunging failure is approaching, reduce load increment to the minimum load (as directed by the Engineer).

5. When the data indicates that the shaft is being failed, i.e., the load on the shaft can be held only by constant pumping and the shaft is being pushed into the ground, (generally about 1.5 inches), stop adding load and immediately take extensometer and total load readings. Allow the shaft to reach equilibrium in load and gross settlement for 5 minutes taking load and extensometer readings at 2½ minute intervals.

6. Release the load slowly back to zero load (about 2½ minutes) and immediately upon complete release of load, record the extensometer readings.

7. When the load has been completely removed, allow the shaft to recover for 5 minutes taking extensometer readings at 2½ minute intervals.

106.3. EVALUATION OF TESTS (DOUBLE TANGENT METHOD)

From the test load data, a Load-Settlement Graph is plotted, load vs. gross settlement (See Figure 7). The value of gross settlement to be used is the value determined just prior to the addition of each load increment (the value determined from the average of all extensometers used). Plot the curve on a scale of one inch equals 100 tons of load horizontally and one inch equals 0.4 inch of settlement vertically, except that a different scale of the same ratio may be used to fit the curve to a standard 8½x11 sheet of graph paper.

On the Load-Settlement Graph, draw one line that originates at zero load and settlement, parallel to the recovery line. Another line is drawn tangent to the portion of the curve that indicates plunging failure, where the rate of settlement equals 0.01 inch per ton of additional load. For the recommended scale or scales of the same ratio, this line is plotted at an angle of 21.8° measured off the vertical.

The ultimate bearing capacity is determined by the point of intersection of the two tangent lines plotted on the Load-

Settlement Graph. This is the load which the shaft will support without excessive settlement but does not have a factor of safety.

The maximum safe static load proven by the test load is 50% of the ultimate bearing capacity, provided gross settlement at the selected design load is not more than one half inch. This value is used to modify the design.

The net settlement is the total settlement after the test load shaft has been allowed to recover for 5 minutes after the load has been removed.

The plunging failure load is the maximum load reached during the test that indicates the shaft is being forced into the ground.

The maximum load on the shaft is the maximum load applied to the test load shaft whether plunging failure occurs or not. It is possible to load a shaft to the limit of the equipment before plunging failure occurs.

The total gross settlement is the maximum settlement obtained during the test.

It is the intent to load the shaft to plunging failure. If the limit of the loading apparatus is reached without plunging, the double tangent method cannot be used for evaluation. In this case the maximum safe static load will be 50% of the load at which 0.25 inch net settlement occurs or 50% of the maximum load applied if the net settlement is less than 0.25 inch.

The load at which 0.25 inch net settlement occurs can be determined by plotting, on the Load-Settlement Graph, a line parallel to the recovery line through the point zero load - 0.25 inch settlement. The load occurs at the intersection of this line with the gross settlement curve.

106.4. APPLICATION OF TEST LOAD DATA

The specifications provide for the use of test load data to modify the design and determine the appropriate shaft lengths to be used in construction which produce bearing capacities that will satisfy the design requirements. Results from a shaft test load establish a maximum safe static load for a particular shaft-soil system.

When the test shaft is fully instrumented, the loads taken out in skin friction along the length of shaft and in point bearing at tip are obtained. The maximum safe static load less the point bearing load is the amount of load carried by skin friction. In this case, the actual soil reduction factor is calculated by dividing the skin friction obtained from test load by the skin friction obtained from laboratory or field data. Then, these values are used in lieu of the soil reduction values discussed in the Foundation Manual, Section 4-404.33.

If the test shaft is not instrumented, the maximum safe static load is obtained, but a break-down into skin friction and point bearing loads are not known. Then it is necessary to calculate the point bearing load from laboratory or field data and subtract that value from the maximum safe static load to obtain the skin friction load. Then, the soil reduction factor is equal this value divided by the value from laboratory or field data.

After the load tests, the remaining shafts used in the structure, or within the limits of influence of the load test, may be lengthened or shortened and constructed to the appropriate tip elevations determined by the test load and approved by the Engineer.

106.5. RECORDING AND SUBMITTING DATA

The field data sheet, Form 1302, Record of Foundation Test Load, should be prepared as illustrated in Figure 6.

Figure 8, Summary of Data, Foundation Test Loading, should be prepared as illustrated in Figure 8.

The Load-Settlement Graph should be prepared as illustrated in Figure 7.

A complete report for each completed drilled shaft test load, prepared for submission, should consist of the following:

1. District Engineer's letter of comment, explanation and recommendations.

2. Summary of Data, Foundation Test Loading (Figure 8).

3. Load-Settlement Graph (Figure 7).

4. Record of Foundation Test Loading (Figure 6).

5. Drilling Log for Test Shaft prepared on Form 513 (Figure 5).

The number of copies to be prepared are as follows:

1 copy for Resident Engineer's Office.

1 copy for District Office.

1 copy for Austin Office for State Projects.

3 copies for Austin Office for Federal Aid Projects.

APPENDIX

Texas Highway Dept.
Form 1276 Revised
7-72

DRILLED SHAFT RECORD

County Hart | Stream or Structure Brady St. Overpass
Highway IH 43 | Structure Number 15 | District 27
Control 500-1-30 | From Station 258+10 | To Station 261+07.5
Project I43-1(132)040 | Res. Engr. J. B. Tobis | PD No. 9072

DRILLED SHAFT No.	Dia. (in.)	Top of Shaft Elev.	Length (ft.)	BELL FOOTING Dia. (ft.)	Vol. (c.y.)	Date Drilled	Casing Used	Drilling Mud	Slurry Placement	REMARKS
Bent No. 1 Design Load Tons per Shaft 80										
A	30	46.5	40			8/20/77	x	x		Slight seapage at tip casing
B	30	46.5	*45			8/20/77	x	x		Lengthened 5' to obtain seal
C	30	46.5	*45			8/20/77	x	x		" " 5' " " "
D	30	46.5	*48			8/20/77	x	x		" " 8' " " "
Bent No. 2 Design Load Tons per Shaft 142										
A	36	38.5	45	6	1.3	1/21/77	x	x		Slight seapage in bell area
B	36	38.5	45	6	1.3	1/24/77	x	x		
C	36	38.5	54	6	1.3	1/24/77	x	x		Lengthened 9' to obtain bell
D	36	38.5	56	6	1.3	1/24/77	x	x		" " 11' " "
Bent No. 3 Design Load Tons per Shaft 197										
A	36	37.0	62			1/19/77	x	x		
B	36	37.5	62			1/19/77	x	x		
C	36	38.0	62			1/18/77	x	x		
D	36	37.0	62			1/18/77	x	x		
Bent No. 4 Design Load Tons per Shaft 197										
A	36	37.0	62			1/28/77	x	x		
B	36	37.5	62			1/27/77	x	x		
C	36	38.0	62			1/28/77	x	x		
D	36	37.0	62			2/2/77	x	x		
Bent No. 6 Design Load Tons per Shaft 105										
A	30	46.7	48			7/13/76	x	x		
B	30	46.7	48			7/13/76	x	x		
C	30	46.7	*52			7/14/76	x	x		Lengthened 4' to obtain seal
D	30	46.7	48			7/14/76	x	x		

SUMMARY FOR PAYMENT

Total This Sheet: Size of Shaft	Length (ft.)	Total This Structure: Size of Shaft	Length (ft.)
30"Ø	374.0	30"Ø	374.0
36"Ø	696.0	36"Ø	696.0
Total Vol. of Bells	5.2 c.y.	Total Vol. of Bells	5.2 c.y.

GENERAL REMARKS

Field change to straight shafts without bells for interior Bents 3, 4 & 5 due to water in seams of sand at founding elevation.
10' surface casing set for shafts of interior bents.

Signed: Ted E. Sommers Engineer I

NOTE: For distribution forward one copy to the Bridge Division. (Submit forms weekly). Indicate any changes from plans in shaft diameter, bell diameter and/or length of shaft as placed by an asterisk, and explain change in remarks. Number drilled shafts from left to right in each bent in the direction of increasing stationing. If necessary, provide a sketch showing numbering system. Complete daily when used for record keeping.

Figure 4

Texas Highway Department
Form 513
Rev. 4-63

DRILLING LOG

County: Morton | Structure: HB&T RR Overpass | District No.: 27

Highway No.: IH 45 | Hole No.: Test Shaft #1 | Date: 8-11-76

Control: 37-13-2 | Station: 137+10 | Grd. Elev.: +66.2

IPE: | Loc. from Centerline: Rt. 10' Lt. | Grd. Water Elev.: +52.2

ELEV. (FT.)	Depth	†	LOG	THD PEN. TEST NO. OF BLOWS 1st 6"	2nd 6"	DESCRIPTION OF MATERIAL	METHOD OF CORING	*
+66.2	0					"Fill Material" sand & clay	36"Ø Auger (0–60')	(1)
+63.2						CLAY, Sandy, light gray, tan, stiff, moist		
	10							
+52.2						(Water at +52.2')		
						SAND, silty, light gray, tan, compact to loose, wet		
+44.2	20					(Casing set to 22' depth)		(2)
						CLAY, silty, light gray, soft, moist, becomes stiff at 25' depth		
+36.2	30					SILT, clayey, red, light gray, dense, wet		
+24.2	40					(Casing set to 43' depth)		(3)
						CLAY, silty, red, light gray, very stiff w/siltstone, moist		
+15.2	50					SILT, clayey, red, light gray, wet		
+9.2						(Casing set to 57' depth)		(4)
						CLAY, slightly silty, tan & gray, hard moist w/slickensides		
+6.0	60							
						Drilled shaft tipped at +6.0'		
	70							

*REMARKS: (1) 5' surface casing
(2) Minor water seepage at tip of casing
(3) Water sealed out
(4) Very little seepage at tip of casing

Driller: Barton Drilling Co. | Logger: Ben Walton | Title: Engr. Tech. IV

†Indicate each foot by shading for core recovery, leaving blank for no core recovery, and crossing (X) for undisturbed laboratory samples taken.

NOTE: Refer to Foundation Exploration and Design Manual for directions in filling out this form. For distribution, forward one copy to the Bridge Division (D-5) and one copy to the Materials and Tests Division (D-9) if samples are submitted and make a note of same on D-5 copy.

Figure 5

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION
FORM 1302 REVISED
8/76

RECORD OF FOUNDATION TEST LOAD

Loading No. .

TEXAS QUICK TEST LOAD METHOD

County Morton Control 37-13-2 Structure HB&T RR Overpass
Highway No. IH 45 Project I45-1(151)037 Structure No. 32
Bent No. 20 Foundation No. Test Shaft Sta. 137+10 Rt. 10' Lt.
Foundation Size & Type 36" Ø Drilled Shaft Total Length 60' Design Load 300 Tons
Foundation Tip Elevation +6' Effective Penetration 50' Ground Elevation +66.2'
Hammer Type & Size Dynamic Resistance
Time Test Began 10:00 A.M. Date 8-18-76 Resident Engineer Roger Staubach

Time	Time Interval	Load Added	Total Load	Extensometer Readings		Total Gross Settlement - Inches		
Min.	Min.	Tons	Tons	Dial 1	Dial 2	Dial 1	Dial 2	Average
0	0	0	0	2.000	2.000	0.000	0.000	0.0000
0	0	50	50	1.995	1.995	0.005	0.005	0.0050
2.5	2.5		50	1.995	1.995	0.005	0.005	0.0050
	0	50	100	1.991	1.989	0.009	0.011	0.0100
5.0	2.5		100	1.990	1.988	0.010	0.012	0.0110
	0	50	150	1.984	1.982	0.016	0.018	0.0170
7.5	2.5		150	1.982	1.980	0.018	0.020	0.0190
	0	50	200	1.977	1.975	0.023	0.025	0.0240
10.0	2.5		200	1.974	1.972	0.026	0.028	0.0270
	0	2.5	725	1.544	1.534	0.456	0.466	0.4610
37.5	2.5	0	725	1.534	1.524	0.466	0.476	0.4710
	0	2.5	750	1.451	1.441	0.549	0.559	0.5540
40.0	2.5	0	750	1.441	1.431	0.559	0.569	0.5640
	0	2.5	775	1.334	1.322	0.666	0.678	0.6720
42.5	2.5	0	775	1.325	1.313	0.675	0.687	0.6810
	0	2.5	800	1.194	1.176	0.806	0.824	0.8150
45.0	2.5	0	800	1.179	1.161	0.821	0.839	0.8300
	0	2.5	825	0.977	0.956	1.023	1.044	1.0335
47.5	2.5	0	825	0.958	0.937	1.042	1.063	1.0525
	0	2.5	850	0.710	0.699	1.290	1.301	1.2955
50.0	2.5	0	850	0.410	0.388	1.590	1.612	1.601
*50.0	0	0	850	1.410	1.388	1.590	1.612	1.601
52.5	2.5	0	**850	0.968	0.946	2.032	2.054	2.043
55.0	2.5	-50	800	0.923	0.901	2.077	2.099	2.088
57.5	2.5		800	0.920	0.898	2.080	2.102	2.0910
	0	-800	0	1.008	0.986	1.992	2.014	2.0030
60.0	2.5		0	1.038	1.020	1.962	1.980	1.9710
62.5	2.5		0	1.042	1.034	1.958	1.966	1.9620

Remarks: *Extensometers reset with 1" spacers immediately after reading.
**Plunge failure load at 850 tons.

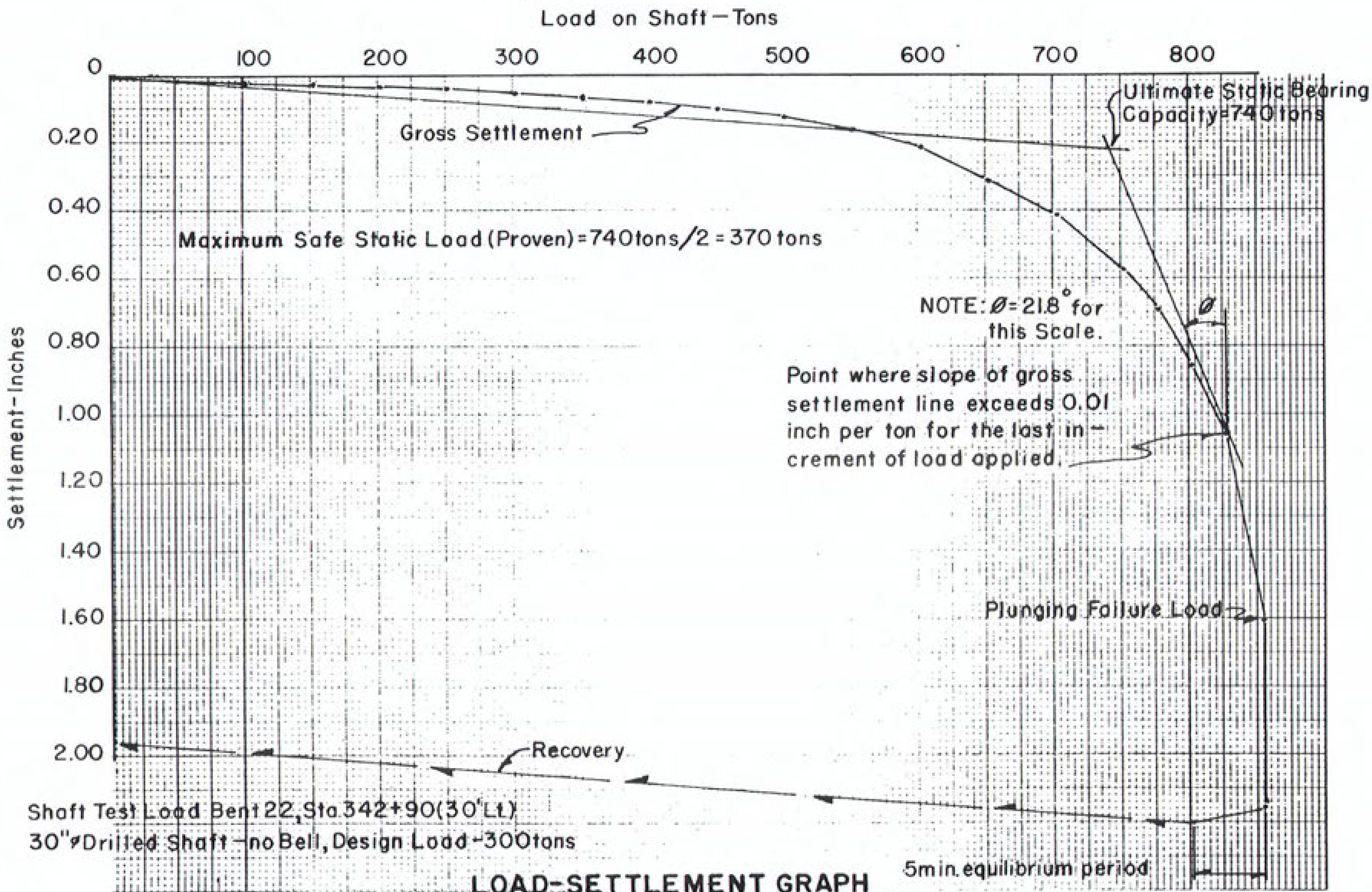
District 27
Date 8-18-76
By Billy Carter

Figure 6

Morton County, IH45 Interchange
Control 37-13-2, Proj. I45-1(151)037

DRILLED SHAFT TEST LOAD-INTERPRETATION

(Quick Test Load Method)



LOAD-SETTLEMENT GRAPH

SUMMARY OF DATA

FOUNDATION TEST LOADING

TEXAS QUICK LOAD TEST METHOD

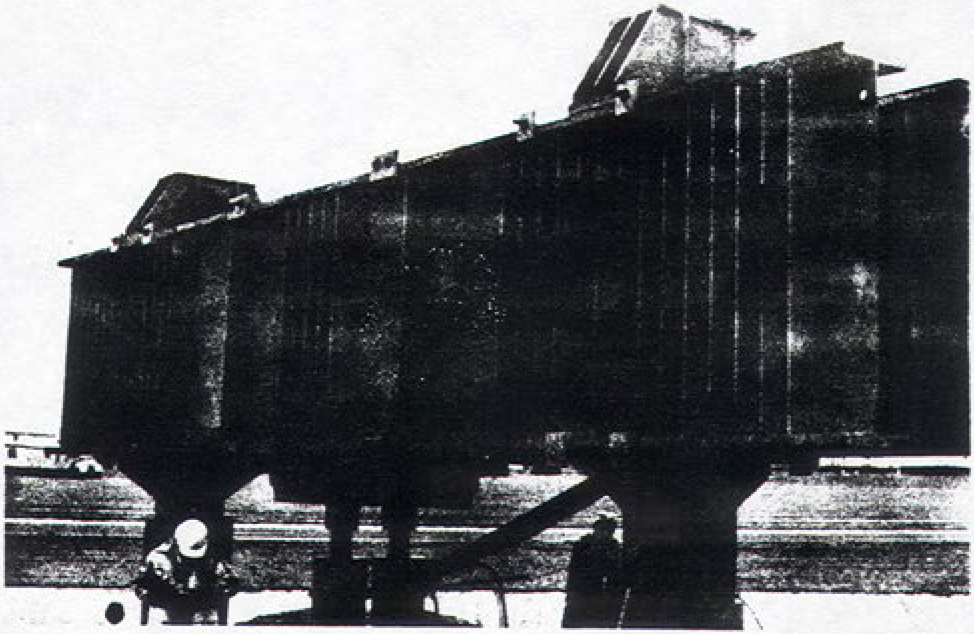
County Morton Structure HB&T RR Overpass

Highway No. IH 45 Control 37-13-2 Project I45-1(151)037

Date of Test Load	8/18/76
Bent No.	20
Location (Station)	137+10 (10' Rt.)
Description of Shaft	36"Ø Drilled Shaft
Total Length	60'
Ground Elevation	+66.2'
Shaft Top Elev.	+66.0'
Shaft Tip Elev.	+6.0'
Effective Pen.	50.0'
Soil Type (General)	Clay, Silt, Sand
Method of Installation	Slurry Displacement
Design Load per Shaft	300 Tons
Allowable Point Bearing Load (Lab. Tests w/F.S. = 2)	73 Tons
Allowable Frictional Load (Lab. Tests w/F.S. = 2)	395 Tons
Duration of Quick Test Load	62.5 Min.
Maximum Load on Shaft	850 Tons
Gross Settlement	2.200"
Net Settlement	1.962"
Plunging Failure Load	850 Tons
Ultimate Static Bearing Capacity	732 Tons
Maximum Safe Static Load (Proven)	366 Tons
"K" Factor (Proven)	0.74

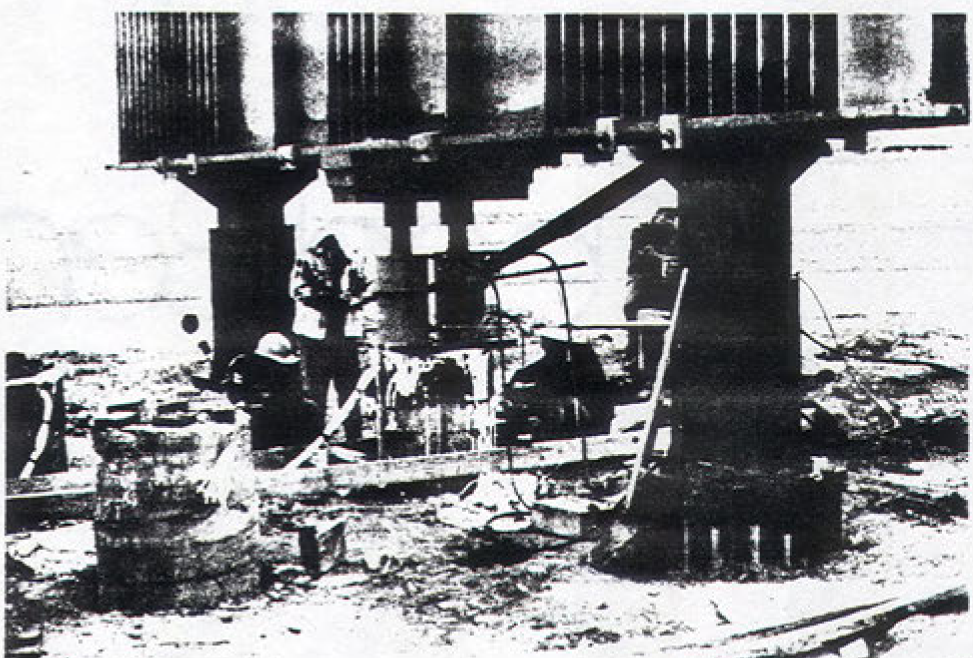
Remarks:

State Department of Highways
and Public Transportation
District 27
Date 8/19/76



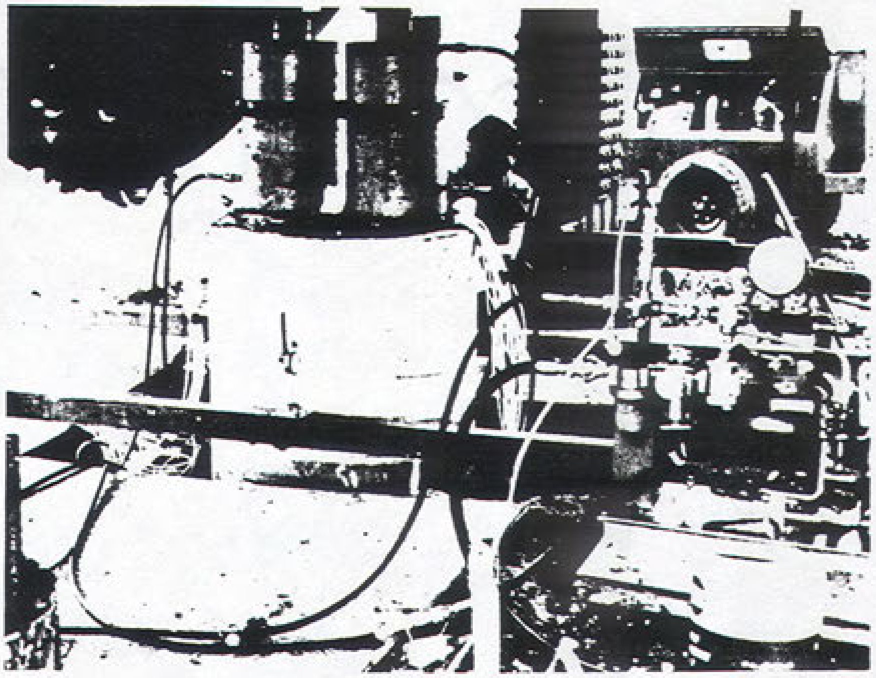
Reaction Beams and Anchor Posts

Figure 9



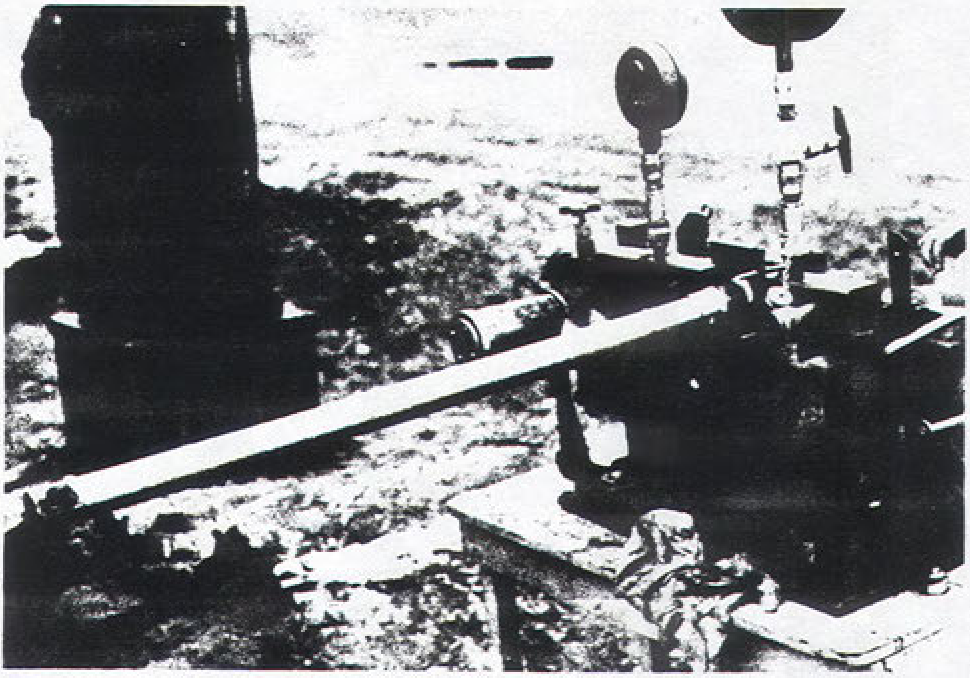
Typical Drilled Shaft Test Load Set-up

Figure 10



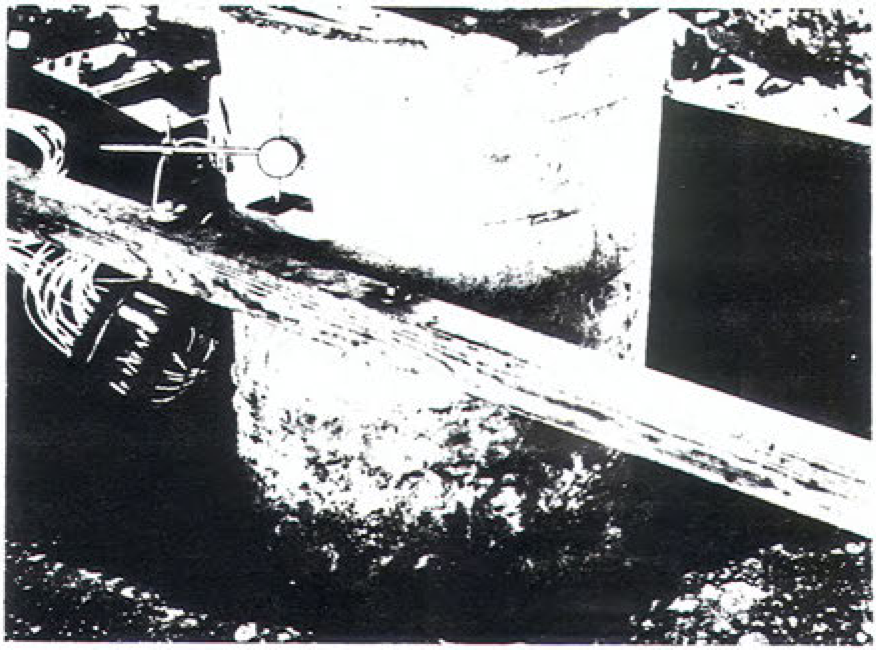
Hydraulic Jacks and Pump

Figure 11



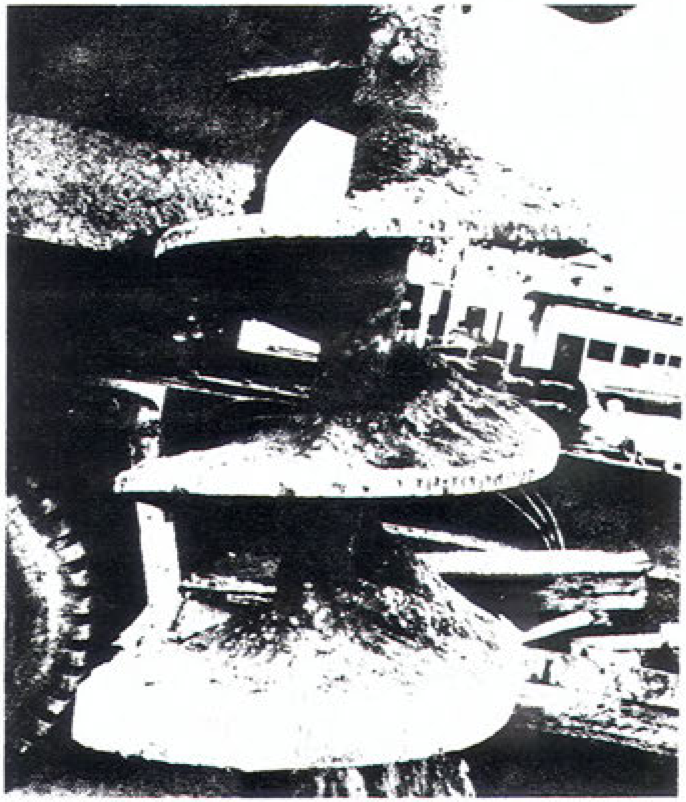
Air Operated Hydraulic Pump
showing Safety Sleeve

Figure 12



Extensometer Support System
Figure 13

Typical Belling Tool
Figure 14

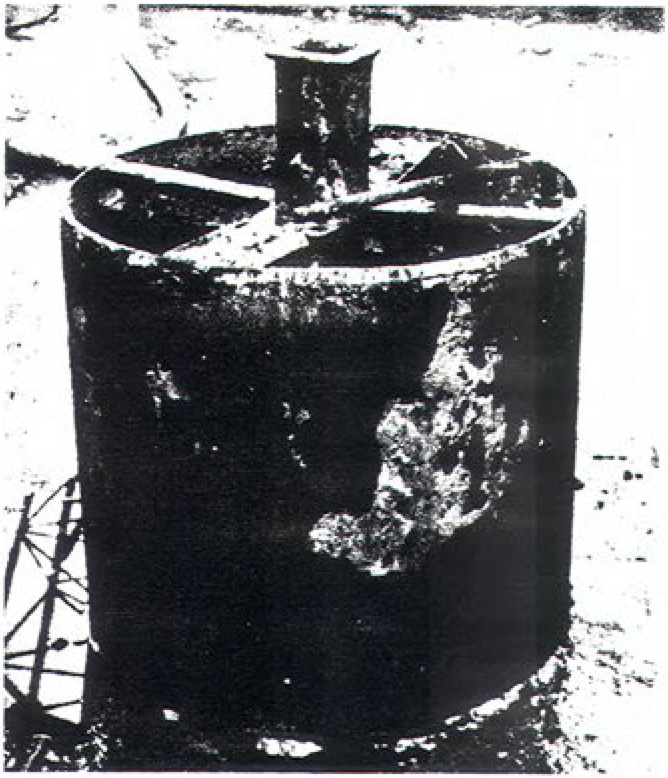


Single Flight Auger

Figure 15

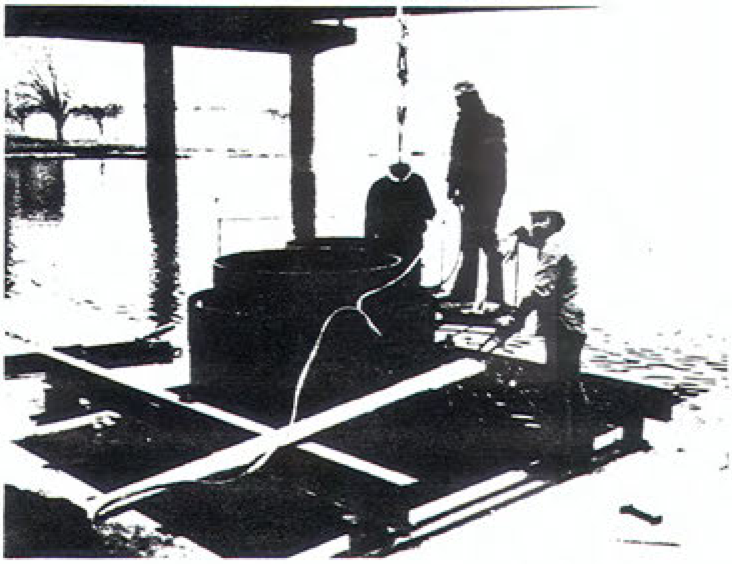
Double Flight Auger

Figure 16



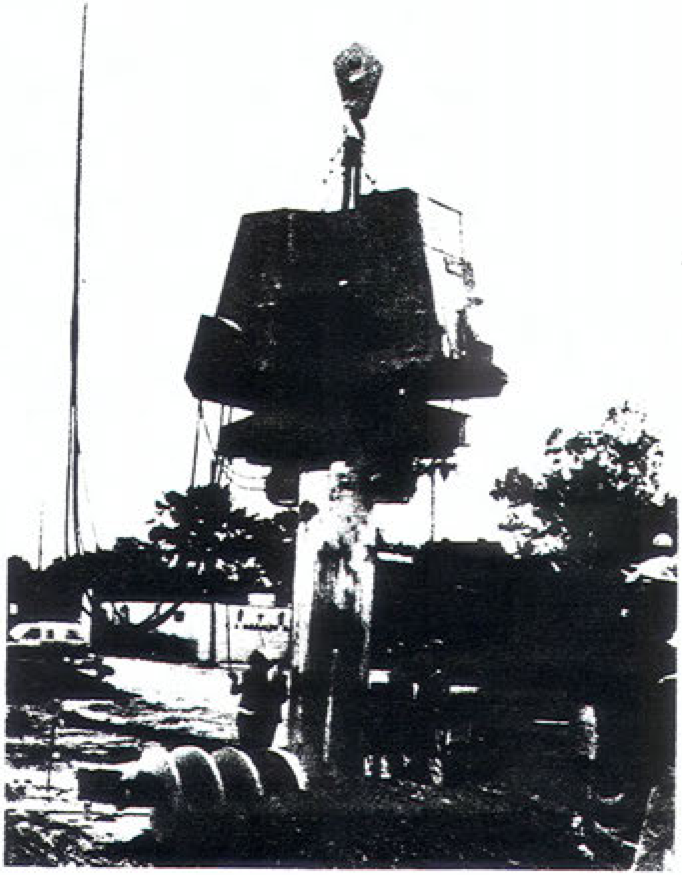
Clean Out Bucket

Figure 17



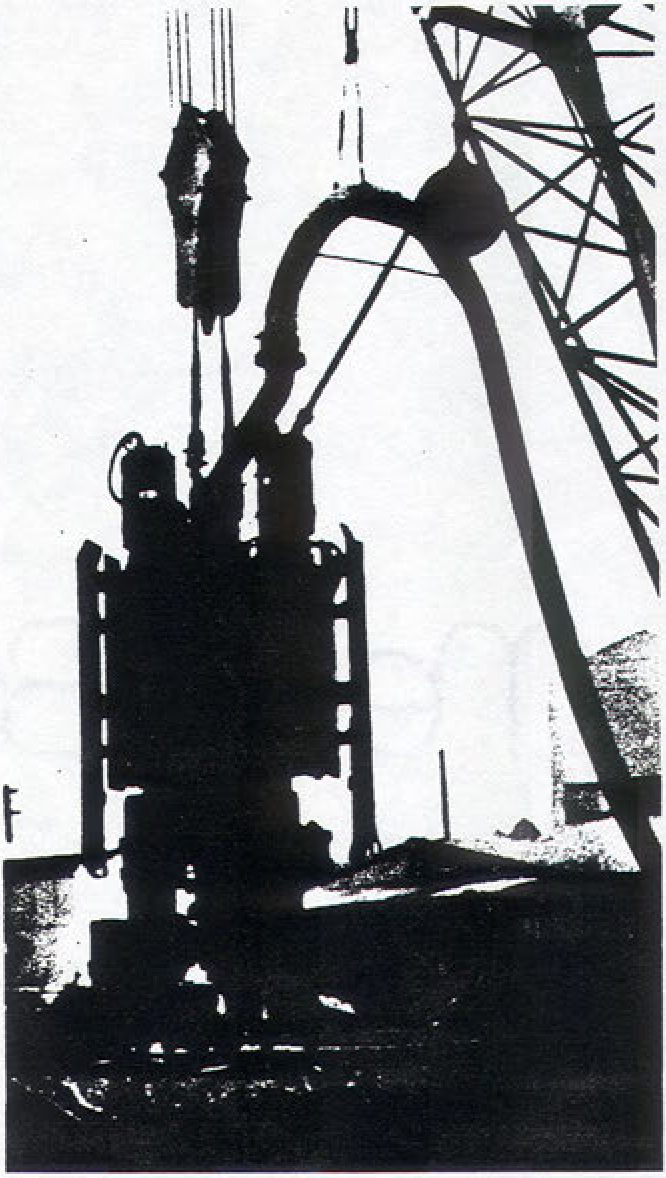
Double Casing when Drilling
in a Body of Water

Figure 18



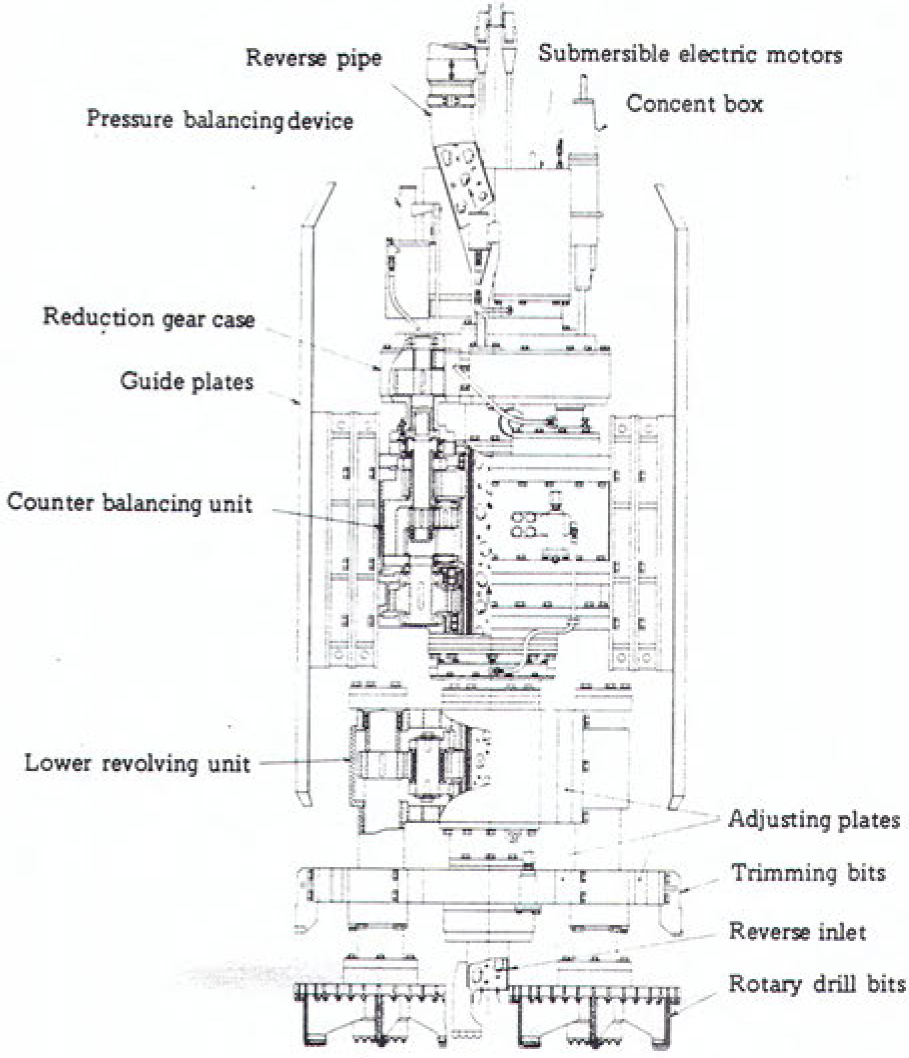
Vibratory Hammer for
Setting and Extracting Casing

Figure 19



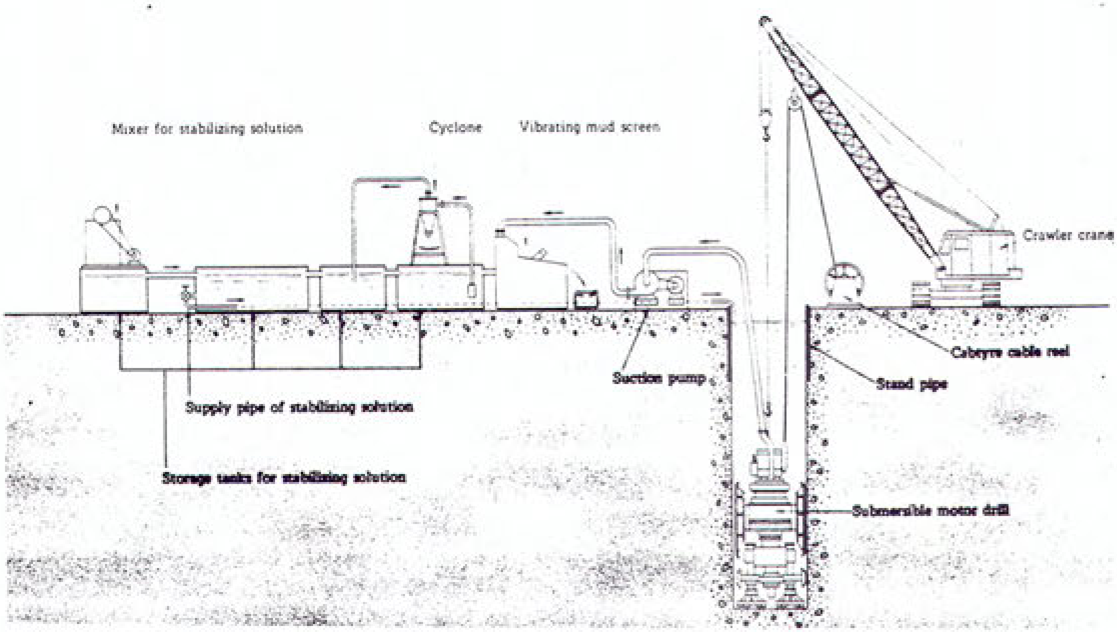
Rodless Reverse Circulation Drill

Figure 20



Schematic of Rodless
Reverse Circulation Drill

Figure 21



Flow Sheet Showing Pumps and Storage Tanks for Use with Slurry Drilling with Rodless Reverse Circulation Drill

Figure 22