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AIR FORCE

WELL DRILLING OPERATIONS

DEPARTMENTS OF THE ARMY, AND THE AIR FORCE

JUNE 1975

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FIELD MANUAL
No. 5-166
AIR FORCE REGULATION
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DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
WASHINGTON, D.C., *30 June 1975*

WELL DRILLING OPERATIONS

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*This manual supersedes TM 5-297/AFM 85-23, 16 September 1965.

CHAPTER 1

INTRODUCTION

1–1. Purpose and Scope

a. The purpose of this manual is to serve as an introductory text on ground water usage and water well drilling operations. It is primarily intended for military personnel responsible for using ground water as a water source in the field, but it may also be used for guidance in drilling water wells in permanent military installations. Auxiliary uses of water well drilling equipment, such as providing geologic or soil data, are also covered. This manual may be used as a text for training personnel in ground water usage, water well drilling operations, and related uses of the associated equipment.

b. The most important aspects of ground water, including its origin, occurrence, quality, and exploration, are covered in this manual. Those well construction methods most frequently used by military organizations (the rotary and down-hole techniques) are covered and miscellaneous methods are presented for use when standard military well drilling equipment is not available. Several types of equipment and methods normally used only in civil practice but which may in certain situations be adopted for military use are also described. The techniques of completing, developing, and testing wells after the hole has been constructed are presented. Arctic well construction and its unique problems are discussed, and the auxiliary uses of well drilling equipment for rock and soil sampling are covered. The different types of pumps that are used to lift water from inside a well to the surface are also described.

c. Additional information regarding ground water supply and the occurrence, location, and purification of water in general may be found in TM 5-700. The geology of ground-water supply is discussed in TM 5-545. Several texts and other references on the subjects of ground water and water well drilling may be found in appendix A.

1–2. Changes

Users of this manual are encouraged to submit recommended changes to improve the manual. Comments should be keyed to the specific paragraph in which the change is recommended. Reasons will be provided for each comment to insure complete evaluation. Comments should be prepared using DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forwarded direct to the Commandant, US Army Engineer School, Fort Belvoir, Virginia 22060.

CHAPTER 2

GROUND WATER

Section I. ORIGIN OF GROUND WATER

2–1. Introduction

a. It has been estimated that about 97 percent of the earth's fresh water (not counting that which is in the ice of glaciers and of the polar ice caps) is located underground.

b. Ground water originates from three possible sources:

(1) *Meteoric water.* Meteoric water is derived from precipitation on the earth's surface, usually in the form of rain or snow.

(2) *Connate water.* Connate water is ground water which was trapped in the sediments of the aquifers (water-bearing beds-para 2–3 *c* (1)) when originally deposited.

(3) *Juvenile water.* Juvenile water is ground water that is derived directly from water vapor that has been released from molten rock as it cools below the earth's surface.

c. Practically all ground water that is tapped by ordinary water wells falls in the first category, i.e., meteoric water.

2–2. Hydrologic Cycle

The origin of meteoric ground water is most clearly understood if it is viewed in the context of the hydrologic or water cycle (fig 2–1), which shows the circulation of the earth's water. When water falls on the earth's surface, much of it is lost to runoff into rivers and finally into the oceans. Another large part is lost to the atmosphere by direct evaporation and by plant transpiration. It is the part of the precipitation which manages to seep through the soil into subsurface aquifers that becomes usable ground water. This subsurface water moves very slowly downhill and ultimately seeps into the ocean.

Section II. OCCURRENCE OF GROUND WATER

2–3. Introduction

a. The depth of ground water below the land surface and the type of geologic formation in which it occurs are extremely variable. The subjects of geology in general and of ground water geology specifically are covered in detail in TM 5-545, but the more important aspects of ground water geology are summarized here.

b. The two most important properties of a subsurface formation, so far as its usefulness as a water source is concerned, are as follows:

(1) The *rock properties* of the formation determine the degree of difficulty in penetrating it with a drill and the ability of the hole to stand without being supported by a casing.

(2) The *hydrologic properties* of the formation determine whether the formation may contain water and, if so, how easily the contained water is permitted to flow through it to a well.

c. Three types of geologic formation must be considered.

(1) *Aquifer.* An aquifer is a formation that contains water and will permit the water to flow through it with relative ease.

(2) *Aquiclude.* An aquiclude may contain water, but it is relatively impermeable, thus blocking the flow of water.

(3) *Aquifuge.* An aquifuge neither contains water nor permits water to flow through it.

2–4. Geologic Properties of Rock

a. Geologists classify rocks into three general categories based on their origin, and two specific groups related to drilling properties.

(1) *Igneous.* Igneous rocks are those that have cooled from a molten magma. Examples are granite and basalt.

(2) *Sedimentary.* Sedimentary rocks, such as sandstone and shale, result mostly from the erosion and redeposition of pre-existing rocks.

(3) *Metamorphic.* Metamorphic rocks are igneous, sedimentary, or pre-existing metamorphic rocks that have undergone transformation as a result of high pressures and /or temperatures, usually at great depths in the earth. However, the temperatures fell short of the melting point of the rocks, or they would have become igneous instead of metamorphic rocks. Examples of metamorphic rocks are schist and gneiss.

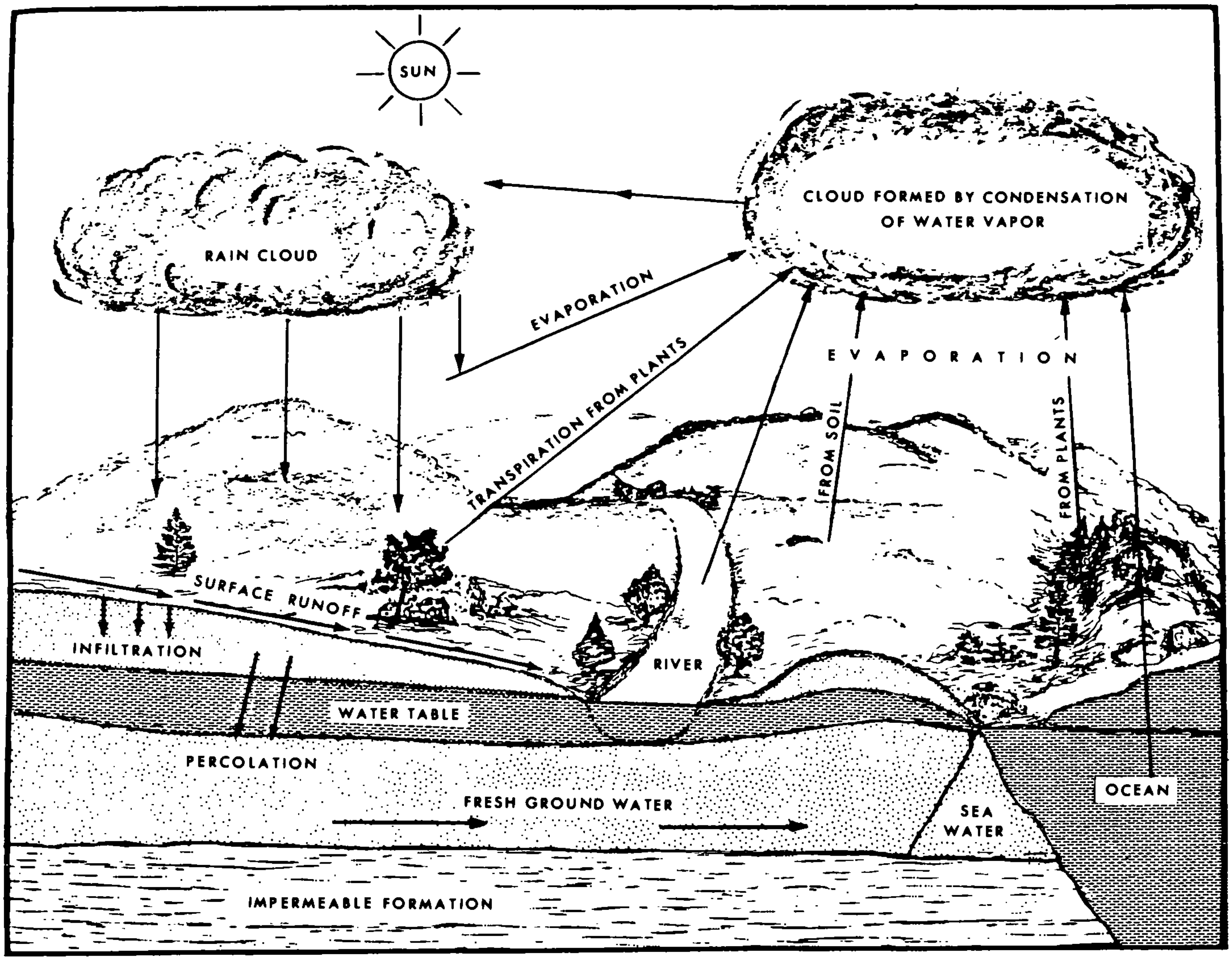


Figure 2-1. The hydrologic cycle.

b. Consolidated and unconsolidated rocks are the two specific groups known. Broadly speaking, igneous and metamorphic rocks are consolidated or unconsolidated.

(1) *Consolidated.* Consolidated rocks are usually hard, massive, and difficult to break. Examples of consolidated rocks are those taken from rock quarries.

(2) *Unconsolidated.* Unconsolidated rocks are made up of rock particles of small size (clay to gravel) that are poorly cemented together or do not hold together at all. An example of an unconsolidated rock would be loose sand or gravel such as that found in sand and gravel pits.

c. Consolidated rocks are generally harder to penetrate with a drill, but a hole drilled into them is usually more stable than a hole in unconsolidated rock. Frequently a well drilled in consolidated rock requires no casing at all to support it. Although unconsolidated rocks are easier to penetrate, this advantage is frequently outweighed by the relative instability of the hole and its tendency to cave in. Wells in unconsolidated rock almost always have to be supported with a casing, but they frequently yield considerably more water than consolidated rock aquifers.

d. Ground water in unconsolidated aquifers is contained in the interstices or pores between the particles or grains of the rock body. Ground water in consolidated aquifers is contained in joints, cracks, or solution channels in the rock; intergranular space for ground water is small or nonexistent in consolidated rocks. As a result, unconsolidated rocks usually contain more water and allow the water to flow through them more easily than do consolidated rocks. Therefore, unconsolidated rocks normally make much better aquifers than consolidated rocks.

2–5. Hydrologic Properties of Rock

a. Confined and Unconfined Aquifers. It has been stated above that a rock body that contains water and will transmit the water to a well drilled into it is called an aquifer. Aquifers are of two types—confined and unconfined (fig 2–2).

(1) *Confined.* A confined aquifer is bounded on both its top and bottom by impermeable beds; i.e., by aquifuges or aquicludes. An aquifer thus sandwiched frequently has its contained water under pressure. Consequently, when a well is drilled into the aquifer, water will rise some distance into the well above the upper boundary of the water-bearing stratum. The level to which the water will rise is called the *piezometric or potentiometric surface.* If the piezometric surface lies above the ground surface at a particular location, then an artesian well drilled there will flow without pumping.

(2) *Unconfined.* An unconfined aquifer is not bounded on its upper surface by an impermeable bed. This upper surface of the water is the highest level that the rock chinks or fractures are saturated with water. This upper limit of saturation is called the *water table.* The different zones at and above the water table are pictured in figure 2–3. In general, it may be said that the water table surface conforms in depth to the land surface, although in subdued form (fig 2–4). The depth to water however, is usually somewhat greater on hills than in valleys. If the water table intersects the land surface, a spring, pond, or swamp is usually formed.

b. Porosity. The porosity of a rock formation is a measure of the amount of pore space or void space in the rock. It shows how much water may be contained in the rock if the rock is saturated. In quantitative terms, porosity is expressed as

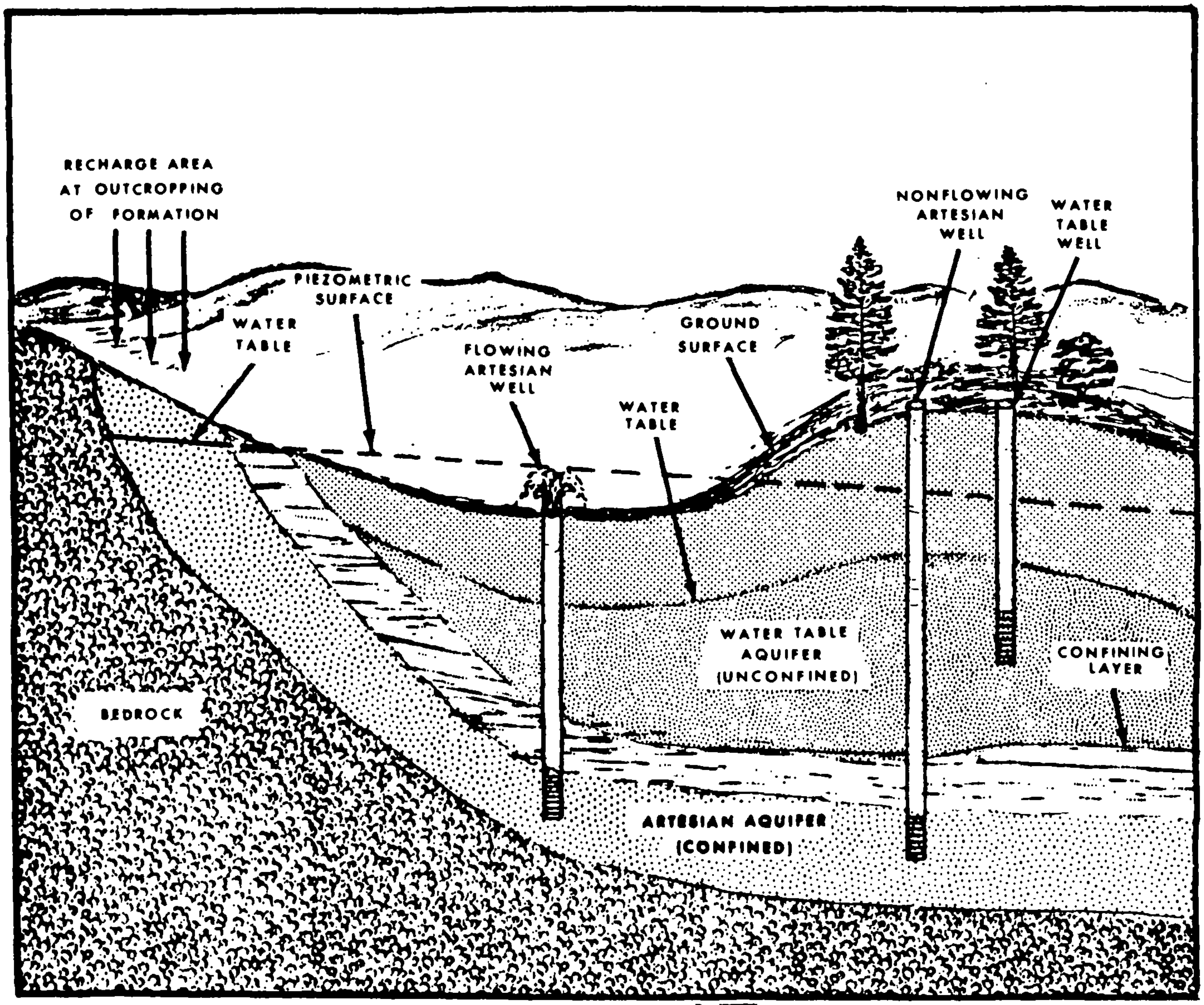


Figure 2-2. Types of aquifers.

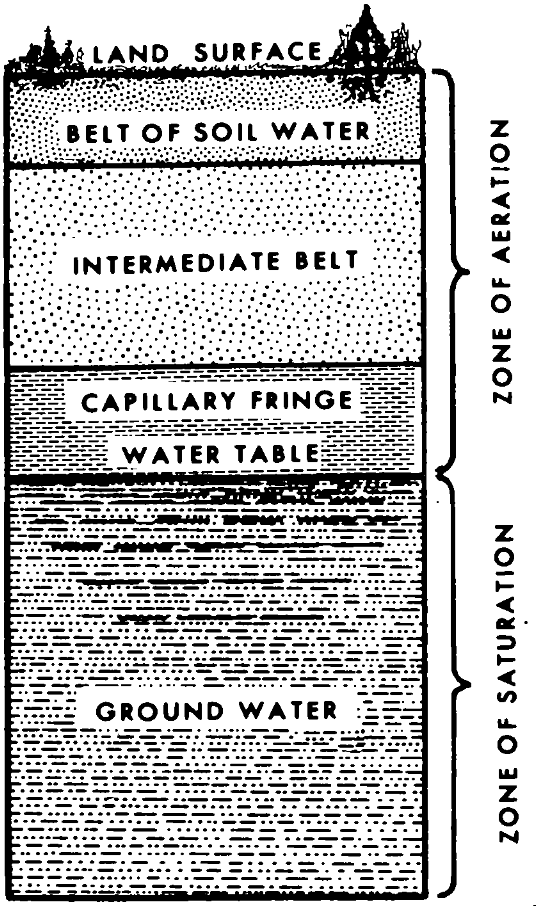


Figure 2-3. Zones of subsurface water in unconfined aquifer.

the percentage of pore or void space in a quantity of rock to the total volume of the rock. In equation form, porosity (Ø) is defined as follows:

$$\text{Ø} = \frac{100V_p}{V_t}$$

Where: Ø = percentage of pore or void space in the volume of a quantity of rock

V_p = volume of water required to saturate or fill pore and void spaces

V_t = total rock volume (cube of space occupied by rock quantity including voids)

The porosity of an unconsolidated formation is a function of grain size, sorting, degree of cementing, packing, and other factors:

(1) *Sorting.* Sorting, a measure of the variation of the sizes of the rock particles making up the formation, is the primary factor controlling porosity. A well-sorted formation has most of its grains approximately the same size, while a poorly sorted formation has a great variety of grain sizes (fig 2–5). Normally, well-sorted materials have higher porosities than poorly-sorted materials.

(2) *Degree of cementing.* Cement, as used here, refers to the naturally occurring adhesive

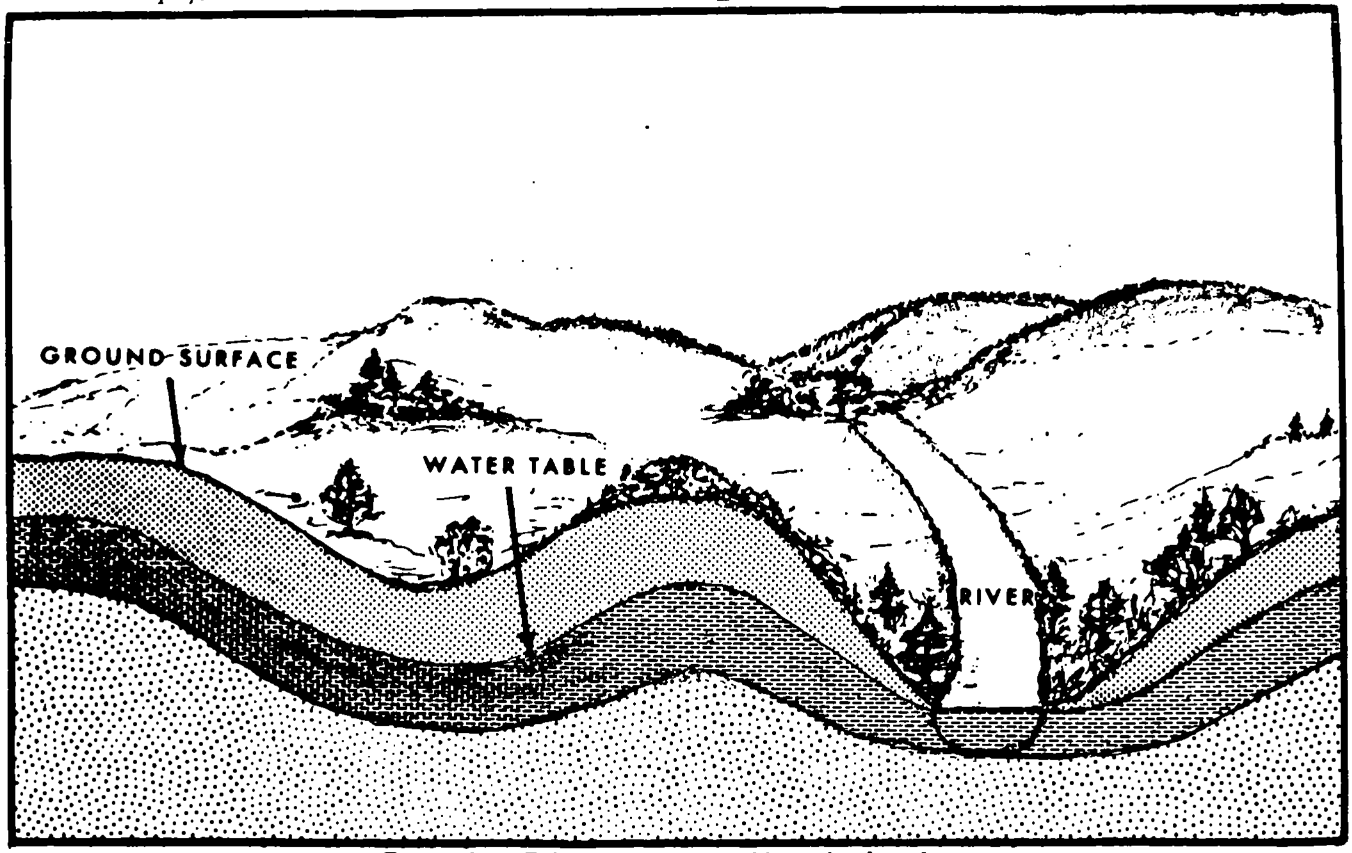


Figure 2-4. Relation of water table to land surface.

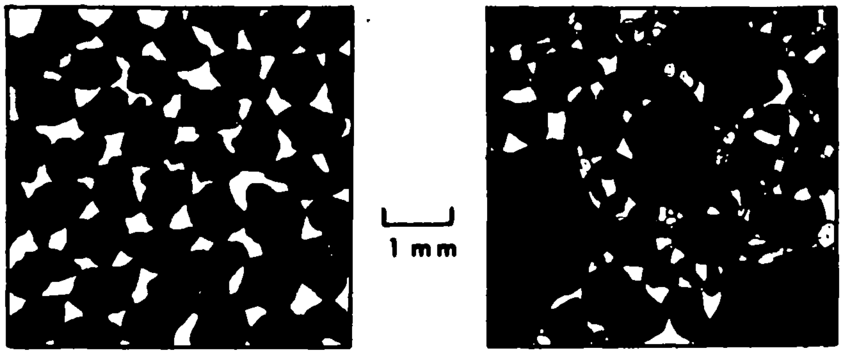


Figure 2-5. Sorting in sand formations.

material that binds the particles of a formation together to form a rock. Examples of common cementing materials are calcium carbonate ($CaCO_3$) and silica (SiO_2). These cementing materials are normally deposited on the rock particles by ground water in the pore spaces. Because the cementing materials occupy pore space that water would otherwise be occupying, the higher the degree of cementing, the lower the porosity for a given rock.

(3) *Packing.* Packing is a description of the way in which the particles of a rock "fit together." Figure 2–6 shows examples of two different kinds of packing arrangements for particles that are perfect spheres. The square arrangement has greater intergranular pore space.

c. Permeability. Permeability is a measure of the ability of a rock to transmit water. When water is forced by pressure to flow through a porous rock, the water flows through the interconnected pores between the rock particles. Because of the friction of the moving water against the rock particles and because the water must follow such a crooked path in flowing

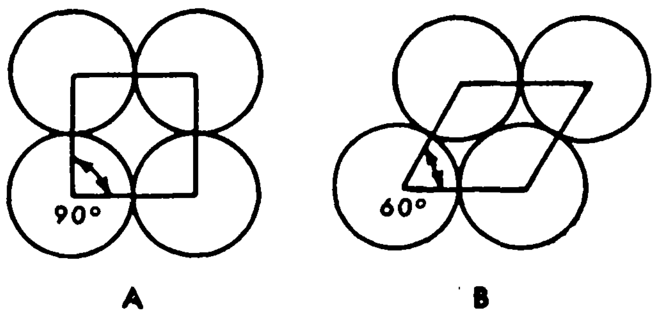


Figure 2-6. Packing arrangements of rock particles.

between the grains, some of the pressure on the water is lost as the water moves through the rock. The greater the pressure loss is in forcing water a given distance through a rock, the lower the permeability of the rock. Permeability may be expressed in equation form as follows:

$$K = \frac{QLp}{A(P_i - P_f)}$$

Where:

K = permeability in gallons per day per square foot
Q = volume of water pumped in gallons per day
L = length of flow in feet
P = density of water in pounds per cubic foot
A = cross-sectional area in square feet
Pi = initial pressure in pounds per square foot
Pf = final pressure in pounds per square foot

Permeability is affected by sorting, the degree of cementing, and packing as is porosity. It is also affected by the size of the grains; the larger the particles, the larger the voids are and consequently the permeability is greater. Figure 2–7 shows the permeability of a porous cube. For

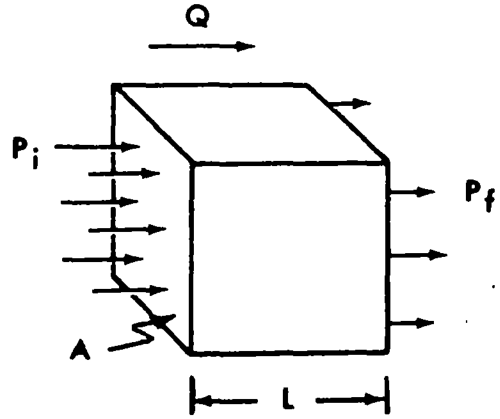


Figure 2-7. Permeability of a porous cube.

convenient use in well problems, K may be expressed as the flow in gallons per day through a cross-section of one square foot of water-bearing material under a hydraulic gradient of 1.00 (head-loss of one foot per foot horizontal flow) at a temperature of 60° F.

2–6. Terrains Likely to Possess Ground Water

The following is a list and description of some of the more promising terrains for ground water availability. The list is not expected to be comprehensive. However, it is designed to describe briefly the kinds of areas where numerous successful wells have been constructed in the past.

a. River Floodplains. A river normally has, in addition to the water that flows in its channels, an "underflow" of water that moves through the porous unconsolidated sediment upon which the river runs. This sediment has usually been deposited earlier in the river's history, such as during flood stages, and normally forms the flat, relatively narrow surface called the river floodplain, which lies parallel to and on either side of the river. If this floodplain is penetrated by a well, ample supplies of ground water can often be found in the cleaner sands and gravels of the sediment.

b. Areas Covered by Glacial Drift. Many areas in the middle latitudes of the world (such as the northern United States, Canada, and northern Europe) were at one time covered with thick ice sheets. When these sheets withdrew long ago, they left behind varying thicknesses of deposits known as glacial drift. Some of these deposits were left behind by meltwater from the glaciers as the ice receded and now make excellent aquifers. Many wells drilled into these uncolsolidated areas produce enough water to irrigate farmlands in the areas of the glacial deposits. It must be emphasized, however, that much of the glacial drift did not receive the washing action of the meltwater and therefore, does not make good aquifers because the deposits are very poorly sorted.

c. Coastal Plains. Along the margins of many of the world's continents, the sea has been retreating for a long period of time, leaving behind considerable thicknesses of unconsolidated sediments. These sediments in many places were winnowed, sorted, and "cleaned up" by wave action before being deposited and now contain large quantities of ground water. When tapped by wells, they often produce sufficient quantities of water for irrigation purposes. A good example of this type of ground water terrain is the southeast and southern coast of the United States.

d. Basalt Plateaus. In a few areas of the world, molten rock called lava has erupted from inside the earth during the geologic past and has spread out in sheets of basalt over many square miles of area. This process is illustrated by the volcanic activity occurring in Hawaii during the present century. There, sheets of lava often build up by successive flows, to several hundreds of feet in thickness. As a sheet of the basalt cools, some parts congeal or harden more quickly than other parts, causing caverns to form within the sheet. Also as the cooling process progresses, joints and cracks form within the lava sheet. At a much later time, after the entire sheet has cooled and hardened, these caverns and fractures may become filled with ground water. If penetrated by a well, these lavas have been known to produce large quantities of water.

Section III. EXPLORATION FOR GROUND WATER

2–7. Introduction

Ground water has the disadvantage of not being directly visible to the eye. Consequently, determining if it is present is one of the major problems in deciding whether it should be used. The purpose of this section is to describe some of the methods, direct and indirect, used to determine if ground water is present in an area.

2–8. Already Existing Wells

Although it can be used only in populated areas, one of the most reliable means of establishing that ground water is present in an area is by searching for wells that have been drilled by the civilian populace. Frequently, this kind of information may be gathered through intelligence operations in the area. Not only do existing wells establish the presence of ground water, but they can also yield information on the type of aquifer (artesian or water table, consolidated or unconsolidated) and what particular method of well construction has been used successfully in the area. Extreme caution must be used when considering using water from already existing wells for military use, as they may be contaminated. Contamination may result from accidental or natural causes (such as unintentional pollution from local waste disposal or animals) or deliberate poisoning by enemy personnel.

2–9. Springs, Lakes, and Swamps

Another prime indication that ground water is available in an area is the presence of lakes or swamps when these result from the rise of the water table above the ground surface. It is difficult, however to establish that any particular lake or swamp is caused by a high water table. A spring, on the other hand, is essentially a point at which ground water leaks out into the ground surface. Therefore, the presence of a spring or springs in an area is an accurate indication of at least some amount and type of ground water in the area.

2–10. Vegetation

In certain desert regions, the type and abundance of the vegetation growing in an area is a good index on the location of and depth to ground water. Figure 2-8 shows examples of vegetation that have been known to indicate the presence of ground water. Use of this technique must be tempered with caution; obviously the correlation of ground water with certain types and number of plants is never certain and the success of finding ground water in this way will depend primarily on the amount of prior use of the technique in a region.

2–11. Geophysical Methods

Ground water presence and depth can sometimes be detected by the use of geophysical techniques such as seismic and resistivity measurements in the earth. Seismic methods are used for determining subsurface rock structure by inducing shock waves in the earth with explosives and determining how they are reflected from subsurface strata. These methods are most successfully used where the occurence of ground water is controlled by subsurface structure. Resistivity techniques, on the other hand, measure the resistance of the earth to electrical current and can thus be used to detect ground water directly. The use of both the seismic and resistivity techniques and instruments (especially the interpretation of the date from the instruments) is very complex, however and in most cases requires equipment and skills not normally available in military engineer troop units. These two techniques would seldom be feasible for military needs.

Figure 2-8. Desert plants which indicate ground water.

Figure 2-8. ① —Continued.

Figure 2-8. ② —Continued.

2-12. Geologic Data

If geologic maps of an area are available, much information on the presence of ground water can be obtained from them. Frequently, the descriptions of the formations on the map will state which areas usually make good aquifers. If outcrops are present in the area, they should be examined even if geologic maps are not available, since they may indicate if rocks in the area are porous and therefore likely to contain ground water. In addition to maps, there are sometimes geologic reports describing the geology of an area. When available, they are often valuable sources of information on the availability of ground water in the area.

2-13. Well Logs

Anooher method of determining that ground water is present in a rock formation penetrated by a drilled hole is to run a well log in the hole shortly after it has been drilled. This is done by lowering an electronic probe called a *sonde* into the hole and withdrawing it slowly and allowing it to measure such rock properties of the formation as resistivity (R) and self potential (SP). An example of the type of curve resulting from this type of test, and the types of formations that cause the different kinds of curves appears in figure 2-9. This technique is used with much success in the petroleum exploration industry, and a number of independent companies that specialize in the logging of wells have been established. However, considerable expertise is needed to interpret well logs properly, especially in determining if a possible aquifer contains water or if the water is fresh enough to be potable. As shown in figure 2-9, the sand beds, that is, those beds most likely to have sufficient porosity and permeability to be aquifers, are characterized by a low SP and a high resistivity value. Use of well logs by military engineer troop units is generally impractical because of the highly specialized personnel and equipment necessary. Where well logs must be employed, advance arrangements should be made for civilian technical assistance or organization of special military units.

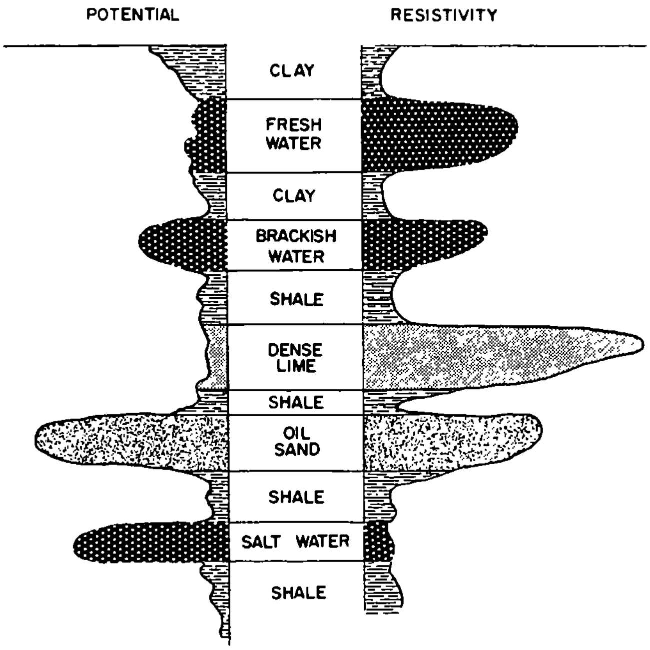


Figure 2-9. Potential and resistivity curves.

2-14. Test Wells

In the final analysis, the best method of determining whether ground water is present in an area is to drill a well or test hole to find out. The techniques described in the preceding paragraphs all give indirect indications, of greater or lesser value, of whether ground water is available. Its presence in a particular location can be definitely established only by drilling a well in that spot and running a pump test. The presence of ground water may be indicated in a formation by the type of cuttings obtained while drilling, such as clean, well-rounded and well-assorted gravel. However, only by running a pump test can it be assured that enough water is present to make a successful well.

Section IV. GROUND WATER QUALITY

2-15. Natural Impurities in Ground Water

a. Generally speaking, ground water is purer in most aspects than surface water and requires much less treatment to make it potable. Naturally occurring impurities in water are classed into three major categories: physical, chemical, and biological. Physical contaminants are undissolved solids, such as clay particles; and chemical contaminants are dissolved substances, such as salt (NaCl). Biological contaminants include the bacteria and viruses. If ground water contains any contaminants, they are most likely to be of the chemical type that have become dissolved in the water as a result of its intimate association with the rocks in which it is contained. High concentrations of dissolved rock materials in ground water are particularly common in situations where the ground water is replenished from the surface very slowly, as in desert areas and in deep aquifers. The kinds of dissolved material in the water depends, of course, upon the chemical makeup of the aquifer in which the water is contained. For example, water from a limestone aquifer may be expected to contain high concentrations of calcium (Ca).

b. Even though ground water is frequently potable in its natural state, it should be tested thoroughly before it is issued for troop use. What, if any, treatment is required should be apparent as a result of these tests. The subjects of water quality, water quality testing, and water treatment are covered thoroughly in TM 5-700.

Section V. GROUND WATER AS A WATER SOURCE FOR THE MILITARY

2–16. Introduction

Ground water presents several advantages and many disadvantages for use as a water source for troops in the field. Generally speaking, ground water should be considered as an auxiliary to surface water to be used when no surface water is available; when the surface water is too badly contaminated to be purified; or, when no surface water purification is available. The following paragraphs cite some of the advantages and disadvantages of ground water and set forth some considerations in deciding if ground water should be used.

2–17. Advantages

a. Availability. Ground water is frequently obtainable where surface water is not, as in some desert regions. Furthermore, it is sometimes available when surface water is not, as in dry seasons or drought conditions.

b. Purity. Unlike surface water, ground water is normally free of contaminants such as silt, micro-organisms, and the like. However, as noted in paragraph 2–15, ground water should be thoroughly tested before it is issued to troops for consumption. In addition to being relatively pure, ground water is also usually available at a constant, cool temperature.

c. Proximity. Wells can often be drilled and ground water tapped in close proximity to the location of the user, thus eliminating the problem of transportation of water over long distances.

d. CBR Invulnerability. Unlike surface water, which is easily contaminated by CBR materials, especially from the air, ground water can be contaminated in a short time only with extreme difficulty. About the only way a well can be contaminated quickly is by directly emplacing a harmful agent in the well.

2–18. Disadvantages

a. Necessity for a Well. Unlike surface water, which is readily available at the ground surface, ground water requires construction of a well, pit, or other excavation. Such construction requires both relatively sophisticated equipment and specially trained personnel. In addition, although ground water may be present in an area, it may be so deep that technical problems of drilling deep wells may prevent its being used.

b. Invisibility of Ground Water. Ground water, unlike surface water, is not readily visible and its presence normally cannot be determined by eye alone. Exploration for ground water resources is covered in paragraphs 2-7 through 2-14.

c. Pumping Requirement. After a well has been constructed, provision must be made to lift the water to the surface where it can be used. Hence, both a pump and source of power to run it must be provided.

2–19. Considerations in Decision Making

In making the decision about the use of ground water in a particular field situation, commanders must weigh the advantages and disadvantages listed in paragraphs 2-17 and 2-18. Permanence of the installation is another very important factor; if pure water requiring little or no treatment is available from wells, then they may be a more effective water source for a long term installation than water hauled over long distances or surface water requiring continuous purification. Availability of well drilling equipment and personnel capable of operating it will, in many cases, determine if ground water can be used. The nature of the tactical situation may, at times, prevent the possibility of drilling wells. Logistical support may or may not be sufficient for well drilling operations. These are just a few conditions that must be evaluated in making the decision whether wells should be drilled.

CHAPTER 3

WELL CONSTRUCTION PRINCIPLES

Section I. INTRODUCTION

3–1. General

Ground water is tapped as a water source by constructing a *well*. Wells are constructed in a large variety of ways, but they all have certain components and principles of construction in common. This chapter will present and discuss these common features. The concepts will be presented by using a typical rotary drilled well constructed in an unconsolidated formation. Variations in the concepts applicable to consolidated rock formations will be described as necessary.

Section II. WELL COMPONENTS

3–2. Introduction

A cross section of a typical well showing its major components appears in figure 3-1. These major components include the *hole*, *casing*, *screen*, *base plate*, *gravel pack*, and *pump assembly*.

3–3. Hole

Access to subsurface water is through some type of hole that is constructed in the earth. Hole sizes vary widely in both diameter and depth; diameters may vary from 2 inches or less to more than 10 feet for some applications. Depths range from less than 10 feet to more than 7,000 feet in some areas, although a well of this depth approaches the economic limits of ground water utilization.

3–4. Casing

Most holes, especially those constructed in unstable, unconsolidated rock, require some type of support in the form of casing to prevent their caving in after they are drilled. Wells drilled into consolidated formations usually need surface casing to prevent entry of soil materials, but the remainder of the hole can usually be left uncased. Chapter 7 will further discuss casings, the materials of which they are constructed, and the methods used to install them.

3–5. Screen

One of the chief functions of the well screen is the same as that of the casing, that is, of hole support. However, the screen also permits the entry of ground water into the well at the same time that it prevents entry of rock materials. Well screens, their construction materials and installation, and selection of the size openings will also be covered in Chapter 7.

3–6. Base Plate

The function of the base plate is to prevent the entry of sand into the well through the bottom of the screen.

3–7. Gravel Pack

In some aquifers, the sand in which the water is contained may be so fine that it is not practical or possible to prevent its entry into the well by use of the screen alone. In such cases, a "shell" of gravel must sometimes be emplaced just outside the well screen to act as an additional filter to the fine sand. Elaboration upon the subject of gravel packing appears in chapter 7.

3–8. Pump Assembly

The pump assembly is the means by which ground water is lifted to the surface after the well has been drilled and completed. This subject will be covered in chapter 9.

Section III. STEPS IN WELL CONSTRUCTION

3–9. Introduction

The construction of a water well can be subdivided into a series of logical steps that are convenient to use for planning purposes when a well is contemplated. These are listed and described in the following paragraphs.

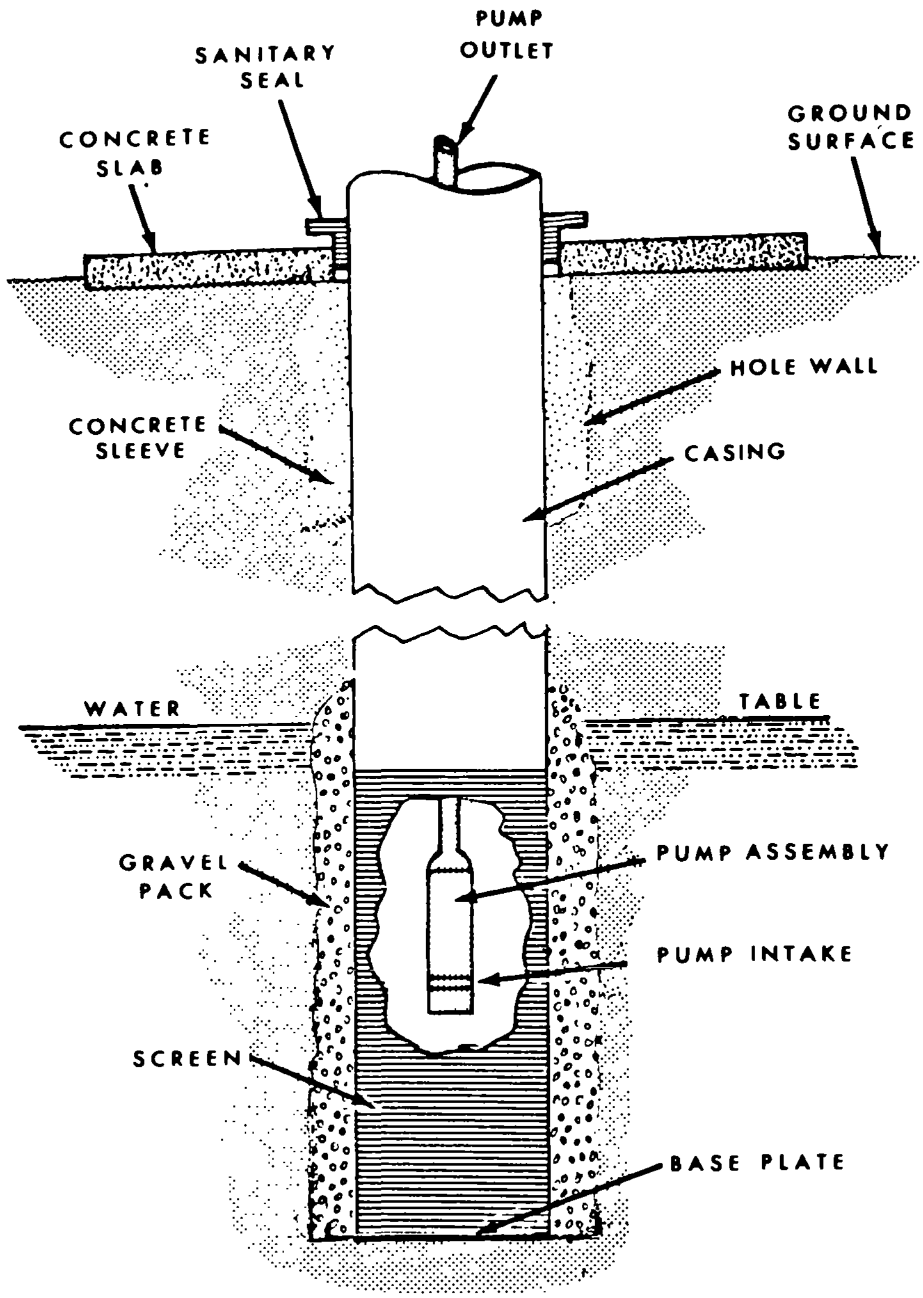


Figure 3-1. Cross section of a typical well.

3–10. Planning and Preparation

a. Reliable sources of information are required when planning a well drilling operation. Recent field reconnaissance reports and observations, interrogation of prisoners of war or the native population, tactical data, and other records are the most important sources of information. Maps give some information about the location of human habitation, drainage lines, existing road nets, access to the site, and area available for storage of materials. TM 5-700 provides more detailed information.

b. When planning for a well drilling operation, one of the most important factors is to be sure that the proper amount and type of equipment and accessories are taken into the field. The well drilling team must arrive on location with the necessary items to accomplish the mission. Certain basic items, such as the drilling machine, must be included in every operation. The need for and the amount of other items, such as casing, will vary with the local situation. In planning for these variable items, either of two methods is used. If something is known of past well drilling experiences in the area, either military or civilian, the amounts of the various components needed can be estimated directly. If no such information is available however, the *basic load* approach should be used, in which the full amount of the item allowed to the team should be taken to each drill site. The estimate based on past experience is the better of the two techniques because it reduces the number of times that excess weight will be transported to the site or that the materials brought in will prove to be insufficient to accomplish the mission.

3-11. Move-In and Set-Up

After preparations are complete, the well construction equipment is transported to the well site and set up for well drilling operations. The transportation and set-up procedures vary with the type of equipment and technique employed in the well construction operation and should be included in the training for the operation of the equipment. The procedures used in any particular situation in the field also vary, depending on the resources available at that place and time.

3-12. Hole Construction

This is the step in which the hole is excavated to gain access to ground water. A large variety of methods have been used to excavate the holes, but the most common are the rotary, percussion, or some combination of these. A fuller discussion of the different hole construction techniques appears in paragraphs 3-19 through 3-23 and in later chapters.

3-13. Hole Support

After the hole has been constructed, the casing and well screen are installed if needed. Ordinarily, they are installed at the same time, since the screen is usually fastened to the casing before installation. Installation of casing and well screen are more completely described in chapter 7. In some hard rock drilling conditions, only a surface casing is needed to prevent cave-in of the weathered soil horizons and the remainder of the hole will be stable without artificial support. Whether a hole may be left permanently unsupported can usually be easily discerned as the hole is excavated.

3-14. Gravel Pack

Once the casing has been installed, the gravel pack, if needed, should be emplaced as described in chapter 7.

3-15. Well Development

After casing, well screen, and gravel pack (where needed) have been installed, the next step is to develop the well. This process involves cleaning the well and removing the fines from the formation surrounding the well screen to prevent later sanding of the well and permit ground water to enter the well more easily. The various methods by which wells can be developed are described in chapter 7.

3-16. Sanitary Protection

After the well has been developed, it is essentially complete except for providing sanitary protection. Entry of contaminants from the surface into the well through the inside of the casing is prevented by the apparatus associated with the well pump. However, contamination of the well through the annulus between the outside of the casing and the hole wall must also be prevented. This is normally accomplished by filling the annular space with concrete, or at least by packed earth, to some depth below the surface. Methods of providing sanitary protection are discussed more fully in chapter 7.

3-17. Pump Installation

When the well has been completed and the pump installed, sanitary protection or well and pump sterilization must be provided. Pump installation is discussed in chapter 9.

3-18. Take-Down and Move-Out

After the well is completed and the pump has been installed, the well construction equipment is taken down and removed from the well site. This process is essentially a reversal of the move-in and set-up procedure.

Section IV. INTRODUCTION TO HOLE CONSTRUCTION TECHNIQUES

3-19. General

A large variety of methods and equipment are available for excavating holes in the earth for wells. The techniques most suited for use by military engineer units in the field are presented in the following paragraphs and described in greater detail in succeeding chapters. The technique that should be used in a particular situation in the field depends upon a number of factors including availability of appropriate equipment and trained personnel. The most important factor governing the method used is the mode of occurrence of ground water in the area. For example, it would be useless to use equipment with only a 100-foot depth capability in an area where ground water lies at a depth of 500 feet. It would also be futile to try to drill a well in a place where the ground water is in hard rock by using equipment capable of drilling only in loose, unconsolidated material.

3–20. Available Methods of Well Construction

At present available methods of well construction may be classed into three broad categories—down-hole percussion, rotary, and miscellaneous. These are described briefly in the following paragraphs and in greater detail in later chapters. In addition to these more mechanized methods, several expedient means exist which can be used if the larger equipment is not available. These are discussed in chapter 6.

3–21. Down-Hole Percussion Techniques

Percussion methods advance the hole in the ground by repeated blows by some type of hammering tool. The down-hole percussion methods uses a pneumatically operated hammering device to advance the hole. This tool is attached to the end of a conventional rotary drill string just above the bit and is rotated as it operates. It is considered as an augmenting tool to rotary equipment and is discussed at greater length in chapter 4.

3–22. Rotary Techniques

Rotary techniques, as the name implies, advance the hole by rotary action of a bit at the bottom of the hole. While the bit is rotated, the cuttings are flushed from the bit face and carried to the surface by a circulating fluid, either water, mud, or air. This technique is currently the most widely used in well construction and is covered more thoroughly in chapter 4.

3–23. Miscellaneous Techniques

A number of other techniques are used to extract water from the ground, but most of them are limited in one or more respects such as depth capacity or formation hardness, in their application. These techniques include well points, jetting methods, bucket and auger boring methods, and others. Most of these techniques are described in greater detail in chapter 6.

CHAPTER 4

ROTARY DRILLING METHODS

Section I. INTRODUCTION

4–1. Basic Components

Regardless of size, rotary drilling rigs all have certain components in common. The chief among these are listed below. The function of each is described in later sections.

a. Frame.
b. Mast.
c. Rotary Table or Rotary Drivehead.
d. Pulldown (Power Feed Mechanism).
e. Leveling Jacks.
f. Power Supply.
g. Mud Circulating System.
h. Water Swivel.
i. Drill Stem.
j. Bit.

4–2. Drilling Process

In the rotary drilling process, the hole is advanced by rotating the drill string with a bit attached to the end of it. As the bit is rotated, it loosens and removes rock chips and cuttings. Simultaneously, a circulating fluid (water, mud, or air) is forced down the inside of the drill pipe and out through ports in the bit. There the fluid picks up the cuttings and flushes them out of the hole through the space or annulus between the drill pipe and the hole wall. If water is used as the circulating fluid, it flows from the annulus to a settling pit where the cuttings are removed from the fluid, and then to the storage pit where the fluid is picked up at the pump suction and recirculated. If air is used as the circulating medium, the air compressor forces the air down to the bit and the air escapes through the annulus, carrying the cuttings with it. The cuttings are normally deposited just outside the hole where they are removed manually. By this method, the hole is advanced one section of drill pipe at a time. When one section has been drilled down, drilling and circulating are stopped and a new section of drill pipe is added (fig. 4-1).

Section II. AIRBORNE ROTARY DRILLING EQUIPMENT

4–3. Introduction

An airborne rotary drilling rig capable of drilling to depths of 500 to 600 feet is used by the Army (fig 4-2). The rig can be bolted to skids, mounted on trucks, or mounted on trailers. The components and operation of this rig are described in the following paragraphs.

4–4. Frame

a. The drill frame is the foundation for all the units making up the drill. It consists of two 5-inch channel iron sills, crossed by 5-inch channel and I-beam members. The sills are interbraced with angle- and structural-shaped members located for maximum strength with minimum weight, electrically welded together. Upon this structure is bolted and then welded a nonskid deck plate. Holes are drilled in the channel iron sills so the frame can be bolted to a truck or trailer frame or skids.

b. The skids are two 10-inch WF-beams with the web cut out at the ends and the bottom flange turned up, giving them a runner effect. Channel irons are welded across the runners. There is a pipe crossmember with pull hooks on the front and rings for pulling or lifting on the rear. The channel iron crossmembers are drilled to match the holes in the drill frame so the skids can be bolted to it.

4–5. Mast

The mast, or derrick, is built in two sections, bolted together with piloted flanges. It consists of four legs reinforced with crossmembers and diagonals, electrically welded together. The mast is attached to the drilling rig by a long bolt through hinge joints on both of the front legs. The mast has three sheaves at the top (fig 4-3) called crown pulleys. The sheaves run on bushings supported by a shaft and separated by spacers. One sheave is for the catline or rope, one for the hoisting line, and one for the sand or bailing line. A hinged hood covers the sheaves. An anchor eye is attached to the underside of the crown block for anchoring the hoisting line when a traveling block is used. The mast is raised and lowered by the power unit.

4–6. Drill Head

The drill head has a rotary drivehead, a hydraulic pulldown mechanism for applying pressure to the kelly, and a breakout for moving the drill head to and from the drilling position. Power is transmitted from the engine to the drill head through a clutch and transmission. Spiral bevel gears drive the rotary drivehead. The pinion is attached to a shaft directly in line with the power input shaft which, when rotating, engages the pinion through the use of a jaw clutch. The pinion turns a bevel gear that is pressed on a drive quill. This quill is vertical and supported in the main frame housing by roller bearings. The inside bore of the drive quill is hexagonal. The quill turns the drive rod, which can move vertically while rotating. The drive rod is supported by bearings in a yoke attached to the hydraulic cylinder piston

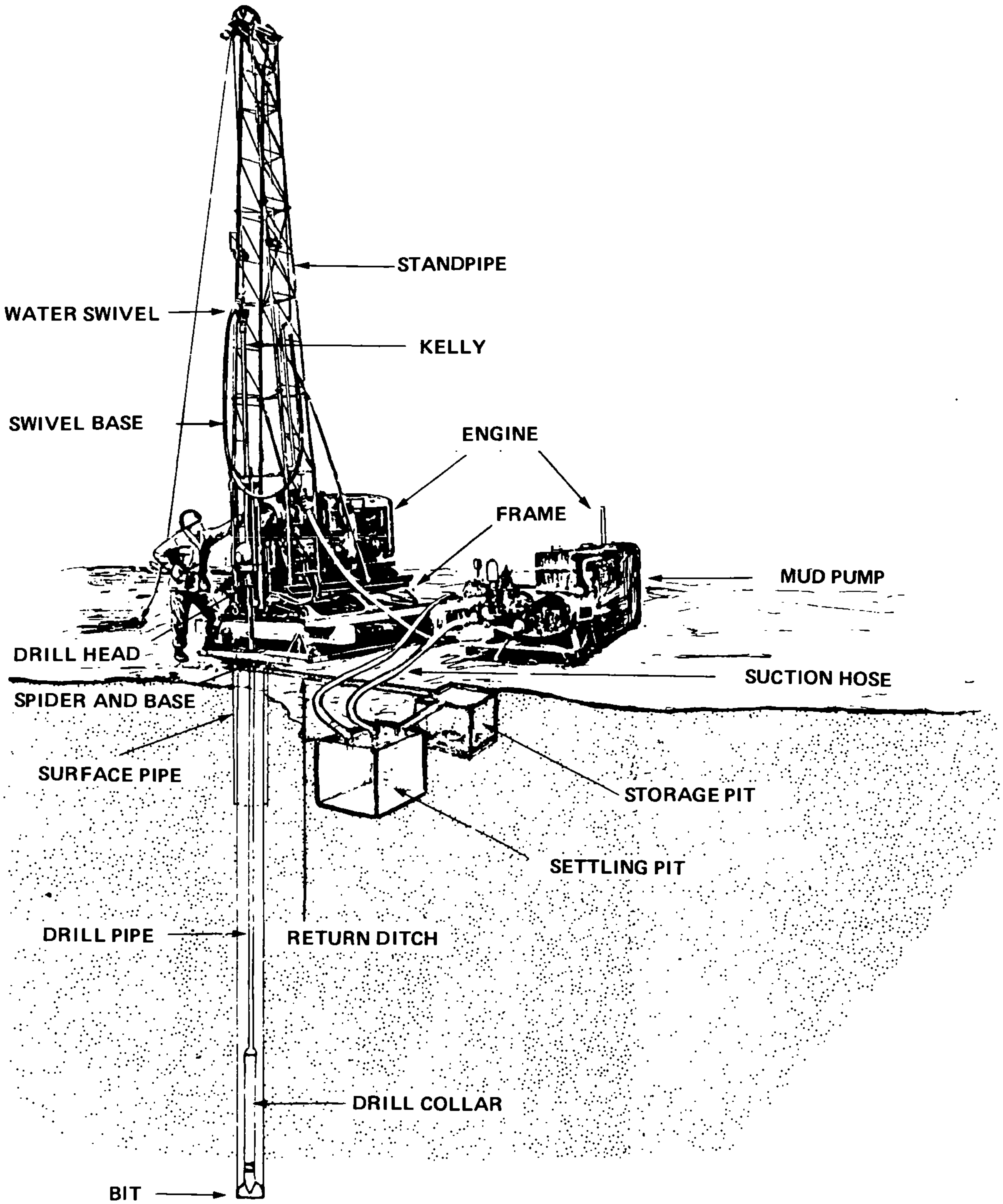


Figure 4-1. Rotary drilling method.

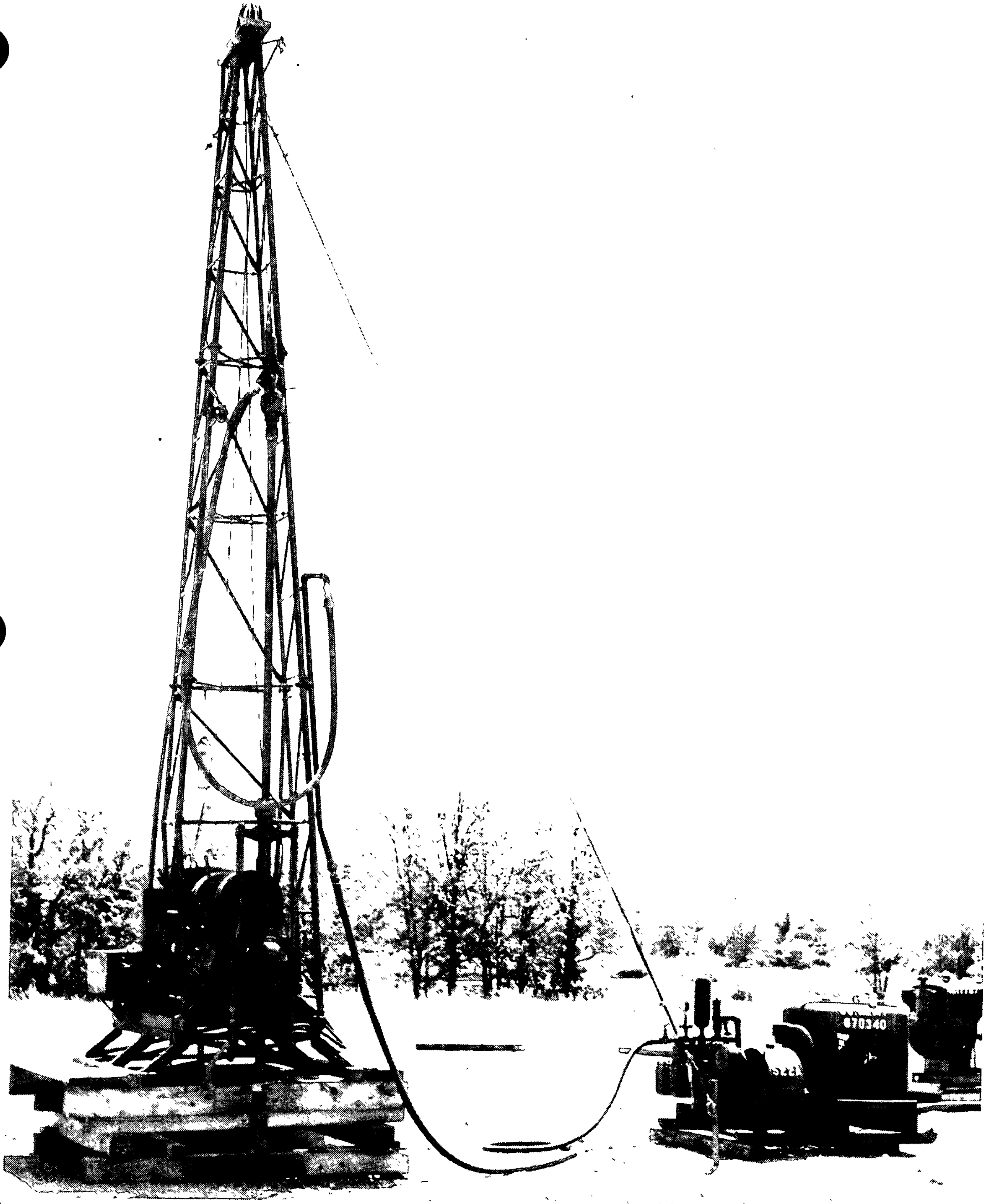


Figure 4-2. Airborne rotary rig.

rods. A slip nut or kelly-drive nut, with two notches for rotating the kelly by means of the kelly-drive bushing, is screwed to the upper end of the drive rod. A chuck is screwed onto the lower end of the drive rod. The chuck has jaws to grip the kelly or drill pipe when hydraulic pressure is applied.

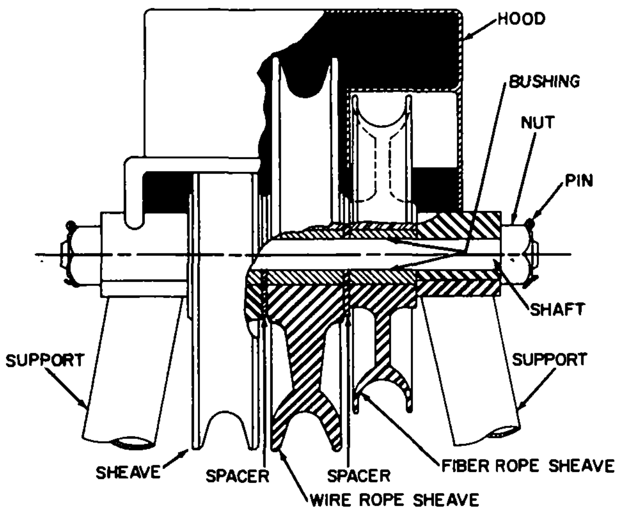


Figure 4-3. Masthead showing sheaves.

4–7. Leveling Jacks

The rig must be level to obtain maximum pulldown on the drill stem. Truck- or trailer-mounted units may be leveled by digging holes for the high side or blocking up the low wheels. Those drilling machines with hydraulic jacks located at each corner of the drill frame can be leveled by using them.

4–8. Power Supply

a. The power supply unit is a water-cooled diesel or gasoline engine with magneto ignition. The engine has an electric starter and generator. The starter button and ignition switch are at the operator's position at the rear of the drill. The speed of the engine is controlled by a hand throttle.

b. The front end of the crankshaft has a fan-drive pulley to transmit power to the fan and generator and the hydraulic oil pump. Power is transmitted from the engine to the drill head through a disk clutch and selective speed transmission.

4–9. Mud Circulating System

a. Mud Pump. The mud pump is the heart of the mud circulating system (fig 4-4). The pump forces the drilling fluid from the storage pit through the standpipe and pressure hose, through the swivel joint, down through the kelly and drill pipe, and out through holes in the bit for return up the annular space to the settling pit. The pump is a duplex double-acting piston type, with removable, hardened steel cylinder liners. It has renewable, hardened valve seats and wing-guided valves. The piston has a one-piece alloy steel body containing replaceable double-lipped cups of abrasion-resistant rubber. The liners, pistons, and valves are the vital parts of the pump and are subjected to the greatest abuse and wear from abrasive material in the circulating fluid. They should be checked frequently to insure efficient and economical operation.

b. Slush Pits. Two slush pits (fig. 4-5) must be located and dug in such a manner that the drill fluid used will drain from the drill hole to the first (settling pit) where the heavier cuttings will settle to the bottom, and then to the second (storage pit) where the smaller particles will settle. The size of the pits varies with the volume of the hole and the stability of the material drilled. The type of material governs the consistency of the mud and the type of bit to be used. Consistency and bit type determine the size and specific weight of cuttings. A main or storage pit for a 6-inch hole (200 ft deep) should be about 4 feet wide, 5 feet long, and 3 feet deep. The settling pit should be at least 2 feet wide, 3 feet long, and 2 feet deep. A ditch to carry the drilling fluid from the drill hole to the settling pit must be about 3 inches deep. The suction hose of the mud pump is placed in the storage pit at the opposite end of the connecting ditch. The hose screen should be submerged at all times, but should not be kept too near the bottom of the pit because it will pick up the settled cuttings. It can be kept off the bottom by driving two stakes into the bottom of the pit so they are crossed in the shape of an X. The suction screen is placed in the upper V formed by the stakes and fastened in position with wire. The circulating fluid must be kept as clean and free of abrasives as possible to minimize wear on the pump parts and water swivel. The crew must clean the pits periodically to remove the settled cuttings.

c. Hoses. Four hoses are used in the mud circulation system. They are the swivel hose, the standpipe hose, the suction hose, and the mud-mixing hose.

(1) *Swivel hose.* The swivel hose has wire reinforcements to withstand high pressure. It forms the flexible connection between the standpipe and the swivel. It has hose nipples and

clamps on each end. The swivel hose is subjected not only to abrasive fluid under pressure but also to continuous flexing. Care must be taken to eliminate short bends and kinks.

(2) *Standpipe hose.* The standpipe hose is of the same construction as the swivel hose. It has couplings of the same type. It connects the discharge outlet of the pump to the standpipe and makes it possible to raise or lower the mast without disconnecting the standpipe from the pump.

(3) *Sunction hose.* The suction hose permits the mud pump to draw drilling fluid from the mud pit. It is reinforced with steel wire. This hose is coupled with band type clamps and hose nipples with male threads. It is connected to the pump by a ground-joint union. All clamps and pipe joints in the suction line must be tight to prevent air leaks. Impacts from heavy objects will damage the hose and pull the inner tube loose from the carcass. Even if the carcass is straightened on the outside, the pump suction may cause the inner tube to close and stop the flow of fluid.

(4) *Mud-mixing hose.* The mud-mixing hose is a wire-wrapped, high-pressure hose, 25 feet long. It has a 2 1/2-inch NPT female fitting on one end and a 6-inch long 1/2-inch diameter pipe nozzle on the other end.

4–10. Water Swivel

The housing portion of the swivel (fig 4-6) is

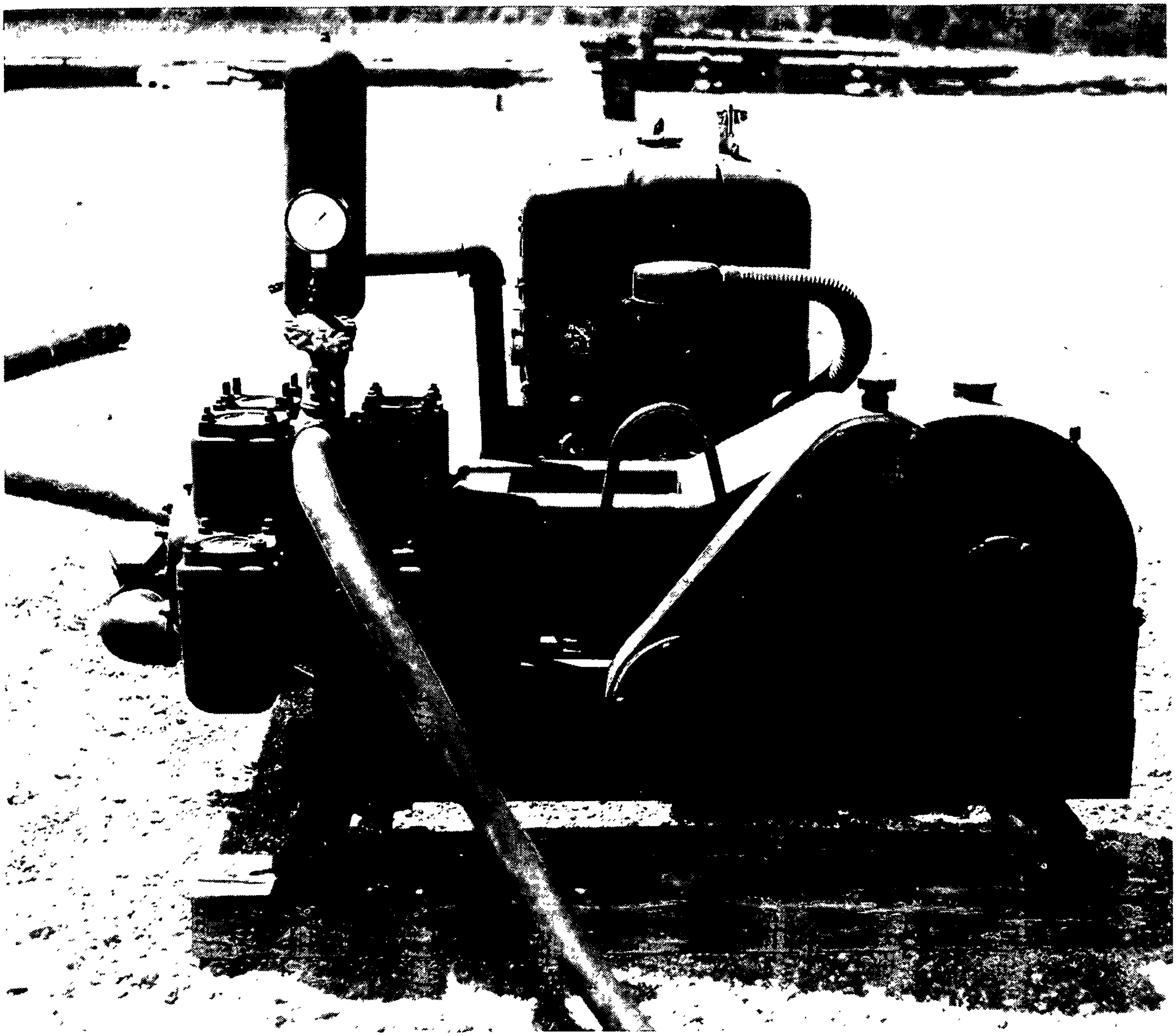


Figure 4-4. ① Mud pump with drive cases.

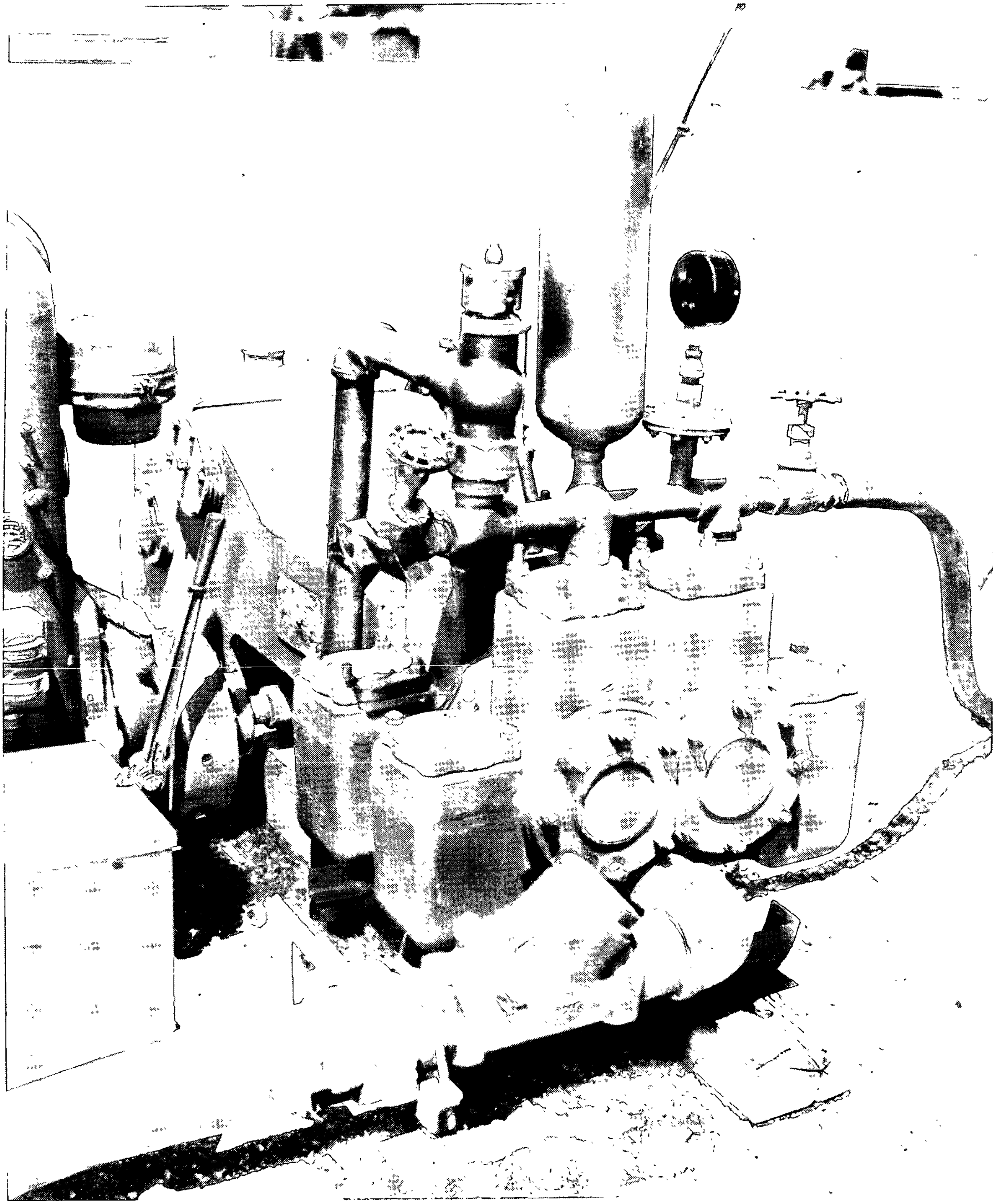


Figure 4-4. ② —Continued.

stationary and connects to the discharge hose of the mud pump by means of a gooseneck. Two trunnions on the outside of the housing and a heavy bail suspend the swivel and its load, which consists of the entire string of drill pipe. A heavy steel tube, which projects below the housing, is mounted on roller and ball thrust bearings inside the housing. It is free to turn in these bearings and its lower end is threaded to screw to the upper end of the kelly. A gland and packing are arranged inside the housing to prevent leakage between the stationary and rotating portions of the swivel.

a. All moving parts, except the upper ball bearing, are lubricated by an oil bath. The upper ball bearing is lubricated through a pressure gun fitting in the upper bearing plate. Oil is put in the housing through a filler plug.

b. The principal wearing parts are the wash pipe and packing. However, the bearings and seal wear excessivley if not properly lubricated at regular intervals. Good performance from the swivel depends upon the packing and its adjustment. The packing gland should be tightened evenly, just enough to seat against the packing; otherwise the swivel does not operate freely, and the hose tends to wrap around the kelly. If the gland is too tight, excessive wear on the packing and wash pipe will result.

4–11. Drill Stem

The drill stem usually consists of three parts: one or more drill collars, one or more lengths of drill pipe, and the kelly. Accessory equipment is discussed in paragraphs 4–16 through 4–28.

a. Drill Collar. The drill collar (fig. 4-7) is a heavy-walled length of drill pipe. One or more drill collars are used just above the bit to add weight to the lower part of the drill stem assembly. This additional weight helps to keep the hole uniform and straight. The drill collar is 10 feet long. Its outside diameter is larger than that of the drill pipe but small enough to clear the wall of the hole. The annular space remaining must allow enough room for an overshot die fishing tool, in case the drill collar twists off. The top of the 3 1/8-inch OD drill collar has a 2 3/8-inch exploration thread box to match the other joints of drill pipe, and the lower end of the drill collar has a 2 3/8-inch American Petroleum Institute (API) box. The 4 1/2-inch drill collar has a 2 3/8-inch exploration box at one end and a 3 1/2-inch API box at the other end. On the 6 1/2-inch drill collar, the upper end is a 3 1/2-inch API regulation pin and the lower end is a 3 1/2-inch API regulation pin and the lower end is a 4 1/2-inch API regulation box. When this large drill collar is used, one of the smaller ones with a 2 3/8-inch exploration thread box at the top has to be used above it to match the joint of drill pipe.

b. Drill Pipe.

(1) Drill pipe, or rod (fig 4-7), is made in many sizes and lengths with various types of joints or couplings. The drill rod used on Army rotary well drilling rigs is internal upset. It is made of special seamless tubing or swedged back on the inside of each end to give enough wall thickness for turning the threads. Standard drill pipe has exploration threads, four V-threads per inch R.H. with 2-inch-per-foot tapers. The pipe is 10 feet long, has a 2 3/8-inch outside diameter,

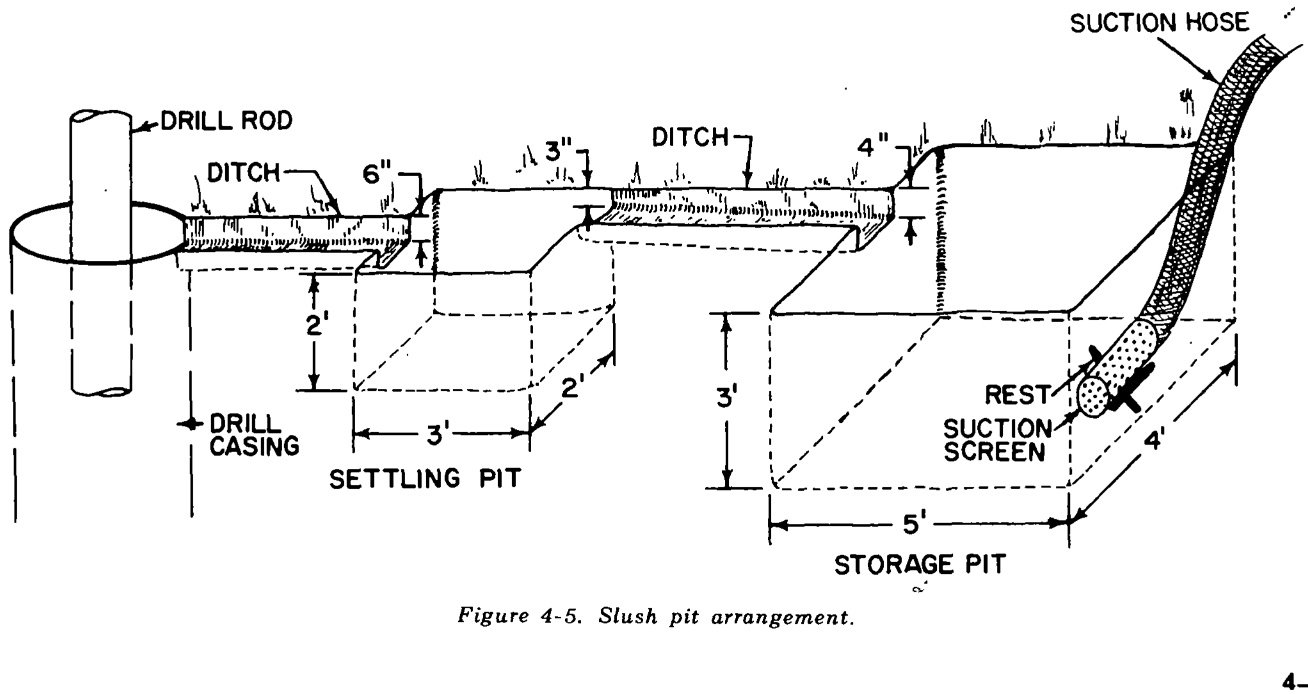


Figure 4-5. Slush pit arrangement.

with a tool-joint pin on one end and a tool-joint box on the other. Both ends have thread protectors.

(2) The drill pipe can be considerably bent between the drive rod at the surface and the bit at the bottom of the hole. The amount of torsional strain will vary with the bit pressure applied, the length of the drill pipe, and the resistance given to the bit by the formation. Under extreme conditions the drill pipe probably revolves with a

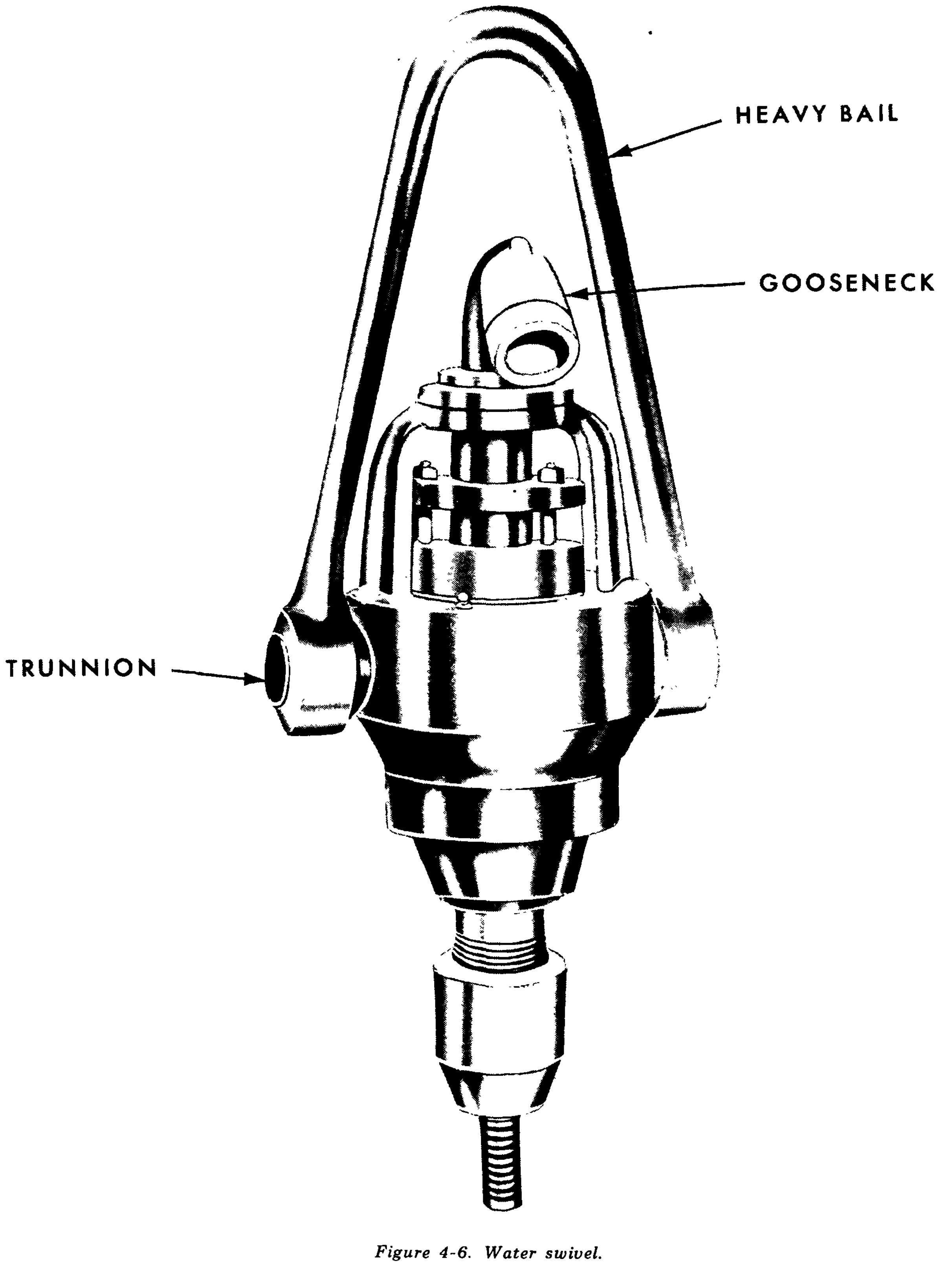


Figure 4-6. Water swivel.

rapid variation in stress as the bit alternately digs into the formation and breaks free.

(3) The stresses developed are sometimes enough to cause failure or twist-off of the drill pipe. Such failures usually occur at the point of maximum bending and stress. High speed rotation, large hole size, and metal fatigue cause failure or twist-off which often results in lengthy and costly fishing jobs.

c. Kelly. The kelly is the uppermost section of the column of drill pipe. It is made of heat-treated steel with a special outer shape which works up and down through drive bushings in the rotary table when the table is in gear and rotating. The entire drill stem and bit are forced to turn with the rotary table, and the bit is fed downward as the hole is drilled. The upper end of the kelly is equipped with left-hand threads so it can be connected to the water swivel. The lower end is threaded to connect to the drill pipe. Figure 4–7 shows the kelly.

4–12. Bit

a. The bit is the device that does the actual cutting or boring in the formations penetrated. It is screwed to the lower end of the drill pipe. The bit to be chosen for a particular job depends on the nature of the formations to be drilled and, to some extent, on the experience and skill of the driller.

b. Initial pressure is applied on the bit by the weight of the column of drill rods, aided by the hydraulic feed. In penetrating the formation, the rotating bit disintegrates it by a shearing or cutting action. The penetration of the bit and its speed of rotation must be controlled to avoid stress in excess of the safe torsional strength of the drill rods.

c. The rotating bit assists in mixing the cuttings with the circulating fluid. It must not cut the formation faster than the circulating fluid can carry the cuttings away. Those bits furnished or likely to be used are described in Section III.

4–13. Description of Airborne Rig

The airborne rotary drilling machine (fig 4–2) is a lightweight rig consisting of a drill unit and an accessory mud pump unit. Each of these units can be mounted on skids or wheels.

4–14. Drill Unit of Airborne Rig

a. The drill unit is similar in operation to the

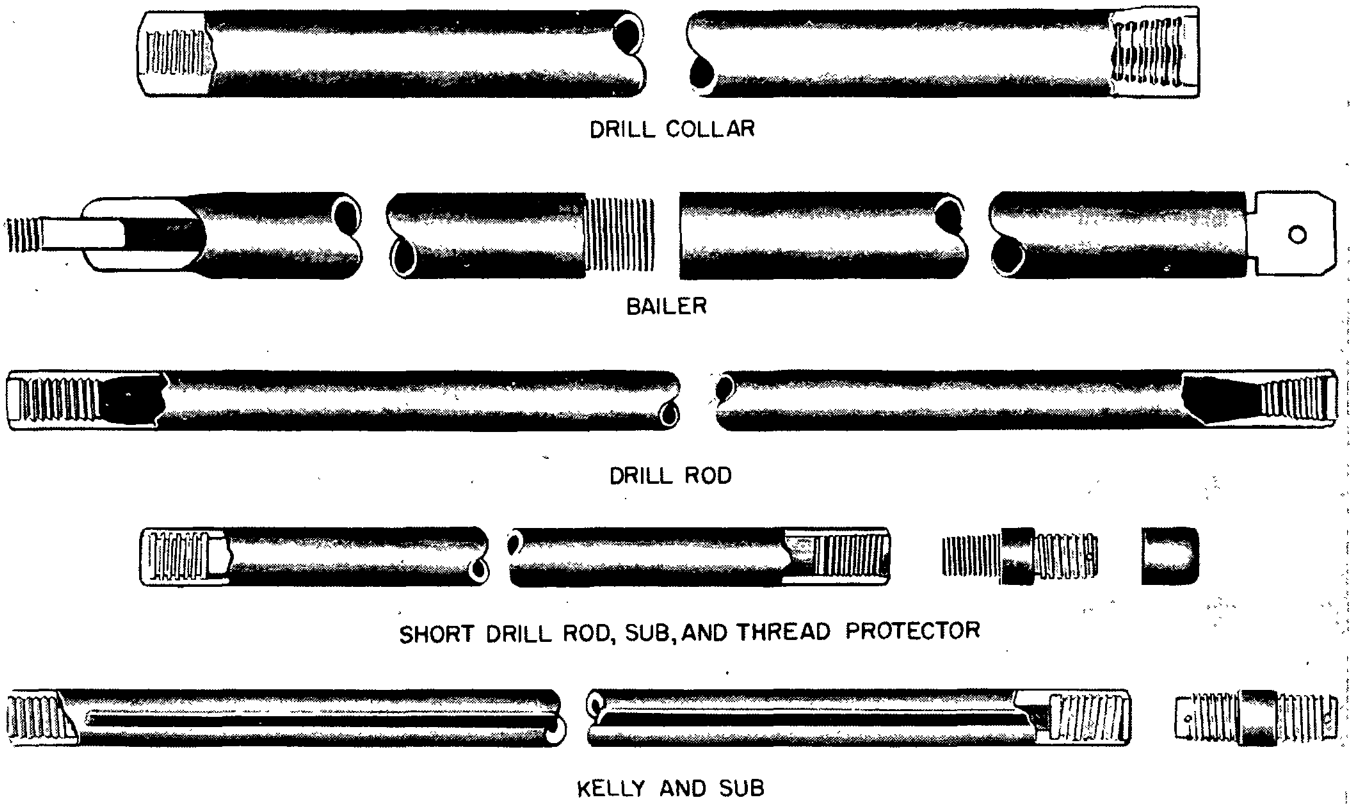


Figure 4-7. Drill rod and drive equipment.

larger rotary rigs with the exception that it has a drive head designed to swivel 360° on its axis, which permits drilling vertical, oblique, or horizontal holes. The drill head is also hinged so that it may be unlatched by an adjustable hand-operated lock and swung aside, giving free space for hoisting or lowering drill rods, casings, or screens.

b. The mast is a collapsible type with a steel tubing frame reinforced by diagonals and crossmembers. Gross capacity is 10,000 pounds, which is a limiting factor in the weight and size of pipe to be used. The drill unit can drill a 3 7/8-inch hole to 500 feet, a 5 7/8-inch hole to 350 feet, and a 7 7/8-inch hole to 150 feet. The sand reel carries 550 feet of wire line to assist in the hoisting operations, bailing, and so on, and enforces the limit of a 500-foot effective depth of the hole.

4–15. Pump Unit for Airborne Rig

The mud pump unit is an independent and self-controlled unit consisting of a pump, power unit, coupling system, and discharge and suction lines.

a. Mud Pump. The mud pump (fig 4–4) is a horizontal, duplex, double-acting piston type. It has a capacity of not less than 47 gallons of mud fluid per minute at a pressure of about 200 psi when operating at 75 strokes per minute. The pump is capable of developing working pressures up to 500 psi.

b. Power Unit. The mud pump power unit is a gasoline engine of the 20-net-continuous-hp basic size group capable of developing not less than 30 maximum net-brake horsepower at 1,800 rpm.

c. Coupling System. The coupling system consists of clutch and reduction drives between the power unit and the pump. All chain and gear drives are oil bath lubricated. The system is contained in a dustproof housing.

d. Discharge Line. The valves on the discharge line are arranged so the standpipe and mud-mixing hose can be used either independently or together. A 17-foot length of 1 1/4-inch ID hose connects the standpipe to a water level.

e. Suction Line. The suction line consists of two 10-foot sections of 2-inch ID hose equipped with couplings and a perforated strainer.

Section III. ACCESSORY EQUIPMENT FOR AIRBORNE RIGS

4–16. Types of Accessory Equipment

Accessory equipment for rotary drilling varies with the drilling conditions and the size of the hole drilled. The accessories most likely to be used are the substitute joints, spider and slips, pipe clamps, bits, traveling block, pipe elevator, wire line and attachments, swab, bailer, hoisting plug, and wicking. This section describes these accessories in detail.

4–17. Substitute Joints

A substitute joint, often called a sub, is an adapter to connect two components when their threads are unlike. Sometimes two subs must be combined to make the connection. Some substitute joints have a box connection at both ends; some have a pin connection at both ends; others have a pin at one end and box at the other (fig 4–8). A special sub called the kelly sub is used at the pin end of the kelly to save the kelly from undue wear. As few substitute joints as possible should be used in the drill string, because most pipe failures occur at joints. All threads should be kept free of dirt and well lubricated to prevent binding. Joints are always made up tightly.

4–18. Spider and Slips

The spider and slips are used to hold the string of drill pipe when it is disconnected from the kelly while a joint of drill pipe is being removed or added.

a. Spider Bowl.

(1) The spider bowl (fig 4–9) is a sleeve with a tapered bore large enough to accommodate the slips and the pipe to be held.

(2) A split ring (fig 4–9), which is a tapered bushing, fits in the spider bowl. It is used when the drill rods or 3-inch pipe are to be held.

b. Slips. The slips (fig 4–9) are curved wedges provided with handles and fastened together in sets or pairs. They are heat treated to insure long life and a good grip on the pipe. Each set of slips is made to hold pipe of a certain diameter. The inside face has teeth which grip the outside of the pipe; the outside face is tapered to fit the taper in the spider bowl or split bushing. When the slips are set around the pipe, the teeth grip it and the weight pulls the slips down in the tapered bore of the spider. This wedges the slips against the pipe, holding it firmly. Slips for the drill pipe and 3-inch casing are used inside the split bushing; slips for 4-inch, 5-inch, and 6-inch pipe are used in the spider bowl without the split bushing. The teeth on the slips should be cleaned regularly so they grip the pipe well.

4–19. Pipe Clamps

Pipe clamps (fig 4–10) are furnished for 4-inch, 6-

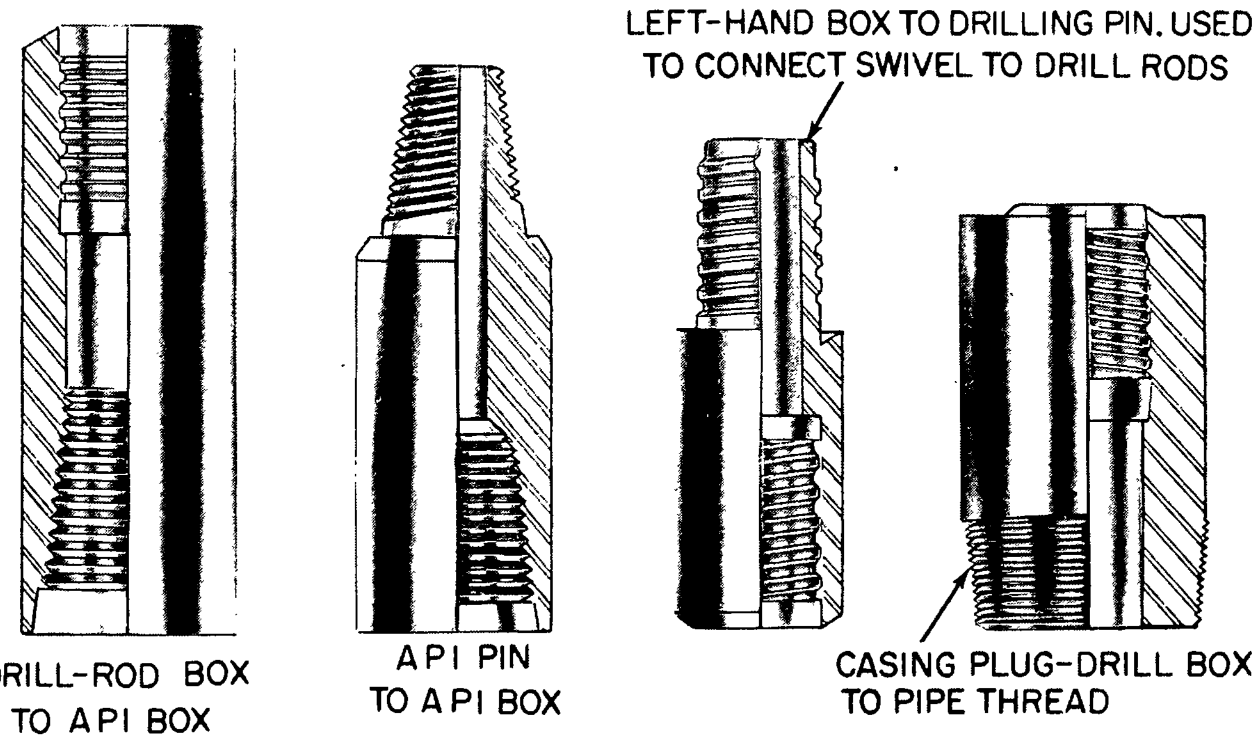


Figure 4-8. Sectional view of subs.

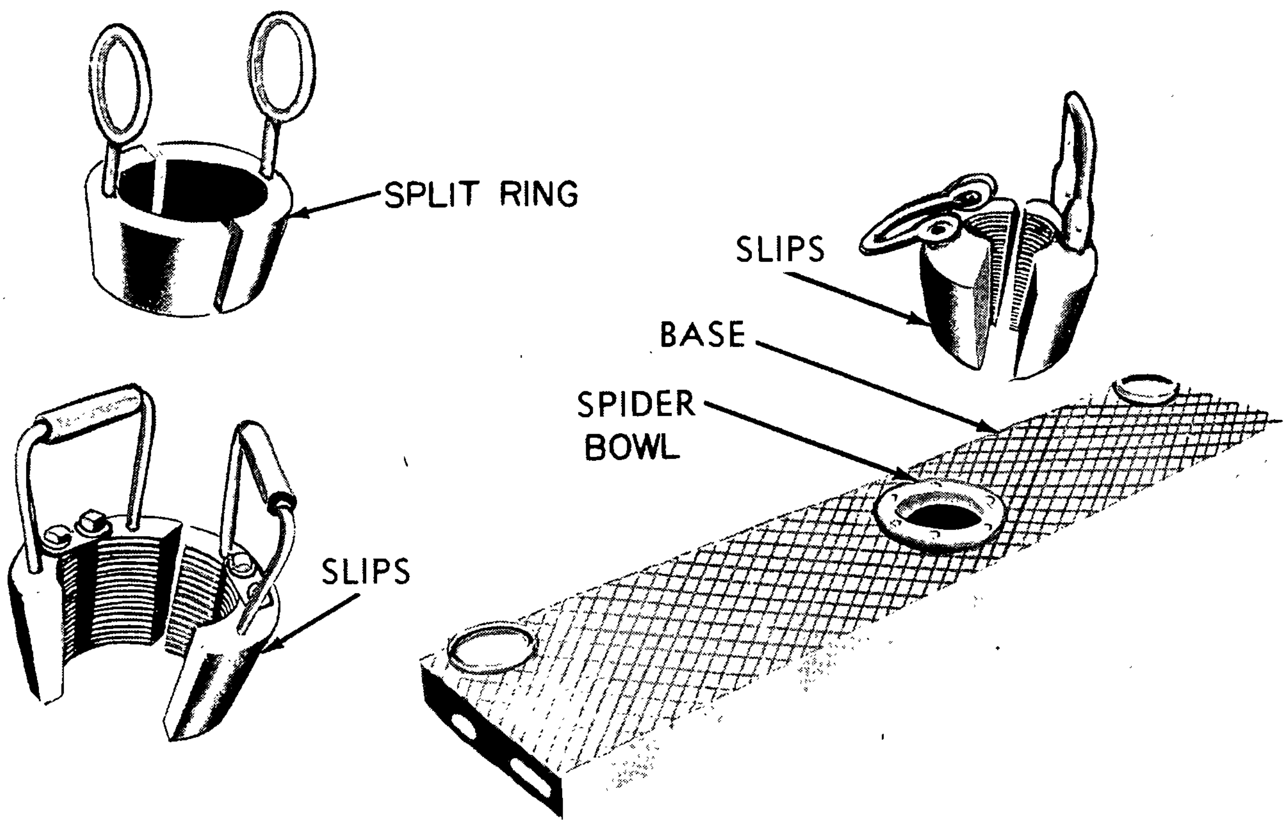


Figure 4-9. Spider and slips.

inch, and 8-inch pipe. They are used for holding the pipe at any desired position in the hole during drilling operations.

4–20. Bits

A general discussion of the purpose of the bits was given in paragraphs 4-3 through 4-15. Specific types of bits and their uses are given below.

a. Fishtail Bit. The fishtail bit (fig 4–11) is made of steel. The blades or wings are forged to a thin cutting edge turned slightly ahead. The cutting edges are faced with hard surfaced metal and have tungsten carbide inserts in the outside corners. The body of the bit is hollow with a hole drilled on each side to direct the fluid toward the center of each cutting edge. This fluid jets down the sides of the cutting edges and keeps them clean. The fluid then is deflected upward by the bottom of the hole and lifts the material loosened by the bit. The fishtail bit is adapted especially for use in sands and clays. When harder formations are encountered, the bit is dulled rapidly and progress is slow. In cemented sands, shattered formations, or formations containing loose boulders, it is not satisfactory because of the irregular torsional strain and vibration it transmits to the drill pipe.

b. Three-Wing Bit. The three-wing bit (fig 4–11) is much like the fishtail in design but has three cutting blades instead of two. The three blades make its action smoother in shattered or irregular formations. It also makes a better hole in semiconsolidated formations and has less tendency to be deflected. In soft formations it cuts a little slower than the fishtail.

c. Pilot Bit. The pilot bit (fig 4–11), sometimes called a six-wing bit, is the same general type as the fishtail and three-wing bits. It has six cutting edges, each with a hole for circulating fluid. Three of these cutting blades cut a hole about one-half the diameter of that cut by the others, and protrude approximately 1 1/2 to 2 inches below them. The two sets of blades are offset 60° from each other. The pilot feature makes this bit better for shattered formations and cemented sands than either the fishtail or the three-wing. It will cut somewhat harder formations, and with less irregular strain on the drill rods.

d. Rock Bits. All the above bits have a shearing or scraping action and are called drag bits. They are not adapted to drilling in rock. For rotary drilling in hard formations, a rock or roller type bit is used. This bit produces a crushing and chipping action as it rotates. The teeth of a rock bit are milled on the surfaces of cones or rollers which revolve as the bit is turned. A jet of the circulating fluid is directed from the inside of the bit to the top of each cone or roller. Rock bits cannot be redressed successfully in the field and must be replaced when worn out. The worn bits should be turned in for rebuilding. Two types of rock bits are in general use. Long teeth bits with wide spacing on the cones or rollers are best suited for soft rock. Harder formations require a bit having shorter teeth more closely spaced. When drilling hard formations, the cone or roller bearings become worn and the cutting elements loosened. If this occurs, the bit should be replaced to prevent the cutting elements from falling out while the bit is in the hole.

(1) *Cone type rock bit.* The cone type bit (fig 4-11) has three cone cutters, a forged steel body, and a cone axle or pin which forms a part of the body. The cones have roller bearings fitted at the time of manufacture. The cones are not removable. The three-cone construction provides smoother operation. The shape of the cutting surfaces and the design of the teeth in different types suit different formations. Some have interfitting or self-cleaning teeth. All cutting surfaces are flushed by the circulating fluid.

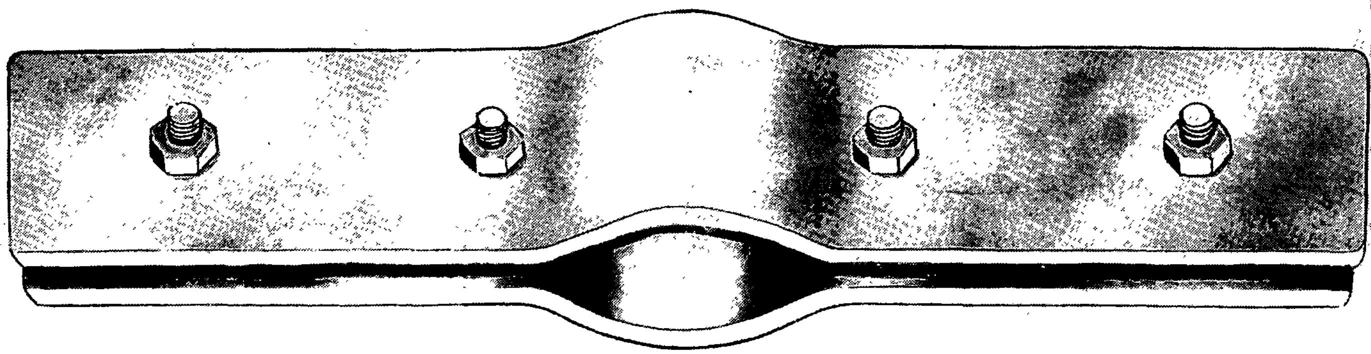


Figure 4-10. Pipe clamp.

(2) *Roller type rock bit.* The roller bit (fig 4–11) has four rollers or cutters and a steel body. Two rollers, on opposite sides of the body, are on inclined axles. The other two cutters or rollers are on horizontal axles set in the housing at right angles to the inclined cutters. The tooth design of the four rollers is made to suit varied formations. The rollers are not renewable. The cutting surfaces are flushed by the circulating fluid. All cutters have roller bearings.

e. Pin Connections. All the above bits have API regulation pin connections. The 3 7/8-inch

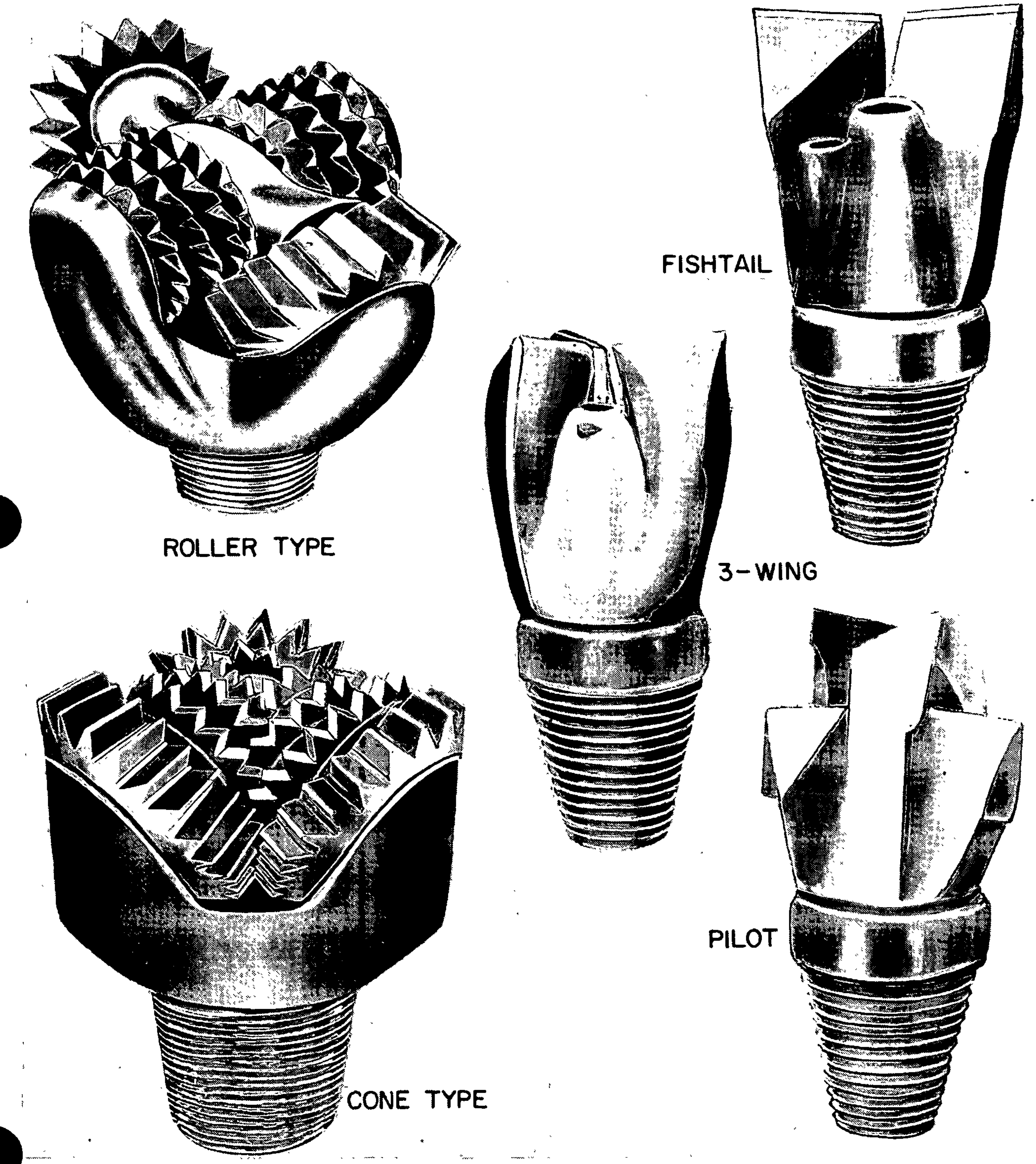


Figure 4-11. Types of bits.

roller bits have 2 3/8-inch pins, the 5 7/8-inch bits have 3 1/2-inch pins, the 7 1/8-inch bits have 4 1/2-inch pins, and the 9 7/8-inch bits have 6 5/8-inch pins.

f. Redressing Bits. All types of rotary drag bits can be sharpened or redressed by building up worn blades with steel and hard surfacing metal, using an oxyacetylene torch to fuse the new metal to the worn edges. Use the following procedures to redress these bits (fig. 4–12).

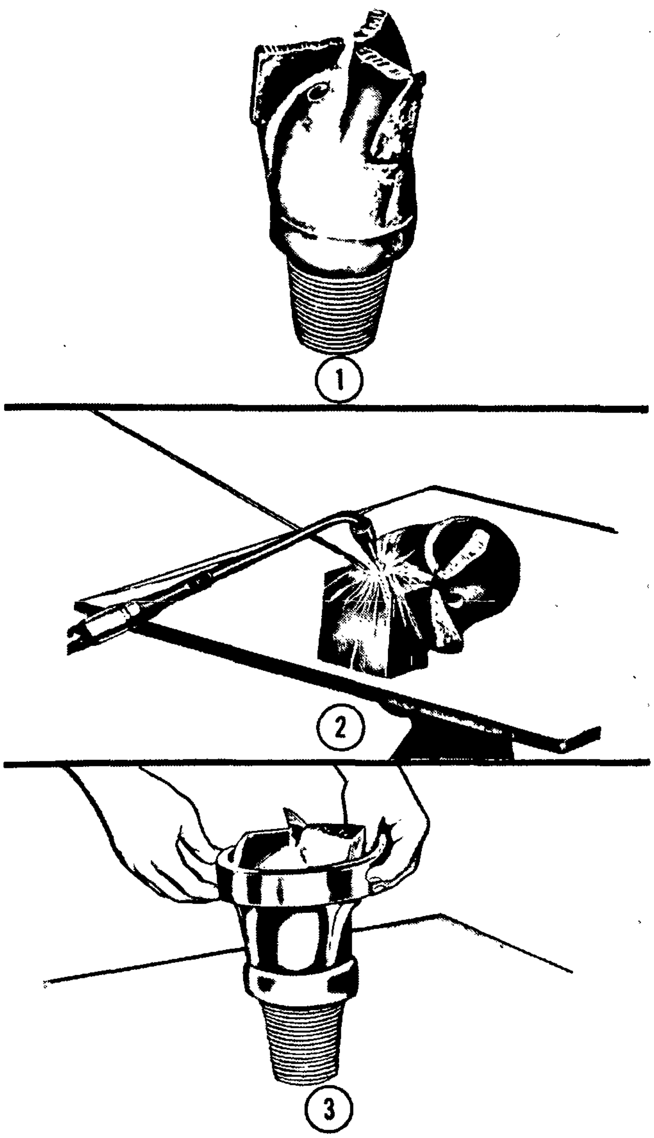


Figure 4-12. ① *Dressing bits.*

(1) Grind down the cutting edges of the dull bit until all metal surfacing from previous dressings has been removed (① fig 4–12).

(2) Using high strength steel welding rod, build up the surface to slightly below the desired finished height (② fig 4–12).

(3) Resize outside diameter of bit (③ fig 4–12).

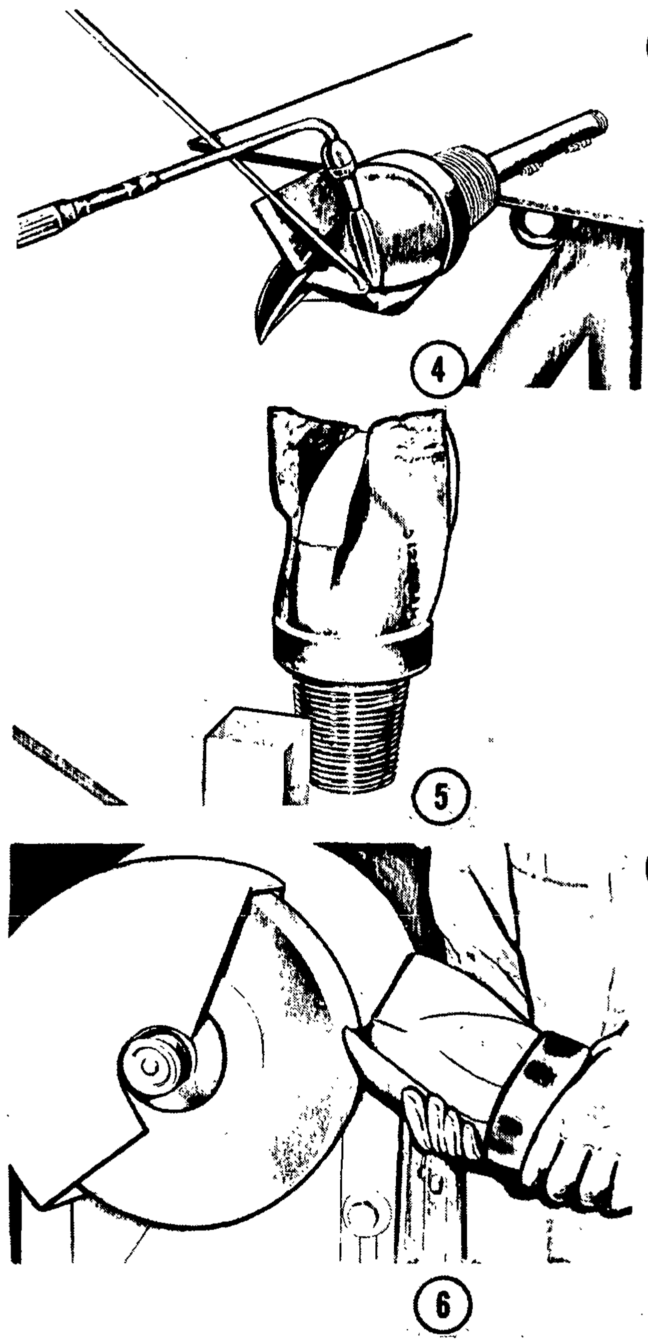


Figure 4-12 ② —Continued.

(4) Using hard surfacing rod, build up surface, especially along the edges, to slightly above desired finished height (④ and ⑤ fig 4–12).

(5) Shape cutting edges by grinding (⑥ fig 4–12).

(6) Recess tips of cutting surfaces and set in tungsten carbide inserts, positioning them as in (⑦ figure 4–12).

(7) Resize the OD of bit as shown in (⑧ figure 4–12.)

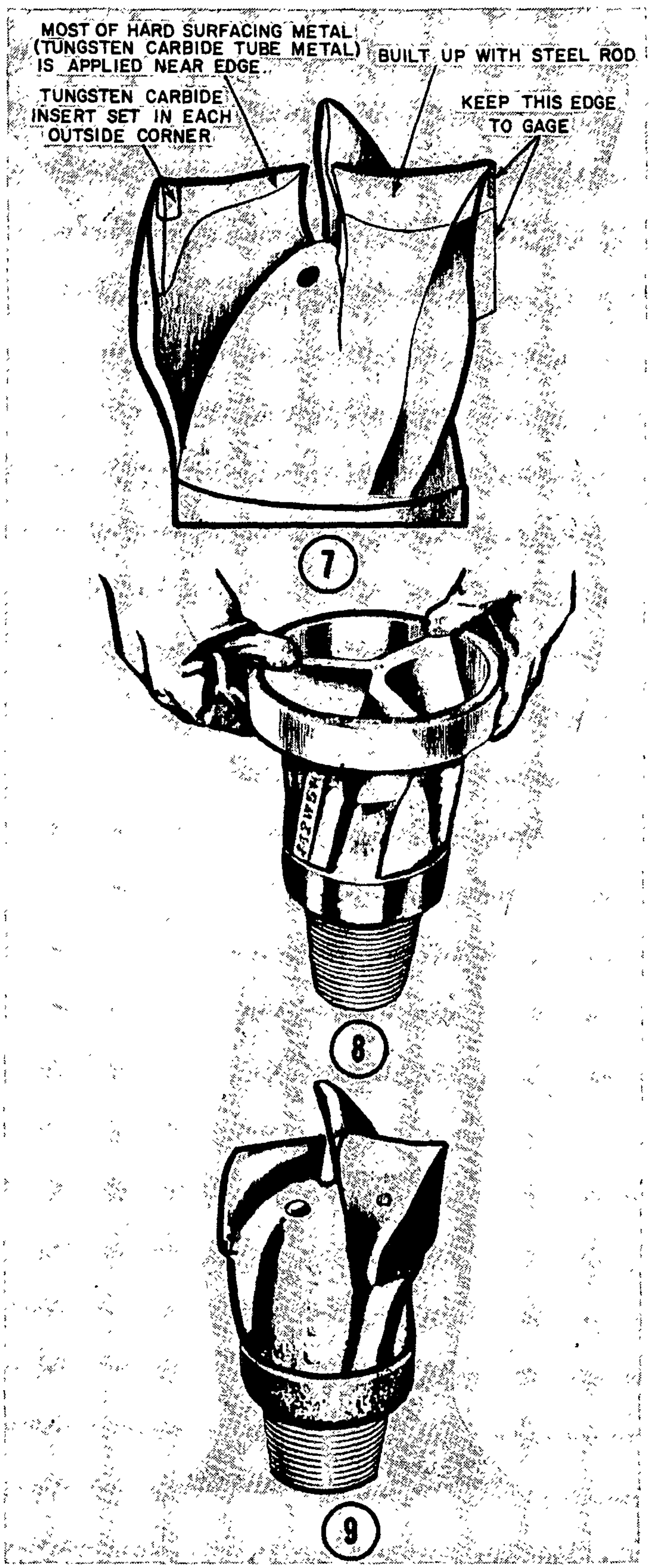


*Figure 4-12*③ —Continued.

(8) Grind bit to size and shape cutting surfaces as shown in (⑦ figure 4-12.) Check bit size again. Redressed bit is shown in (⑨ figure 4-12).

4-21. Core-Barrel and Crackerjack Bit

a. Core-Barrel. The core-barrel carried in the rotary rig (fig 4-13) is used instead of a regular bit to obtain a large sample or core from the bottom of the hole.

b. Crackerjack Bit. The crackerjack bit (fig 4-13) is used with the core-barrel. It is designed to cut either consolidated or broken medium hard formations. The bit is equipped with a core-catcher and the cutting edge is set with tungsten carbide chips.

4-22. Traveling Block

a. The mechanical advantage necessary to handle a long string of pipe safely is gained through the hoisting or traveling block (fig 4-14). This block has one sheave 12 inches in diameter, supported by heavy metal sides held together by three bolts. The sheave has a bronze bushing and is lubricated by a pressure gun fitting. A bail is fastened to the bottom of the block. A swiveling safety clevis is fitted in a vertical hole in the bail.

b. This block can safety handle a 25,000-pound load. The block is attached by removing the two bolts holding the bracket to the sides, putting the line around the sheave, and replacing the bolts. The safety clevis (fig 4-15) on the end of the drum-hoisting line is then fastened to the anchor eye at the top of the mast. The load is raised at half speed.

4-23. Pipe Elevator

A pipe elevator shown in figure 6-11 is a device used to facilitate dragging and lifting pipe or casing by a hoisting line. The simplest kind is a hinged clamp or ring with a quick-locking device to hold the two parts clamped around the pipe. The elevator links are fastened to a lug or eye on each side. The elevator is suspended on the hoist line by these links. The bore of the elevator is slightly larger than the outside diameter of the pipe, permitting it to slip up against the coupling or collar at the end of the pipe being lifted.

4-24. Wire Line and Attachments

Wire line is manufactured in many designs and sizes. Only two designs and sizes are used on the Army rotary water well drills.

a. Hoisting Line. The hoisting line is a 1/2-inch nonrotating wire line about 80 feet long. It consists of 18 strands of 7 wires each, the 12 outer

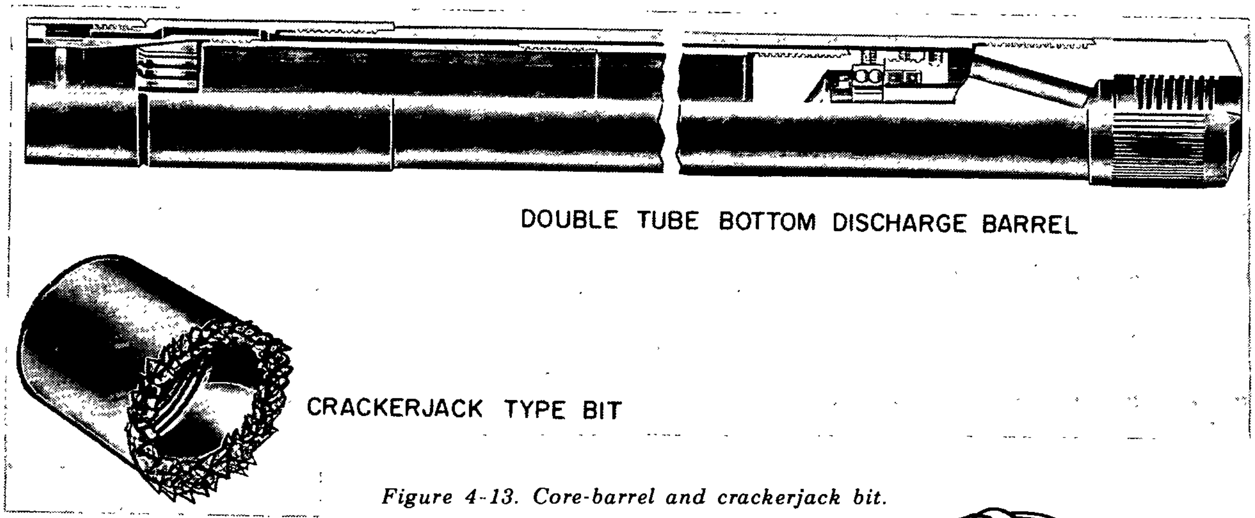


Figure 4-13. Core-barrel and crackerjack bit.

strands laid or twisted in one direction and the 6 inner strands in the opposite direction. This reduces the tendency of the line to twist. A safety clevis (fig 4-15) is attached to the free end of the hoist line to make an easy connection to the water swivel, the hoisting plug, or other tools.

b. Sandline. The sandline is a 3/8-inch wire line 550 feet long. It is made of 6 strands of 19 wires each, twisted around a hemp center. A swivel socket is attached to the free end of the line. The socket screws to the sinker bar or the swab, or to a clevis mounted on a threaded pin. This mounted clevis is used as a connection to the bailer when that tool is connected to the sandline.

c. Care of Wire Line. Do not strike wire line with a hammer or other object. Keep the line tightly and evenly wound on winding drums. Kinking the line should be avoided at all times. Keep it well lubricated with a good grade of noncorrosive wire line lubricant. When it is to be out of service for any length of time, clean it carefully and lubricate it.

d. Attaching Clevis or Socket. The following procedures must be followed when attaching the safety clevis to the hoist line or the swivel socket to the sandline. Figure 4-16 shows how a closed socket is attached to the line. Attachment of the basket of a swivel socket or clevis is made in a similar way.

(1) Whip or seize the wire line with wire or seizing strand at a distance from the end of the line equal to the length of the basket of the fitting to be attached (①fig 4-16). The seizing must be tight and it must have enough turns to keep the strands of the wire line from untwisting. If the line untwists back of the seizing, there will be unequal tension on the strands after attaching the clevis or socket.

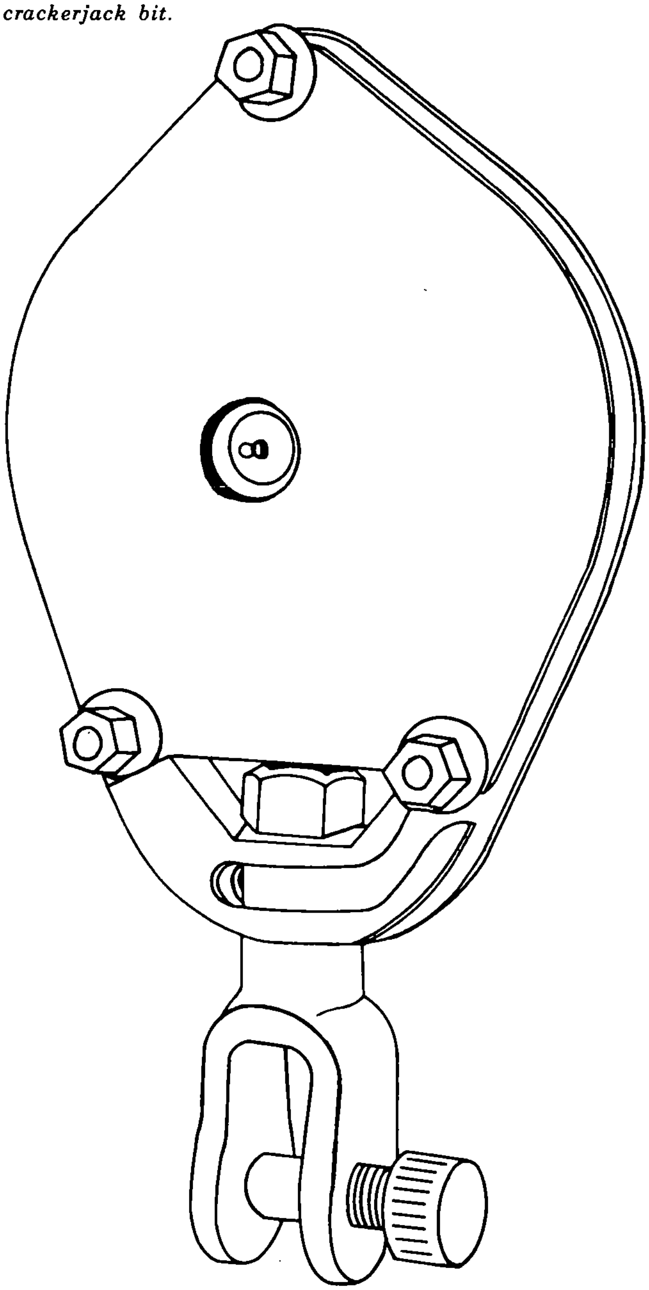


Figure 4-14. Traveling block.

(2) Untwist the strands and wires at the free end, and cut off the hemp center at the seizing (② fig 4–16). Separate the wires but do not straighten them.

(3) Separate the strands (③ fig 4–16) and clean the broomed-out wires well in cleaning solvent or volatile mineral spirits. If a 50 percent solution of muriatic acid is available, dip the loose wires in the acid long enough to clean them

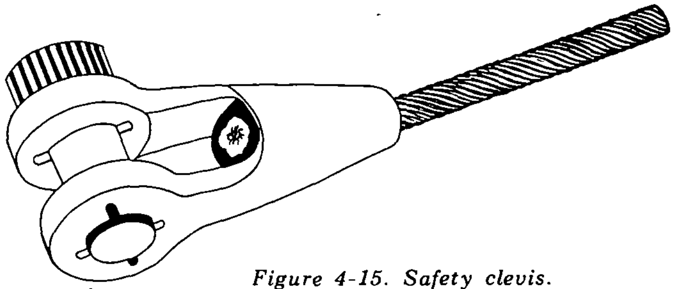


Figure 4-15. Safety clevis.

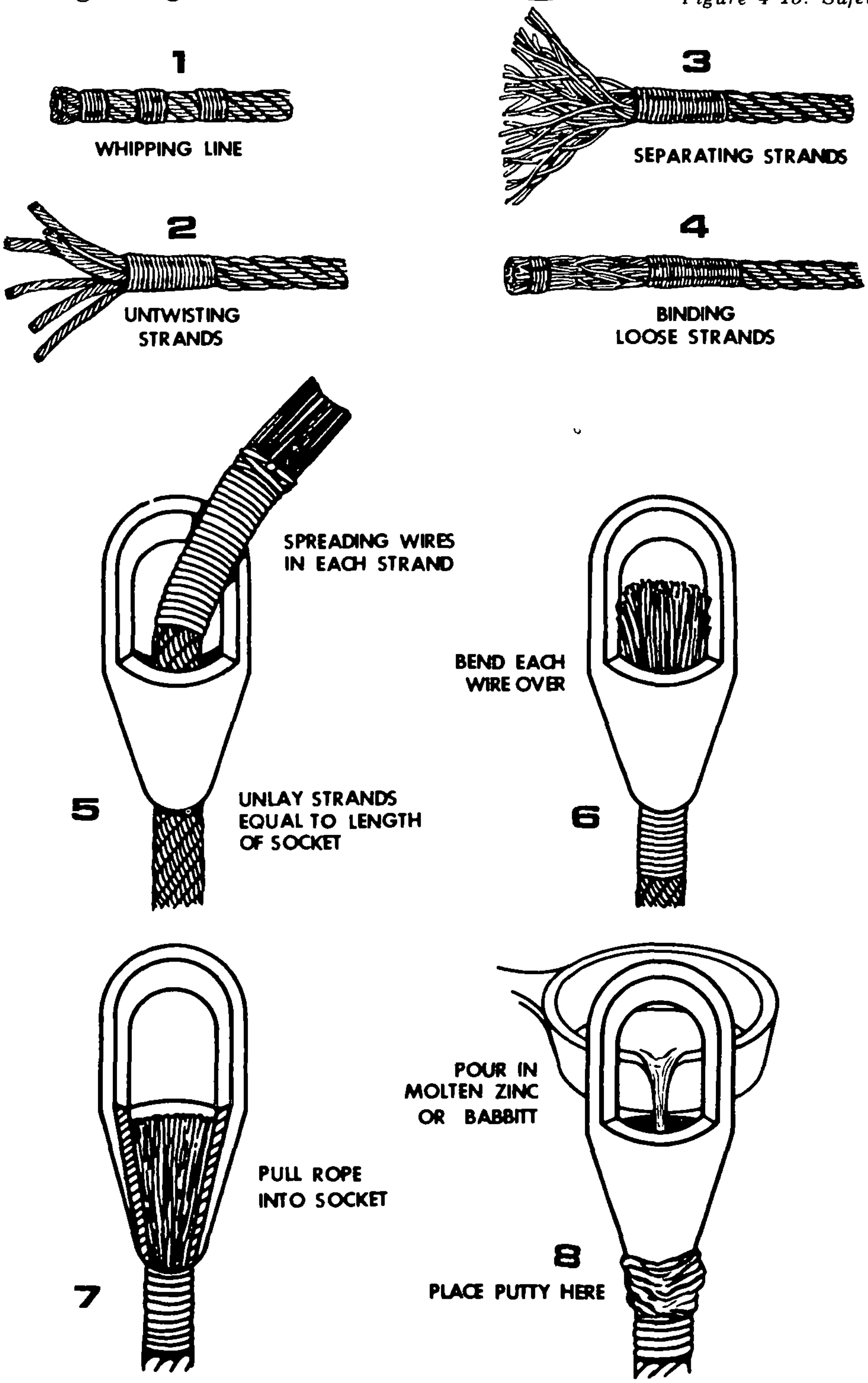


Figure 4-16. Attaching wire line to closed socket.

thoroughly. Prevent the acid from touching the wire back of the seizing. Rinse the wires with water and dry them with a clean rag.

(4) Draw the loose ends of wire together and bind temporarily (④ fig 4–16).

(5) Push the temporaily bound end through the hole in the basket of the fitting to be attached until the seizing is up to the hole (⑤fig 4-16).

(6) Remove the temporary seizing, spread the wires inside the basket, and bend each wire over (⑥ fig 4-16).

(7) Pull the wire into the socket (⑦fig 4-16).

(8) Seal the base of the basket with putty (⑧ fig 4-16). Heat the wire and the basket a little, pour in molten zinc or babbitt.

Caution: **When pouring molten metals, protective goggles and gloves should be worn.**

4–25. Swab

A swab is attached to the sandline to pump the drilling fluid out of a well after the casing and screen have been set in the hole. Besides pumping out the mud, the operation of the swab surges the well lightly as a valve type surge plunger (para 7–10). The device is similar to the piston in a single-action well cylinder, and it is operated with a reciprocating motion as a pump piston is. It consists of a mandrel on which two rubber rings are mounted a short distance apart. These rings are large enough to slide inside the well casing. A valve is provided which allows the fluid to pass through the tool on the downstroke, but which closes at the start of the upstroke. The swab furnished with the Army rig is for a 4-inch casing (fig 4–17). The mandrel of the 4-inch swab (fig 4–17) is hollow and is fitted with a ball valve. It has two cup type pistons. A flexible wire basket protects each rubber cup from damage. On the downstroke, the ball valve opens and allows the fluid to pass. On the upstroke, the valve closes and the swab lifts the fluid in the casing. After swabbing, a bailer is usually needed to remove the sand or other sediment from the bottom of the well. Well development is discussed in chapter 7.

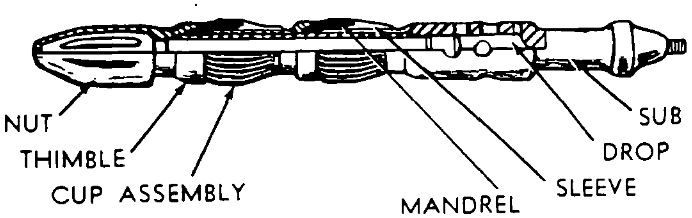


Figure 4-17. Four-inch swab.

4–26. Bailer

A sectional 3 1/2-inch outside diameter (OD) 20-foot long dart valve bailer (fig. 4–7) is furnished with the Army rigs. It is used for sampling and testing the yield of water-bearing strata and for removing sand and sediment from the bottom of the hole. It is connected to the sandline and lowered in the well until it rests on the bottom. A slight up-and-down movement will cause the sediment to work through the bottom valve into the body of the bailer. The bailer will sink as it becomes loaded. When it is loaded, lift the bailer out of the well and empty it.

4–27. Hoisting Plug

The hoisting plug (fig 4–18) is a threaded plug that screws into 1 inch of the drill pipe as a fitting by which the drill pipe can be readily lifted. The plug has a bail for suspending it and the drill pipe on the hoist line. With a suitable adapter the plug is also used to lift sections of casing and lower them into the hole after it is drilled. The plug has a bumper wheel to enable the operator to make or break tight joints quickly and easily. The hoisting plug should be kep clean and the threads and bearings should be oiled.

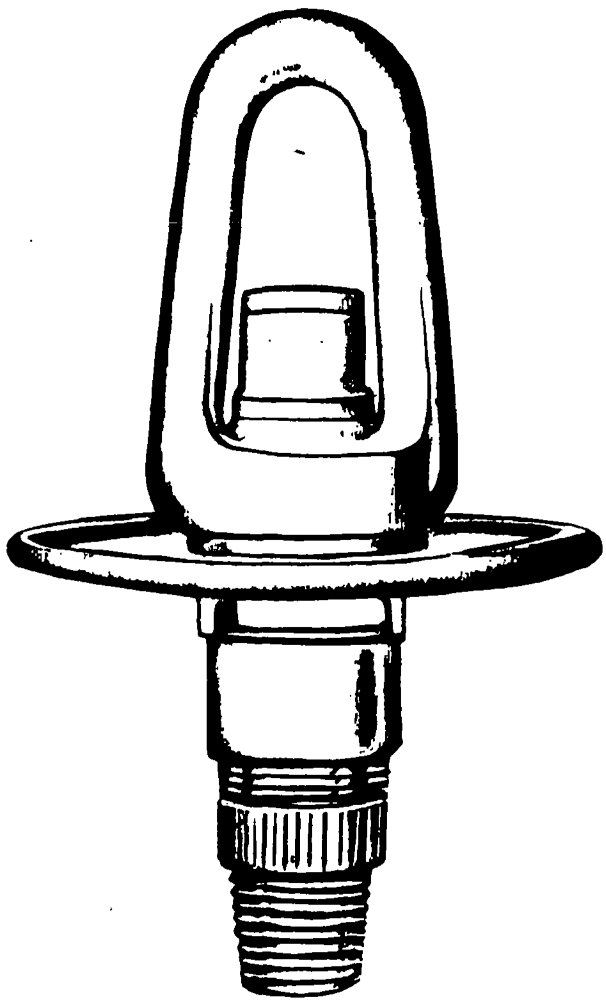


Figure 4-18. Hoisting plug.

4–28. Wicking

a. Since the drill rods are subjected to great torsional strains, the threads are thoroughly cleaned, greased, and wrapped with cotton yarn, called wicking, before making up each joint. At the same time, each joint is examined for cracks and wear. If a section is cracked or badly worn, it is discarded.

b. The wicking seals against leakage and keeps joints from becoming too tight. It is a 6-strand cotton yarn, issued in balls. For use, wicking is cut in 8-inch lengths and separated into pieces having two or three strands. The pieces then are twisted tightly together and tied around the coupling pin just below the shoulder. The wicking should be kept out of the threads.

Section IV. OPERATION OF ROTARY RIGS; AIRBORNE AND SEMITRAILER MOUNTED COMBINATION RIGS

4–29. Drilling Crew

a. Normal operations require a three-man crew, consisting of the driller and two helpers. Additional men are attached for hauling water, moving equipment, and placing the rig in position. The driller is in charge of all operations and is responsible for the care and maintenance of the equipment. The helpers keep the settling pit cleaned, maintain an adequate water supply, keep fuel and water in the engine, and lubricate the equipment. When running the drill pipe in or out of the hole, one helper works on the ground and helps the driller break the joints. He sets the slips, screws the hoisting plug in and out, and helps handle the pipe. The other helper works on the mast platform. He screws or unscrews the hoisting plug and helps guide each section of pipe while it is suspended in the derrick.

b. It is the driller's duty to enforce normal safety precautions around a drilling rig. Operations near heavy equipment are hazardous, and the driller should not tolerate careless practices. A combat helmet will protect the wearer from small equipment falling off the rig. Clothing should be tucked in so it will not catch in the rotating mechanism. Safety shoes with reinforced tops will protect toes from being crushed by heavy falling equipment. Tools should be put in their proper place and care should be used in moving or hoisting drilling equipment.

c. Success in well drilling depends largely upon the efficiency of the crew. The drilling rig and its controls are not complicated and can be mastered in a short time, but a knowledge of the mechanical operations is only the beginning. Training and experience are highly important.

d. Adjustments in rotating speeds and bit pressures cannot be put into set rules. The same formation may require different drilling techniques in holes spaced only a short distance apart. A driller should be able to visualize conditions at the bottom of the hole and know the reaction of the bit in different formations. He should also be able to recognize formation changes and keep an accurate log of them.

4–30. Rigging Machine

a. Drilling requires a level site. After it is selected and leveled, if necessary, the drill is moved into position. If it is on skids, it should be set on cribbing about 24 inches high. The cribbing, which is carried with skid mounted machines, supports the machine during operation, provides a firm base in soft soil, and is used as a leveling device on sloping or uneven terrain. The rig is jacked up or hoisted with a power winch so it can be placed on the cribbing, or unloaded directly from the truck down the ramp onto the cribbing. The cribbing is leveled and set on matting or a firm foundation. The rear end of the skids should overhang the cribbing by about 2 feet. If the unit is truck or trailer mounted, level it by digging holes for the wheels on the high side or blocking up the low wheels. After the unit is leveled, raise the mast. Next, take a slight tension on the hoisting line and tighten the brake. Loosen the clamp holding the upper end of the kelly and remove the cap from the lower end. Lift the kelly a few inches with the hoist and lower it through the drive bushing. Turn the kelly so the lugs on the drive bushing drop in the driving slots of the slip nut. Tighten the Allen setscrews. A bit now may be attached to the kelly with the proper substitute joint.

b. During this operation, one or two men should be digging the mud pits shown in figure 4-5. One fluid-return ditch is dug from the hole to the settling pit and another from the settling pit to the storage pit. The ditches enter and leave the settling pit so that the direction of flow (fig 4–5) is changed, thus giving more time for the cuttings to settle and keeping them from filling the storage pit. Fill the pits with water and put the suction hose screen in the storage pit. Submerge the screen but support the hose so it does not lie on the bottom.

c. The circulating fluid (drilling mud, a mixture of clay and water) is kept as clean and free of abrasives as possible, to protect the pump parts. Cuttings are periodically shoveled out of the settling pit to prevent carryover to the storage pit.

4-31. Drilling Fluid

The drilling fluid used with the hydraulic rotary system of well drilling is commonly known as mud or circulating fluid. The drilling mud or fluid may consist of a mixture of native clay and water, commercial clay and water, or a combination of native clay, commercial clay, and water. Mud is used in the drilling operation to clean the drill bit and remove the cuttings from the hole, to cool the bit and reduce friction between the drill rod and the sides of the hole, and to plaster the sides of the hole to prevent lost circulation. The porosity of the earth formation in which the well is to be drilled determines the viscosity of mud that must be used as a drilling fluid. If the formation near the surface is sandy or porous, the mud should be mixed before starting the well.

a. Native Clay. If native clay is available, it may be mixed with water to prepare the drilling mud. As long as this mixture functions satisfactorily, a commercial mud preparation need not be used. If the earth formation near the surface is clay, the well may be started using clear water as a drilling fluid. The water will mix with clay in the drill hole to form the necessary drilling fluid. Drilling may be continued, using only this natural mud, until a lost circulation zone is encountered and too much drilling fluid is being consumed.

b. Commercial Mud. Commercial mud should be added to the drilling fluid if zones of lost circulation are encountered or if the consumption of drilling fluid becomes too great. This is a particular type clay, called bentonite, that is dried and pulverized and packed into 100-pound bags. It is gel-forming, free of abrasive particles, and contains nearly 100 percent colloidal material. Several bags of this treated bentonite, called Aquagel, are carried on each drilling rig. When added to native clay in small quantities, it greatly improves the drilling fluid. It increases the viscosity of the fluid and improves the sealing qualities of the mud by forming an impervious film of gel on the wall of the hole. The film keeps the seepage of drilling fluid into the formation being drilled to a minimum. When used alone, 100 pounds of Aquagel will make 250 to 300 gallons of good drilling fluid. One part of Aquagel to three parts of native clay is a good proportion when both materials are used.

c. Additional Additives. Other substances such as bran, finely chopped straw, mica, or a pregelatinized cornstarch powder may be added to reduce consumption of drilling fluid. Soda ash, in the proportion of 2 pounds per barrel of mixed mud, or lime, used in the proportion of 3/4 pint per barrel of mud, makes a good mud thickener. If mud is too thick, polyphosphates or commercial water softeners in the amount of 1/2 pound per barrel of mud can be used.

d. Water Supply.

(1) A supply of water is essential for the drilling fluid. The water sources locally available dictate the type of water used in the drilling fluid; but generally the water should be reasonably free of dissolved salts. Some salts soluble in water tend to alter the clay suspension properties of the mud. Salty water or water with a high chloride content will tend to flocculate (curdle) the clay particles and destroy the colloidal (finely divided) properties of the mud, which are required in wall building and in sealing off permeable formations. Special muds for saltwater application are commercially available. Some of these are attapulgite clay and the organic and polymer fluids.

(2) Water must be added to the fluid from time to time as drilling proceeds to make up for that which seeps out through the wall of the hole and is lost. The amount lost depends upon the clay content and porosity of the formation penetrated. Three to 8 gallons of water per foot of hole are enough when drilling compact formations; but more fluid is lost in loose, porous formations, and a relatively large supply of water may be needed as the result. For average conditions, a requirement of 1,000 gallons per 10-hour shift should be expected. In tests conducted by research agencies the amount of water used varied from 1 1/2 to 17 gallons per foot while drilling 5-inch holes.

e. Mixing Operations. The drilling fluid usually should be prepared in the slush pits before starting the drilling operations. If the pits are dug in sandy or loose soil, a mixing box or a barrel must be used. The box should be about 2 feet wide, 4 feet long, and 2 feet deep. A screen-covered hole near the bottom of the box will provide an outlet into the slush pit. A steel drum, with one end removed, will do for a mixing barrel. The following procedure should be used when mixing the mud:

(1) Partially fill the settling and storage pits with clear water.

(2) Place the suction hose and attached

screen in the storage pit and the discharge hose valve on the pump. Connect the mixing hose to the mixing hose valve and open the valve.

(3) Place the native or prepared clay in the drum, mixing box, or storage pit, and start the mud pump.

(4) Direct the stream from the mixing hose into the drum, box, or slush pit. (When using a drum for mixing, empty the filled drum into the pit. When using a mixing box, allow the mixture to flow into the pit.)

(5) Circulate the mud through the mud pump until it is thoroughly mixed.

(6) Add prepared or native clay to the mixture until the desired viscosity is obtained.

(7) When the slush pit is filled with mud, disengage the mud pump clutch, close the mixing hose valve, open the discharge hose valve, and engage the pump clutch to circulate the mud through the drill stem. (The pressure of the circulating fluid is controlled by the manually selected speed of the mud pump engine as required by the drilling operations.)

(8) The viscosity of the mud will change as the mud is circulated through the drill hole. The soil formation of the hole will absorb some of the moisture from the mixture, leaving it thicker than is desirable. If a water-bearing formation is encountered, the mud is apt to become thin. Therefore, water or clay will have to be added to the mixture to maintain the desired viscosity and suspension qualities of the fluid.

4–32. Drilling

a. Procedure.

(1) Engage the mud pump, and when circulation has started, engage the rotary clutch and lower the bit by releasing the hoisting drum brake. In a soft formation, the weight of the kelly probably is enough to make the bit cut. If not, stop the rotation, tighten the chuck bolts, and resume rotation. Apply pressure to the bit by pulling back the hydraulic control valve and closing the pressure control valve enough to make the bit cut. When the end of the hydraulic feed is reached, stop rotation, loosen the chuck bolts, and raise the chuck by reversing the hydraulic control valve. This operation is repeated as long as added pressure is needed to make the bit cut.

(2) When the length of the kelly is drilled down, loosen the chuck bolts, hoist the kelly so the bit and couplings can be removed, and disengage the mud pump clutch. Pull the drill head away from the hole by pulling back the head-transfer valve and closing the pressure relief valve. Screw the bit on the drill collar and lower it into the hole by either the catline or the hoisting line attached to the hoisting plug; set the slips in the spider around the drill collar. Next, move the drill head back to drilling position and lower the kelly carefully into the box of the drill collar, rotating it slowly until the threads are tight. Before tightening, be sure there is wicking on the kelly coupling. Engage the pump clutch and hoist the kelly and drill collar until the slips can be removed; then lower to the bottom of the hole and resume operation.

(3) At intervals of 10 feet down, this procedure is repeated except, instead of a drill collar, a joint of the drill rods is added each time. The catline may be used for lowering the drill rods into the hole, or pulling them out at depths not over 100 feet. If the hole is deeper than 100 feet, the safety clevis is disengaged from the kelly as the drill head is retracted, and attached to the hoisting plug for handling the drill rods. Then the clevis must be reconnected to the swivel before the drill head is moved back to drilling position.

(4) If the bits must be changed before the hole is completed, the kelly is disconnected and the drill head moved back in the manner described for adding another joint of drill rod. The hoisting line is detached from the swivel and fastened to the hoisting plug. The rods then are pulled in doubles or in 20-foot lengths. A board is placed on the ground so the bottom ends of the rods will not get dirty. When the hole is completed, the drill rods are pulled singly and placed on a rack.

b. Drilling Speeds.

(1) *Drilling unconsolidated formations.* When drilling a 4-inch hole, drilling speeds of about 60 feet per hour in soft formations may be reached.

(2) *Drilling hard rock.* Drilling rates of 6 feet per hour may be reached in granitic rock, and 7 feet per hour in basaltic rock. In drilling this type of rock however, the expenditure of rock bits is high. The rotary rock bit is a highly specialized part of the equipment and cannot be economically resharpened or built up in the field; therefore, it must be replaced when worn out. The worn out bits should be turned in for rebuilding.

4–33. Casing Rotary Drilled Holes

a. By using proper drilling mud and operational procedures, deep holes in unconsolidated caving formations may be kept open without the use of casing while the hole is being drilled. Where the surface formations are soft or sandy, surface casing should be set to keep the walls of the hole from caving, and to prevent the hole from being enlarged by the washing action of the circulating fluid.

b. To set surface pipe, the hole is drilled or reamed through the upper strata so it will adapt to the casing. Surface pipe is set in the hole and seated in a firm formation. To run the casing, a sub is attached to the hoisting plug and screwed into a joint of casing. It is then lowered in the hole the same way as the drill pipe. If the hole has caved so the casing will not go down, the swivel is attached to the casing with a sub and fluid circulated through the casing. This is called washing down and sometimes must be used to wash the pipe to the bottom of a caving hole.

c. The top of the surface casing should be just below the spider base. A pipe clamp (fig 4–10) prevents the pipe from dropping into the hole if the formation is washed from beneath it.

d. After completing a hole, the walls must be supported to prevent caving and to protect them against contact with the water.

e. The casing is set in the hole as described in *b* above, except that in handling heavy or long strings of casing a traveling block (fig 4–14) is used for safety. Each joint must be made up tightly. One or more pipe clamps are used to suspend the pipe string as each new joint is added.

4–34. Recognition of Water-Bearing Formations

a. If little is known of the geology of the area, the search for water-bearing beds must be done carefully and deliberately and all possible water-bearing horizons tested. Many wells capable of producing water are abandoned as dry because of incompetent drilling.

b. There are no sure standards for recognizing water-bearing strata. They may be fissured or cavernous limestone or basalt, crushed or fractured zones in consolidated sedimentary, igneous, or metamorphic rocks, loose sands and gravels, sandstones and conglomerates, or hard fractured shales. Sticky clays, tough plastic shales, thoroughly cemented sandstones and conglomerates, and massive unfractured limestones or other dense rocks seldom yield usable quantities of water.

c. An experienced driller generally can make a rough estimate of the permeability of the formation by examining the drill cuttings. The following criteria, based upon changes in the character and circulation of the mud, are some of the most important means of recognizing water-producing zones.

(1) There usually is a slight loss of circulating mud while drilling, caused by natural seepage. This requires the continuous addition of small quantities of water to maintain enough volume for circulation. When the loss becomes excessive (5 gallons per minute or more in a 5 5/8-inch hole), the depth at which the loss occurs should be noted carefully and formation samples taken frequently. A suitable screen can then be set at this level.

(2) A noticeable increase in the volume of the returning circulation fluid invariably means that an artesian water-bearing formation with a higher hydrostatic pressure than the mud column in the hole has been penetrated. When this occurs, the circulating mud rapidly loses viscosity and weight and, in extreme cases, is displaced completely by water coming from the formation.

(3) Complete loss of circulation usually means that a very porous formation has been entered, and the ground water in the formation is being pushed back by the drilling fluid invading the formation. Chapter 11 discusses related sampling and coring.

4–35. Testing Water-Bearing Strata

a. If the hole is being drilled in a hard, noncaving formation, the mud should first be displaced by circulating clear water through the drill pipe the full depth of the hole. Water may be bailed out of the hole, thus lowering the fluid level and allowing the water in the suspected zone to come into the hole. This will wash out some of the mud sealing the hole. The yield can then be estimated from the rate of bailing. If the well is being drilled in a soft caving formation, displacing the mud with water will result in slumping or caving and this method cannot be used.

b. One generally successful procedure is to drill a rathole, or small diameter hole, until a suspected zone is penetrated. When such a zone is met, the hole is reamed out to a full size to within a few feet of the top of the suspected zone. A test string of casing, which will pass freely through the reamed portion but will not enter the rathole, is then set. The temporary casing is wedged or driven firmly into the rathole, thus sealing off the bottom of the reamed portion of the hole. The space outside the casing is kept full of mud fluid to maintain the hydrostatic pressure on the wall of the hole and prevent caving.

c. The drill pipe or wash pipe is run through the casing to the bottom. The mud in the suspected zone may be washed out with clear water, and the fluid inside the casing can be bailed out to test the volume and quality of the water in the suspected zone. While bailing, the level of the mud fluid outside the casing is carefully watched. If the level remains stationary, it is certain that the bottom shutoff is satisfactory and that all fluid being bailed out is coming from the formation under test. If the mud outside the casing drops while bailing, the shutoff is unsatisfactory and fluid is leaking past the bottom of the casing. When this happens, the casing should be reseated before proceeding with the test. After completing the test, the casing should be filled with drilling fluid before it is pulled from the hole. This will prevent caving and permit drilling deeper after the test, if desired.

4–36. Drilling Difficulties

a. Lost Circulation. Zones of lost circulation, sometimes encountered in shallow water well drilling, are zones of high porosity and usually will yield large quantities of water. Hence, a test of the well always is made when circulation is lost. Formations which drain off or absorb all or part of the circulating fluid offer problems ranging from minor inconveniences and loss of time to extreme conditions which render rotary drilling impracticable. These formations can be divided roughly into three classes:

(1) Difficulties may arise with formations which contain specific joints and fissures, quartzite, sandstone, limestone, and dolomite. The chief difficulties found in drilling these formations are caving, abrasion, and total loss of circulation.

(2) Shale which is jointed and fissured seldom drains off an excessive amount of the circulating mud, but the amount that is absorbed causes the shale to swell and heave, filling up the drill hole. Modern drilling practice has largely overcome this difficulty by the use of special circulating equipment and drilling mud not available to the Army driller. However, the conditions outlined above seldom are encountered, and satisfactory drilling progress usually is made by using a mud of high viscosity and weight. Another way to keep the hole open under these circumstances is to raise and lower the rotating drill string through the formation several times at the end of every 25 feet of drilling in swelling shale. This has a swabbing action and eliminates much of the danger of stuck drill pipe.

(3) Sands and gravels seldom absorb enough of the drilling mud to hinder progress seriously. The loss, which is continous, is replaced not with water but with mud. Water, when used to maintain enough volume for circulation, soon lowers the viscosity and weight of the mud and caving results.

b. Regaining Lost Circulation. Where it is desirable to regain lost circulation, one of the two methods described below is used.

(1) The method usually found most satisfactory in water well drilling is to drill through the zone of lost circulation and to set a string of well casing somewhat below the highly porous zone. The chief requirement is a plentiful supply of water to circulate the cuttings away from the bit and into the formation. Mud is desirable for this purpose, but the quantity needed usually prevents its use. When using water to carry off the drill cuttings, the pump should always be operated for a few minutes after drilling has stopped. This flushes the cuttings out of the hole and prevents the drill pipe from sticking when it is stopped to make a connection. In extreme cases where as much as 100 feet or more must be drilled, a small quantity of rotary mud is "spotted" around and above the bit while an additional joint of pipe is installed in the drilling string. This prevents excessive settling-out of the drill cuttings and consequent sinking while the drill pipe is standing. When the bottom of the porous zone has been reached, drilling is continued into the underlying formation for about 5 feet, to give room for cementing the casing. When the casing has been run and cemented, ordinary rotary drilling procedure may be resumed.

(2) Usually the circulation can be regained by mixing a fibrous material with the drilling fluid. This material may be obtained commercially. In an emergency, cottonseed hulls, bran, sawdust, shredded hay, or like substances may be substituted. In some cases the hole must be abandoned. If circulation is lost in cavernous lime, the fluid level in the hole is checked and tested for fresh water.

c. Straight Holes.

(1) A straight hole is an essential requirement. Much depends on the experience and ability of the drill operator when drilling through difficult formations. Some of the important requirements for straight hole drilling are—

(*a*) An adequate quantity of drill collars (up to 100 feet per typical drilling string).

(*b*) Speed of bit rotation of at least 150 revolutions per minute.

(*c*) Mud circulation of 5 gallons per minute per inch of the bit diameter.

(2) The above mechanical considerations are not always feasible for the small rotary drilling machine, though they can be offset to some extent by an experienced operator. The harder

formations, especially those which are dipping and those which are broken and creviced, present many difficulties. The only bits used in the difficult formations are the roller type rock bits and the three- or four-wing drag bits.

d. Crooked Holes.

(1) One way to detect crooked holes is to watch for wear on the drill pipe. If it occurs at a set distance from the top of the ground, it indicates the hole was deflected at this point. It is not always easy to detect deflections of the bit and drill pipe while drilling, because the hole can be quite crooked without noticeably affecting the operation of the rig. The driller must be alert to any indication that the hole is going crooked.

(2) To avoid crooked holes, the bits should be of a form and size that prevent undue eccentricity during rotation. They must be sharp, and dressed to proper gage. The drill collar which holds the bit to the lower end of the drill pipe must be large enough in diameter to hold the pipe centrally in the hole and to prevent the bit from working off to one side. Excessive bit pressures are to be avoided.

(3) The usual method of straightening crooked holes is to set the bit where the hole starts off the vertical and rotate it until a shoulder is started, gradually working down to the bottom of the hole. This is a slow, difficult operation and is not successful in the harder, more difficult formations. The best method is to enlarge or ream the hole to the largest possible diameter, to give the well casing or pump pipe a chance to aline itself in the hole. This method often succeeds where other methods have failed.

e. Recovery of Drill Pipe. Recovery of stuck drill pipe in wells drilled with the smaller rotary equipment is limited by the amount of auxiliary equipment available. Every precaution should be observed to prevent the drill pipe from sticking. However, there are certain measures which sometimes can be taken successfully with the equipment at hand, depending upon how tightly and in what manner the drill pipe is stuck.

(1) When the pipe is stuck by "balling up" while drilling in soft shale or clay, it can often be loosened by circulating clear water. An upward strain should be kept on the pipe while the water is being circulated.

(2) When the pipe is stuck by sand or drill cuttings accumulating in the hole, circulation should be maintained with the heaviest mud obtainable. If possible, the pipe should be worked. Any movement transmitted through the pipe, however slight, helps dislodge the sand particles into the mud stream, where they are carried to the surface.

(3) When a drill pipe is stuck because of loss of circulation, little can be done to recover the entire string of pipe. However, an attempt should be made to pull the pipe with the jacks. Compressed air can also be used occasionally to restore circulation.

(4) Sometimes the pipe can be recovered by using the proper drilling fluid and circulating it while working the pipe with both rotation and hoisting mechanisms. If circulation has been lost and cannot be regained, the drill pipe must be washed over with casing to recover it.

f. Fishing. The most frequent type of fishing in rotary drilling results from twisting off the drill pipe. Such twist-offs usually occur near the lower end of the pipe; they may consist of a simple shearing off of the pipe or a fracture at a coupling. The accidental dropping of drill pipe into a hole makes a similar fishing job. Other less common accidents requiring fishing are the dropping of tools, such as slips or wrenches, into the hole. Certain general principles apply to all fishing jobs. Fishing tools and techniques are discussed in chapter 5. In drilling shallow wells, it is often cheaper to abandon the hole and the lost tools than to spend time fishing for them. In some cases lost tools may be avoided by drilling past them.

4–37. Swabbing and Bailing

Swabbing and bailing operations were described in paragraphs 4–25 and 4–26. Both are important in removing sands and other sediment from wells and are steps in well development which is discussed in chapter 7.

4–38. Installing Well Screens

Details of the use and installation of well screens in wells drilled by the rotary method are given in paragraphs 7–4 through 7–8.

Section V. SEMITRAILER MOUNTED ROTARY DRILLING EQUIPMENT

4–39. Introduction

In addition to the rotary drilling equipment described in paragraphs 4–1 through 4–38, the Army also uses heavier, semitrailer mounted rotary drilling equipment (fig 4–19). The semitrailer mounted machine is capable of constructing a 1500-foot deep water well in all types of formations. Figure 4–20 shows the operating controls for this machine. This machine is described briefly here, but the manuals accompanying each machine should be consulted for operating instructions.

4–40. Description of Major Components

All components, including the mud pump and air compressor, are mounted together on a semitrailer.

a. Power Unit. The source of power is a 2-cycle, (V) 6-cylinder diesel engine having 365 horsepower.

b. Power Transmission. Power transmission is controlled by a main clutch at the rear of the engine and is carried through a series of transfer cases and drive shafts and finally through dry multidisc clutches to the major components.

c. Mast. The mast is of one-piece construction and has a gross lifting capacity of 40,000 pounds. It is hinged on pins at the lower end and is held by a bracket, located just behind the engine, when it is collapsed. The mast is raised and lowered by two hydraulic rams.

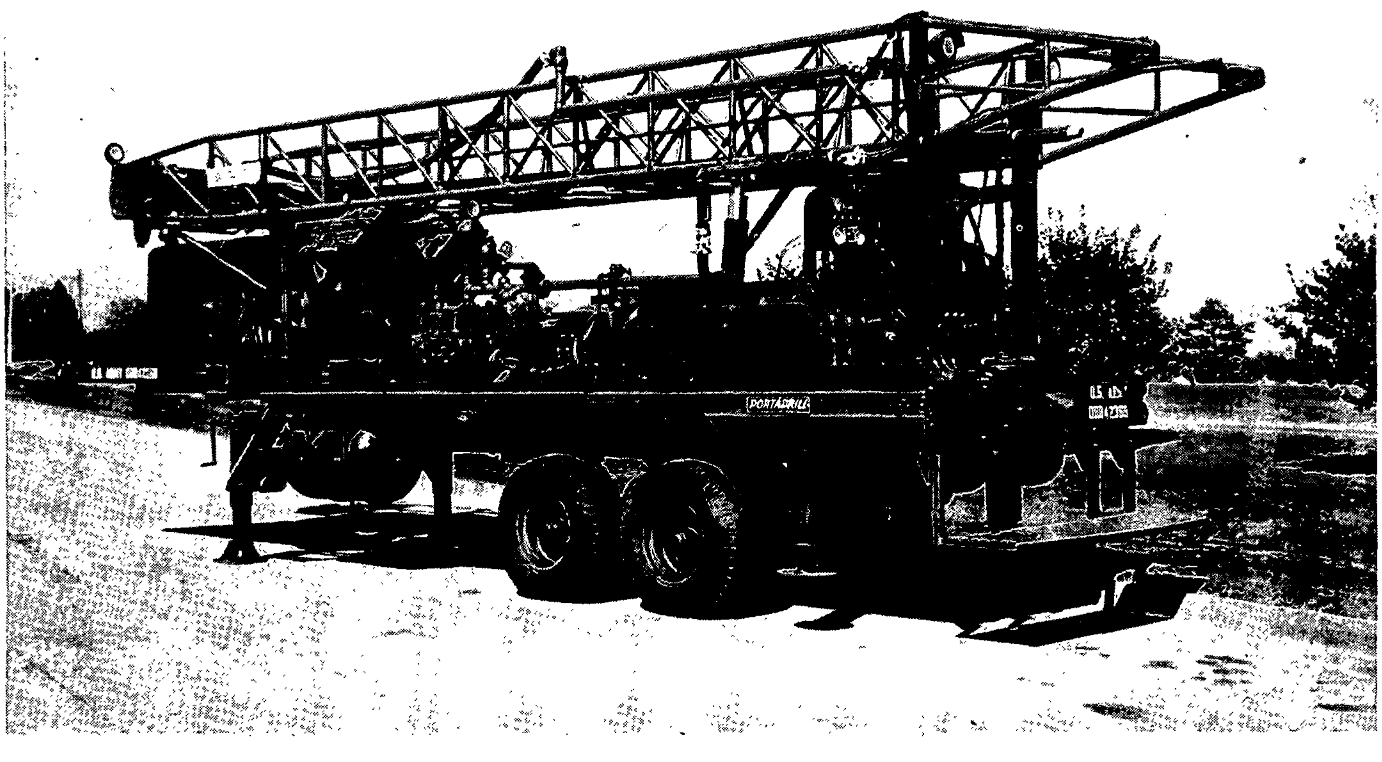
d. Draw Works. The draw works is made up of three separate hoists.

(1) The *kelly hoist* is used to raise and lower the kelly in the rotary table.

(2) The *utility hoist* is used for lifting or lowering drill stem or casing lengths into position over the hole so they can be added to or removed from the drill or casing string.

(3) The *sandline hoist* is used for running a bailer or sand pump to the hole bottom to clean and develop the well.

e. Power Feed Mechanism (Automatic Pulldown). The power feed mechanism (fig 4–21) is the means by which axial thrust is applied to the drill stem at shallow depths when the weight of the drill stem cannot provide adequate pressure to the bit. One component of the power feed mechanism is a hydraulic pump that is connected to the pulldown transmission. This transmission is connected to a ring and pinion transfer case which, in turn, is connected to two continuous chains. The chains are attached to the kelly by means of the water swivel. This system can apply 20,000 pounds of pulldown.



4-19. ① Semitrailer mounted rotary rig.

f. Power Breakout. The power breakout (fig 4–22) allows the drill stem to be broken joint by joint as it is being removed from the hole. Single breakout tongs on shock hammer mountings eliminate use of cathead and wrenches when backing off the top drill pipe. The tongs retract when not in use. Two-piece roller slips securely hold the lower length of drill stem suspended in the hole. The rotary table is engaged to produce the breakout.

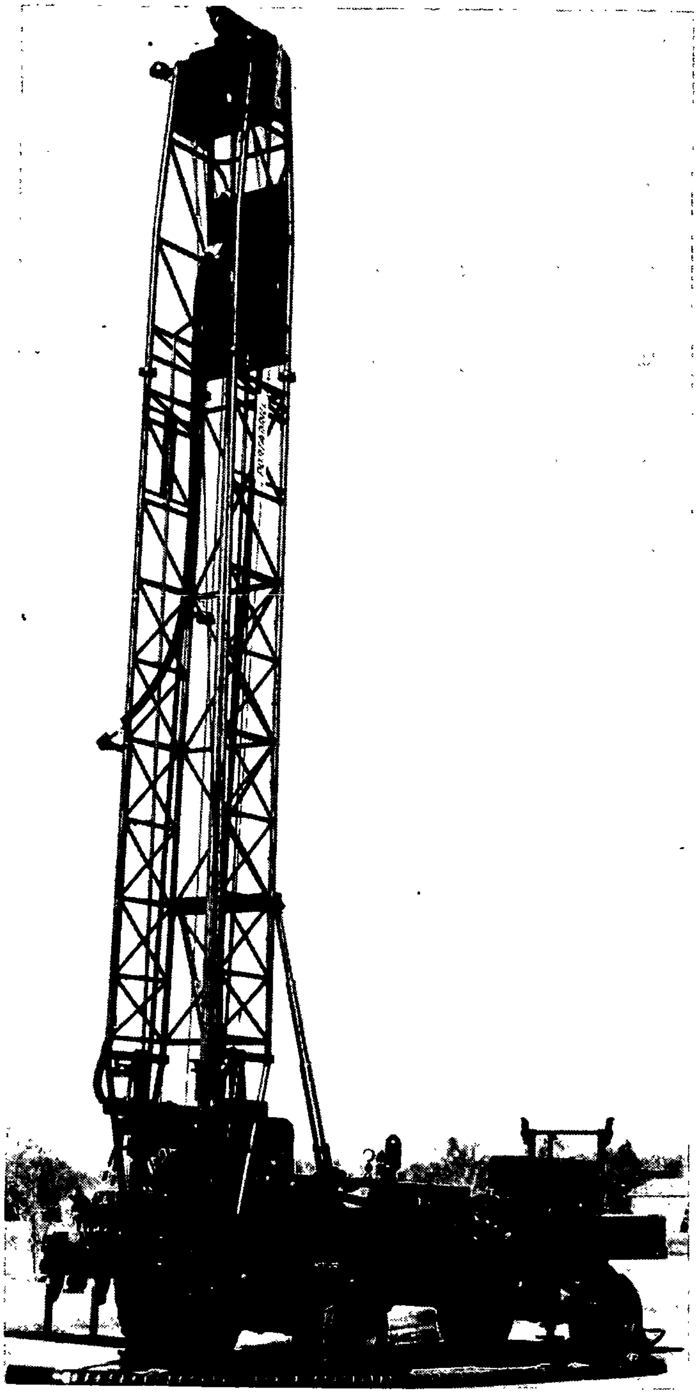


*Figure 4-19*② —Continued.

g. Rotary Table and Kelly. The rotary table and kelly provide the means of rotating the drill string in the hole. After a new section of drill pipe has been added, the kelly is screwed into the drill string. The rotary table rotates the kelly which in turn rotates the drill string. As the hole advances, the kelly slides through the rotary table. When water or a mud circulation is used, the rotary table is mechanically driven, but when air circulation is used, hydraulic drive is employed to prevent binding of the bit and slippage of a manual clutch.

4–41. Principles of Operation

The semitrailer mounted machine is equipped to function in three different modes of operation:

a. Standard rotary operation with water or mud circulation.

b. Standard rotary operation with air circulation.

c. Down-hole hammer operation with air circulation.

4–42. Rotary Operation With Water or Mud Circulation

The standard rotary technique with water or mud circulation is used to drill soft formations with a drag bit or medium hard formations with a roller cone bit. This mode of operation is essentially the same as that described for the airborne rig in paragraphs 4–29 through 4–38.

4–43. Rotary Operation With Air Circulation

a. Rotary operation using air circulation is similar to the mud or water rotary technique except that the circulating fluid (air) is not recirculated. When the cuttings are carried to the surface, they are deposited around the outside of the hole and either shoveled away, or if a blower is attached to the machine, they are carried by air to a cuttings pile. A certain minimum air velocity must be maintained in the hole annulus between the drill pipe and the hole wall to assure efficient removal of the cuttings. The standard accepted value, when air is used without additives, is 4,000 feet per minute. The amount of annular velocity for any given hole size, drill pipe size, and compressor capacity may be determined by using the graph in figure 4–23.

b. Air may be used without injecting water or other additives if drilling conditions are very dry, so that the cuttings are removed as dust; or if quite wet, so that the cuttings are flushed out in a mixture of air and water. In drilling conditions in which only a little water is produced from the formations as drilling progresses however, the

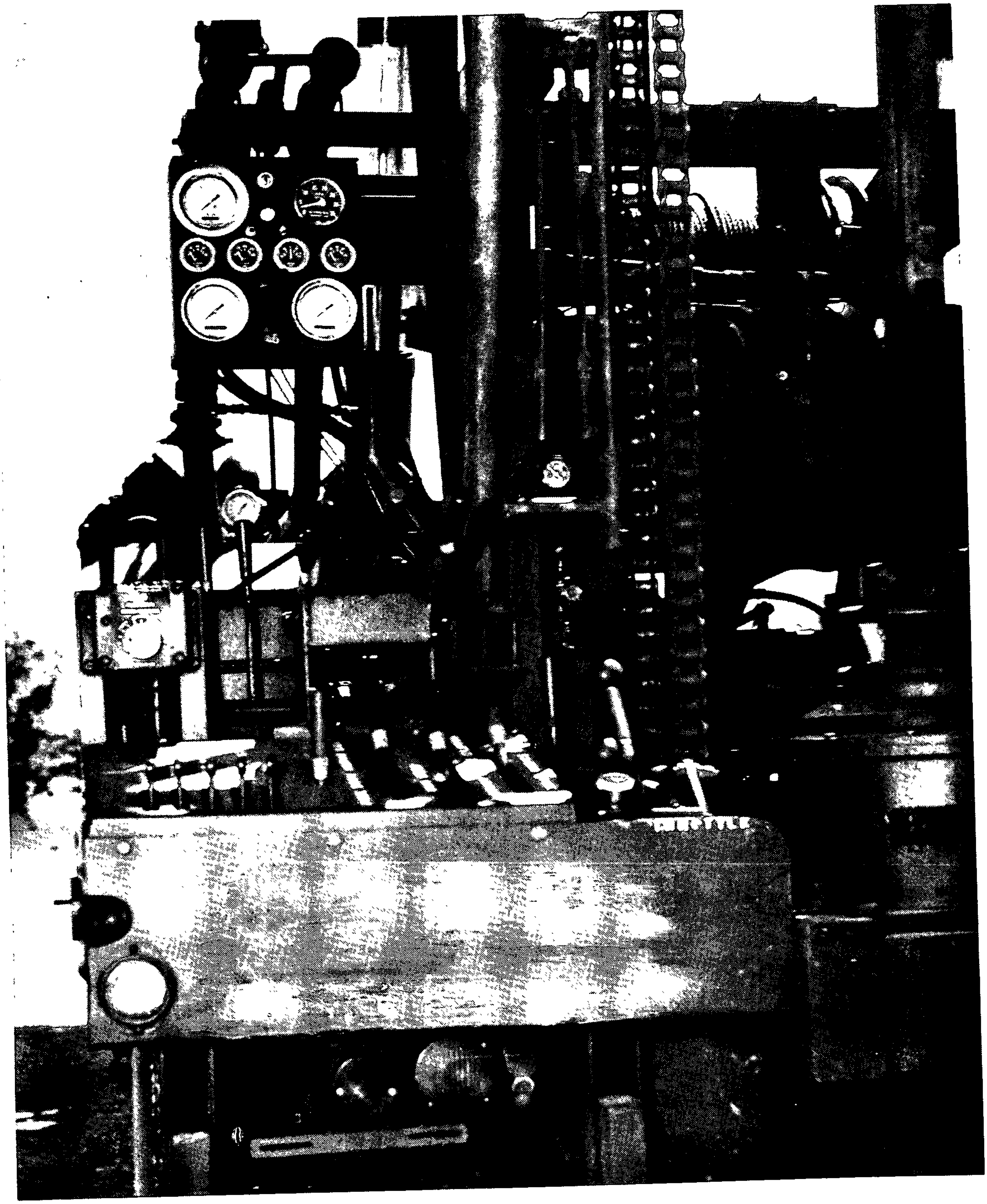


Figure 4-20. Operating controls on rotary drilling machine.

cuttings tend to adhere to each other and form balls of varying sizes. These balls may become quite large and may stick to the drill pipe and hole wall to cause "bridging over" of the hole. This condition results in choking off of the annulus and may eventually result in the drill pipe becoming stuck in the hole. This problem can be avoided by injecting a small amount of water (approximately 3 gpm) into the air stream shortly after the air leaves the air compressor. This injected water assures that the cuttings will not stick to each other and will be flushed out of the hole with ease. Water should also be injected in extremely dry hard rock drilling conditions to control the dust that is generated during drilling operations.

c. Air drilling offers a number of advantages over water or mud drilling. Removal of the cuttings from the face of the bit is often faster, resulting in less regrinding of cuttings and resultant waste of cutting energy and decrease in penetration rates. Also, all water that enters the hole from the formation being penetrated is almost immediately flushed to the surface and is easy to see. Hence, it is normally much easier to determine when a good aquifer is encountered when drilling with air than when drilling with water or mud.

4–44. Down-Hole Hammer Operation

a. A new tool that greatly increases drilling rates in hard rock conditions is available for use with the semitrailer mounted machine. This tool is the *down-hole hammer* (fig 4–24), a pneumatically operated percussion tool fastened to the end of the drill string just above the bit.

b. When operating, the hammer is rotated much more slowly (10 to 30 rpm) than conventional air or mud rotary tools. The hammer is powered by air pressure from the same air compressor that provides air circulation for

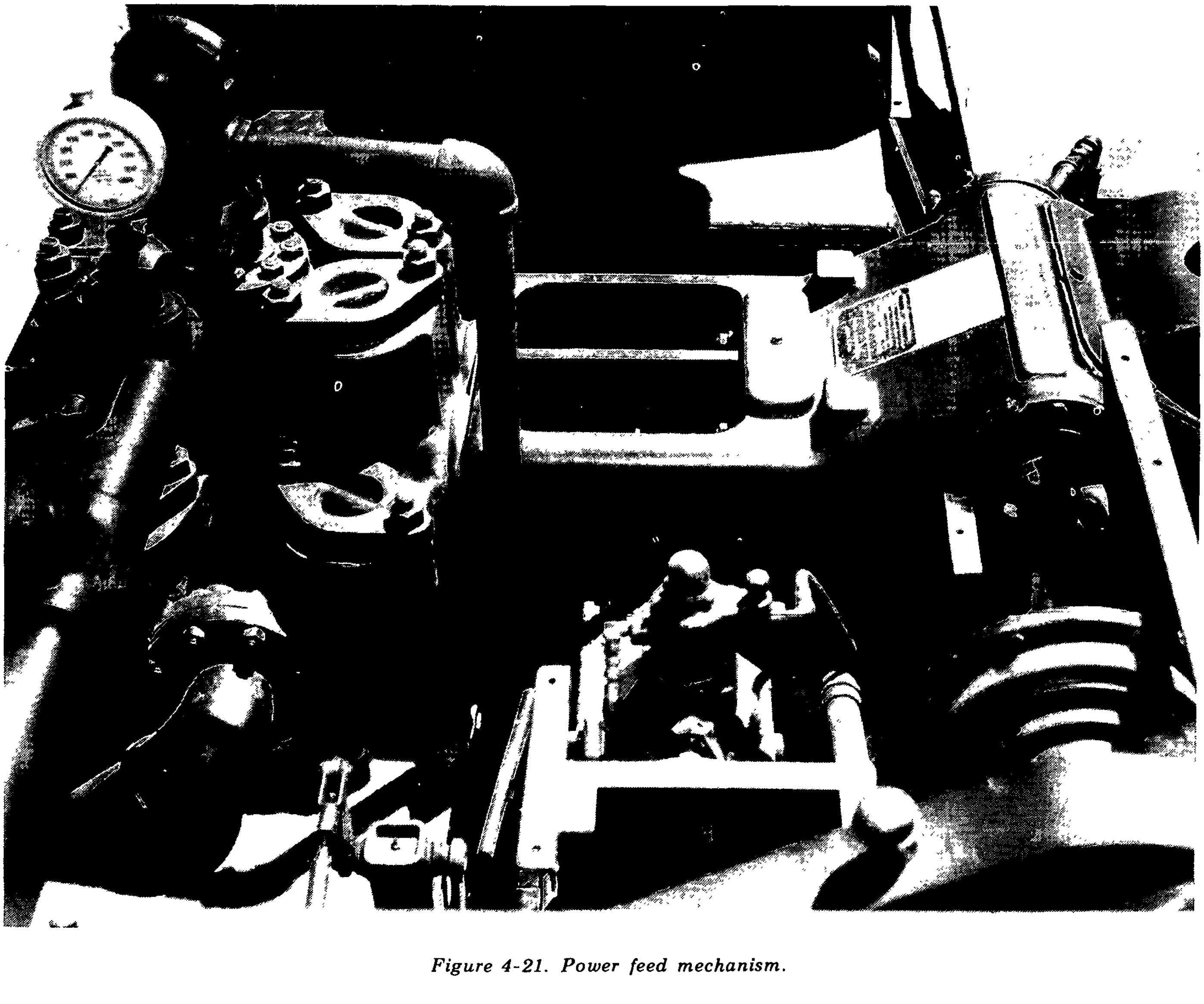


Figure 4-21. Power feed mechanism.

cuttings removal. Higher air pressure (125 to 250 psi) is required to operate the down-hole hammer than for standard air rotary drilling (30 to 50 psi). Water should always be injected at a rate of about 3 gpm when the hammer is operating. Also, rock drill oil must be injected at a rate of 1 pint per hour or more to provide lubrication for the tool.

c. The down-hole hammer is constructed in a number of different sizes, from 4 inches to as much as 9 inches for special applications. The bits for the hammer are of two basically different designs (fig 4–25). The "X-bit" (①and②fig 4–25), which is an earlier design, requires periodic sharpening, a process necessitating considerable skill and equipment, whereas the "button bit" (③ fig 4–25) does not require sharpening but does not work as well in some drilling conditions as the X-bit.

d. As in standard air rotary drilling, the air compressor, hole size, and drill pipe size must be sized in relation to each other according to the graph in figure 4–23. In most cases, the air volume requirements to maintain proper annular velocity in the hole considerably exceed the air volume required to operate the tool.

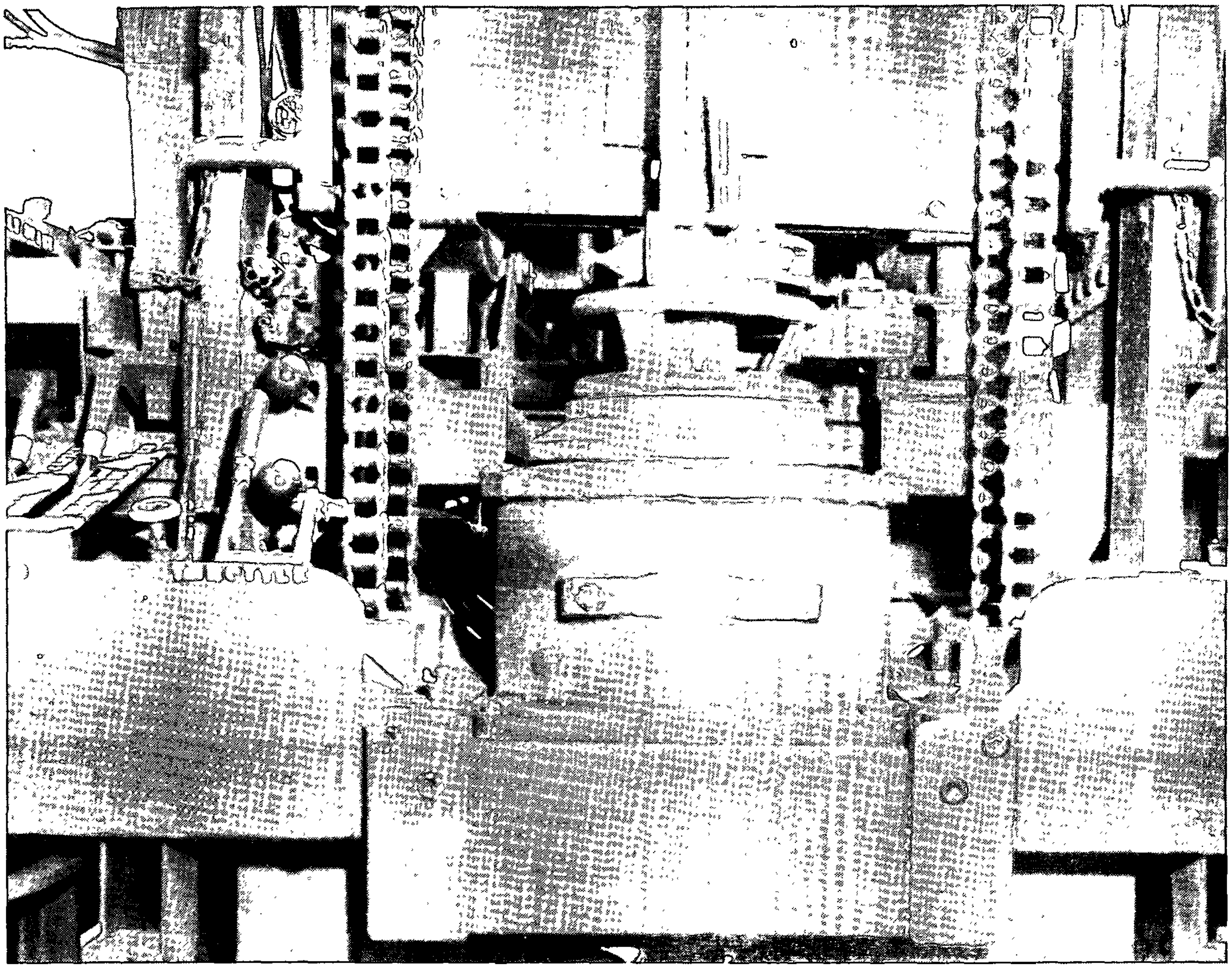
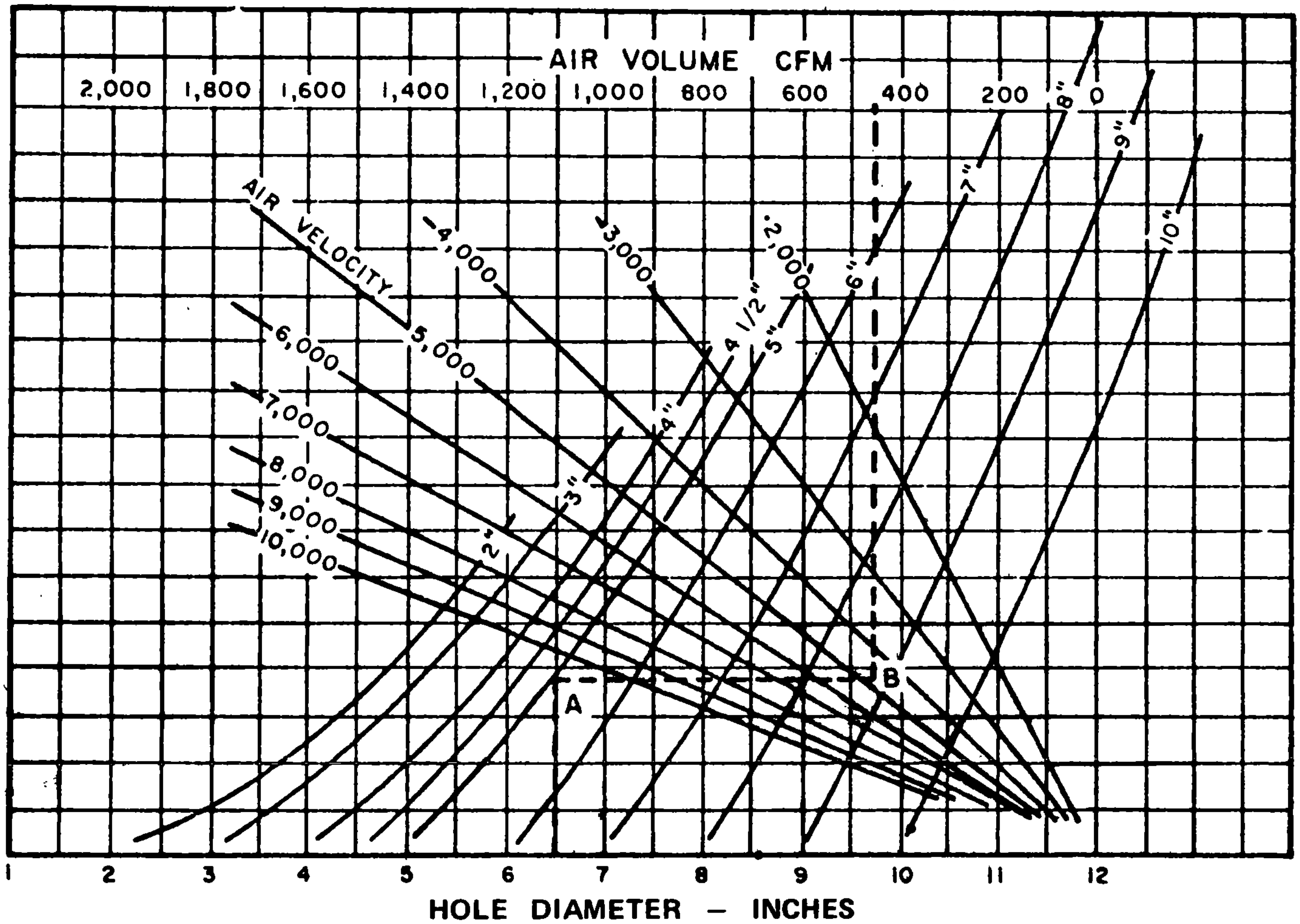


Figure 4-22. Power breakout.



To determine air velocity in annulus when pipe size, hole diameter and air volume are known, follow vertical Hole Diameter line upward to its intersection with Pipe Size line. Move horizontally to intersect Air Volume line. Read Air Velocity on diagonal Air Velocity line.

EXAMPLE: Drilling a 6-1/2 inch hole using 5 inch drill pipe and with 450 cfm air volume passing through the annulus, follow the Hole Diameter line to Point A, its intersection with Pipe Size line. Move horizontally to Point B, to intersect Air Volume line. Read annulus Air Velocity at Point B (interpolating between 4,000 and 5,000 FPM.) or 4,700 FPM.

Figure 4-23. Air velocity determination chart.

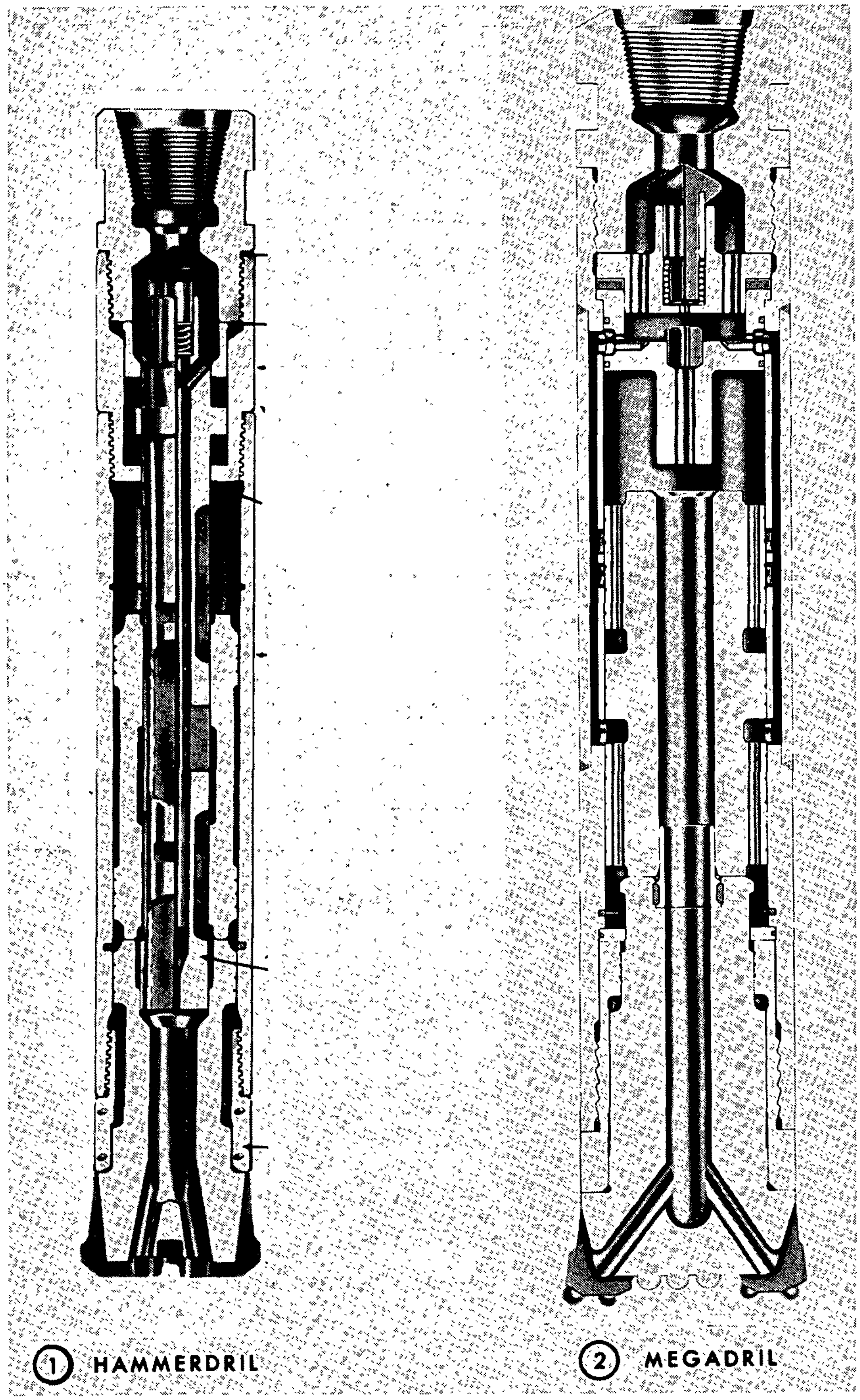
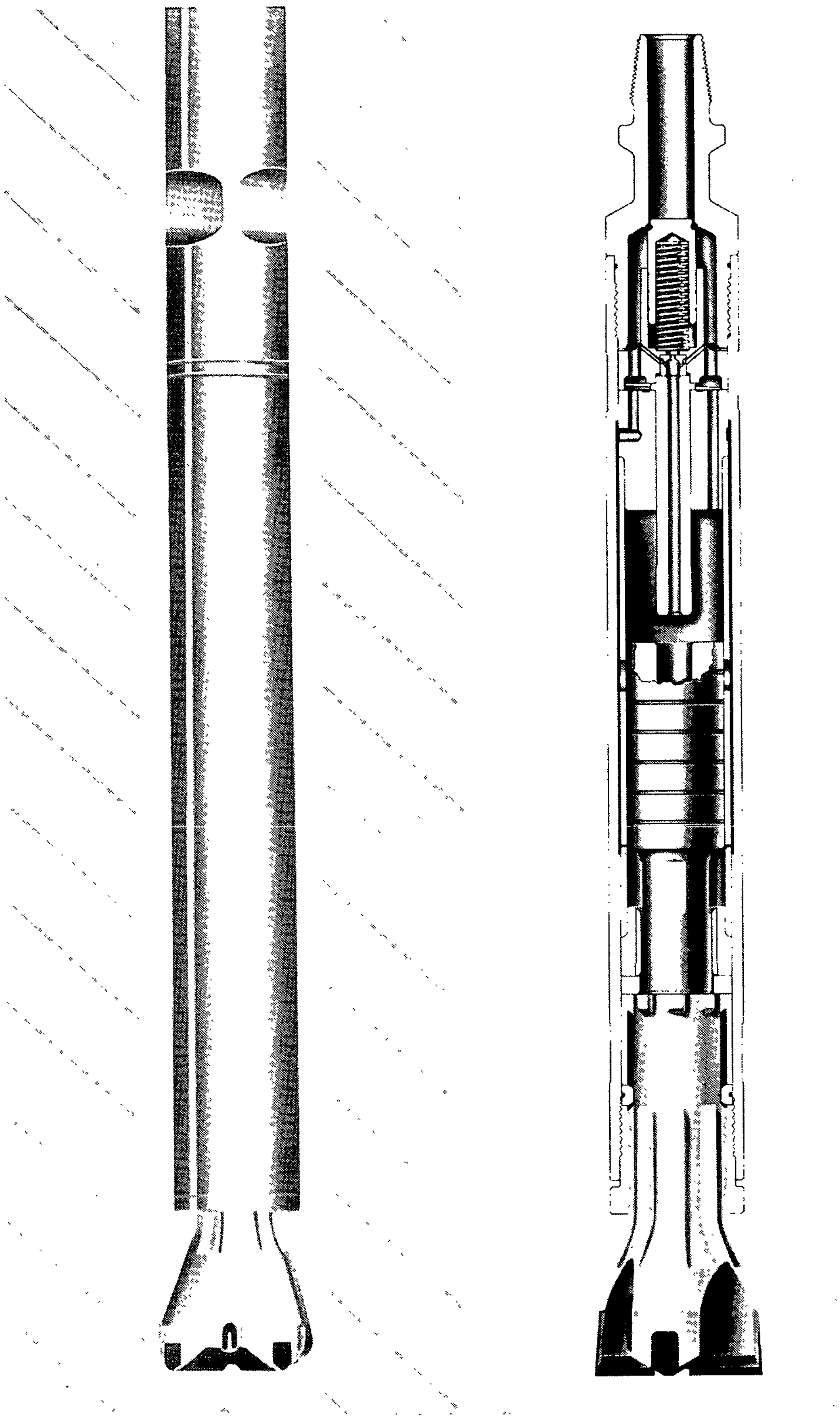


Figure 4-24. ① *Types of down-hole hammers.*



③ DHD 16

Figure 4-24 ②—Continued.

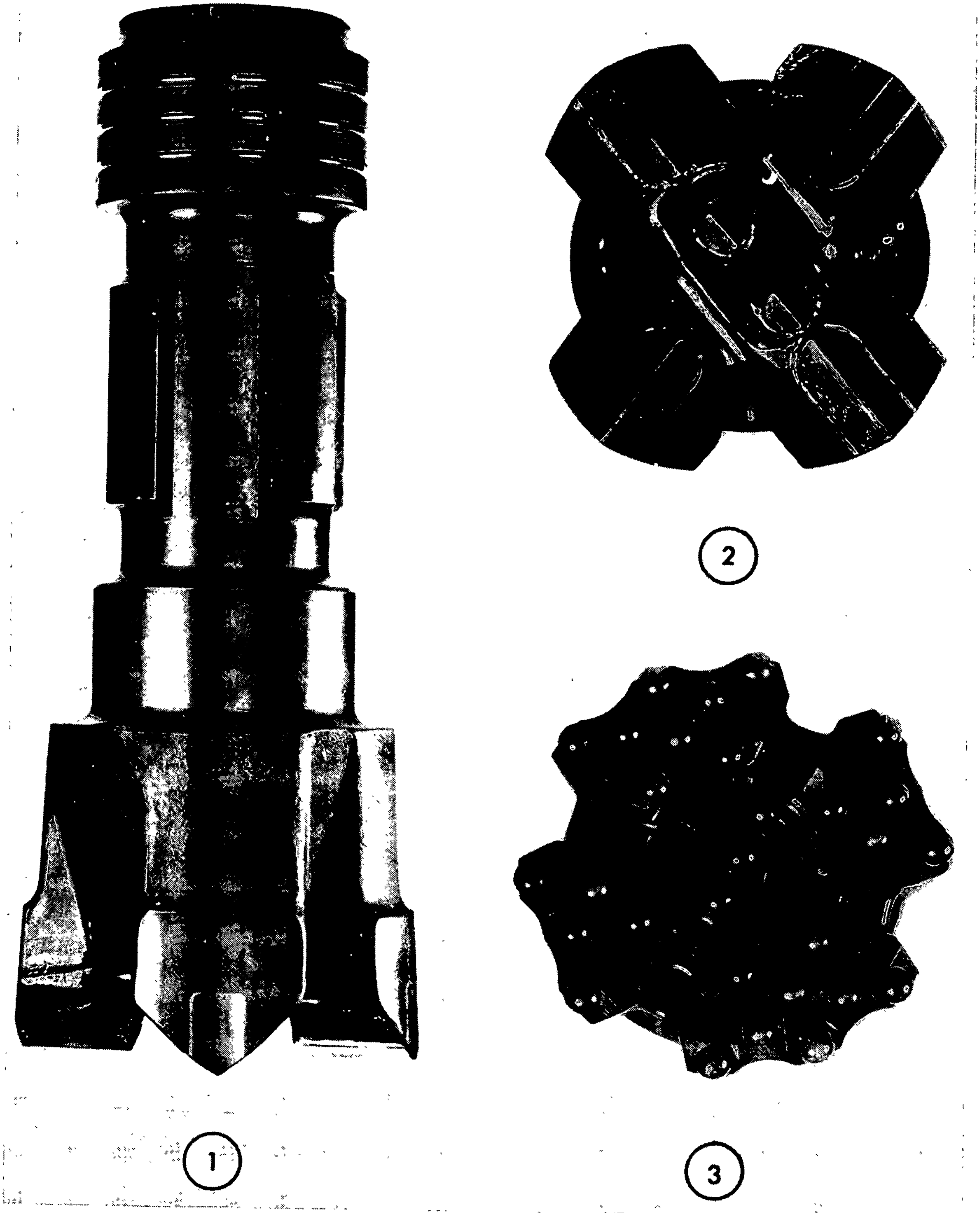


Figure 4-25. Down-hole hammer bits.

Section VI. TRANSPORTING ROTARY DRILLING EQUIPMENT

4–45. Basic Considerations

Rotary well drilling machines used by the Army are heavy, but completely portable. Their method of transportation varies with their mounting. The truck mounted machines are self-propelled; the trailer mounted machines are self-contained rigs that require only a prime mover. The skid mounted machines need special handling for transportation; the methods are described in the following paragraph. Airborne rigs, which can be mounted on skids or wheels, can be transported by most heavy cargo aircraft.

4–46. Movement to New Location

If the skid mounted airborne well drilling machine is to be moved only a short distance (several hundred yards), it can be towed or skidded. If the new location is at a considerable distance, the machine must be moved by truck or trailer, or even by rail.

a. Towing or Skidding. If the terrain around the drill unit is fairly level, the drill and mud pump units can be towed by a tractor or heavy truck. First, disconnect and remove the mud hoses. Then connect a cable from the towing vehicle to the lifting rings on the skid frames and tow the machine to the desired location. Skidding may be done in essentially the same way except that the sandline is reaved through the traveling block, which is fastened to a convenient anchor. The machine is then moved by reeling in the sandline. If the terrain around the drill unit is not reasonably level, the mast must be lowered and removed.

b. Moving by Truck or Trailer. For moving the skid mounted well drilling machine a long distance, truck or trailer transport is preferred over rail transportation, because the machine can be moved directly to the drill site without reloading. In addition, it will not be necessary to package all of the on-equipment tools and supplies. Listed below are, operations performed before and during loading of the drilling machine.

(1) *Disconnection of hoses.* Disconnect the standard pipe hose, pump discharge hose, and discharge head of the mud pump. Uncouple the mixing hose and suction hose from the mud pump. Be sure that all the hoses and hose connections are clean and free of mud that could cause loose connections when hoses are recoupled.

(2) *Kelly removal.* To facilitate removal of the mast, which is often required when moving the rig a long distance, the kelly must be removed. First the drill bit and sub are removed from the kelly drive rod, followed by removal of the kelly drive rod up and out of the drive head yoke. The mast is then ready for removal.

(3) *Mast removal.* To remove the mast, the mast raiser is installed on the drill unit. Using the sandline on the mast raiser, the mast is lowered and disconnected from the rig. For ease in handling, the mast is disassembled into three sections.

(4) *Loading on truck or trailer.* The machine is lifted and loaded on the truck or trailer by a hoist or crane. A plate bearing a diagram for lifting the machine is fixed to the drill unit; it illustrates the configuration of slings and sling attachments for use in loading. All tools and accessories are loaded on the truck or trailer and secured in place. Loading ramps may be available.

CHAPTER 5

FISHING TOOLS AND TECHNIQUES

5–1. Drilling Difficulties Requiring Fishing

a. Quicksand.

(1) *Character of material.* In some areas the most serious difficulty is caused by beds of quicksand which, as a rule, are interlaid with beds of coarser sand and clay. The quicksand comes into the drill hole and must be bailed out in large quantities before the casing can be driven farther down and drilling continued. A driller may find pockets or lenses of clay or coarse sand in the quicksand layer, and these cause him to think he has passed through the quicksand. Coarse sand will not rise if the velocity of the water through it is less than 2 1/2 feet per minute. The drive pipe shuts off the water and quicksand above such a pocket of coarse sand or clay, but as soon as the drill penetrates the pocket, the quicksand flows in and may rise to the height of the deposit. If the bed is 20 feet or more thick, the pipe cannot be driven through it because of the resistance of the compact sand. If the water in it is under great head, enough to force the sand up to or above the point at which the bed was struck, further progress may be almost impossible. In some wells, quicksand has risen in the pipe 100 feet above the depth at which it was struck.

(2) *Pressure of material.* If the drill hole is not kept full of water, the pressure put on the casing wall by quicksand may be great. Quicksand saturated with water puts a lateral pressure equal to about one-half its vertical pressure. Beyond the point of saturation the pressure is hydrostatic, the vertical and horizontal pressures being equal. Saturated material this fine flows like water.

(3) *Withdrawing tools.* When quicksand is reached, not only does the material require considerable labor to excavate but, unless the drill is withdrawn rapidly, it becomes jammed in the hole and is buried by the sand. The driller then not only must clean out the hole but also recover the drill before he can resume drilling. In this situation it is usual to bail out the quicksand to the point at which the drill is stuck and then bring into the well a wash pipe 1 or 2 inches in diameter. With this the quicksand is agitated or jetted. This operation continues until the drill is partly free, then a slip socket is put over its upper end and, with the aid of fishing tools, it is jerked free from the quicksand. During the up-and-down motions of the drill, while it is being removed from the quicksand, a little more of it should be raised with each stroke until it is freed. The same procedure is needed where quicksand comes into a well suddenly. The drill is moved up and down as if it were cutting into rock, while at the same time it is slightly raised at each upstroke. This operation must be carried on so rapidly that the sand cannot pack about the drill and prevent its removal. Quicksand may be partly overcome by filling the bottom of the well with mortar or portland cement. The hole then may be drilled through the cement, which forms a wall that prevents the further flow of quicksand.

(4) *Water pressure.* Some drillers maintain that quicksand can always be penetrated by keeping the drill full of water. If the quicksand lies at a depth of several hundred feet and its head is 100 to 150 feet below the surface, a column of water in the well will exert a back pressure on the quicksand of 43.4 pounds per square inch for every 100 feet of drill hole. This will prevent it from rising in the pipe. The sand bailer than may be inserted and the well can be bailed of quicksand through the column of water. Sometimes after bailing out large quantities of quicksand, the pipe becomes bent. This is explained by assuming that the quicksand bailed out is removed from beneath a higher layer of firmer material, such as till or clay, on only one side of the pipe, and that the pressure of this material against one side of the lower end of the pipe causes it to be thrown out of alinement. The remedy is to keep the hole full of water. This prevents the formation of such an artificial cave; or, if the pipe already has become crooked, it corrects the trouble by causing the pressure to be equal on all sides of the pipe.

b. Lost Tools. Drilling tools in the hole usually are lost because of one of the following reasons:

(1) *Broken pins.* Broken pins are a common cause of trouble in down-hole hammer drilling, due mainly to excessive tightening of the joints when they are made up. Crystallization as a result of drilling rock causes slight additional pin breakage, but this is small. The 2 1/4- by 3 1/4-inch by 7 threads per inch API pins, which are standard issue equipment, are especially likely to be damaged by excessive tightening of the joints.

(2) *Loose or unscrewed tool joints.* These occur in the hole for one reason only, imperfect

seating of the pin shoulder against the box face. The efficiency of the joints depends altogether on the mating of these two points. Both the pin shoulder and the box face should be thoroughly cleaned and free of imperfections that prevent a full, even contact. Modern drilling practice is to use a small quantity of light machine oil on the threads and the shoulders when they are made up. This prevents rolling and scoring when the joints are unscrewed.

(3) *Boulders falling into the hole.* Boulders occasionally fall into the hole and wedge the drilling tools so tightly they cannot be loosened. The tendency of shattered rock formations to cave or fall into the hole is greatly aggravated by the motion of the drilling tools in the water surrounding them. Usually this trouble stops after the hole has reached a depth that places the tools below the caving formation. Fishing techniques and tools and equipment used to recover lost tools are discussed in paragraphs 5-2 and 5-3.

5–2. Fishing Techniques

Fishing to recover pipe or tools lost in the hole requires a great deal of skill. The most frequent fishing job in a rotary drilling is the recovery drill pipe twisted off in the hole. The break may be due to shearing of the pipe or to failure of a threaded joint. Sometimes the drill pipe is dropped in the hole accidentally. When a break occurs, the first thing to check is the exact depth where it occurred so the fishing tool can be accurately placed.

a. The fishing job must be performed with care. A mistake can complicate a fishing job to the degree that recovery of the lost tools or pipe is difficult. Doing nothing at all is better than running a weak or unsuitable fishing tool into the hole.

b. Present issue fishing tool equipment consists of the primary tools required; however, often tools may have to be fabricated or existing tools altered to fit special conditions.

c. Lines should be examined for broken and worn places.

d. A careful record must be kept of the depth of the hole and of the overall length of the drilling tools, since this information is essential in calculating the position of the tool.

e. The fishing tool may let go of the lost tools while they are being pulled from a deep, dry hole. Filling the hole with water to a depth of 175 to 200 feet before pulling the tools will cushion their fall and minimize damage if they are dropped.

f. Sockets having slips may be run the first time without the slips, to see if the hole will let them pass through, whether the socket will go over the lost tool, and what hitch is required.

5–3. Fishing Tools and Equipment

Many special fishing tools have been devised, but only those furnished with Army rigs are described here. The tapered tap and die overshot are simple tools that are usually effective if they are used immediately after the failure occurs, before the cuttings in the hole settle and freeze the drill pipe. Fishing out lost drill pipe involves setting the fishing tool on top of the pipe and achieving a hold strong enough to lift the pipe. When the pipe is frozen by cuttings settling around it, it is usually necessary to circulate drilling fluid in the hole to loosen the pipe so it can be lifted. The circulating-slip overshot is the best tool to use in this case. Other fishing tools are listed also.

a. Tapered Tap. The tapered fishing tap (fig 5-1) tapers about 1 inch per foot from a diameter somewhat smaller than the inside diameter of the coupling to a diameter equal to the outside diameter of the drill rods. This tapered portion is threaded and is fluted the full length of the taper. The tool is made of heat-treated steel. It operates like a machine tap, cutting its own threads when rotated and making a connection with the drill pipe. The flutes permit the escape of chips cut by the tap. The upper end of the tap has a box thread to fit the drill rods. There is a hole through the center of the tap. Care should be exercised in using the tapered tap so it does not twist off in the fishing operation. Once the tap has engaged the

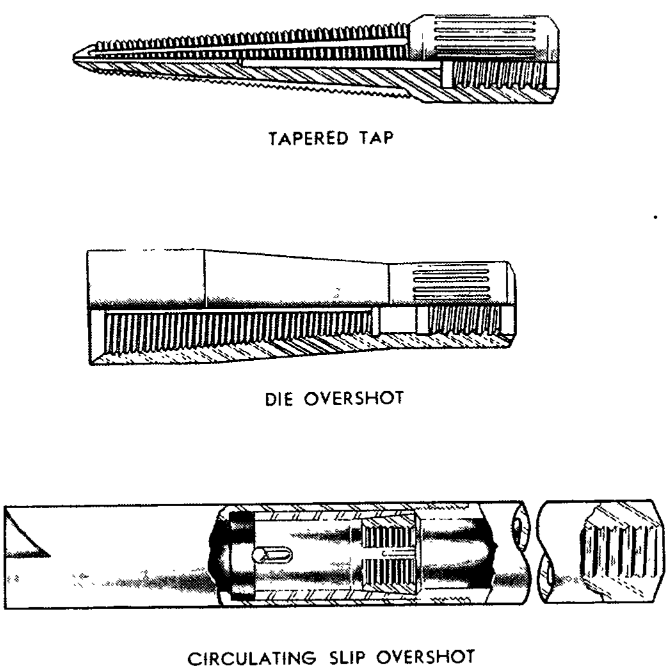


Figure 5-1. Tapered tap and overshots.

lost pipe, the rotary speed should be very slow or the pipe should be turned by hand. Circulation at low rates should be maintained until the tap is in the lost pipe, then stopped until the tap is threaded into the pipe. An attempt should be made to reestablish circulation through the drill string before the lost pipe is pulled.

b. Die Overshot. The die overshot or die coupling (fig 5–1) is a long tapered die of heat-treated steel. It tapers 1 inch per foot from a diameter somewhat smaller than the outside diameter of the small end of the drill rod coupling to a diameter somewhat larger than the outside diameter of the drill rods. Like a machine die, it cuts its own thread as it is rotated on the top of the lost pipe. The tapered die is fluted to permit the escape of metal cut by the die. The upper end of the tool has a box thread to fit the drill rods. The tool is hollow, but circulation can be completed to the bottom of the hole through the lost pipe because the flutes allow the fluid to escape.

c. Circulating-Slip Overshot. The circulating-slip overshot (fig 5–1) is a tubular tool about 3 feet long, with inside diameter slightly larger than the outside diameter of the drill rods. The bottom is belled out and has a notch to aid the tool to center and slip over the lost drill rods. The outside tube or body is made of two pieces screwed together. The top of the lower section of the body is recessed to receive a rubber packer ring and a sleeve. The bore of the sleeve is tapered. Inside the sleeve is a ring type slip with a bore which is threaded with left-hand threads. This slip has a slot cut through one side so it can expand as the tool is lowered over the broken drill pipe. It tightens against the pipe when the slip is pulled down into the tapered sleeve as the tool is raised. The body, sleeve, and slips are fastened together with lugs so they rotate as a unit, yet they may move vertically a little, independently of each other. The upper end of the tool has a box thread to fit the drill pipe. When the circulating-slip overshot has been placed over the stuck drill rods and pulled upward, the slips grip the pipe and the sleeve is pulled down against the rubber ring, which expands and makes a seal between the fishing tool and the drill rods. This assures that drilling fluid can be pumped through the lost drill rods to reestablish circulation. In operating the issue rigs, a releasing type overshot should be used so the fishing tools may be withdrawn if it is impossible to pull the lost pipe.

d. Impression Block.

(1) Fishing for lost tools is more successful when their position in the hole is definitely known. A tool may lean to the side of the hole, or into a caved area in such a way that a fishing socket will not take hold. The top of the tools may be covered with caved material. A pin or rope socket neck may have become changed in shape and size during fishing operations. An impression block can determine these conditions.

(2) The materials required for an impression block (fig 5–2) are a rounded piece of wood, 3 feet long, 7 3/4 inches in diameter for an 8-inch hole, or 5 3/4 inches in diameter for a 6-inch hole; one piece of sheet metal 7 by 24 inches; one bolt, 5/8 inch by 4 1/2 inches; 2 pounds of tenpenny nails; and 10 bars of yellow soap or 5 pounds of parawax.

(3) One end of the woodblock is reduced in size to that of the outside diameter of the bailer used in the hole. This end is slotted for attachment to the dart of the bailer by a bolt extending through the slotted portion of the woodblock and the bailer dart. Nail the sheet metal around the solid end of the woodblock so it extends about 3 inches beyond the end of the wood. Drive a number of nails part way into the end of the block surrounded by the sheet metal. Warm the soap until it becomes somewhat plastic, and fill the hollow end of the block formed by the projecting edge of sheet metal. The nail heads help to hold the soap in the block.

(4) Without the block, lower the bailer into the hole and find the depth at which the dart touches the top of the rods. Mark this point on the sandline so it can be easily recognized. This mark will be guide when setting the impression block on the lost tools. Make allowance for the length of the impression block and make a second mark on the line.

(5) Attach the block to the bailer dart and lower it into the hole. Allow the bailer to set down firmly but not too hard. Pick up the bailer gently with moderate speed, and pull it out of the hole without letting it down a second time. Carefully remove the block from the bailer and look for impressions in the soap or wax.

e. Friction Socket. When a bit is unscrewed or broken off in the hole, a friction socket (fig 5–3) is used first for the attempted recovery. Do not try to recover the lost tool while running this socket for the first time. Set the fishing tool down on top of the lost tool and drive down lightly with hydraulic pulldown. Then, pull the fishing tool to the surface and examine the marks and abrasions on the socket. If they show the socket went over the end of the tool, run the fishing tool back in the hole and drive the socket far enough over the lost tool so that it takes a friction hold sufficient for

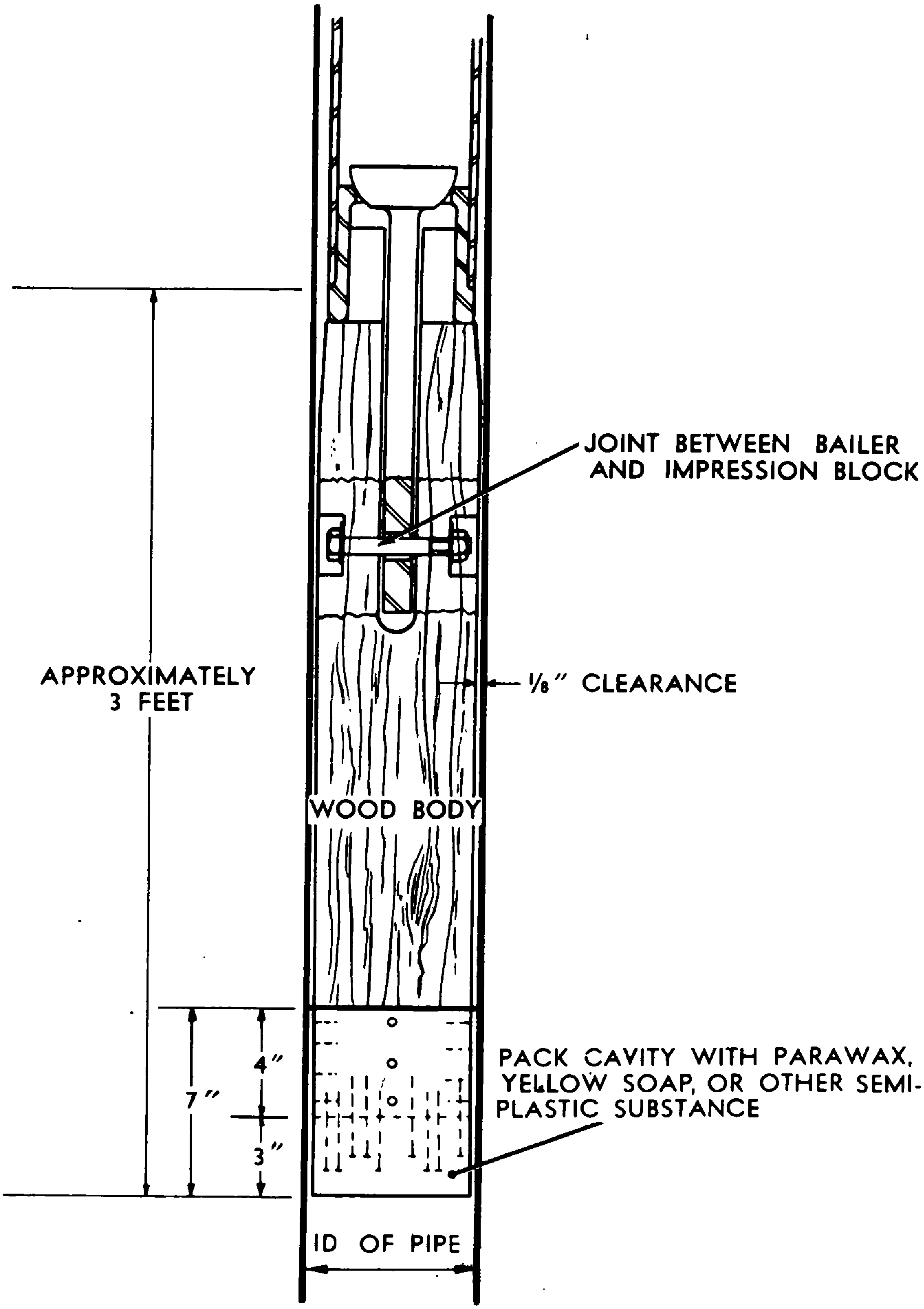


Figure 5-2. Impression block.

recovery. When the marks on the friction socket show it went down beside the lost tool, no further effort should be made with this tool, since its use will only drive the tool deeper into the well.

f. Full-Circle Slip Socket.

(1) The full-circle slip socket (fig 5-3) has hardened steel slips, so it will take a firmer hold on the lost tool than the ordinary friction socket. The slips are in two sizes, 4 3/8 inches for catching a broken drill stem box and 4 1/4 inches for catching the pin collar of a bit or drill stem. Use of the socket is desirable when the tools to be recovered are "frozen" in the hole by cavings or drill cuttings. The slips are not used with the socket until after it has been run to determine whether or not the socket goes over the lost tool; otherwise, the slips are likely to be lost or badly damaged. After catching hold of the lost tool with this socket, avoid pulling down on it hard with hydraulic pulldown. This will break or damage the slips so that their hold on the tool is broken.

(2) The split design of the slips permits four slips to be held in their proper position in the socket by two reins. The reins are fastened

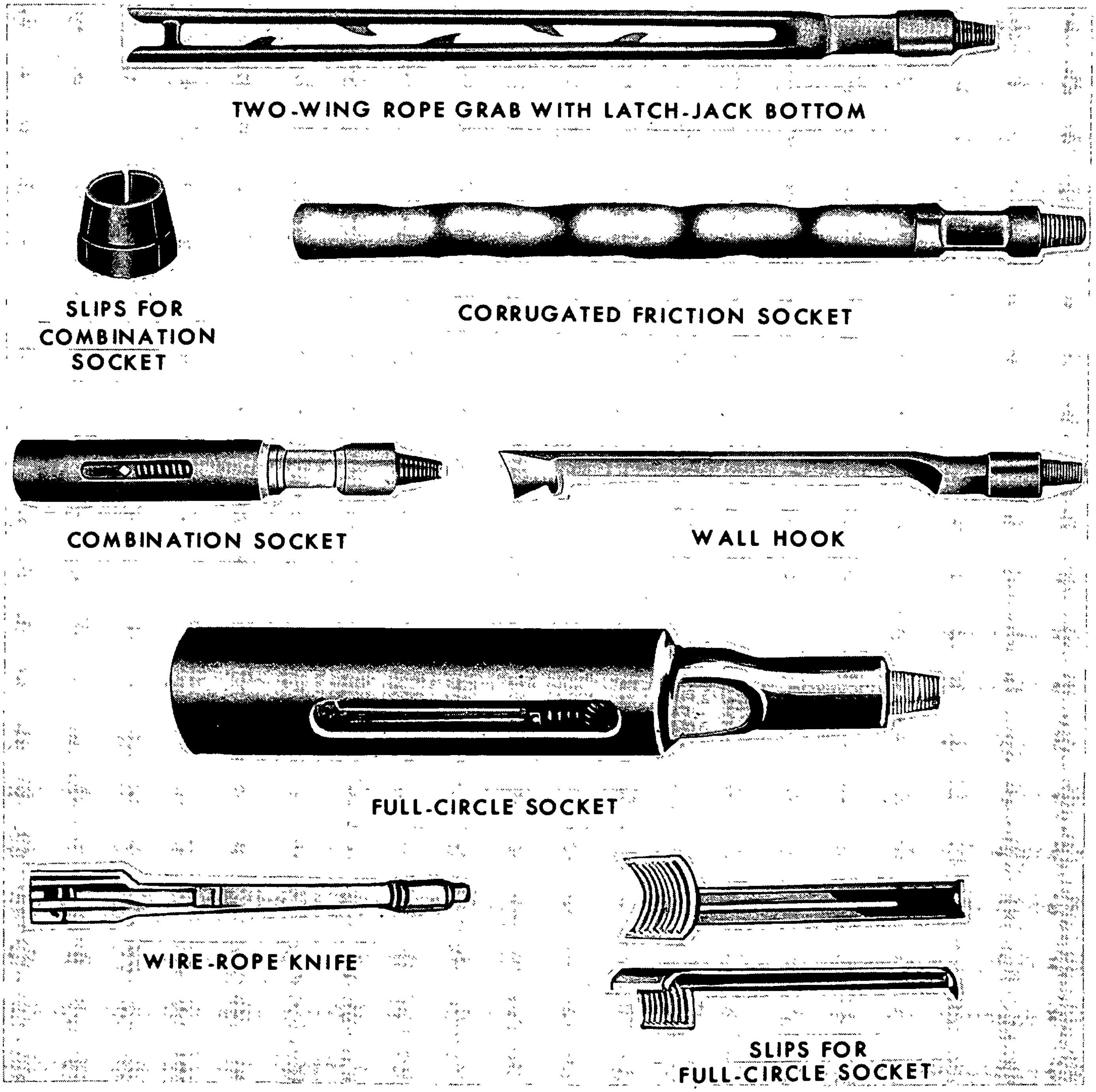


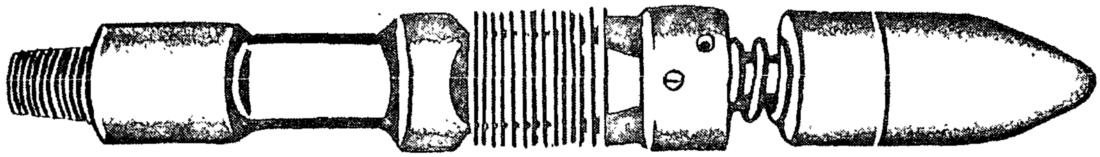
Figure 5-3. Fishing tools.

together at the top end by a bolt. A short distance below this bolt a pin passes across the body of the socket. The purpose of the pin is twofold; it prevents the socket from going over the lost tool too deeply, and prevents damage to the slip assembly and tension spring. The pin will not stand much pulldown; it is important, therefore, to flag the line or drill stem to indicate the top of the lost tools and keep careful check of measurements when taking hold. It may or may not be necessary to pull down to set the slips. When pulling up the drill pipe, hold with one hand to determine if the hold has been secured. Do not pull both ways unless the lost tool cannot be loosened otherwise and it is desired to break the hold, since considerable damage may result to both slips and socket.

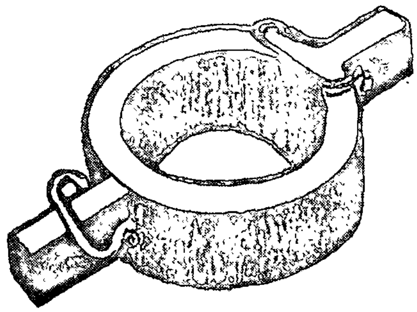
g. Combination Socket.

(1) The combination socket (fig 5-3) is made to catch the neck of the rope socket or pin of any bit or tool which becomes unscrewed in the hole. This is probably the most reliable of all fishing tool equipment. Once a firm grip is established on the lost tool, nothing can shake it loose. For this reason, use the combination socket only when there is no doubt that the lost tool can be jarred loose by the weight of the fishing tools used.

(2) To use the socket, clean and lubricate it inside, then set the joint into the box of the drill stem. Dismantle the socket and make a trial run into the hole without slips. This will determine whether the hole is full size down to the lost tools, whether the socket will go over the lost tools, and the proper hitch. When these facts are known, assemble the socket by inserting each half of the split sleeve into the socket through the slots inside the socket, placing the sleeve so the end with the hole is at the pin end of the socket. Pass the coil through the bottom of the socket, and telescope the spring and split sleeve into the upper part of the socket body. Clean, polish, and lubricate the rear side of the three slips and place them, tapered end down, in proper position in the bottom of the socket. Hold the spring in the top of the socket and drop the split sleeve down on the slips. Insert the ring through the side slot into the side of the socket, and fasten both parts of the split sleeve and ring together tightly with the bolt. Drop the spring on top of the sleeve ring, and insert a wooden block in the space between the body of the socket and the spring. The wooden block should be of a size that will compress the



TRIP-CASING SPEAR



CASING RING

Figure 5-3.—Continued

spring enough to exert firm pressure against the slips.

(3) Run the socket into the hole and set it down on top of the lost tools. Without picking up the socket, jar down with hydraulic pulldown. Stop and pull up the drill stem to determine whether a hold has been made on the lost tools. If the tools cannot be pulled, work the drill stem up and down. If the lost tools do not come free and it is desired to pull out the fishing tools, break the hold of the combination socket by jarring both ways, or in other words, by allowing the drill stem to hit the tools on the bottom of each stroke. The operation is rather uncertain. It may be done in a few minutes with no damage to tools; or it may take hours, and result in broken or lost slips as well as damage to the body of the socket and to the neck of the pin for which the fishing is being done.

h. Babcock Socket. For fishing work the babcock socket is used instead of the regular drilling or swivel socket. For a particular fishing job the babcock may be desirable, but for most fishing jobs it is not suitable because it allows the drilling line to change in overall length. Changing the length of the drill line even 1 inch may prevent a fishing tool from taking hold of a lost tool, or may result in breaking the hold at the wrong time.

i. Wall Hook. When the top of the lost tool has fallen into a cave in the side of the hole, the wall hook (fig 5–3) is the most efficient fishing tool for realining so the socket can be used. This can be done by running the tools at moderate speed, allowing the down motion, and gradually working down to the top of the tools. The operation requires considerable patience and is not always successful. Make several trials before abandoning the attempt.

j. Two-Wing Rope Grab with Latch-Jack Bottom (Fig 5–3).

(1) This tool is used when the sandline breaks and leaves the bailer in the hole, with the line on top of the lost tools.

(2) In the case of a bailer with a relatively small amount of lost line, the rope grab may reach down through several coils of wire so the latch-jack bottom can catch on the bail of the bailer.

(3) If a hold is secured on the wire and the lost tools are lifted off the bottom of the hole, stop when 15 or 20 feet up and allow the brake to give a short, quick slip to test the hold. If the hold is insecure, it will be broken; but no damage will result to the tools by the short fall back to the bottom, whereas a longer fall might damage them. As the fishing tools are pulled up, the driller will know by the load whether the lost tools are attached. In either case, pull out. If the hold has broken, there may be some strands of broken wire on the grab, which should be removed from the hole rather than left on top of the lost tools.

(4) As the grab comes out of the hole, be careful that the broken ends of the line do not slip off its prongs. Do not pull the grab completely out of the hole; stop as soon as the broken wires appear. Tie the strands to each other and to the prongs of the grab to prevent the line from unraveling and releasing the hold. Make the tie carefully, as severe injury to the hands can result from a slip while tying. The tie itself does not carry the load but binds and holds the broken wires in position as the grab is pulled out.

k. Wire Rope Knife. The wire rope knife (fig 5–3) is used for cutting the wire line if the tools become stuck in the hole. The knife is lowered onto the drilling line with the sandline and, when the knife strikes the rope socket, it is jerked upward. If the bailer becomes stuck, the wire rope knife is run in with the drilling line.

l. Trip-Casing Spear. The trip-casing spear (fig 5–3) is an effective tool for pulling pipe, especially when used with jacks and a casing ring (fig 5–3). The chief precaution in using the spear is to unseat it after 2 hours of operation and to reset it in a slightly higher position. Continued jarring with the spear seated in one place distorts the pipe to such an extent that it is impossible to unseat the spear.

CHAPTER 6

MISCELLANEOUS WELL CONSTRUCTION TECHNIQUES

Section I. INTRODUCTION

6–1. General

In addition to the rotary down-hole hammer techniques described in earlier chapters, there exist a number of other methods of gaining access to ground water. These techniques require varying amounts of specialized equipment which may or may not be readily available. The bored, driven, and jetted wells generally require less equipment than dug wells; expedient wells, of course, are constructed with little or no equipment at all. The time required for construction of wells by the different methods varies and, along with equipment availability, will normally be the determining factor in deciding which of the methods is used. Generally, the mechanized rotary methods described in chapter 4 are superior to the methods described in this chapter and therefore should be used when the option to use them exists. The chief limiting factor of the miscellaneous methods is the relatively shallow depth capacity of each of them.

Section II. BORED WELLS

6–2. Description

Bored wells, like dug wells, can be constructed by hand labor. Boring is commonly done by using an earth auger turned by hand, but power-driven earth augers are also used when available. Boring is practical where ground water can be obtained at shallow depths and when only small quantities are needed. Hand augers can be used to penetrate clay, silt, and those sands in which an open hole in the material will not cave at depths of 25 to 50 feet. The hole may vary from 2 to 32 inches in diameter. Small diameter bored wells can be made by general engineer troops using organizational equipment.

6–3. Augers

a. Earth augers are of two general types, the hand auger and the power-driven auger. Common types of hand augers are shown in figure 6-1. They consist of a shaft or pipe with a wooden handle at the top and a bit with curved blades at the bottom. The standard engineer auger has fixed blades but there are bits with blades adaptable to different diameters. Hand augers are usually furnished with several shaft extensions and couplings. Extensions are added by removing the handle, coupling a section to the pipe, and then replacing the handle.

b. Power augers (fig 6–2) are rotated, raised, and lowered by power-driven mechanisms. The turning force is transmitted to the auger through pointed square or polygonal stems. The standard power auger issued to engineer troops is limited to a depth of about 10 feet and therefore is satisfactory for well drilling only in areas where the water table is close to the surface.

6–4. Constructing Bored Wells

a. Boring with an auger is started by forcing the blades of the auger into the soil while turning the tool. The auger will cut its way into the ground at a rate determined by the hardness of the soil. When the space between the blades is full of material, the auger is removed from the hole and emptied. This operation is repeated until the desired depth of hole is reached.

b. In constructing bored wells, small rocks or boulders may be encountered that will prevent further penetration. When this occurs, lift the auger from the hole, remove the cutting bit, and replace it with a spiral or ram's horn auger (fig 6-3). This tool is lowered into the hole and turned in a clockwise direction. The spiral will usually twist around the rock so that it can be lifted to the surface. The regular bit is then replaced and boring continued. If an extremely large boulder is encountered and it cannot be removed with the spiral auger, the hole will have to be abandoned and another one started elsewhere.

c. Wells less than 15 feet deep ordinarily do not require equipment other than the auger. When greater depth is desired, it is necessary to use a light tripod with a pulley at the top, or a raised platform, so that the longer auger rod can be inserted and removed from the hole without damage and without unscrewing all sections of pipe at each withdrawal.

6–5. Casing and Completing Bored Wells

a. When loose sand and gravel are encountered, progress in boring below the water table is often difficult or impossible. However, this difficulty may be overcome by lowering a pipe or other casing to the bottom of the hole and continuing with the removal of material while adding weight at the top of the casing to force it down. If material cannot be removed from the hole in this manner, a bailer or sand pump may be used to make the hole deeper. Bailing is described in paragraph 4–26.

b. Bored wells may be completed by installing well screens in the water-bearing sand and developing the well as described in chapter 7. Drive-well points may also be used (para 6–7).

c. There are areas where ground water is found only in jointed clay. In such areas, bored wells

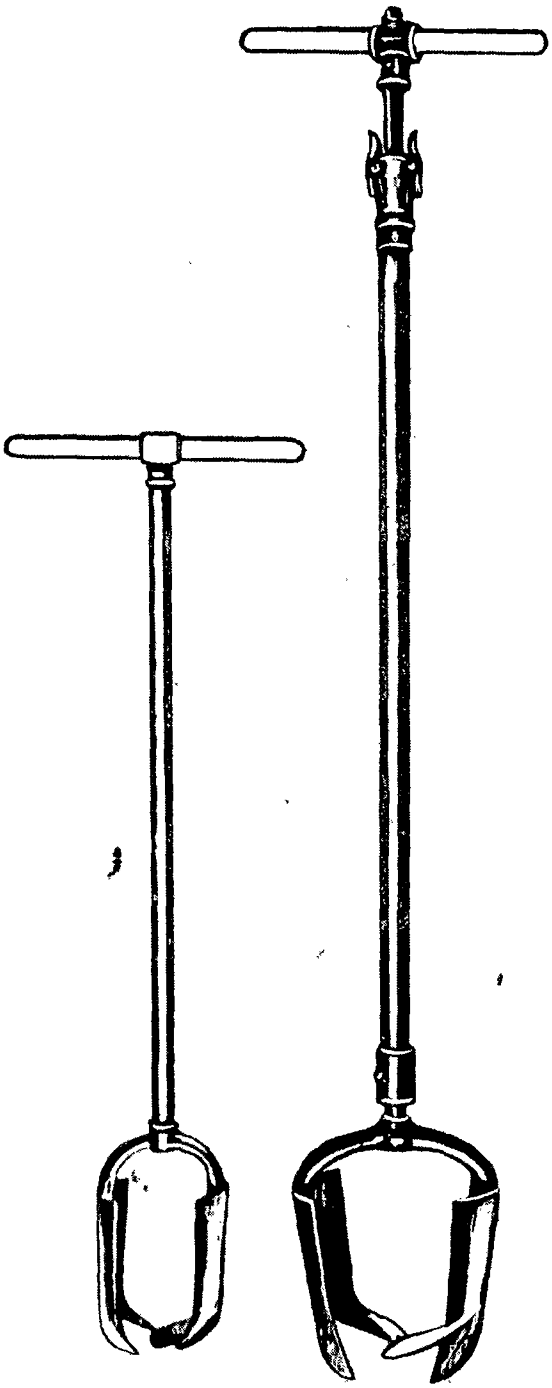


Figure 6-1. Hand augers.

may be completed by lining the hole with clay tile. Tile of the bell-and-spigot type, set in the hole with the bell ends down, should be used. Coarse sand should be poured in around the tile. Since it is impossible to insure a sanitary well by this means, this type of well completion is strictly an expedient to be used where it is the only possible solution.

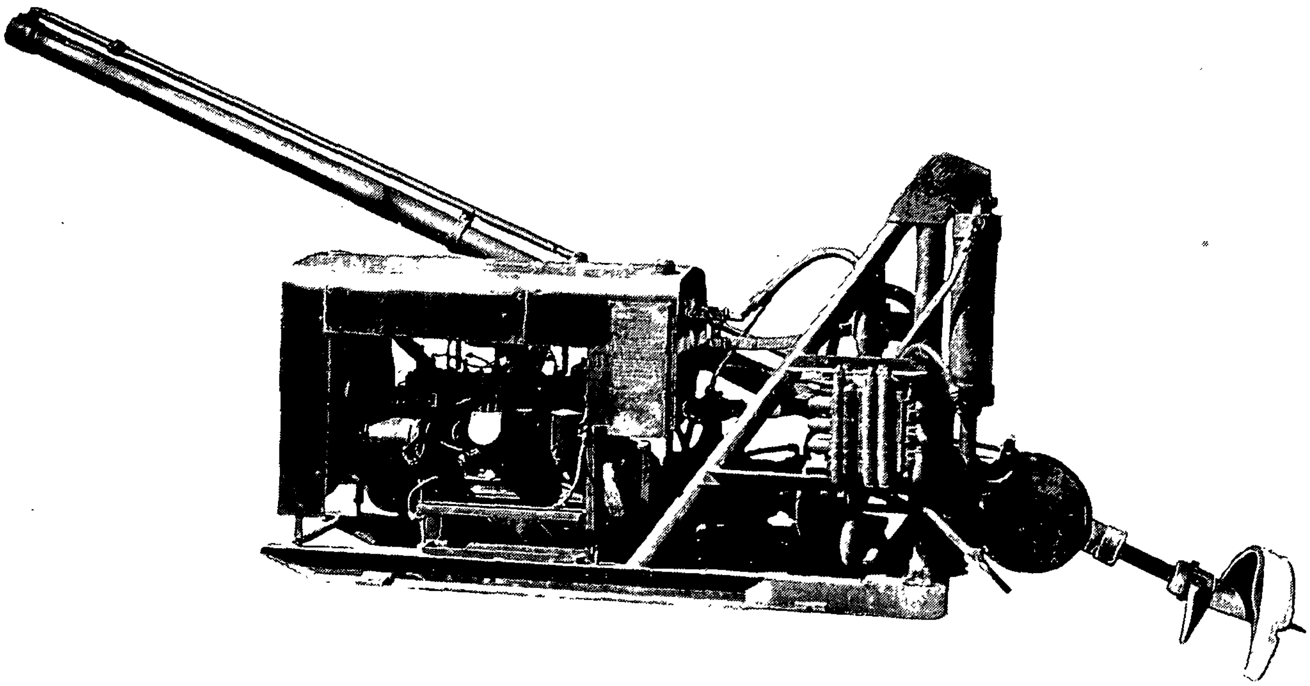


Figure 6-2. Power auger.

Section III. DRIVEN WELLS

6–6. Description

a. Small diameter driven wells are constructed by driving into the ground a drive point fitted to the lower end of tightly connected sections of pipe (fig 6–4). The drive point consists of a perforated pipe with a steel point at its lower end to break through pebbles or thin layers of hard material. The drive point must be driven deep enough to penetrate a water-bearing formation below the water table. It should not exceed 25 feet in depth for shallow wells. Sections of pipe 5 to 6 feet in length are generally used for the pipe string and serve as the casing for the completed well. Driven wells are usually 1 1/4 to 2 inches in diameter. The small diameter pipe required for these wells is light, portable, and easily installed by hand labor methods. Larger wells up to 4 inches in diameter are also constructed. The larger casing used in these wells, although heavier and more difficult to drive, has the advantage that deep well pumps can be installed in the pipe casing to a depth of 25 feet or more below ground.

b. The chief use of driven wells in military operations is for emergency well construction where the water table is near the ground surface. If the well is to be pumped with a common pitcher pump or a centrifugal pump (used with shallow wells), the pumping water level should not be deeper than 25 feet.

6–7. Drive Points

Drive points (fig 6–5) are made in various types and sizes. The most common drive points are 1 1/4 to 2 inches in diameter.

a. The continuous-slot well point has a screen with horizontal openings. It is of one-piece welded construction and does not contain an internal perforated pipe to restrict the intake area. It will withstand hard driving but should not be twisted while being driven.

b. The brass jacket type consists of a perforated pipe wrapped with wire mesh. The mesh is covered with a perforated brass sheet. Because the pipe body of the drive point must be strong, the number and size of holes in the pipe are limited. These holes, less the obstruction offered by the brass jacket, form the effective intake area in this type drive point.

c. The brass tube type consists of a brass tube slipped over perforated steel pipe. This forms a more rugged construction and has about the same intake area as the brass jacket type.

d. All well points have forged or cast steel-point bottoms and pipe-shank tops. The brass jacket types have steel points with a widened shoulder to push gravel or rocks aside and reduce the danger of ripping or puncturing the jacket.

e. For mesh covered well points, the sizes of openings are designated by the mesh size. The common sizes are 40-, 50-, 60-, 70-, and 80-mesh (number of mesh per linear inch).

f. For well points with slot type openings, the sizes of openings are designated by numbers that correspond to the actual width of opening in thousandths of an inch. No. 10 slot is 0.010 inch wide, No. 12 is 0.012 inch wide, and so on. Figure 6–6 shows the slot openings corresponding to various mesh sizes of wire gauze.

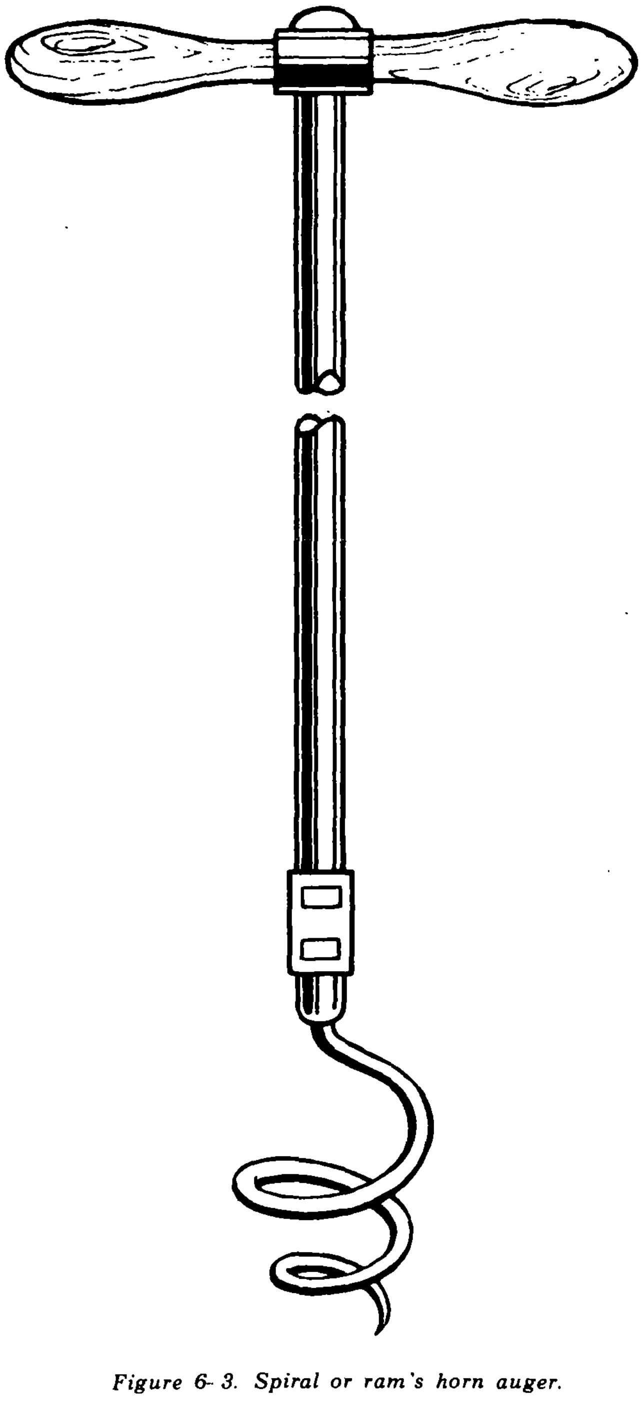


Figure 6–3. Spiral or ram's horn auger.

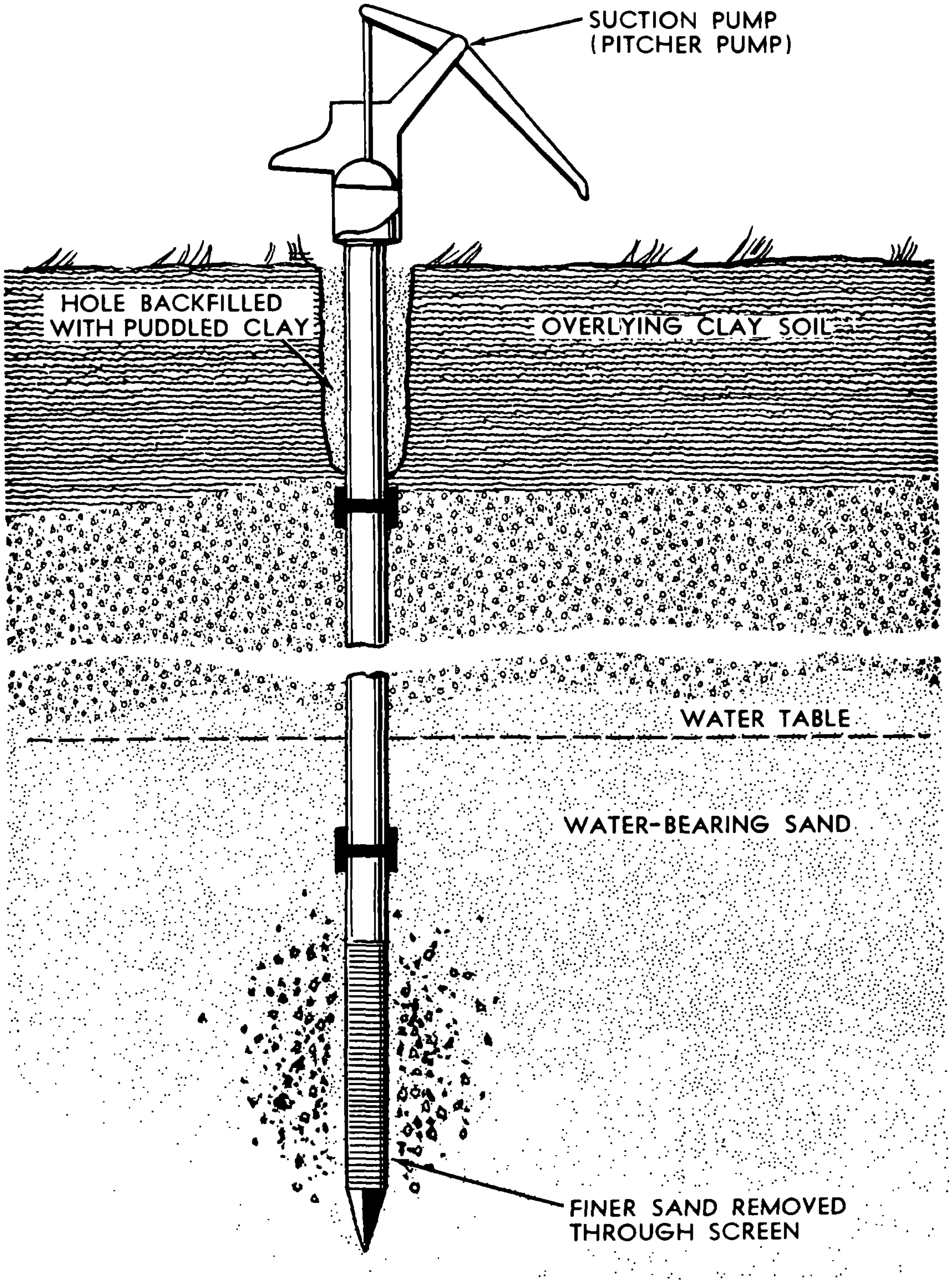


Figure 6-4. Finished drive point well.

6–8. Drive Pipe and Accessories

a. Description of Pipe. Standard drive pipe is furnished in 6- and 8-inch sizes, with the dimensions as shown in table 6–1. In making up drive pipe, the two ends of the pipe meet in the center of the coupling, making a butt joint (fig 6–7). Drive pipe threads are not interchangeable with standard pipe threads.

Table 6-1. Dimensions of Drive Pipe

Size (inches)	Weight (pounds per foot)	Diameter (inches)		Couplings (inches)		Threads per inch	Taper-inches
		O.D.	I.D.	Length	O.D.		
6	19.45	6.625	6.065	5 1/8	7.482	8	3/16
8	25.55	8.625	8.071	6 1/8	9.596	8	3/16

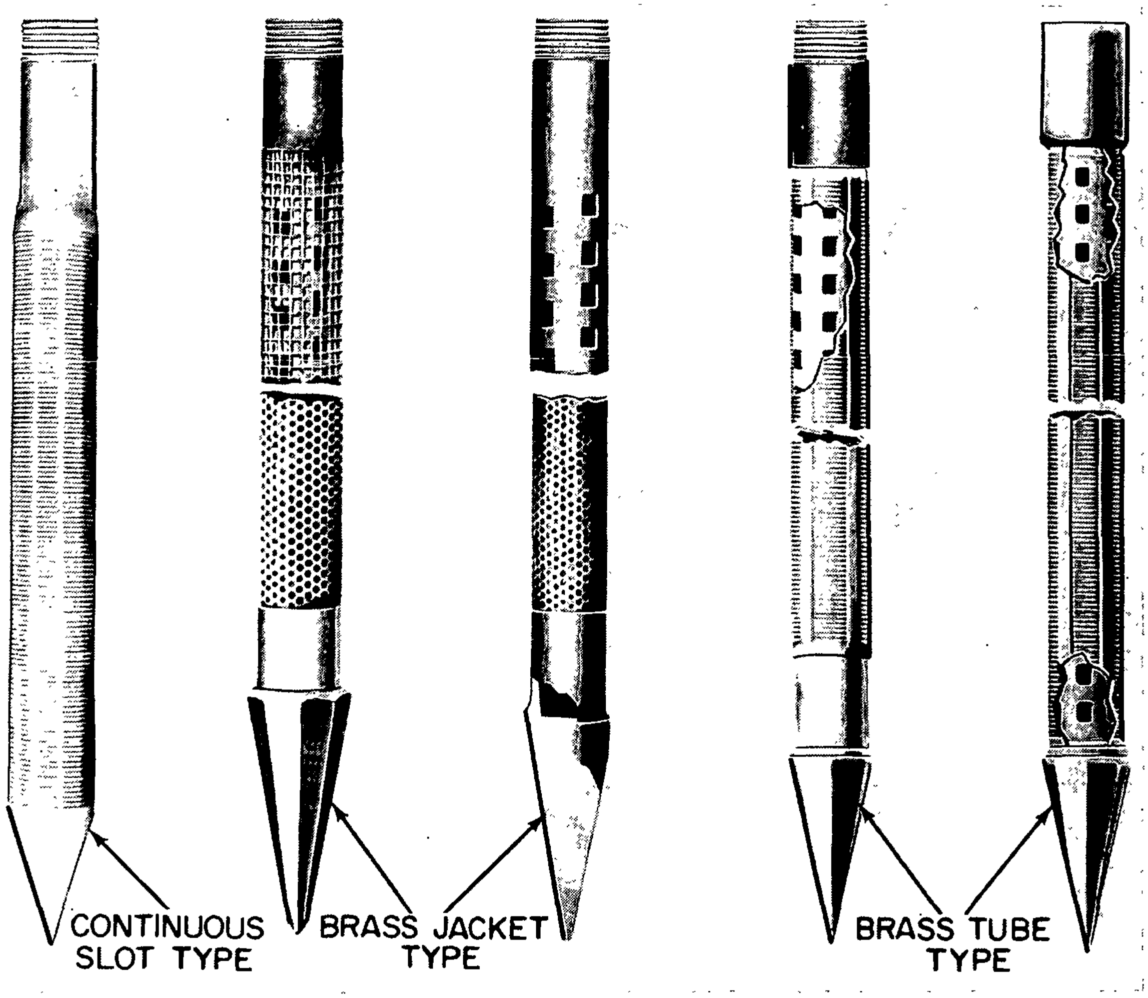


Figure 6-5. Drive points.

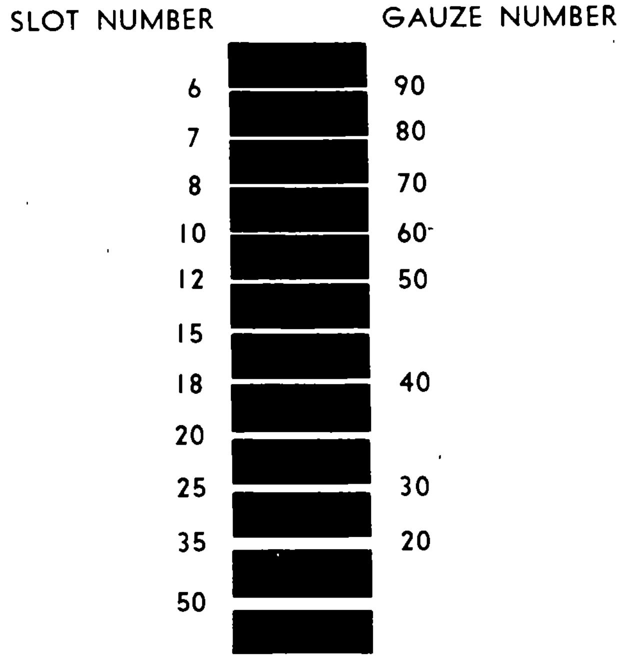


Figure 6-6. Standard slot numbers and equivalent gauze numbers.

b. Drive Clamps. Drive clamps (fig 6–8), used in driving casing or pipe, are attached to the square of the drill stem. When driving the clamps, strike the drive head or coupling at the top of the casing. The stem acts as a guide through the head and furnishes the needed weight for driving.

c. Drive Heads. Drive heads are used at the top of the pipe to protect the threads from the driving blows of the drive clamps. They are made in the following types: outside drop, inside drop, and hollow male screw (fig 6–9). The drive heads are put on by unscrewing the bit, slipping the drive head over the drilling stem, and making up the joint again. If the screw drive head is used, be sure the drive head is unscrewed from the pipe coupling before pulling the tools from the hole.

d. Drive Shoes. A drive shoe (fig 6–10) always is attached to the lower end of the pipe to prevent the pipe from collapsing or crumbling while being driven. Drive shoes are threaded to fit the pipe or casing, and the inside diameter of the shoe below the shoulder is the same as the inside diameter of the pipe. These shoes are forged of high carbon steel, without welds, and are hardened at the cutting edge to stand hard driving. The drive shoe is screwed up tight, and the inside shoulder of the shoe butts against the end of the pipe.

e. Elevators. Casing elevators (fig 6–11) are used to handle pipe. The device clamps around the pipe directly under the coupling. The sandline may be used with the elevator for lifting one or two half-lengths of pipe. For heavier strings of pipe, use the elevator with the swivel hook attached to the rope socket on the drilling line.

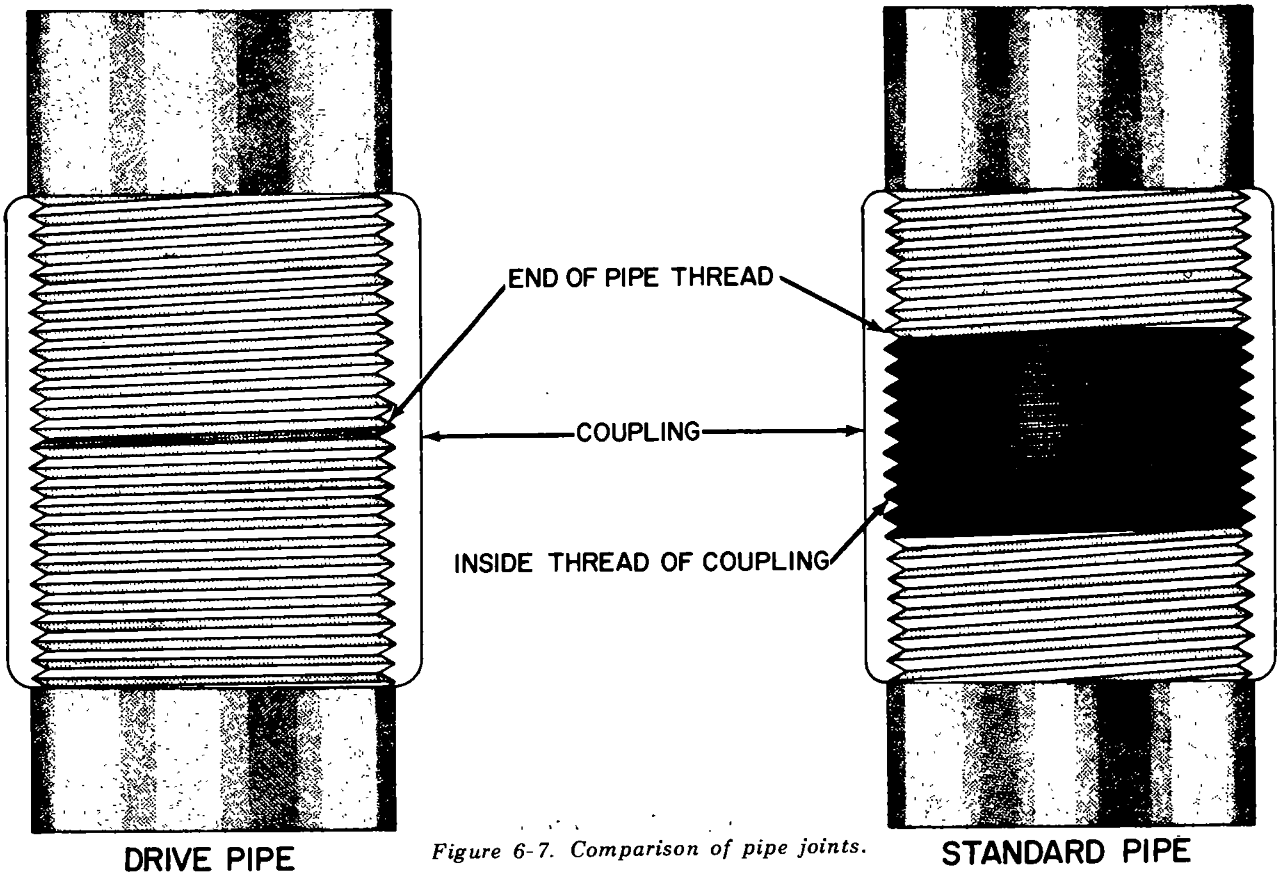


Figure 6-7. Comparison of pipe joints.

Smaller elevators are furnished to handle the pipe column when setting the Peerless Hi-Lift pumps.

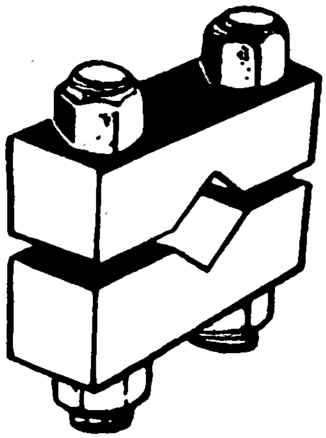


Figure 6-8. Drive clamp

and are fitted with flexible cables for handles.

h. Pipe Tongs. Two chain tongs (fig 6–11) are for screwing up the 6- and 8-inch drive pipe. Should the pipe turn in the hole while the top length is being added, hold the lower pipe with one tong and tighten the top length with the other. If friction in the hole is enough to hold the pipe while making up top lengths, use both tongs on the top length, one opposite the other. This puts an even strain on the pipe, easing the operation and making a better joint. Pipe joints must be tight and kept tight while driving pipe but without tong pressure great enough to collapse the pipe.

i. Pipe Clamps. Wooden pipe clamps (fig 6–12) are furnished for 6- and 8-inch drive pipe. They are used to hold the pipe at any desired position in the hole during drilling operations.

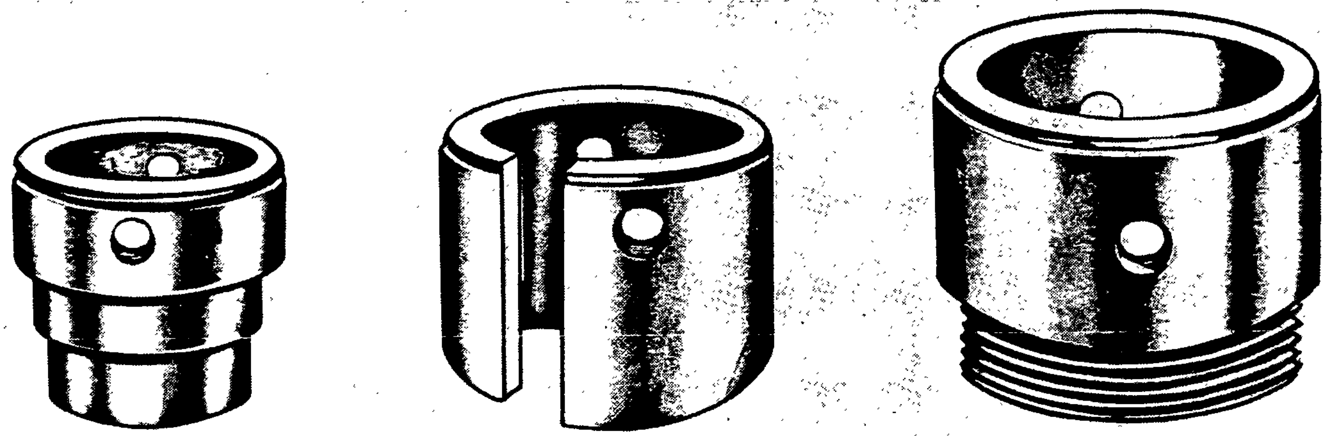


Figure 6-9. Drive heads.

f. Swivel Pinhook. The swivel pinhook (fig 6–11) is attached to the rope socket on the drilling line and is used for lifting heavy strings of pipe with the elevators. It can also be used to pick up heavy pieces of equipment within working radius of the drilling line.

g. Casing Ring and Slips. The casing ring (fig 6–11) is used to suspend the casing at the ground surface. Two sets of slips are furnished, one set for 6 5/8-inch OD pipe and the other for 8 5/8-inch OD pipe. The casing ring is also used when pulling pipe from the hole by jacks placed under each side of the casing ring. Great pressure can be applied by these jacks, so they must be set on solid and even foundations. Equal pressures must be maintained on both sides of the casing ring. The rings are made of cast steel, accurately machined, and fitted with handles. All slips are cast steel, with sharp teeth properly hardened,

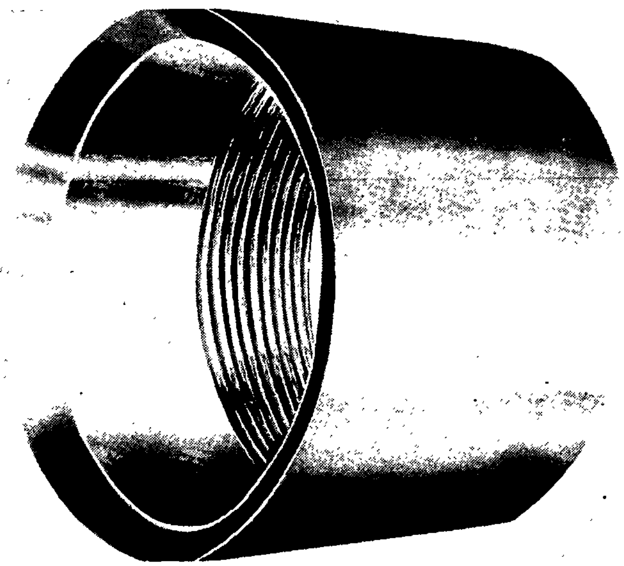


Figure 6-10. Drive shoe.

6-9. Wire Rope

a. Sandlines. Sandlines (fig 6-13) are right-lay, have 6 strands, 7 wires to the strand, and a hemp core. Mild plow steel sandlines are used for all bailing operations, for some fishing work, for swabbing, and for other lightweight lifting purposes within the working radius of the line.

b. Unreeling and Spooling.

(1) When removing wire rope from the spool in which it is received, the spool must rotate as the rope unwinds. Efforts to unwind wire rope from stationary spools result in kinking it, and a kink ruins the rope beyond repair at that point.

(2) To unwind the wire, mount the spool on a shaft supported by blocking on either end, anchoring the shaft on the blocking so the spool revolves on the shaft. Pull the rope from the underside (machine side) of the spool up, over, and through the sheaves to the machine reel on which it is to be spooled.

(3) When unreeling from spool to machine reels, keep the rope under tension (allow no slack) to obtain tight and even spooling on the machine reel. Use a plank, pried against the side of the spool, to act as a brake. It should take a definite pull to unreel the rope.

(4) The method described below for one-layer winding may be used to determine the proper direction of rope lay for spooling or winding on flat or smooth-faced drums. When a rope is wound on a drum, any tendency of the rope to twist when tension is released will be in a direction that would untwist the rope at the free end. The advantage of rope of proper direction of lay is that when the load is slacked off, the coils on the drum hug together and maintain an even layer. With

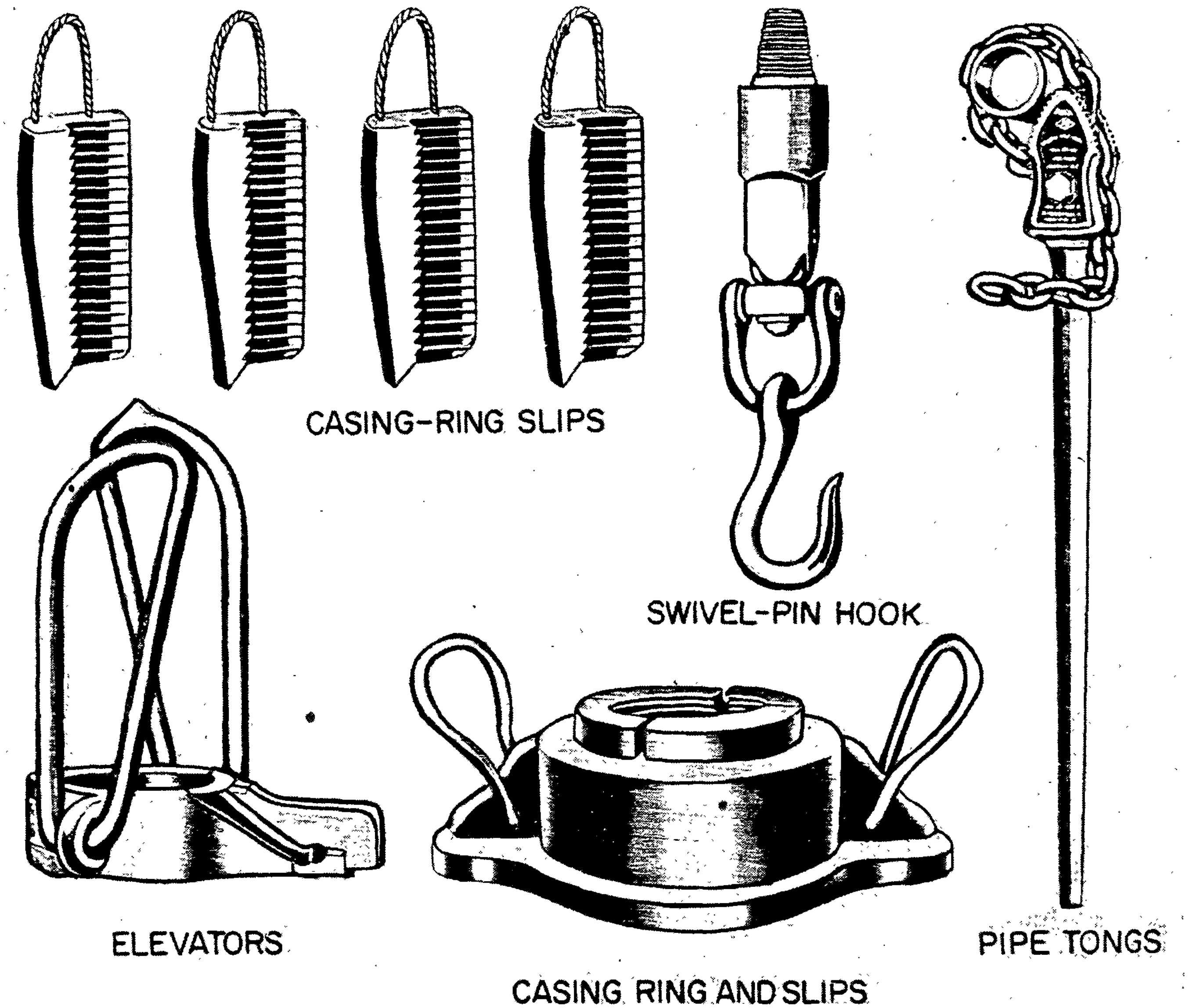


Figure 6-11. Casing tools.

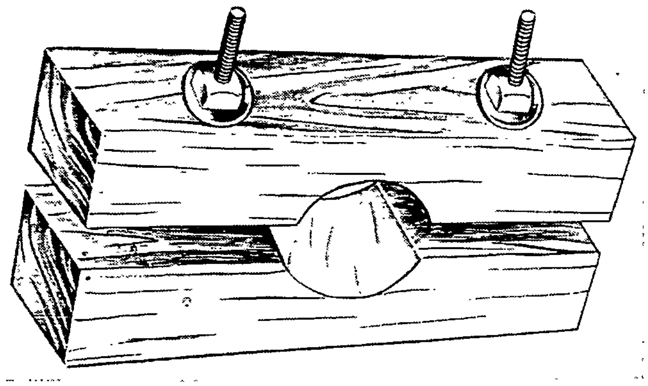


Figure 6-12. Wooden pipe clamp.

rope of improper lay, the coils spread apart at each removal of load, and the rope may crisscross and overlap on the drum when winding resumes. The rope is flattened and crushed as a result.

c. *Efficiency of Wire Rope Attachments.* Fastenings or attachments often are needed to fasten pieces of wire rope together or to tools. The different attachments and ways to make connections may affect the efficiency or strength of the gear or rigging. If the breaking strength of wire rope is taken as 100 percent, a zinc socket properly made will be as strong as the wire itself, or 100 percent; but if babbitt or lead is used, the efficiency may be as low as 25 percent, or 1/4 the strength of the wire rope. Wedge type sockets develop about 70 percent of the wire rope strength. In using clips of the Crosby type (fig 6-14) the efficiency of the connection depends on their arrangement, the number of clips, and the care used in tightening them. With a properly made attachment, that is, with a clip basket on the load rope and a U-bolt on the loose end, the efficiency is 80 percent; with U-bolts all on load rope, 70 percent; with knot and clips, 50 percent; staggered clips, 75 percent; and with improperly tightened clips, 50 percent or less. An attachment that develops about 75 percent of the strength of a 6 by 19 plow steel rope requires the number of clips shown in table 6-2. Ropes less than 3/4 inch should have not less than 4 clips.

Table 6-2. Clips for Approximately 75 Percent Strength Fastening of 6 by 19 Plow Steel Rope

Diameter of rope (in.)	Number of clips	Space between clips (in.)	Efficiency of fastening (percent)
3/4	5	4 1/2	77.4
7/8	5	5 1/4	70.1
1	5	6	77.9

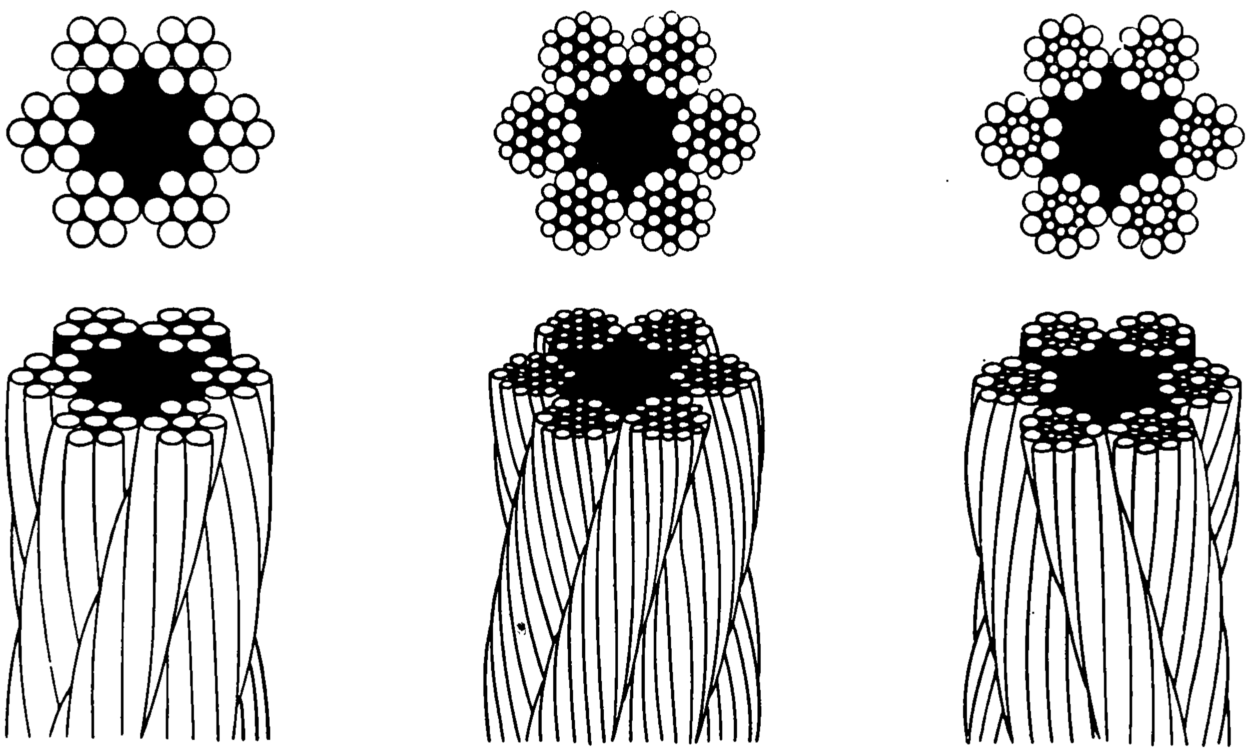


Figure 6-13. Wire rope.

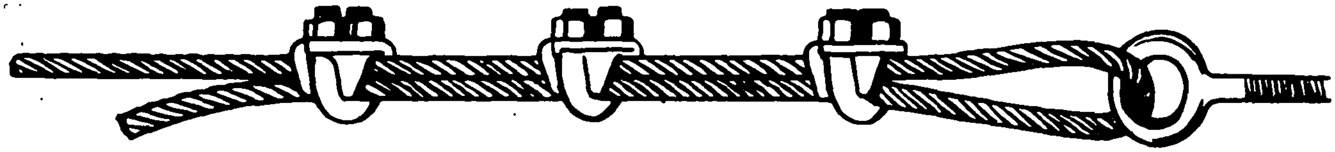


Figure 6-14. Crosby clip.

d. Setting Wire Line in Swivel Socket. Wire cable can be attached to the swivel socket either by using zinc or babbitt metal, or by the dry method. The dry method is used when it is impractical to use the zinc or babbitt method (which is much more difficult) and does not provide as satisfactory an attachment because the strain may be placed on only a few strands of the cable. The correct procedures for fastening the cable in the socket are as follows:

(1) *Zinc or babbitt method.* First wrap the end of the cable with a binder of small wire or electrician's tape to keep the cable from unlaying and to make it easier to insert the swivel. Pull the cable through the socket and insert it in the top or coneshaped end of the swivel. Push the cable through the swivel for 2 or 3 feet. Place another binder of wire about 5 inches from the end of the cable to prevent unlaying back of this point. Remove the end binder and unlay the strands back to the second binder. Cut off the core at this point and untwist each strand so the individual wires are separated. This operation is called "mule tailing." Pull the swivel back over the end of the cable until the ends of the wire are even with the end of the swivel; then wrap a string or rag tightly around the cable at the point where it enters the swivel. Tie the swivel to a stake in an upright position where it will be convenient for pouring the molten metal. Heat the metal carefully, since overheating or burning results in a weak binding between the metal and the swivel. When the zinc is melted or the babbitt is heated enough to "flash" a pine stick, pour it immediately into the swivel, filling it to the top. *Caution:* **Wear protective goggles and gloves when pouring molten metal.**

(2) *Dry method.* When no zinc or babbitt metal is available, another method of fastening the wire in the socket is as follows: Insert the cable through the socket and swivel as described in (1) above. Wrap the cable with a wire binder about 6 inches from the end to keep the cable from unlaying past this point. Take a piece of soft wire or cotton string and wrap it tightly around the binder, building it up to a diameter of 1 1/2 inches and a length of 3 inches, tapering in each direction from the center to the ends. Next, unlay the strands, bend them back over the knot of soft wire or string, and cut off the core. Then pull the ends of the strands against the cable and insert them in the swivel; use a hammer to drive the knot into the swivel. This method, if properly used, will be satisfactory in all shallow water well drilling.

e. Proper Working Loads for Wire Rope.

(1) The working load of a wire rope, particularly running ropes, for general purposes should not exceed 1/5 of the breaking strength; that is, the factor of safety should be not less than 5 (table 6–3). To find the correct working load, divide the breaking strength by the proper factor of safety. A 7/8-inch diameter, 6 by 19 plow steel rope has a breaking strength of 28 tons; with a factor of safety of 5, the proper working load would not be over 5.6 tons.

Table 6-3. Safe Working Load of New 6 by 19 Wire Rope

Diameter (inches)	Weight (pounds per foot)	Safe working load (tons)			Smallest sheave diameter (inches)		Factor of safety
		Iron	Crucible steel	Plow steel	Iron	Steel	
3/8	0.22	0.48	0.96	1.02	27	18	5
1/2	.39	.78	1.68	1.75	36	24	5
3/4	.89	1.70	3.50	4.00	54	36	5
1	1.58	2.90	6.00	6.00	72	48	5
1 1/4	2.45	4.60	9.40	10.40	90	60	5
1 1/2	3.55	6.60	12.80	14.80	108	72	5
2	6.30	11.00	21.20	28.00	144	96	5

(2) Factors of safety in excess of 5, up to 8 and even more, often are required for safe and economical operation. To determine the proper factor of safety all pertinent data are considered carefully and thoroughly. Such data include all loads, acceleration, deceleration, rope speed, rope and drums, existing conditions causing corrosion and abrasion, length of rope in service, economical rope life, and the degree of danger to life and property.

(3) No values for factor of safety can be properly set for various classifications of service. They can safely vary, within limits, with the conditions met in individual installations. Safety factors of 5 and 3 have been used in handling drill pipe and in setting casing, respectively.

f. Lubrication of Wire Rope. To obtain maximum service from wire rope, the hemp core needs frequent lubrication so it does not become dry. A dry core wears and crushes more quickly and absorbs moisture, causing serious damage to rope service. A good lubricant retards corrosion of the wires and reduces internal friction and external wear. Any one of a number of special wire rope lubricants will give excellent results if properly applied at stated intervals. Any kind of lubricating oil is better than none. The smaller the sheaves or the heavier the load, the more often the rope is lubricated. Lubricating wire rope too often is better than not often enough.

6-10. Preparation for Driving

a. Driven wells generally are started in a hole bored with a hand auger. The diameter of the hole should be a little larger than that of the well point, and the hole should be as deep as the auger will work. In clay soils, boring with an auger is much faster than driving.

b. Pipe joints must be made up carefully to insure airtight joints and to prevent thread breakage. If available, use special drive pipe couplings (fig 6-15). Screw all joints tight after threads are carefully cleaned and oiled. Use joint compound to improve airtightness. Protection of the threads by caps or couplings during transportation and storage is advisable. To insure that joints remain tight, give the pipe a fraction of a turn with a wrench after each blow until the upper pipe joint first becomes permanently set. It is thereafter only necessary to tighten each joint similarly. Do not attempt to twist the whole string of pipe while driving.

c. Where unthreaded casing must be used the successive lengths of casing must be butt-welded. The alignment collar shown in figure 6-15 is required for initial tack welding. This device is used to aline the pipe or casing as an aid in obtaining a straight and tight joint. The welded casing permits a continuous string to be driven and eliminates possible casing damage often encountered with threaded casing. The collars are removed upon completion of the tack welding.

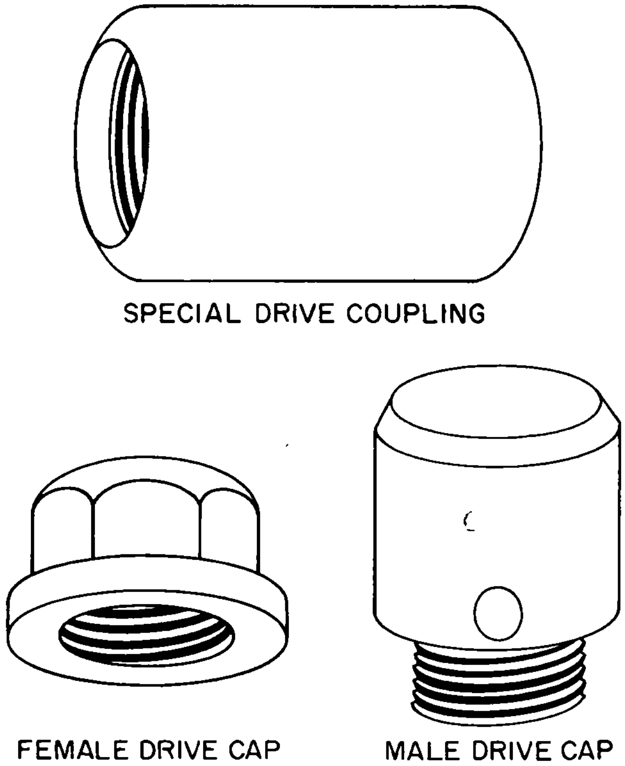


Figure 6-15. Drive fittings.

d. The well pipe must be kept vertical. Check this with a plumb bob held at arm's length from the well pipe, and from two directions at approximately right angles to each other. If the pipe is slightly out of vertical during the early part of the driving, it may be straightened by pushing on the pipe while the blows are delivered. If it cannot be straightened, withdraw the pipe and start again in a new place.

6-11. Driving Methods

a. Driving may be done by using a maul or sledge to strike directly a drive cap (fig 6-15) fitted to the well pipe. Be careful to hit the drive cap squarely. Glancing blows may damage the pipe.

b. Manual driving may be done as illustrated in figure 6-16. This operation uses a driver (fig 6-17) which fits over the drive cap and is struck with a maul or sledge. If available, use a pneumatic tamper or sheet piledriver from an air compressor, provided the pipe is strong. Weak pipe will break at the couplings, particularly if a butt joint is not used.

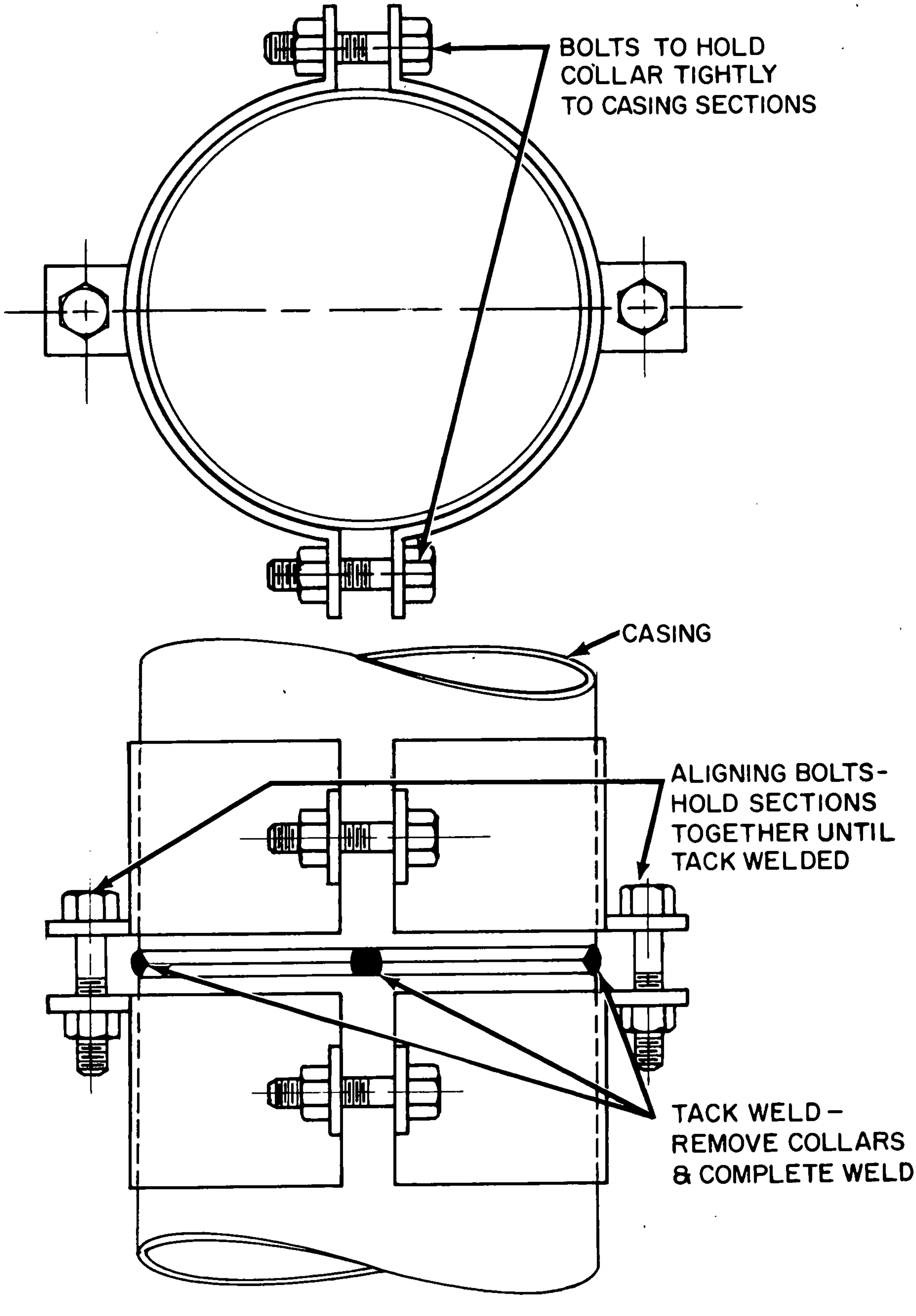


Figure 6-15—Continued.

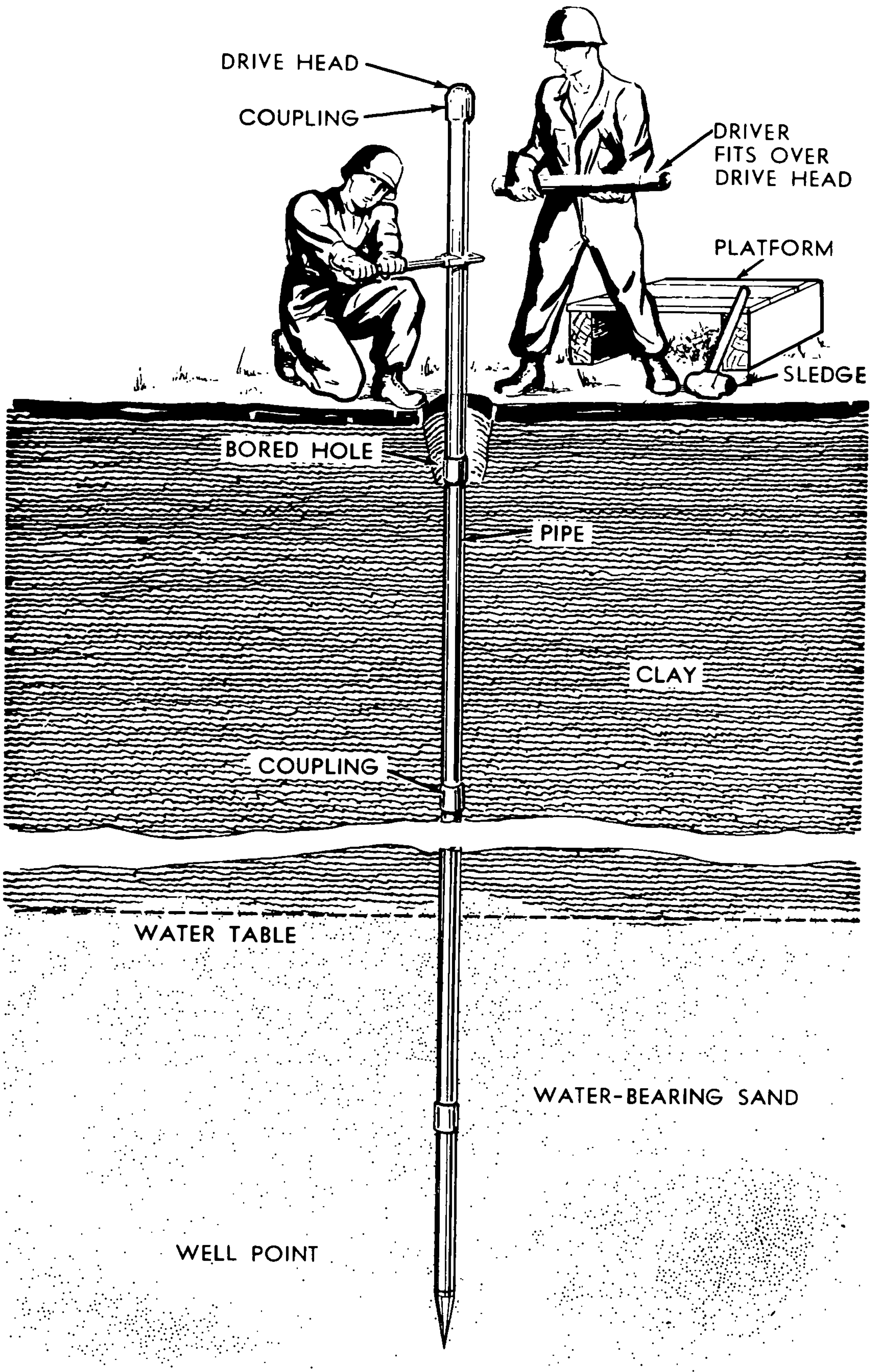


Figure 6-16. Driving a well point with a driver.

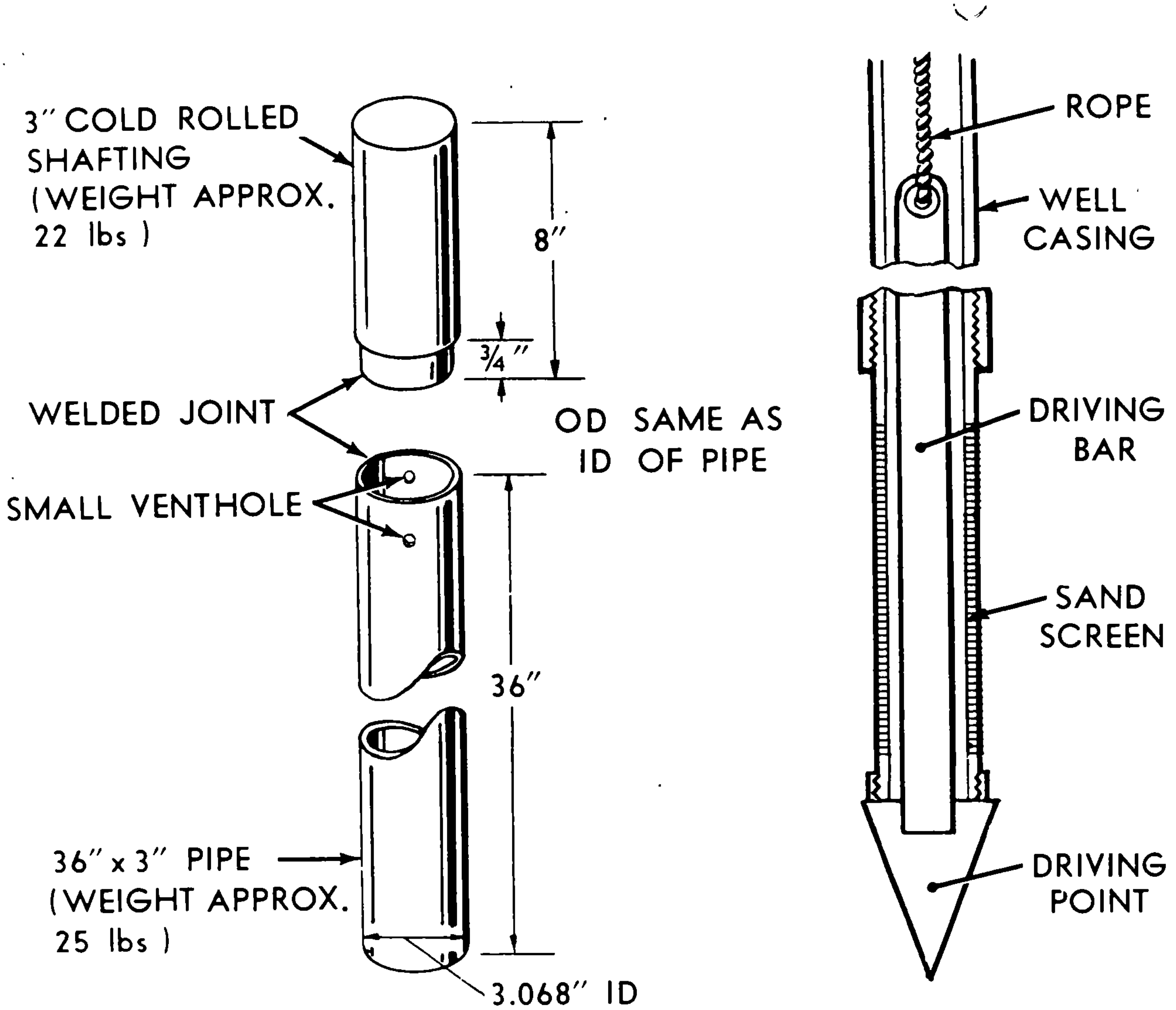


Figure 6-17. Drivers.

c. Another method of driving is to use a steel driving bar attached to a rope. The bar falls freely inside the pipe and strikes the base of the drive point as shown in figure 6–17. This is one of the safest methods of driving because it does not weaken the pipe.

d. A variation of the falling weight method is applied by using a drive monkey. A drive monkey is a weight that slides over the pipe (fig 6–18). The simplest arrangement is one in which the monkey slides on a bar supported by the well pipe itself. In this arrangement a drive cap as illustrated in figure 6–18 must be used. An alternate method is to allow the drive monkey to slide over the well pipe to strike a drive clamp placed around the well pipe. A tripod may be used with either method.

6–12. Rates of Driving

a. In soft formations the rate of descent may be 2 or 3 inches per blow. Driving in sand or compact clay often is made easier by introducing water in the pipe or around it. Extremely compact clay is difficult to penetrate, and dozens of blows may drive the pipe only a few inches.

b. Successful construction of driven wells depends upon close observation and correct interpretation of certain aspects of the work while driving. Interpretation of such details as the penetration made with each blow, the drop and rebound of the maul or weight, the sound of the blow, and the resistance of the pipe to rotation, helps the well driver to determine the character of the materials being penetrated. Table 6–4 outlines a guide for the identification of the formation being penetrated by drive points.

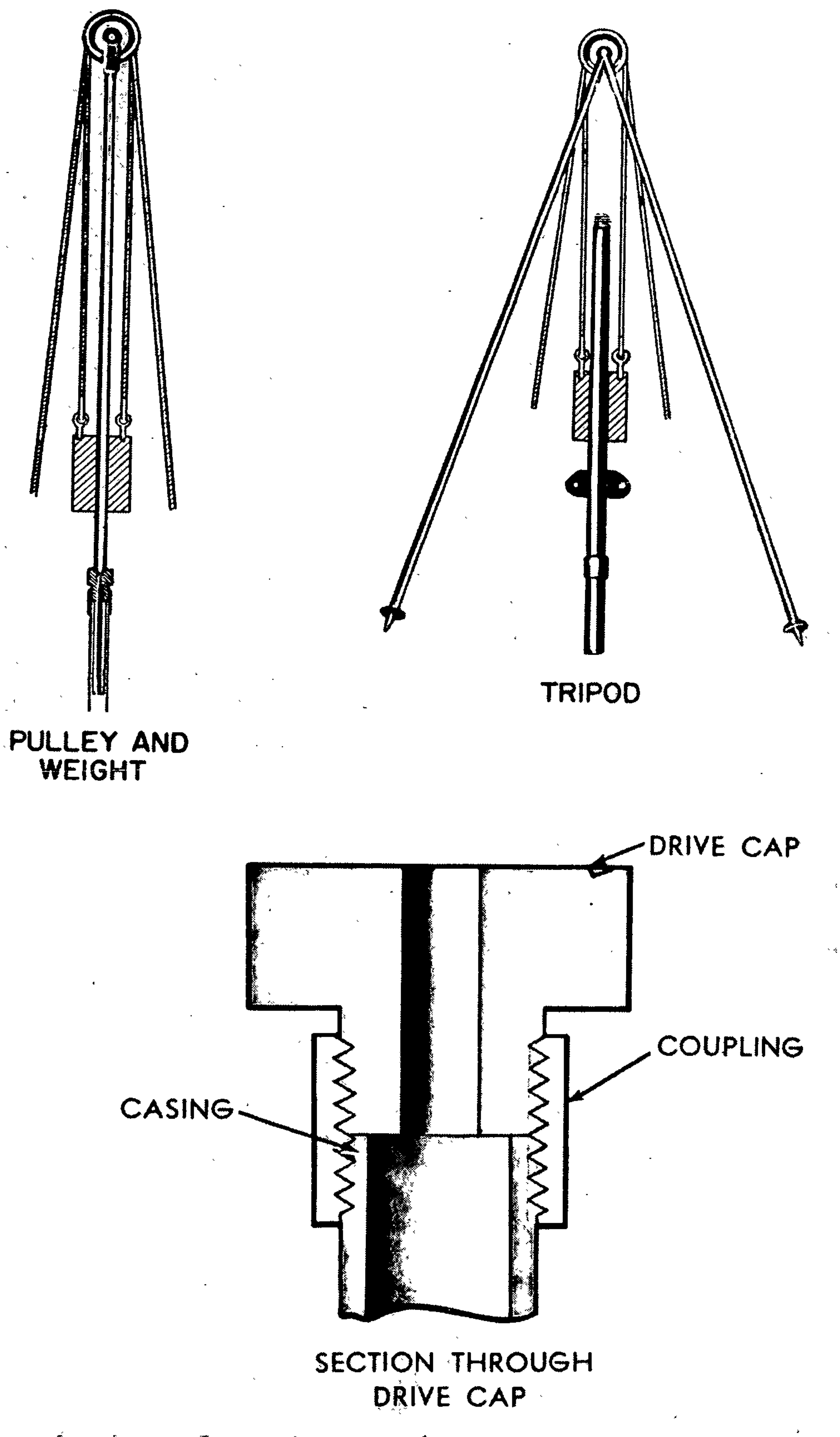


Figure 6-18. Drive monkey arrangement.

Table 6-4. Identification of Formation Being Penetrated

Type of formation	Driving conditions	Rate of descent	Sound of blow	Rebound	Resistance to rotation
Soft moist clay	Easy driving	Rapid	Dull	None	Slight but continuous.
Tough hardened clay.	Difficult driving	Slow but steady	None	Frequent rebounding.	Considerable.
Fine sand	Difficult driving	Varied	None	Frequent rebounding.	Slight.
Coarse sand	Easy driving (especially when saturated with water).	Unsteady irregular penetration for successive blows.	Dull	None	Rotation is easy and accompanied by a gritty sound.
Gravel	Easy driving	Unsteady irregular penetration for successive blows.	Dull	None	Rotation is irregular and accompanied by a gritty sound.
Boulder and rock.	Almost impossible	Little or none	Loud	Sometimes of both hammer and pipe.	Dependent on type of formation previously passed through by pipe.

6–13. Development of Free Flow

a. An increase in the rate of descent usually indicates entry of the well point into water-bearing sand. This increase is sometimes as much as 6 inches at a single blow, although in fine sands the penetration per blow may change little or none at all. When it is suspected that the well point is in water-bearing sand, driving is stopped and a weighted line is lowered into the well to check the depth to the water level. If water stands above the well point and within 15 to 25 feet of the surface, a pitcher pump may be attached to the top of the well pipe and the well tested for yield.

b. Another simple method of testing is to pour water into the well. If the well point is in dry sand, all of the water added will drain into the sand. If the well point is in water-bearing sand, the added water also will seep out but only to the static level or the water table elevation. When the well point is in water-bearing sand, the quantity of water that can be poured into the well continuously is a rough indication of the rate at which the well can be pumped, since the saturated sand yields water about as freely as it absorbs it. Sometimes lowering the well point a foot or more brings a greater length of the screen into contact with the water-bearing sand and a greater yield results.

c. Although a well site may have been properly selected, the strata correctly interpreted, and the presence of water accurately judged, a well may fail to yield water at first since the sand around the well point is clogged with fine particles that need to be removed by development. This silt and fine sand may also have washed through the screen openings, partially filling the well point. This difficulty may be overcome with a pitcher-spout hand pump, usually supplied for drive point wells. The common pitcher-spout pump has a plunger and a check valve arranged so that the check valve can be tripped when the pump handle is raised as high as possible. It is, therefore, possible to pump for a while and then trip the check valve to allow water to run back down the well pipe. By alternately applying a heavy suction on the well and tripping the valve to let the water run back, a surging action is produced through the screen openings. Even if there is only a small flow of water at first, the reversal of flow due to the surging tends to loosen the fine material plugging the screen openings and to bring the fine sand and silt into the well point. This fine material may be pumped from the well if continuous hard pumping is done for a few minutes. The well is ready for use after it has been pumped enough to clear up the flow. The pump should be checked to see that there is no sand on the valves or on the plunger.

d. If all the sediment cannot be cleared from the well point by pumping, one of the following methods will be used:

(1) Lower a series of connected lengths of 3/4-inch pipe into the well with the lower end resting on the sediment in the well point. Clamp the pipe in position and attach a hand pump to the upper end. Run water into the well pipe (not the 3/4-inch pipe) and operate the hand pumps. By steadily pumping, the sediment will be lifted through the 3/4-inch pipe. Continue to lower the 3/4-inch pipe to the sediment level until the well is cleared.

(2) Insert a string of 3/4-inch pipe into the well and fill the well with water. Repeatedly raise and lower the pipe sharply by hand. By holding

the thumb over the top of the 3/4-inch pipe during the upward movement and removing thumb during downward movements, a jet of muddy water is expelled on each downward stroke. When the material has been loosened and put into suspension, the muddy water can be pumped out.

(3) Water pumped into a string of 3/4-inch pipe resting on the sediment will remove the fine material by a jetting action. This procedure requires a large supply of water and a motor-driven or hand-force pump.

e. It may be impossible to develop a successful well if too fine a screen is used. The openings must be large enough to permit the finer particles of water-bearing soil to enter the well point while retaining the coarser particles. With properly sized screen openings, development expels the finer material next to the well point and retains the coarser particles to form an envelope of highly porous and permeable material around the screen.

f. Where the water-bearing level is too deep to permit the use of a pump at ground surface, it may be possible to sink a shaft or pit to allow the installation of a pump within the suction lift above the water-bearing level.

6–14. Multiple Wells

a. Since the yield from a single driven well is small, generally only a few gallons per minute, the maximum under exceptionally good conditions ranges from 20 to 40 gallons per minute. Batteries of these wells connected with a single header can supply relatively large quantities of water. The wells should be staggered on opposite sides of the header with a maximum distance of 30 feet between wells.

b. When two wells are connected to a common suction, the pump should be placed about halfway between them to equalize the suction. For a battery of several wells, the pump should be installed where it will insure equal suction at each well. Usually, there are no difficulties in group pumping when the water table is near the surface. However, when the water table is 15 to 20 feet below the surface, air locking in the horizontal pipe may cause trouble in starting the pump. This difficulty can be avoided when the well is constructed by installing a valve at each well in the pipe connecting the well to the header. The valves are opened successively after the air has been removed from the preceding well. With all of those valves closed, the system can be primed by filling the suction header full of water before starting the pump. A check valve installed in the line to each well will keep the system primed after it has been placed in operation.

c. The temperature of the pipes at each well indicates which of the wells are producing. The pipes which have water running through them are usually cooler. The sound of water flowing through a pipe can be heard by placing a rod against the pipe and close to the ear.

6–15. Removing Pipe

Well points and pipe may be withdrawn by upward blows by a drive monkey striking on a pipe clamp attached firmly to the well pipe. Another method is to apply levers or jacks against a pipe clamp or pipe puller head, or by a chain wound around the drive pipe and connected to a long lever operating against a solid fulcrum. Rotation of the pipe by wrenches will assist in removal. After the pipe has been raised a few feet, the rest of the pipe can be lifted by hand.

a. Cutting Pipe in Hole. A casing cutter may be used at any depth to cut pipe in the hole. The cutter is lowered on drill stem, and the mandrel is run on the sandline and lowered inside the tubing. When the cutter has been lowered to where the casing is to be cut, the mandrel is run in and, by jarring downward, the cutters are forced out against the wall of the pipe. At the same time the drill stem is revolved by the drill table. A complete outfit consists of cutter, mandrel, sinker, and rope socket. A casing cutter is not regular equipment with the Army machine.

b. Shooting Well Pipe. To shoot off a portion of well pipe to recover a part of it, dynamite is lowered to the point where the pipe is to be cut. Usually, for 6-inch pipe, three to five sticks of dynamite are enough to make a break. Set the dynamite as near a joint as possible.

Caution: **Do not cover the hole when shooting dynamite. Make personnel stand clear. After hearing the shot and feeling its shock wave, wait a few minutes for the probable discharge of water and mud from the well opening.**

c. Recovering Pipe. To recover pipe from abandoned wells, or the outer string of pipe from wells that have two strings of pipe, the casing ring with slips and jacks is used. The casing spear can be used also.

Section IV. JETTED WELLS

6–16. Description

In the jetting method of well construction, a hole is drilled into the earth by the force of a high velocity stream of water. This stream loosens the material it strikes and washes the fine particles upward out of the hole. This method of well

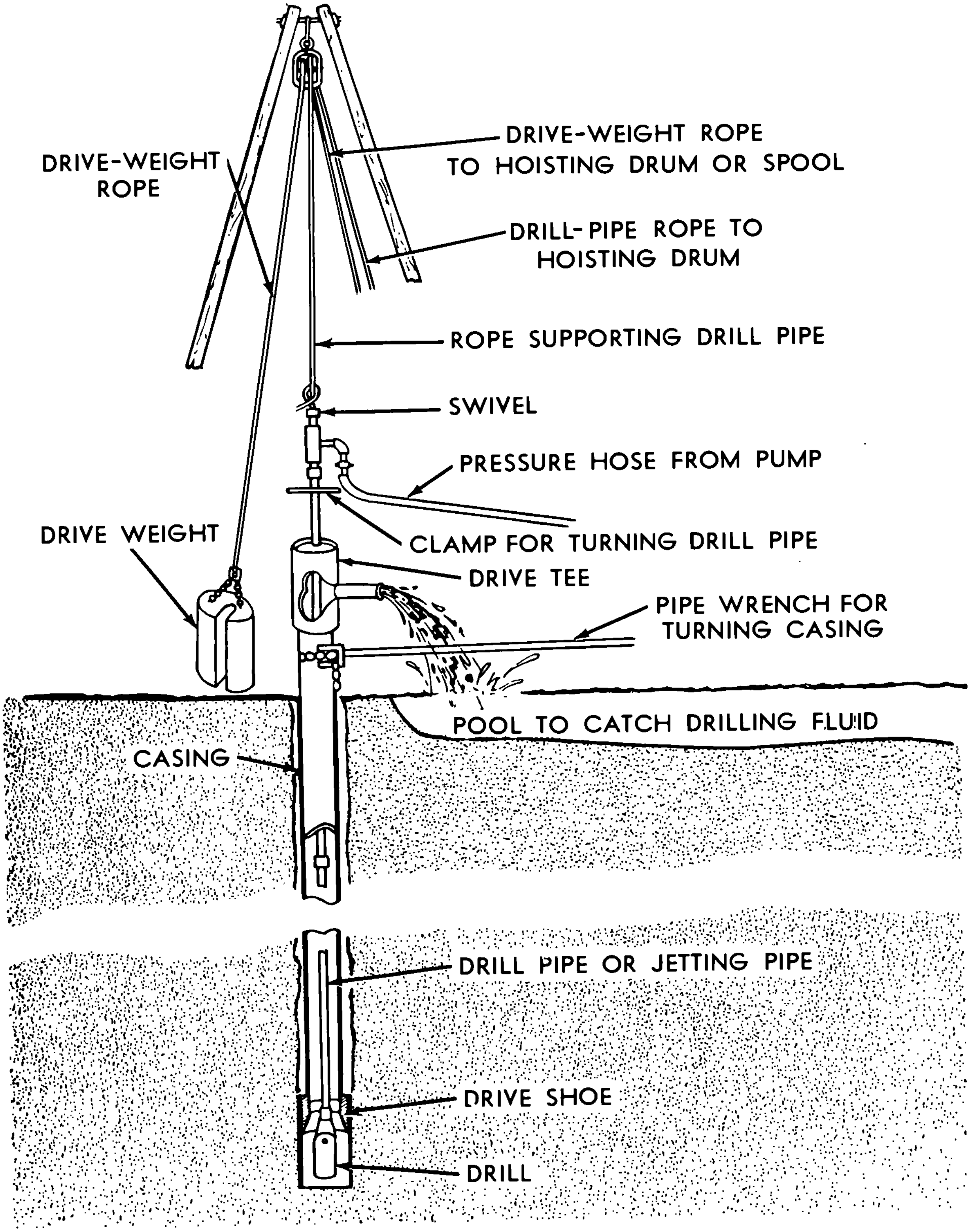


Figure 6-19. Simple jetting rig.

construction is particularly successful in sandy soils when the water table lies close to the ground surface. It is a simple and dependable method that can be carried out entirely with handtools. Success does not depend upon bulky drilling equipment which is difficult to transport. Generally, two techniques of construction may be used: washing in a casing, or sinking a self-jetting well point. In addition, jetting may be used to sample the general character of a formation by examination of the cuttings brought to the surface in the return flow.

6–17. Jetting Equipment

a. The essential jetting equipment includes a hoist, a jetting pump with hose, a water swivel, an adequate supply of jetting fluid, a drive weight, and a set of heavy pipe tools.

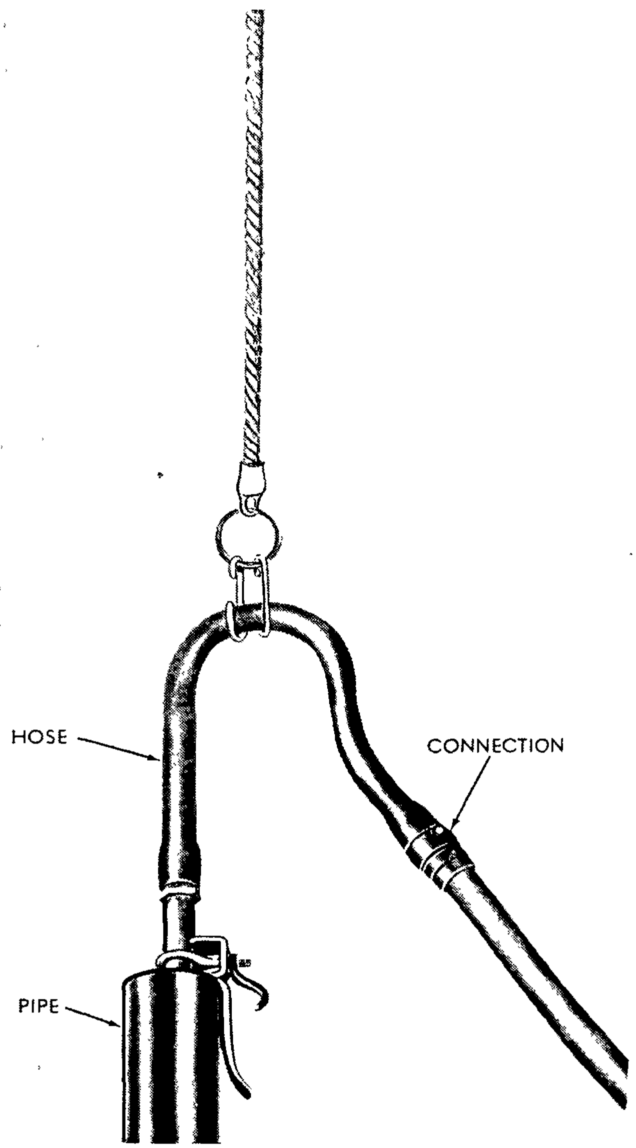


Figure 6-20. Connection used in place of water swivel.

(1) *Hoist.* A hoist is needed to handle the drill pipe and casing. Hand-operated equipment such as a tripod with tackle may be used (fig 6–19). If available, it is desirable to use a percussion type drilling rig with a power hoist.

(2) *Pump.* A pump with suitable hose connection and capable of delivering 50 to 100 gallons per minute at a pressure of 50 pounds per square inch is adequate. The quantity of water needed to jet a well varies with the type of sediment being penetrated. Sand soils require the most water, but high pressure is not necessary. Forty pounds per square inch nozzle pressure at the bit is adequate in most cases. Clay and hardpan require less water but they are not readily displaced except by a small cutting stream delivered at high pressure. Pressure as high as 200 pounds can be obtained from small nozzles in the drill bit.

(3) *Swivel.* The water swivel must be able to carry the weight of the drill pipe and to sustain the maximum pressure delivered by the pump. Figure 6–20 shows a connection that may be used at the top of small diameter jetting pipes in place of a swivel.

(4) *Jetting fluid.* Plain water is commonly used in jetting wells, but a jetting fluid of greater viscosity and weight may be prepared by mixing clay or a commercial bentonite with water. This heavy fluid tends to seal the wall of the hole and to prevent loss of water into the formation being penetrated. In addition, jetting fluid is led from the hole to a settling pit where cuttings (material washed from the hole) settle to the bottom. The fluid can be picked up again by the jetting pump and recirculated. Under certain conditions in the Arctic, steam is used to construct jetted wells. Chapter 10 contains specific information with regard to the Arctic well.

(5) *Drive weight.* A small weight, illustrated in figure 6–19, is dropped manually on the pipe to help it penetrate clayed or semifirm soil.

b. Self-jetting well points and bits, illustrated in figures 6–21 and 6–22, respectively, may be used and are described as follows:

(1) *Self-jetting well points.* The continuous-slot self-jetting point has a screen constructed of a narrow ribbon of metal wound spirally around a skeleton of longitudinal rods. Each point of contact between the metal ribbon and the rod is electric welded. The brass jacket-type self-jetting point consists of a woven wire gauze wrapped around a perforated pipe. For protection, a perforated brass sheet covers the wire gauze.

(2) *Jetting head.* The jetting head is the self-closing bottom. It contains a spring-loaded disk or ball type valve which opens when water is

forced through it during the jetting operation. The spring-loaded disk valve closes automatically when jetting is stopped. The ball type valve closes when the well is completed and pumping begins.

(3) *Bits.* The various types of bits used in jetting are illustrated in figure 6-22. In soft materials, a paddy or expansion bit may be used to make a hole slightly larger than the casing. When a hand rig is used, hard layers of formation are penetrated by the percussion method using one of the straight bits. With heavier rigs, one of the drill-like bits can be used to penetrate hard layers that do not yield to the water jet.

6–18. Jetted Well Construction

a. Setting Casing and Well Screen. When the jetting fluid effectively prevents caving or collapse of the drilled hole, the casing can be inserted in a single string after the jetting has been carried to the full depth. Otherwise the casing is sunk as fast as jetting proceeds. If too much resistance is encountered, a certain amount of driving is required to force the casing down. One size of casing, such as 4-inch diameter pipe, can be used for depths to 200 or 300 feet. An additional string of smaller size, such as 3-inch diameter pipe, is placed inside the first string if

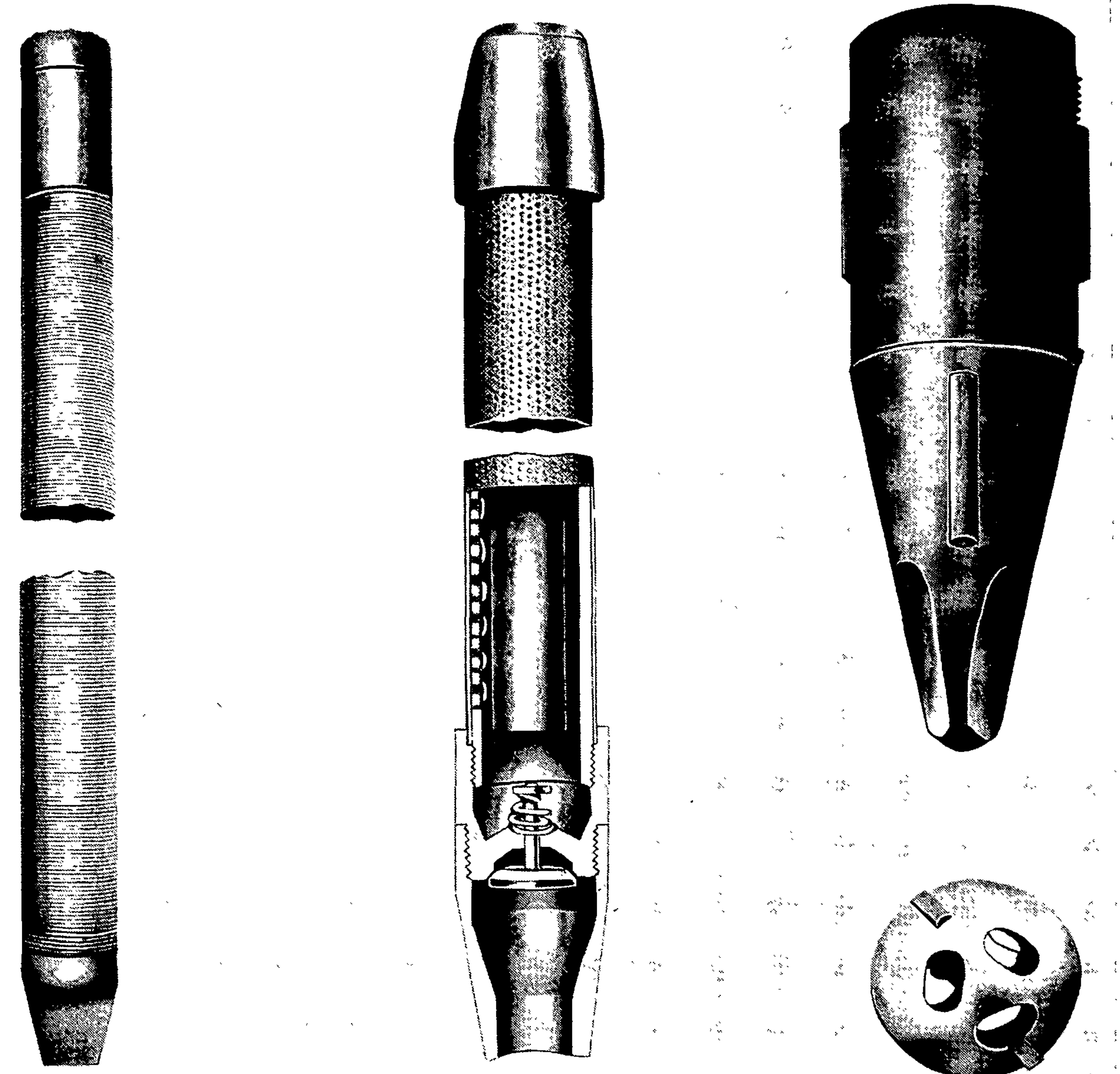


Figure 6-21. Self-jetting well points.

the well is sunk much deeper.

b. Washing in Casing.

(1) Before washing the casing into the hole, cut the lower end of the casing to form a toothed cutting head (fig 6-23). Four to six teeth, 1 inch in length (or longer) are usually enough. Mark the outlines of the teeth on the casing. Using a power drill or cutting torch, drill or cut holes in the casing to form the gullets of the teeth. Then cut the sides of the teeth with a hacksaw or oxyacetylene torch to meet the outside circumference of the drilled holes. Rounded holes are desirable so the teeth can readily clear themselves of gravel or other material. Half of the teeth should be bent outward so they cut a hole slightly larger than the casing.

(2) Place a cap on the top of the casing and attach the discharge hose from the pump to the connection provided in the top of the cap. Suspend the casing vertically by using a hoist. Permit the cutting head to rest on the ground, preferably in a shallow hole dug by hand. Almost the entire weight of the casing should rest on the ground. Operate the jetting pump at full capacity. The casing will fill with water and begin to sink by its own weight as the ground is washed out from under it. The hoist should keep enough tension on the casing to hold it vertical. If some resistance stops the downward movement of the casing, it can be lifted 2 or 3 feet and dropped. Chain tongs or wrenches can be used to rotate the casing so the teeth at the lower end will cut into the bottom of the hole.

(3) If more than one length of casing is to be washed in, the hole and first length of casing must be kept full of water at all times while the second length of pipe is being attached and the pump connected to it. This process maintains fluid pressure against the wall of the hole and should prevent caving.

(4) When the casing reaches the desired depth, stop the pump and remove the cap at the

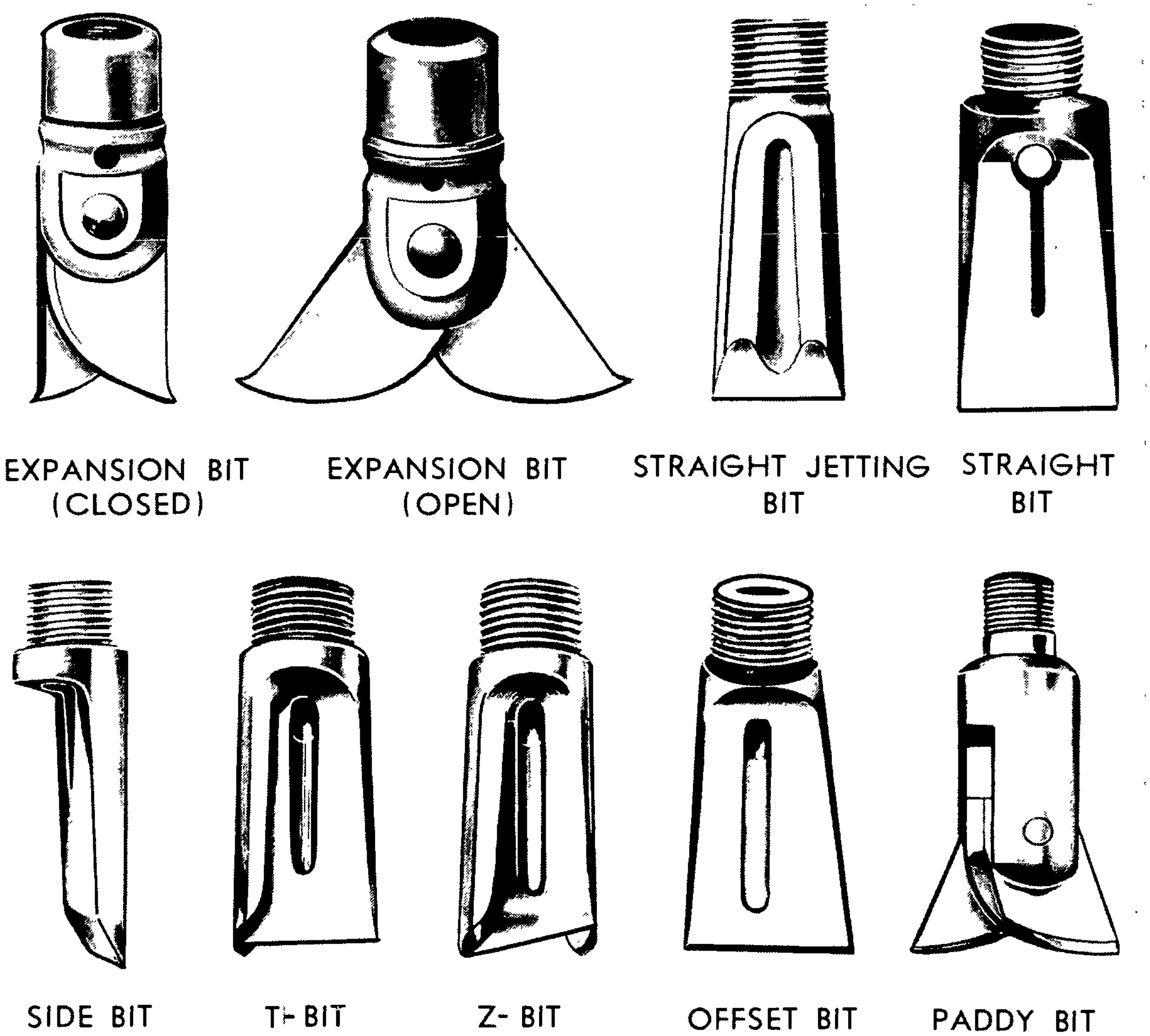


Figure 6-22. Bits for jetting equipment.

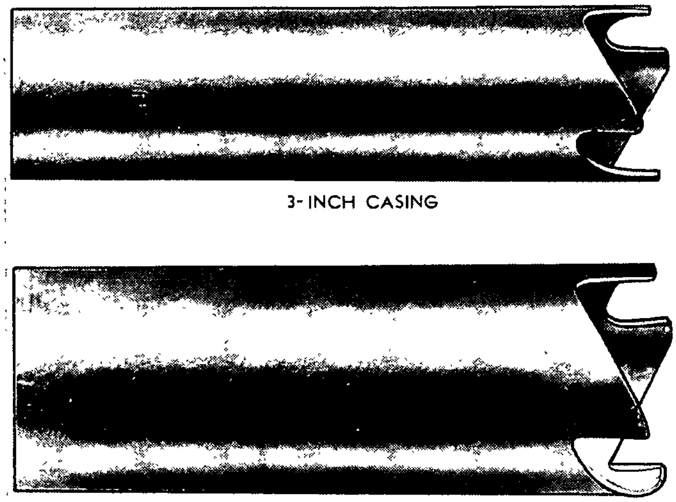


Figure 6-23. Teeth cut on lower end of casing.

top of the casing. If the casing is to remain in the hole, telescope a well screen through the casing until it rests on the bottom of the well. Pull the casing up until the screen is exposed to the water-bearing formation, and cut the casing off at a point about 1 foot above the ground surface. If the casing is a temporary installation, attach a well pipe to the screen before lowering it into the casing. When the screen is resting on the bottom of the hole, pull the entire length of casing out of the hole. This casing can be used again for drilling at another site.

c. Sinking Self-Jetting Well Point.

(1) The equipment necessary to sink a well point of this type includes the self-jetting well point, a well pipe, a small swivel to permit turning the pipe to facilitate jetting, a pressure hose, a pump, and a source of water.

(2) Couple the well point to the bottom of the riser or well pipe. Attach the swivel to the other end of the well pipe. Connect the discharge hose of the pump to the swivel.

(3) Dig a shallow hole. Upend the well point assembly with the well point standing vertically in the hole. Start the pump and partially open the discharge valve. The jet of water will displace the self-closing valve in the well point and flow through the openings in the head. The soil is washed from under the well point, allowing the point to sink into the ground. Up-and-down movement of the well point assembly will speed penetration.

(4) As the jetting continues, increase the flow of water by further opening of the pump discharge valve. In most sands a pressure of 40 pounds per square inch (psi) at the well point nozzle will displace material readily. Pressures of 100 to 150 psi may be needed to move gravel or penetrate clay. If a regular jetting pump is not available, two standard centrifugal pumps operating in series may work satisfactorily.

(5) When the well point has been sunk to the desired depth, remove the hose from the riser pipe. Couple the pipe to the suction side of the pump. Develop the well by quickly opening and closing the discharge valve while the pump is operating at a moderate speed. Continue this operation until all of the fine material is cleaned from the well point screen.

6–19. Completing the Jetted Well

To complete the jetted well, a hose is connected to the exposed end of the well pipe and then coupled to the intake of the pump. The well will yield water immediately, if the pump is in good condition and the well screen has been properly placed. When water is obtained, it is a good practice to direct a stream into the hole around the well pipe at the ground level. This practice washes soil into the hole and packs it firmly around the well screen and pipe. The well is then ready for continuous pumping. At first, a considerable quantity of fine sand will be drawn into the well screen and discharged with the water at the ground surface. This will allow the coarse sand and gravel to pack solidly around the well screen, resulting in gradual clearing of the discharged water.

6–20. Multiple Well Installations

Since the yield from a shallow well is seldom enough to meet the need, a series of wells is usually constructed. The connection and operation of a multiple well installation are discussed fully in paragraph 6-14. Figure 6–24 shows a cross section of a jetted well that has been sand-packed and connected into a multiple well system.

Section V. DUG WELLS

6–21. Description

a. Before modern tools and equipment for well construction were developed, it was common to dig an open pit in the earth to the water table for use as a well. This method is still used in many underdeveloped nations, and in areas where well drilling equipment is not reasonably available. To prevent caving, dug wells are curbed or lined with wooden staves, masonry curbing, or metal curbing. The bottom of the well is left open. Most

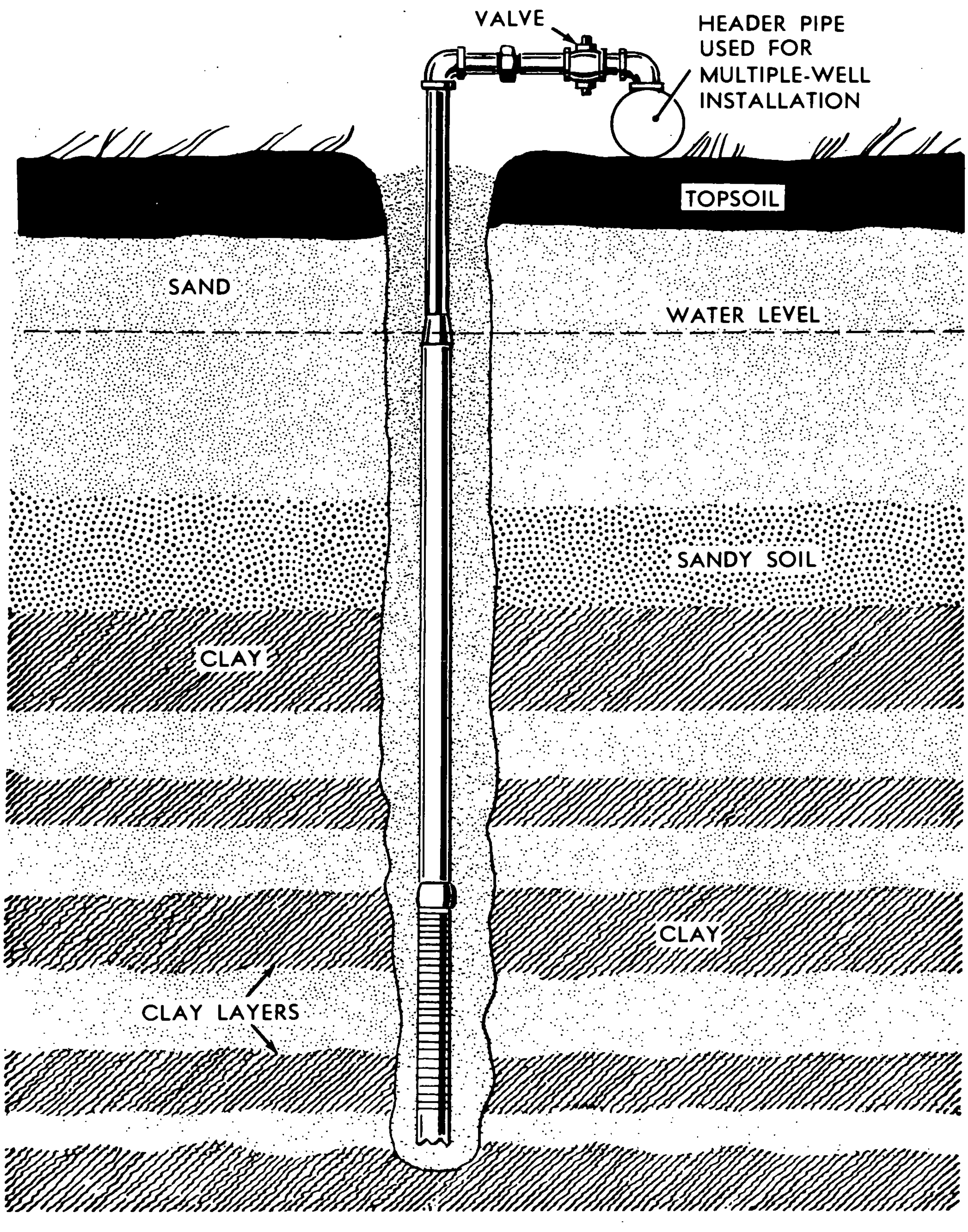


Figure 6-24. Cross section of jetted well.

of the water flows into the well through the open bottom, and is removed by use of a suction pump.

b. Dug wells (fig 6–25) are necessarily shallow and are used where the water table is fairly close to the ground surface. The diameter may range from 3 to 20 feet, generally. Depths of 10 to 40 feet are common. The principal advantage of dug wells is that they can be constructed with handtools. Also, their large diameter provides a reservoir of fair size within the well itself. However, dug wells are subject to contamination by surface seepage, by windblown material, and by refuse falling into them. Their yield is limited because they usually do not penetrate the waterbearing sand to an appreciable depth. Because of these shortcomings, dug wells are rarely used in military operations. However, the dug well is easily constructed as a civil aid in underdeveloped nations. In areas where surface water is highly polluted a dug well (infiltration gallery) near the shore of a lake or stream will yield a better quality of water because of the filtering action of the porous soil.

6–22. Constructing Dug Wells

a. Dug wells are commonly constructed circular in shape, since a circular hole has less tendency to cave. Material is usually excavated with a pick and shovel. A sand bucket or clamshell bucket with a power hoist can be used in digging in sand or gravel, but these machines do not work as well in clay or hardpan (cement-like layers of soil). When digging by hand, a windlass or hoist with a bucket and rope is used to lift the excavated material from the hole.

b. A curb or lining is placed in the excavation before danger of caving develops because of the depth of the open hole. In soft or sandy soil the curb must be begun as soon as the digging is started and moved downward as the pit is deepened. To help sink the curb into the material being excavated, a metal or wooden cutting shoe may be provided at the bottom of the curb (para 6–26). Sheet piling may be used to support the sides of the hole temporarily. This sheeting is later removed when the well is lined permanently with brick, stone, concrete, or metal curbing.

c. When the excavation reaches the water table, a pump is required to keep the water in the pit from interfering with further digging. The pump must be kept within 15 to 25 feet of the water surface; that is, within the limit of suction lift. A foot valve on the suction pipe is desirable to avoid losing the prime each time the pump is stopped. A valve on the discharge side of the pump is needed to regulate the flow of discharge water so it will not exceed the flow that seeps into the well. This will allow the water to be maintained at a desired level without frequently stopping and starting the pump. A sump (reservoir) for the collection of the water draining into the pit should be kept 1 or 2 feet deeper than the floor of the pit as the digging proceeds. The end of the suction pipe should be placed in the sump. A strainer on the end of the suction pipe prevents coarse gravel and rocks from entering the pump and seriously damaging it. An old pump is preferred for this work, since the sand and the fine gravel entering the pump will cause it to wear rapidly.

d. The weight of the material behind the curb and the velocity of the water entering the well under the curb cause sand and gravel to wash into the well. At times, a great amount of sand and gravel comes into the well at one time. This is known as heaving and usually occurs while the well is being pumped. Continued washing or heaving can result in a cave-in. To avoid these difficulties, the cavities which are formed by the washing of sand from behind the curbing should be filled with gravel. The gravel can be fed down on the outside of the curb. If this is not done, a large area around the well may sink. Sinking is particularly likely if a layer of fine sand is encountered, for it is difficult to keep such sand from running under the curb. To prevent the sand from coming in, the sheet piling or staves of the curb should be driven down into the sand and considerable distance ahead of the excavation. If this is not possible, the digger can either stop digging and use the well as it is, or adopt another method of construction. When neither of these alternatives is possible, the well must be abandoned.

Caution: **Until properly ventilated, wells dug by power tools may contain dangerous gases or lack oxygen. Before anyone enters a well it should have been open for several hours. Just before entering, a lighted gasoline or carbide lantern should be attached to a rope and lowered to the bottom of the well. If the lantern remains lit, the well is reasonably safe to enter.**

6–23. Wooden Loose-Stave Curb

a. This curb consists of a series of vertical staves which line the pit and are braced against the walls of the excavation by several rigid frames of metal or wood placed inside the stave lining (fig 6–26). The staves are usually 8 to 16 feet long and 2 or 3 inches thick. Each stave is beveled at the bottom from the inside. The beveled ends force the bottoms of the staves outward as they are

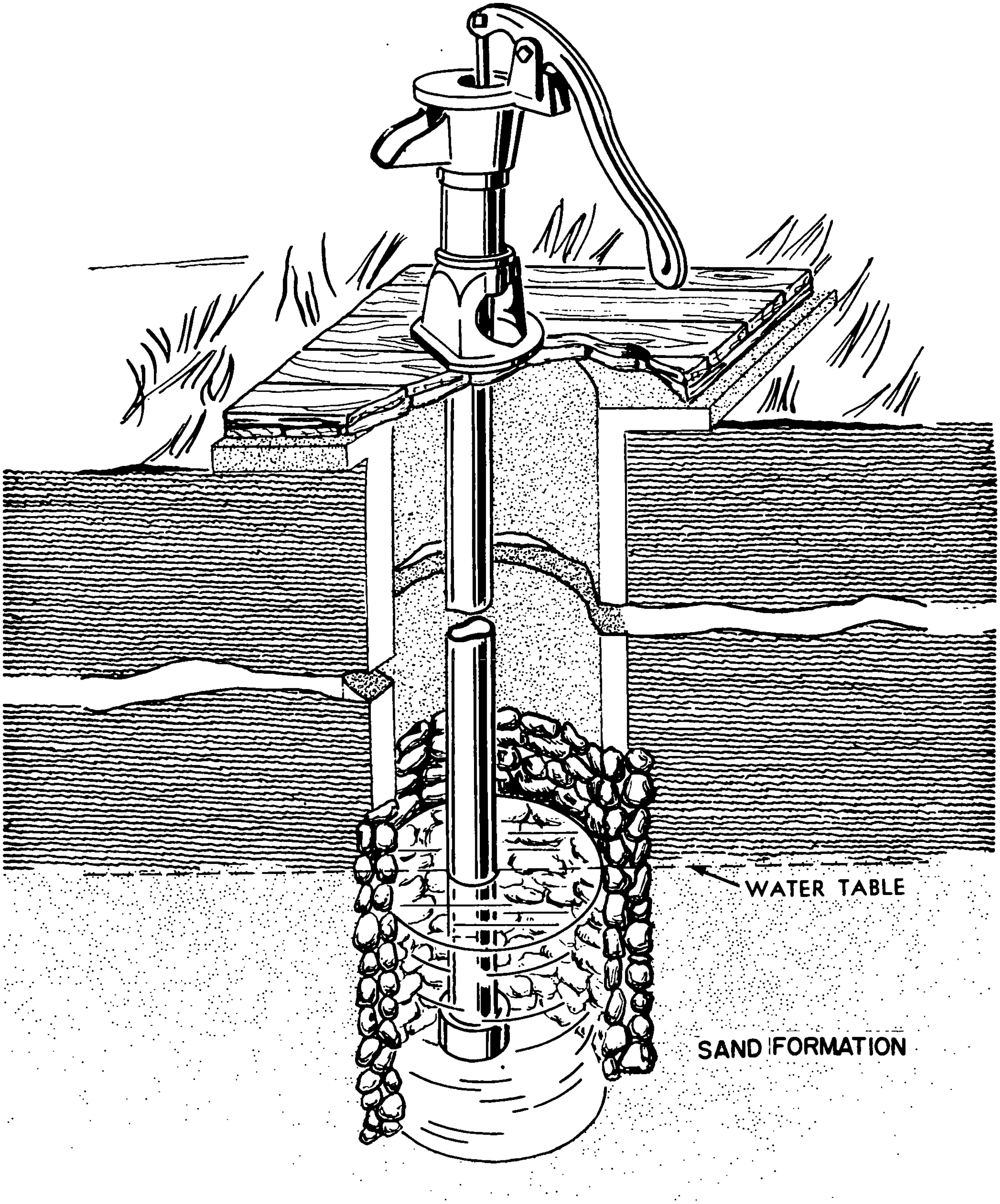


Figure 6-25. Dug well with manual suction pump.

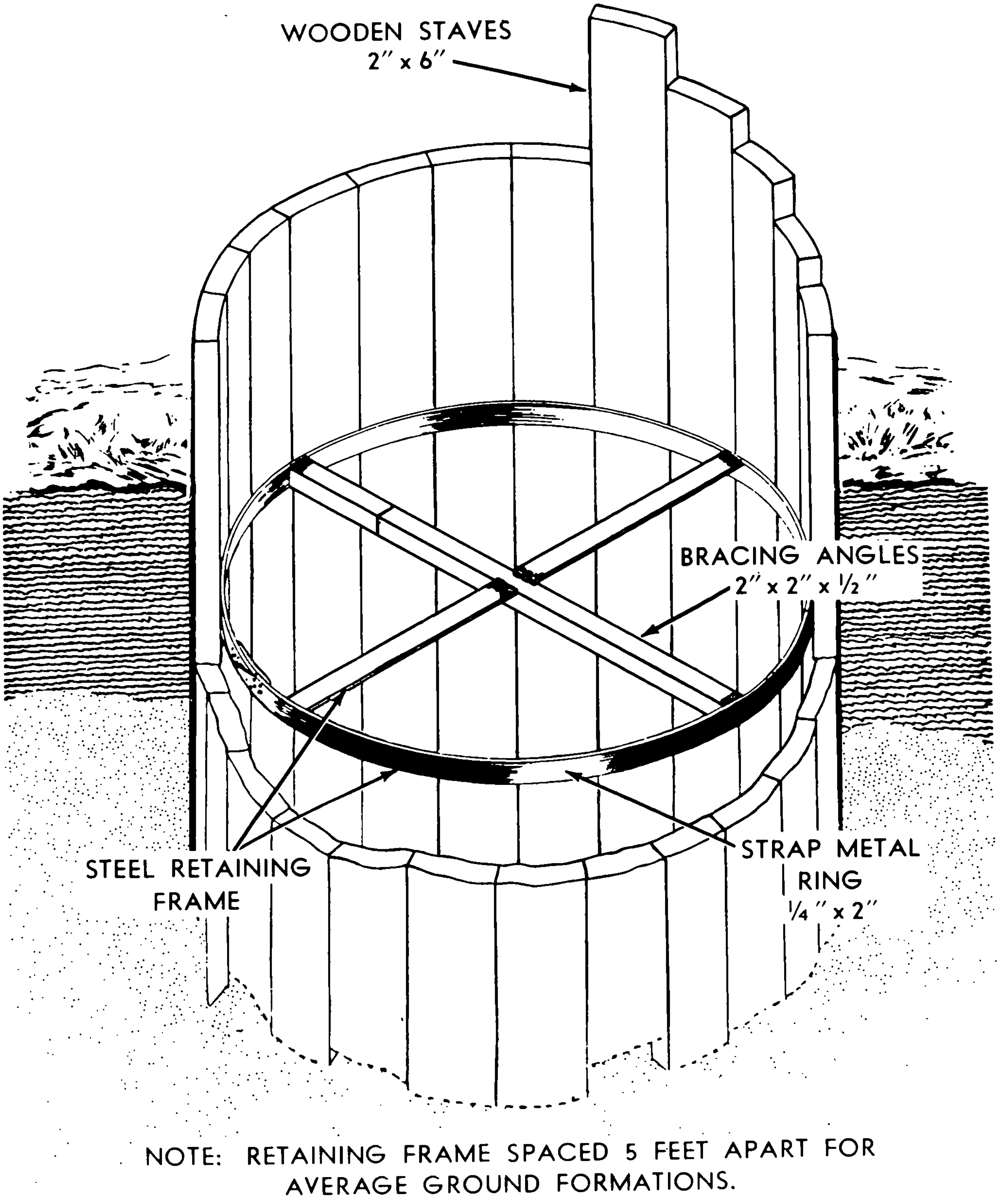


Figure 6-26. Elements of wooden loose-stave curb.

driven into the ground. The upper ends of the staves are chamfered and wrapped with a few turns of wire to prevent the ends from splitting while they are being driven. The staves are placed close enough together to hold out the sand and gravel of the water-bearing formation. As the excavation proceeds, the staves are driven down one by one. The rigid frames hold the staves against the wall of the hole. The frames are driven down occasionally so that the lowest one will be near the lower ends of the staves, thus providing the bracing required at that point.

b. When one set of staves has been driven down as far as possible, a second set is installed inside the first. This reduces the inside diameter of the well. Therefore, the diameter of the hole at the ground surface should be large enough to allow for the necessary reductions.

c. The pressure of the earth on the curb increases as the depth of the well increases. The removal of water from the well to facilitate digging tends to further increase the outside pressure on the staves. Unless the staves are sufficiently reinforced, these factors can produce caving.

6–24. Wooden Fixed-Stave Curb

a. This curb consists of a cylinder formed by attaching vertical staves to a series of rigid frames in the shape of rings (fig 6–27). The frames are made of wood, frequently with angle iron cross braces. The curb is sunk the same way as the loose-stave type, except that bricks, concrete blocks, or other weights are used to force it down.

b. When a fixed-stave curb is used, the water is removed from the well by the methods explained in paragraph 6–22. As the excavation proceeds, gravel is fed around the outside of the curb to prevent heaving. If the well is carried to a solid rock formation, the bottom of the curb should be in contact with the rock at every point, or heaving may result. When the curb is stopped in clay, the excavation should be carried 1 or 2 feet into the clay so sand cannot come in under the bottom of the curb. If the well is carried down to a layer of soft or sandy soil, it can be backfilled with about 2 feet of coarse gravel. If the well is backfilled, a pit should be made for the suction pipe of the pump to keep the pump from sucking air when the well is drawn to the limit. An oil drum, with the head cut out and holes punched in the side, makes a suitable lining for this pit.

c. Under favorable conditions a fixed-stave curb can be sunk as much as 25 feet into the water-bearing formation, but under ordinary conditions 10 feet is the limit, if the hole is kept free of water and the digging done by hand. Some of the difficulties in sinking this type of curb may be eliminated if the water is not removed from the well during the excavation. Excavation may be continued by removing material from the well with a sand bucket or a clamshell bucket hoist. This method gives better results because the water in the well reduces the pressure on the curb and also tends to keep sand from running into the well. If no boulders or layers of clay are encountered, this method is particularly satisfactory.

6–25. Monolithic Concrete Curbs

a. These curbs are concrete poured into rings 3 or 4 feet high. The rings are usually reinforced and cast with a lap joint which is cemented or grouted to the preceding ring. Inside and outside forms are used in pouring monolithic curbs to get a smooth surface that will sink easily. The portion of the curb in the water below the limit of drawdown (para 8–1) is perforated to allow water to flow into the well. These perforations are usually made by casting several short pieces of 1-inch pipe, thin tubes, or pieces of garden hose, when the curb is poured. The tubes are plugged with clay before they are placed in the concrete and are cleaned out after the concrete has set and the forms have been removed.

b. When monolithic curbs are used in constructing a dug well, the rings sink into the ground as the excavation is made and additional rings are added as needed.

6–26. Masonry Curbs

a. Dug wells may be constructed with brick or concrete block curbs. This type of curb must be built upon shoes strong enough to support its weight and to resist distortion. Usually the shoe is made of layers of planks similar to the rings used in wooden curbs, but much heavier. At times a metal shoe is used (fig 6–28).

b. In constructing wells with masonry curbs, the inside corners of the bricks or blocks are broken off to provide passages for the water. The bricks are laid flat. Only a single row of bricks (4-in wall) is required for the walls of small wells, but large wells require two rows (8-in wall) laid end-to-end and tied together every four or five courses by a row of bricks (bound course) laid side-by-side (fig 6–28). The same procedure is used for stone and tile.

6–27. Metal Curbs

Metal curbs are generally made of used material. The bottom of the curb is strengthened by a steel

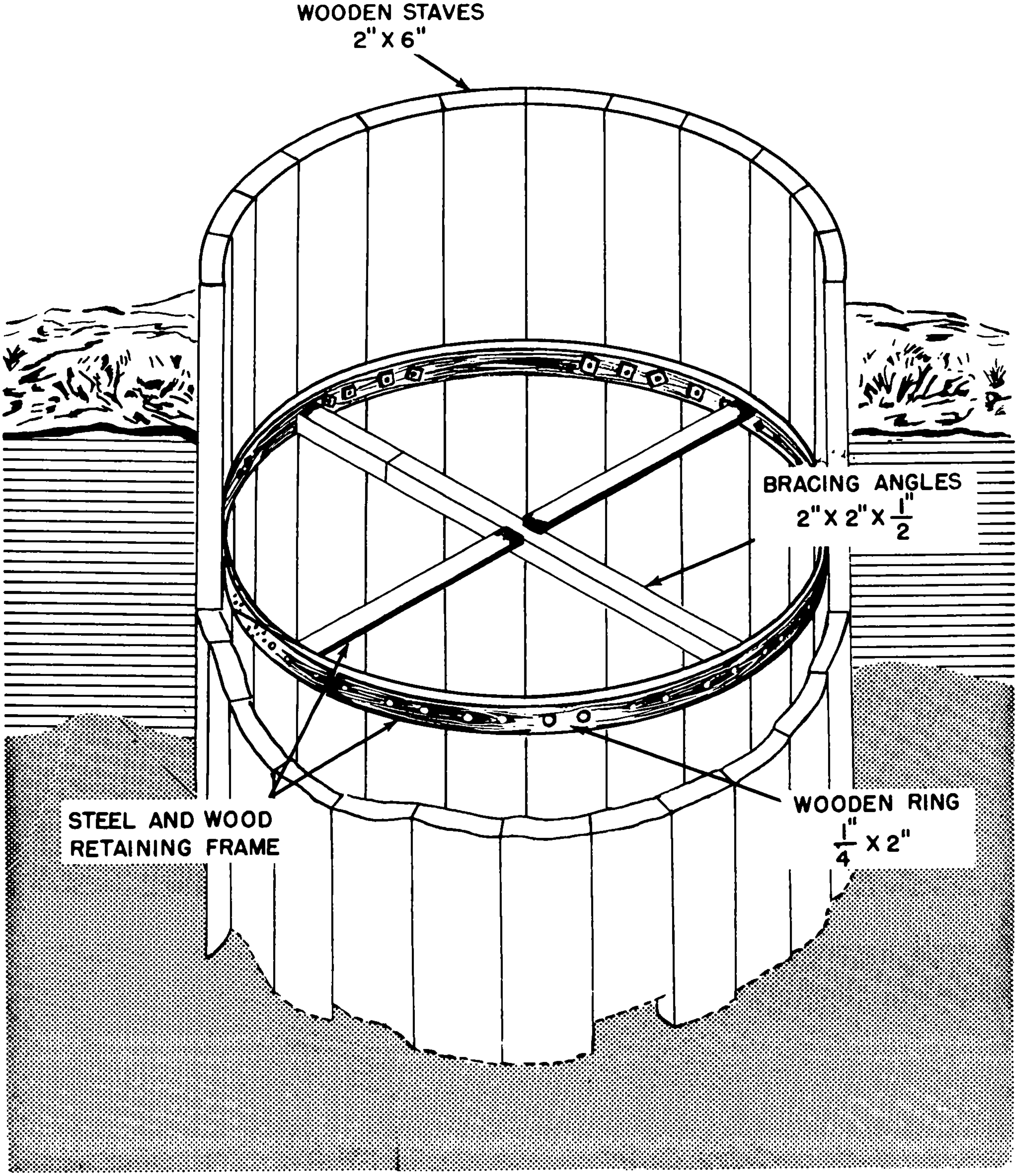


Figure 6-27. Elements of wooden fixed-stave curb.

ring made from a heavy flat bar or angle iron (fig 6-29). If the curb is not rigid, additional stiffening rings are added at intervals throughout its length. Before the curb is placed in the well, it is perforated below the limit of drawdown by punching holes from the inside, by cutting slots with an acetylene torch, or by drilling holes 3/8 to 1/2-inch in diameter. If the curb does not sink readily, it can be weighted on the inside with brick. When this is done, an angle iron, instead of a flat bar, should be used for the stiffening ring at the bottom of the curb to support the bricks. Corrugated culverting, having a diameter of 3 feet or larger, may also be used for curbing. Empty oil drums can be used as an expedient for a metal curb.

6–28. Completing Top of Dug Well

After the excavation of a dug well has been completed, the next step is to complete the top of the well and to prepare it for operation.

a. The curbing of the well should extend at least 1 foot above the ground. A watertight cover must then be placed over the curbing. A concrete

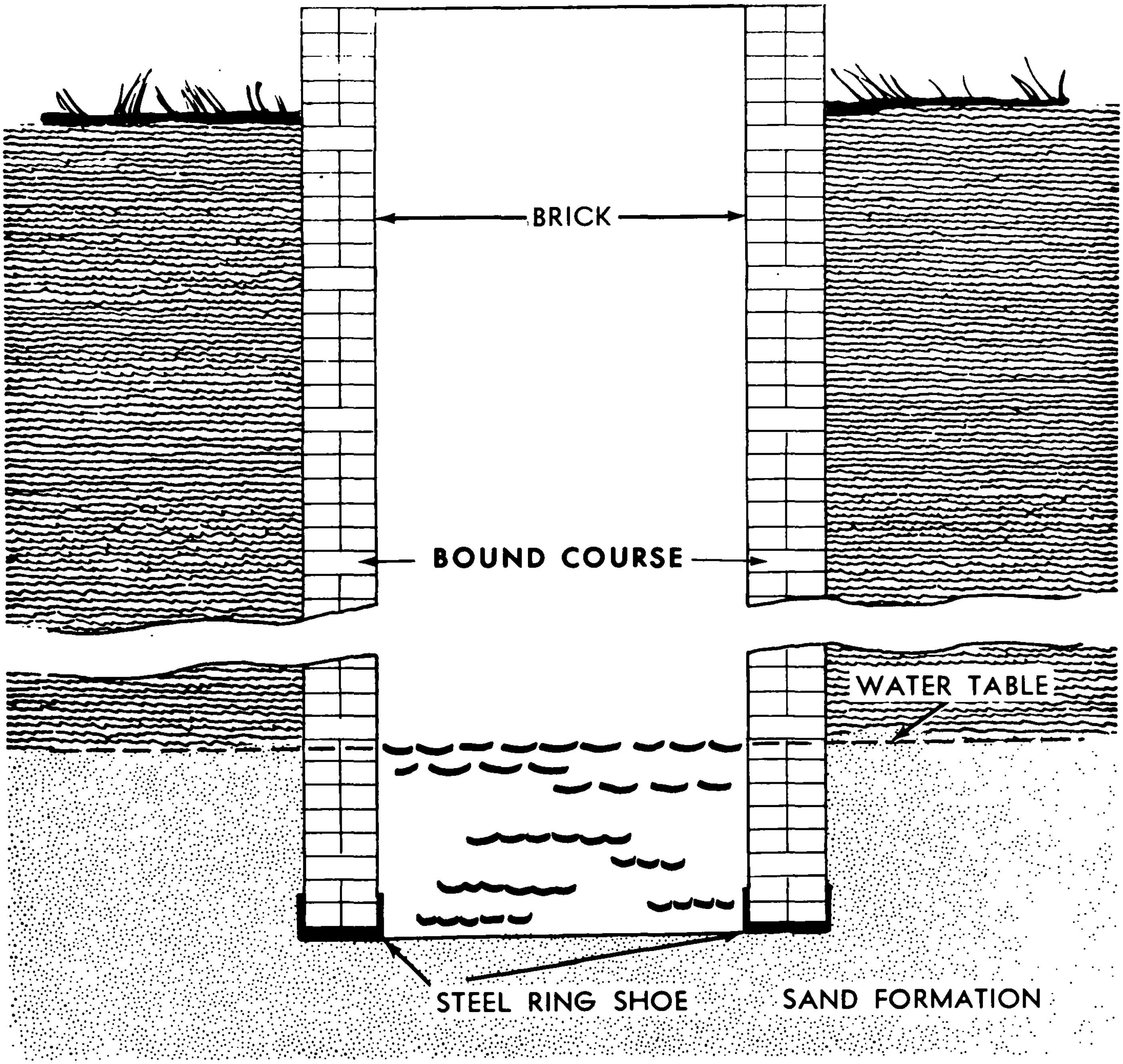


Figure 6-28. Cross section of dug well with brick curb.

cover is preferable since wood covers cannot be kept watertight. An opening must be provided in the cover to allow insertion of a suction pipe.

b. If a relatively small amount of water is to be taken from the well, a pitcher-spout pump may be used. This type pump (fig 6-25) consists of a hand-operated plunger that moves up and down in a cylinder. The cylinder is designed to stand upright on the well cover. The suction pipe screws into the bottom of the cylinder. For more information on this type of pump, see paragraph 9-3.

Section VI. EXPEDIENT WELLS

6-29. Applicability

To develop ground water supplies in areas where standard well drilling equipment is not available, expedient means must be used. Expedient means may be any device, commercial or hand fabricated, used in place of standard well drilling equipment. Factors which govern the use of expedients to construct wells are—

a. Urgency of need for ground water supplies.

b. Availability of qualified local personnel who

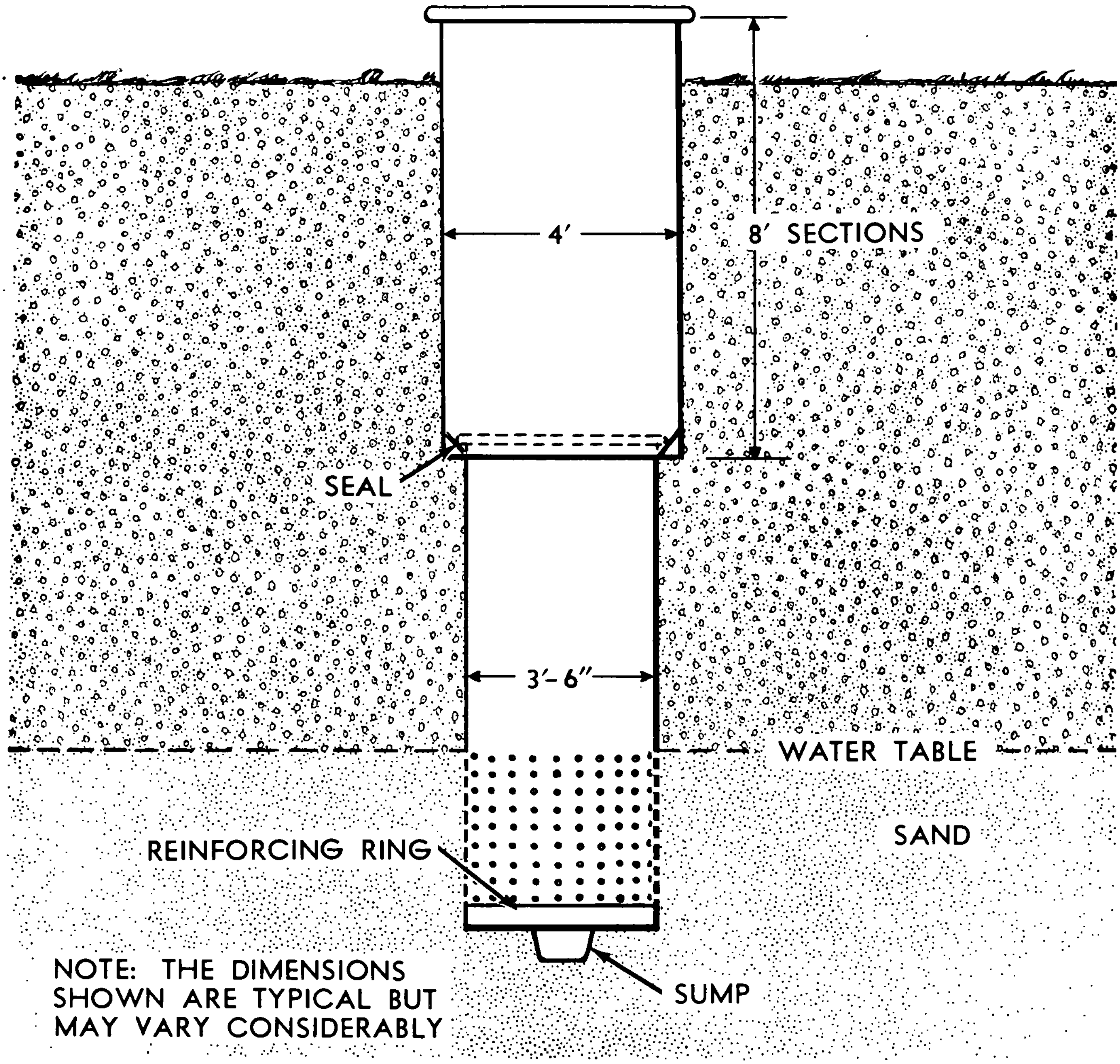


Figure 6-29. Metal curb in place for a dug well.

can construct wells as a civic aid.

c. Adaptability of native equipment and materials for use with available commercial devices.

d. Lack of standard well drilling equipment.

e. Inaccessibility of site to standard well drilling equipment.

6–30. Planning

As in any other type of well drilling, when expedients are to be used, the project must be well planned and coordinated to insure successful accomplishment with minimum delays. In planning expedient well construction projects, primary consideration should be given to three major areas—organization, logistics, and operations. Military personnel engaged in or responsible for such projects must understand and apply the principles involved in each of these three areas to achieve a smooth operation.

a. Organization. The organization need not be made up of skilled personnel. However, the project supervisors should have a basic knowledge of handling pipe and tools, and of choosing proper site locations. They should know the construction methods described in previous chapters and their application to the construction of expedient wells. They must also be familiar with rigging, plumbing, and basic hydraulics. Where project supervisors lack this knowledge, they should receive training in it, or be provided with qualified assistants.

b. Logistics. The logistics required will vary with the type of well to be constructed and its intended use. Material estimates should be developed, minimum requirements determined for the following materials, and action taken to obtain them: piping, including pipe sizes and quantities; timber or other suitable materials for rigs and for constructing cribbing, bracing, and curbing; POL (petroleum, oils, and lubricants) supplies; and miscellaneous construction and administrative supplies. To insure a continuous operation, construction materials should be obtained and located on the site before starting the construction.

c. Operations. The basic purpose of constructing wells by expedient means is to establish ground water supplies by the quickest and most efficient means available and as soon as possible, to meet the water supply needs of military operations and, if necessary, the local populace. To achieve this, the unit or crew must be organized to provide ample personnel for tasks such as digging, driving pipe, and handling well construction materials. The choice of construction methods will depend on the type of tools and equipment available and the capability of the assigned personnel to handle them. The equipment may consist of simple rigs for jetting and driving wells, augers of all types, pressure pumps, air compressors, and lifting and pounding equipment. In many cases, handtools only will be used. A set plan must be developed for the operation, using any of the methods described in previous chapters. Once the crew has been selected, a plan developed, and the needed materials are on hand, operations may begin and proceed step-by-step according to established practice. Although the basic procedure remains unchanged, the drilling techniques used will vary with the equipment available and the climate in which the unit is working.

6–31. Expedient Techniques in Temperature Climates

In temperate climates, digging, boring, jetting, and driving devices into the earth are relatively easy, except where hardpan or rock formations are encountered. Generally, materials and equipment which should be used in well construction can be locally procured. They are likely to be reasonably available in these areas because of heavy population and more extensive use of commercial devices. Therefore, the techniques described in previous chapters should remain essentially unchanged. The only differences expected would be in the equipment used. The construction normally performed by standard well construction equipment would be performed by use of expedient means such as standard military pioneer tool sets, self-priming centrifugal pumps, air compressors, pneumatic tools, lightweight pile-driving equipment, water trailers, and water distributors. With various combinations of the equipment mentioned, and use of methods for both dug and driven wells described in paragraphs 6-6 through 6-15 and paragraphs 6-21 through 6-28, deep wells can be constructed by expedient means. Bored and jetted wells can also be constructed. The operation would proceed according to a set plan.

a. Dug Wells. Using an air compressor with pneumatic clay digger, the soil can be loosened and the spoil material then removed from the hole without much difficulty with a windlass or hoist and bucket. This procedure is continued until the water table is reached. The minimum crew for this operation should be one supervisor, two men to operate the windlass or hoist, two men to operate in the hole alternately, and one air compressor operator. In uncemented soils, a crew this size should be able to complete a minimum depth of 10 to 15 feet per day. A ladder, commercial or handmade, will be needed to make it easier to enter and leave the hole and to provide access to the bottom of the well for making pipe connections to complete the well.

b. Driven Wells. Upon completion of the digging phase the procedures for driven wells are followed, using expedients shown in figure 6–30. The same size crew is used, with one supervisor, two men to handle and assemble pipe, two men to drive pipe, and one man to turn the pipe during driving. A standard well point is connected to the first of a series of 10-foot sections of pipe 2 inches or more in diameter. The pipe is driven, with new sections added as needed, to a depth of 25 feet below the ground surface. If pumps other than pitcher-spout or centrifugal types are used, such as piston, ejector, or turbine pumps, the depth to which the pipe is driven may exceed 25 feet. Driving is continued into the water-bearing formation until hardpan or rock formations are encountered, at which time driving is stopped to prevent damage to the well point. The driven pipe serves as the well casing.

c. Completion of Well. After digging and driving operations are complete, the driven pipe is cut and threaded. Following this, a standard 1/3-horsepower pump jet assembly is attached. A smaller diameter pipe with a foot valve connected to its lower end is extended down inside the casing to the well point. The pipe sizes required for this type of installation are determined by the size of the pump and pump connections used. Refer to appendixes B and C for pump data, capacities, and general specifications. As the final step in completing the well, a suction line and pressure line are connected from the jet assembly to the pump. After pumping operations begin, all leaks detected are corrected, after which the hole is backfilled to the surface. Figure 6–31 shows a typical hookup for a deep well using a jet assembly. Chapter 7 discusses well completion and development in detail.

d. Bored and Jetted Wells. Bored and jetted wells, like dug and driven wells, can be

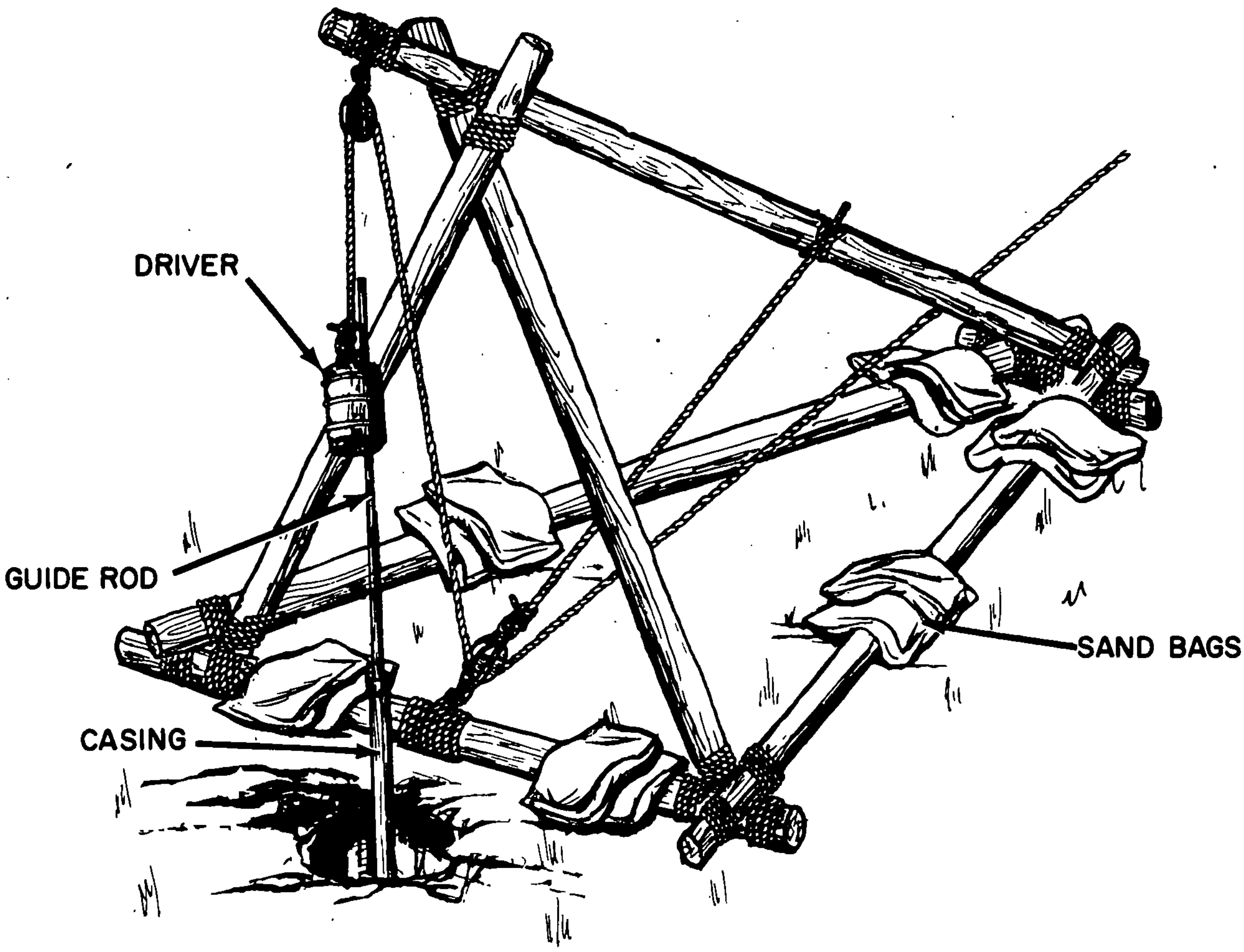


Figure 6-30. Expedient support for driven well.

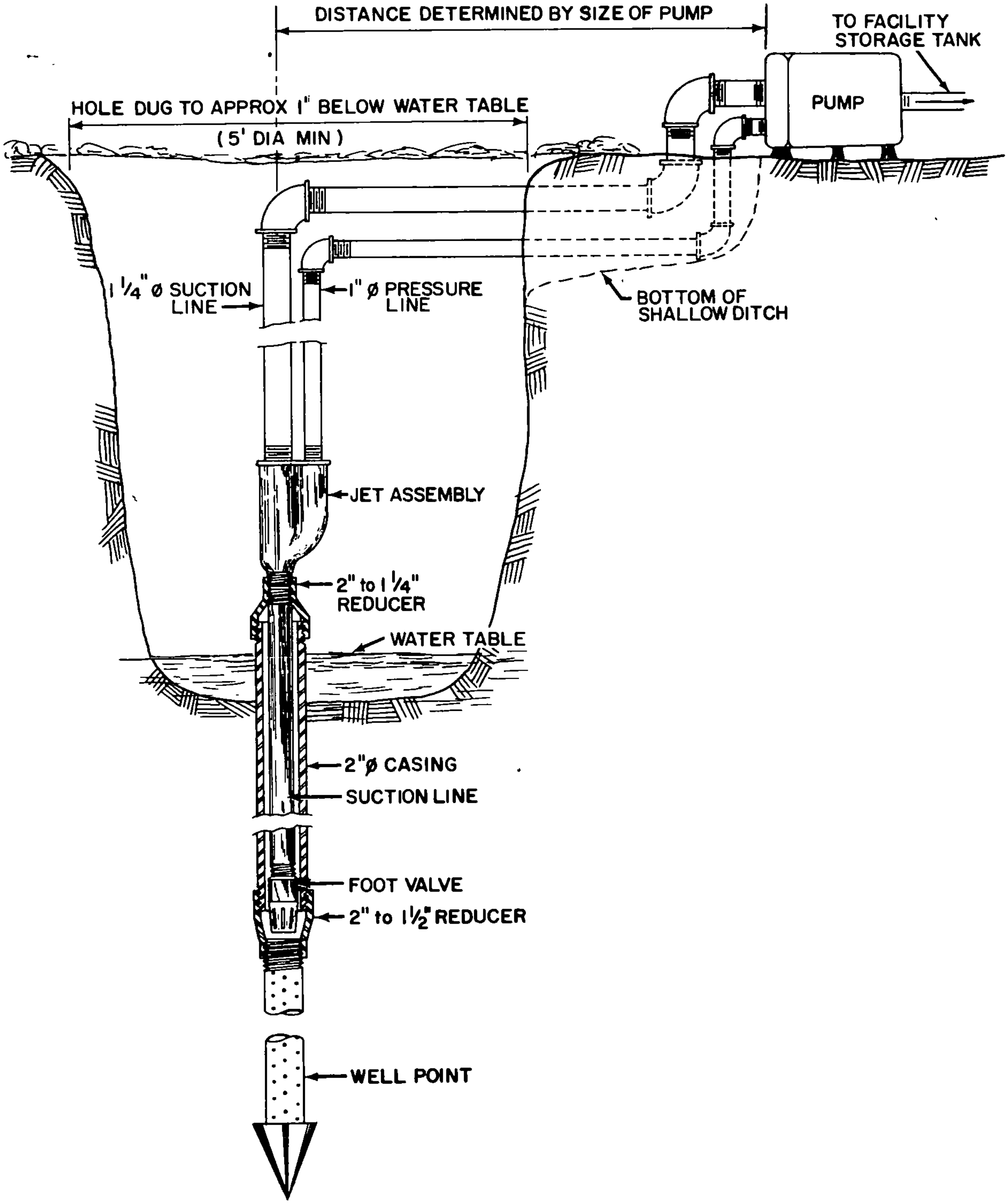


Figure 6-31. Typical hookup for a deep well using a jet assembly.

constructed in temperature climates by using standard construction procedures carried out by expedient means. As an example of expedient techniques for a bored well, the military hand auger (fig 6–1) can be modified to increase its efficiency at greater depths by adapting ratchet and holddown type devices to increase the rate of boring. Large ratchet wrenches and extensions to the auger handles can be used to do this. The handle extensions will provide increased length to allow personnel to apply greater pressure as the auger is rotated. The ratchet device will provide better leverage for turning the shaft, and so increase the rate of boring. For jetted wells, the military standard 60 gpm centrifugal pump can be used to provide high velocity streams of water for jetting. The necessary water can be obtained from lakes or large streams. Figure 6–32 shows a typical expedient setup for jetting. Where water sources are not located near the well site, water distributors and trailers can be used to provide enough water for continuous operation. When water for jetting is in short supply, an air compressor can be used with the water to gain desired results in jetting.

6–32. Expedient Techniques in Polar Climates

Techniques which may be used in polar climates differ slightly from those used in temperate climates, depending upon the polar region. In some regions the wells have to be constructed in permafrost; elsewhere, the underlying material may be a glacier. Wells may be constructed in permafrost by the jetting or driving method. Glaciers may be melted to furnish water. Snow and ice melting devices can be fabricated and used with steam generators to provide an excellent means of obtaining adequate water supplies from glaciers. Details of this procedure are covered in chapter 10. In polar regions where the snow and ice melt during the spring and summer, the jetting method described in paragraphs 6–16 through 6–20 will be used.

6–33. Expedient Techniques in Arid and Tropical Regions

a. The techniques for temperate climates are

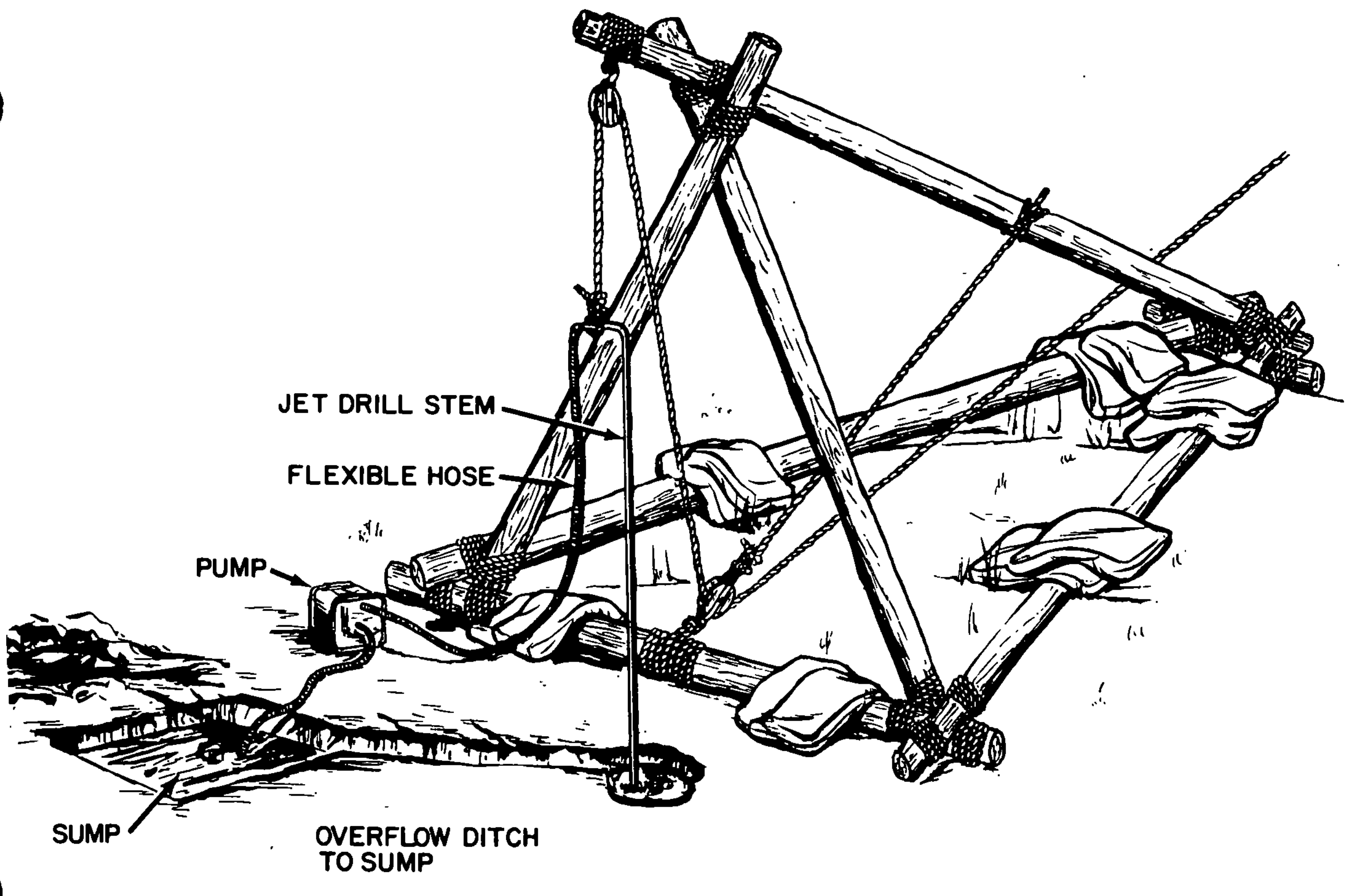


Figure 6-32. Typical expedient setup for jetting.

adaptable to arid and tropical regions, so the methods described in paragraphs 6–2 through 6–5 remain essentially unchanged for these regions. For military operations of long duration in arid regions, provisions are made to develop ground water sources by standard well drilling methods with the appropriate type of equipment. Even in arid regions, some ground water is likely to be available. The Sahara desert in northern Africa, for example, has been studied and it has been determined that at most oases and many other places in the Sahara, ground water is present at depths of 50 to 60 feet, in quantities sufficient to support company size or even larger units. In arid regions, air, rather than drilling fluid, is used with standard military drilling equipment to remove drill cuttings from a borehole. When such equipment is not available, established or expedient methods for dug, bored, and driven wells, or combinations of each, may be used.

b. In tropical regions, or where arid areas adjoin tropical regions, natural tropical materials will be used to assist in constructing wells. The use of materials such as bamboo, small trees, and vines reduces well construction costs considerably. In tropical areas where formations are highly porous and permeable, wells can be constructed by the jetting method, using the techniques discussed in this section and in paragraphs 6–16 through 6–20.

6–34. Tools and Equipment

Tools and equipment which are made from expedients or which can be adapted to expedient use in well construction include such devices as handmade wooden sledge hammers and drivers, driveheads, standard military rigging equipment, jetting devices, pumps, water distributors, piledrivers, augers of various types, and air compressors.

a. Expedient Drivers. Expedient drivers may consist of handmade wooden sledges fabricated from small tree trunks, fitted with handles cut from small saplings. Drop type hammers may also be made from tree trunks. A hole is drilled in the section of trunk and a rod or stick is inserted to serve as a guide to insure uniform striking of the drive head when dropped. Some expedient hammers and driveheads are illustrated in figure 6–33.

b. Jetting Devices. Essentially, all that is needed to jet a well is a device to direct a high velocity stream of water through appropriate piping to force a hole into the earth to the water table. Figure 6–34 illustrates an expedient device which can easily be improvised for jetting purposes, using water only or air and water in combination, with simple pipe connections. The device as fabricated includes a handle for applying downward pressure to aid in penetrating tightly compacted soils. Provision is also made for easily adding more jetting pipe and casing as required.

c. Other Tools and Equipment. A detailed discussion of rigging and the equipment involved is contained in TM 5–725. The well driller should carefully examine the components, capabilities, and performance data of water distributors, piledrivers, power augers, and air compressors as contained in TM 5–331B and TM 5–331C. This will give him an understanding of the potential application of each type in well drilling operations.

6–35. Use of Tools and Equipment for Well Drilling

Since tools and equipment suitable for well drilling may not always be readily available, the devices discussed previously in this chapter may be used to supplement other available equipment, or substituted for unavailable equipment. Improvisation is limited only by the ingenuity of the well driller and the personnel responsible for establishing adequate ground water supplies. However, personnel attempting to improvise with standard military equipment should check carefully whether it is suitable without modification for use in well drilling operations. Further, the well driller is responsible for avoiding and preventing abuse to any tool or piece of equipment used in well construction. Examples of abuse that may occur are continually running the pump on a water distributor after the tank is empty, which damages the pump; and continually applying downward pressure on a power auger when obstacles are encountered during drilling, which eventually damages the auger.

6–36. Civil Aids and Practices

Many tools and aids that are widely used in civil practice are not normally found in military use. Some of these items increase the efficiency of the drilling rigs while others are used to overcome difficulties encountered in drilling operations. Since the number of these tools and aids is so great, only a few of the more widely used items are covered in paragraphs 6–37 through 6–42.

6–37. Mud Pumps

Many mud pumps in use are equipped with variable speed transmissions. These transmissions provide a greater selection of pump speeds, which is very practical, especially in

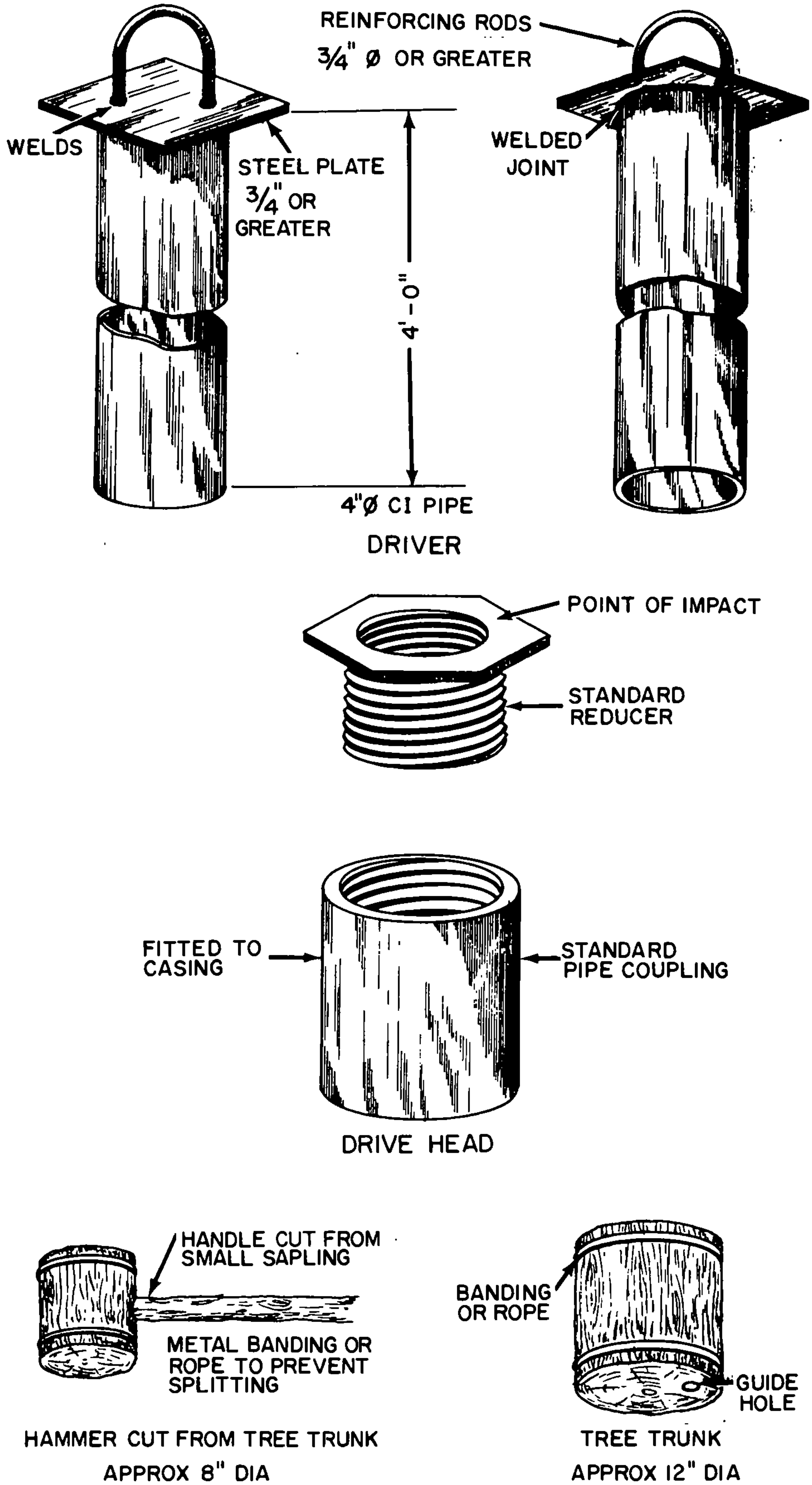


Figure 6-33. Expedient hammers and driveheads.

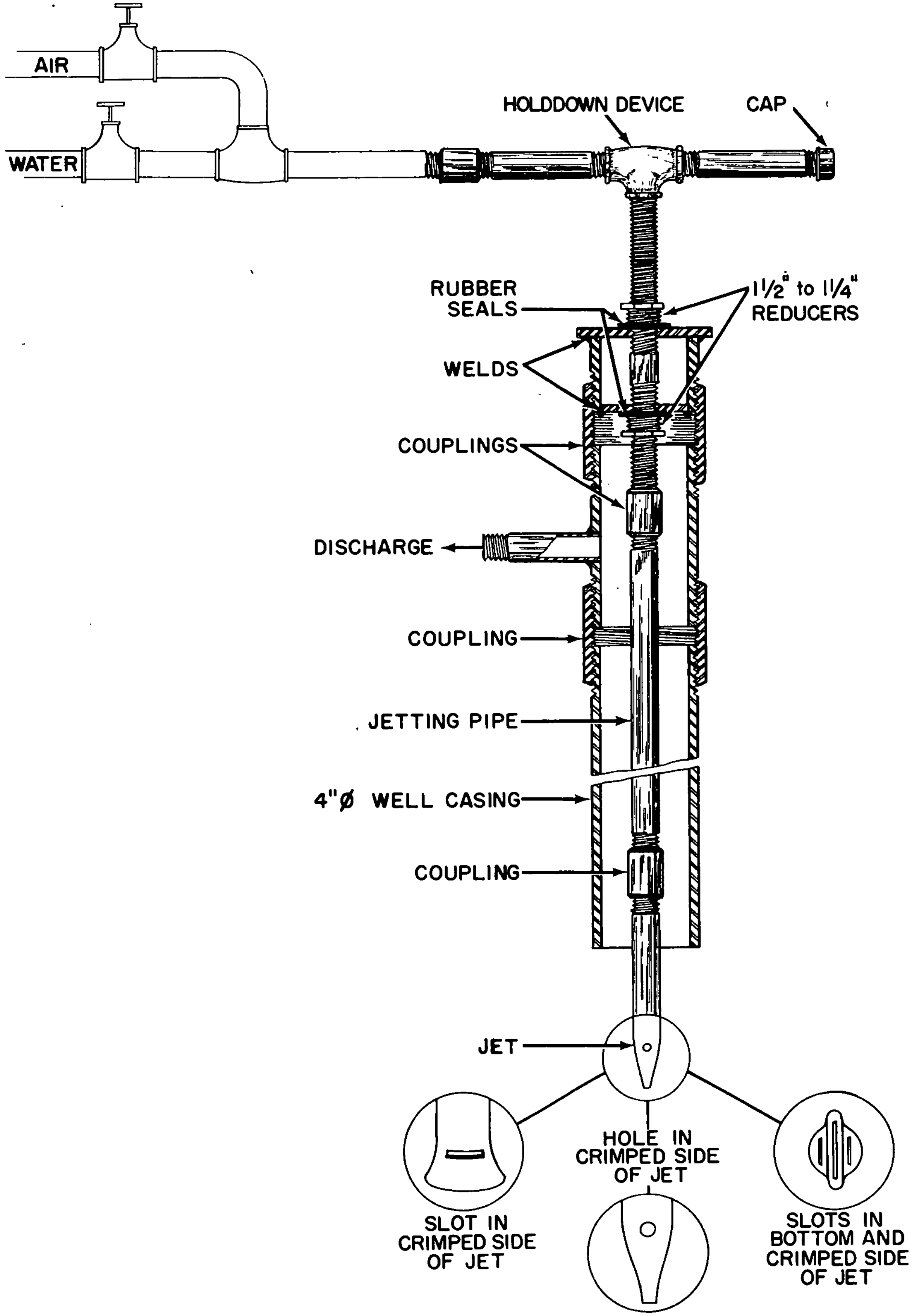


Figure 6-34. Improvised jetting device.

coring operations. Figure 6–35 shows the drive system with the guards removed to give a better view.

6–38. Drilling Fluid

A detailed discussion of drilling fluid used with military drilling equipment is found in chapter 4. This includes coverage of Aquagel, an additive used to increase the viscosity of drilling fluid. Some other additives used in civil practice to increase the viscosity, density, and sealing qualities of drilling fluid are discussed in this paragraph.

a. Hydrated Lime. This product is added to the drilling fluid to increase its viscosity. Drilling fluid thus treated, commonly known as mud, is often used when drilling the first 100 feet or more of hole, to form a cake on the wall of the well. Mud of less viscosity, when used at a shallow depth, may not have enough. hydrostatic head to force itself into the wall to form the correct cake.

b. Weighing Material. This material is added to the drilling fluid to give the mud a greater density, making it better able to offset high water pressure. Barite, iron oxide, and galena are the materials most widely used for this purpose. The weighing material must be finely ground so that 90 percent or more will pass through a 200-mesh screen. Barite, the most commonly used of these additives, has a density of 4.2 and, when mixed with an equal volume of water, will produce a fluid of about 2.4 specific gravity (150 pounds per cubic foot). A specially prepared barite, called Baroid, to which 5 percent Aquagel has geen added, may be obtained on the commercial market.

c. Fibrous Materials. Various fibrous or flaky materials, such as straw, beetpulp refuse, and cottonseed hulls, are added to the drilling fluid when it becomes necessary to seal off a highly permeable formation. These additives tend to seal off such porous formations and reduce the loss of water to a minimum. They also help to prevent caving.

6–39. Drilling and Fishing Tools

Often tools or pipe are lost in a borehole during drilling operations. These tools can be recovered by fishing with specially designed devices. Standard military drilling and fishing tools are covered in detail in chapter 5.

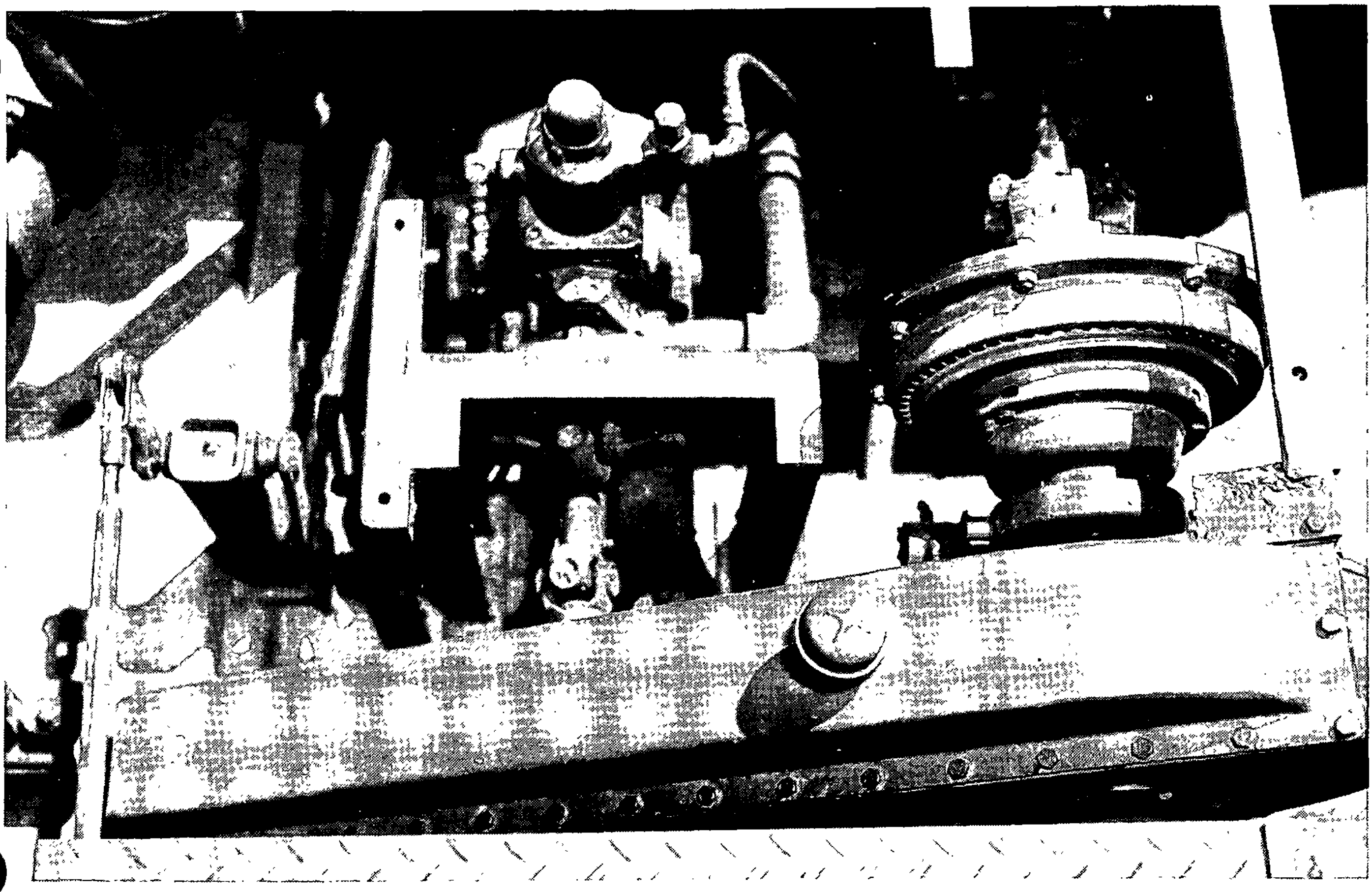


Figure 6-35. Drive system for mud pump.

6-40. Well Completion and Development

a. Selecting Proper Well Screen. When determining the proper well screen to be used in any particular well, it is a general practice in civil operations to wash the drilling fluid from sample cuttings of the water-bearing formation. These cuttings are then analyzed by sieving the material on testing sieves with various sizes of openings. The percentages of the various grain sizes making up the sample are calculated from the amounts of material caught on each sieve. These percentages are plotted against grain size on suitable graph paper, and a curve representing the grading of the sample is drawn. The curve permits accurate selection of the proper slot size for the well screen. For military well drilling, the sieves in the soil test set and the techniques for sieve analysis outlined in TM 5-530 are used. Selection of the proper well screen is based on the plotted curves obtained from the sieve analysis.

b. Artificial Gravel Treatment. In civil practice the pilot hole method of gravel treatment is sometimes used when conditions are favorable. In this method the coarse material is fed through

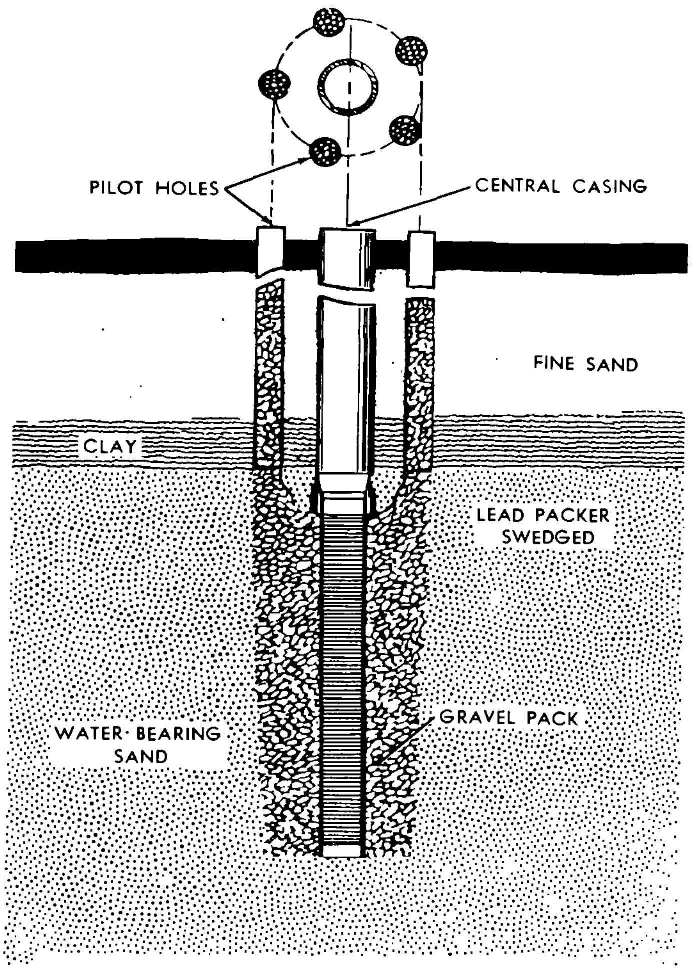


Figure 6-36. Pilot hole method of gravel treatment.

pilot holes drilled just outside the main well as illustrated in figure 6-36. Fine material is brought into the well by surging and bailing, and the coarse material moves down to take its place around the screen.

6-41. Grouting and Sealing Casing

a. Inside-Tubing Method of Grouting. This method of grouting is covered in detail in paragraph 7-17. In this method the grout is gravity-fed or pumped through a pipe set inside the casing. In civil practice, a packer that tightly seals the space around the lower end of the grout pipe (fig 6-37) is sometimes used. This packer is designed to resist the maximum grouting pressure required.

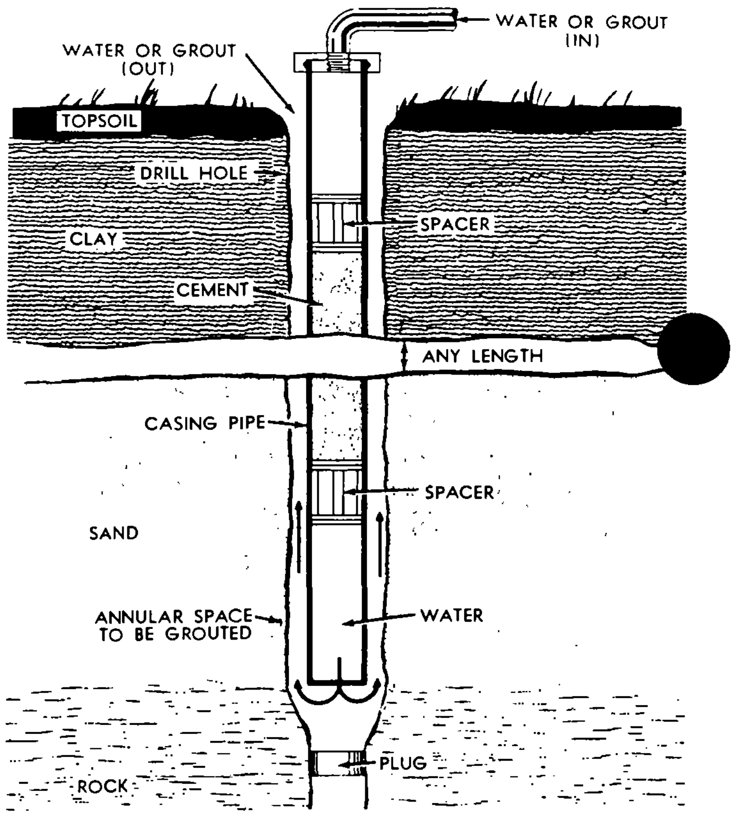


Figure 6-37. Inside grout pipe with packer in bottom of casing.

b. Casing Method of Grouting. There is a patented method (fig 6-38) of grouting used in civil works practice. Briefly, the method consists of the following: the casing pipe is suspended in the drill hole and held several feet off the bottom. A spacer, also called a go-devil, is inserted in the casing pipe. The casing pipe then is capped and connected to the grout pump. The estimated quantity of grout, including a suitable allowance for filling crevices and other voids, is pumped into the casing pipe. The spacer moves ahead of the grout, forcing the drilling fluid out the lower end of the casing. Arriving at the lower end of the casing, the spacer drops or is forced to the bottom of the drill hole, leaving enough clearance to permit the flow of the grout into the annular space and upward through it. After the desired amount of grout has been pumped into the casing pipe, the cap is removed and a second spacer is placed in the casing on top of the grout. The cap is replaced, and a measured volume of water (enough to fill all but a few feet of the casing pipe) is pumped into it. The water pressure forces the upper spacer or traveling plug down to within a short distance of the bottom of the casing, so that most of the grout is pushed out of the casing and up around it. The whole string of casing is then forced to the bottom of the hole and the grout is allowed to set firmly. The plugs and the grout in the bottom of the casing are then drilled out, and the well is completed as desired.

6–42. Reverse Circulation Drilling

a. Reverse circulation drilling is a technique recently developed and is used in civil practice. In this process, the flow of water moves in reverse to that of conventional rotary methods. The mud

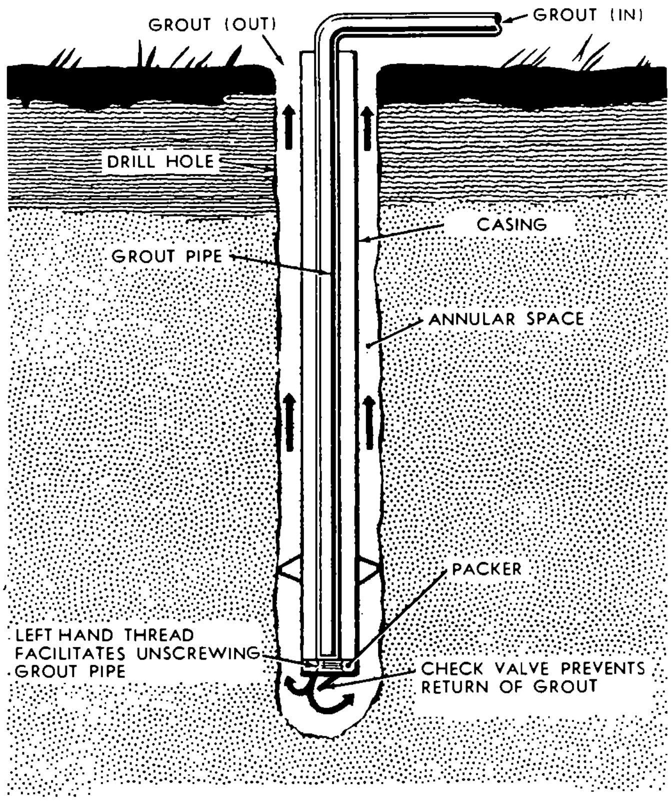


Figure 6-38. Arrangement for placing cement grout through casing pipe.

pump draws the drilling water, cuttings, and solids from the bottom of the hole up through the drill stem, discharging them into the settling pit. This upward velocity (great enough to remove all solids which enter the circulation system) is maintained regardless of the size of the hole. Following discharge into the settling pit, the water is returned to the hole by gravity flow. A drill rig capable of reverse circulation drilling is shown in figure 6-39.

b. Advantages resulting from reverse circulation drilling include faster drilling, elimination of construction casing, greater water yield, and faster casing setting and gravel packing. It should be noted, however, that head differential must be 7 to 10 feet, and the hole must be kept continuously full of water.

(1) *Faster drilling.* In most instances, drilling rigs using reverse circulation will complete a large diameter hole in a fraction of the time required in conventional methods. The positive upward flow and full water course throughout the system remove without pulverizing all cuttings, rocks, and solids which enter the circulation system. Since the major portion of "grinding action" is eliminated, bit life is extended despite the faster drilling.

(2) *Elimination of construction casing.* Along with faster drilling, hole completion and development are speeded since the hydrostatic pressure of the slowly downward moving body of water outside the drill stem supports the hole wall, prevents caving, and eliminates the necessity of construction casing or other time-consuming methods of "holding the hole."

(3) *Greater water yield.* Since little or no drilling mud is used in reverse circulation drilling, the tendency to "seal off" water-bearing strata is eliminated and productive veins are left undisturbed. In addition, well development is speeded since the aquifer or water-bearing formation actually gives and takes water while the hole is being drilled. This action results in the cleaning of the hole during drilling and eliminates extensive development after the hole has been completed.

(4) *Faster casing setting and gravel packing.* In reverse circulation drilling, hole diameters from 12 inches to 18 inches larger than the casing to be set are normally drilled. The resulting large, clean hole permits the casing to be set easily and swiftly, and gravel packing can be completed with a minimum of time and labor.

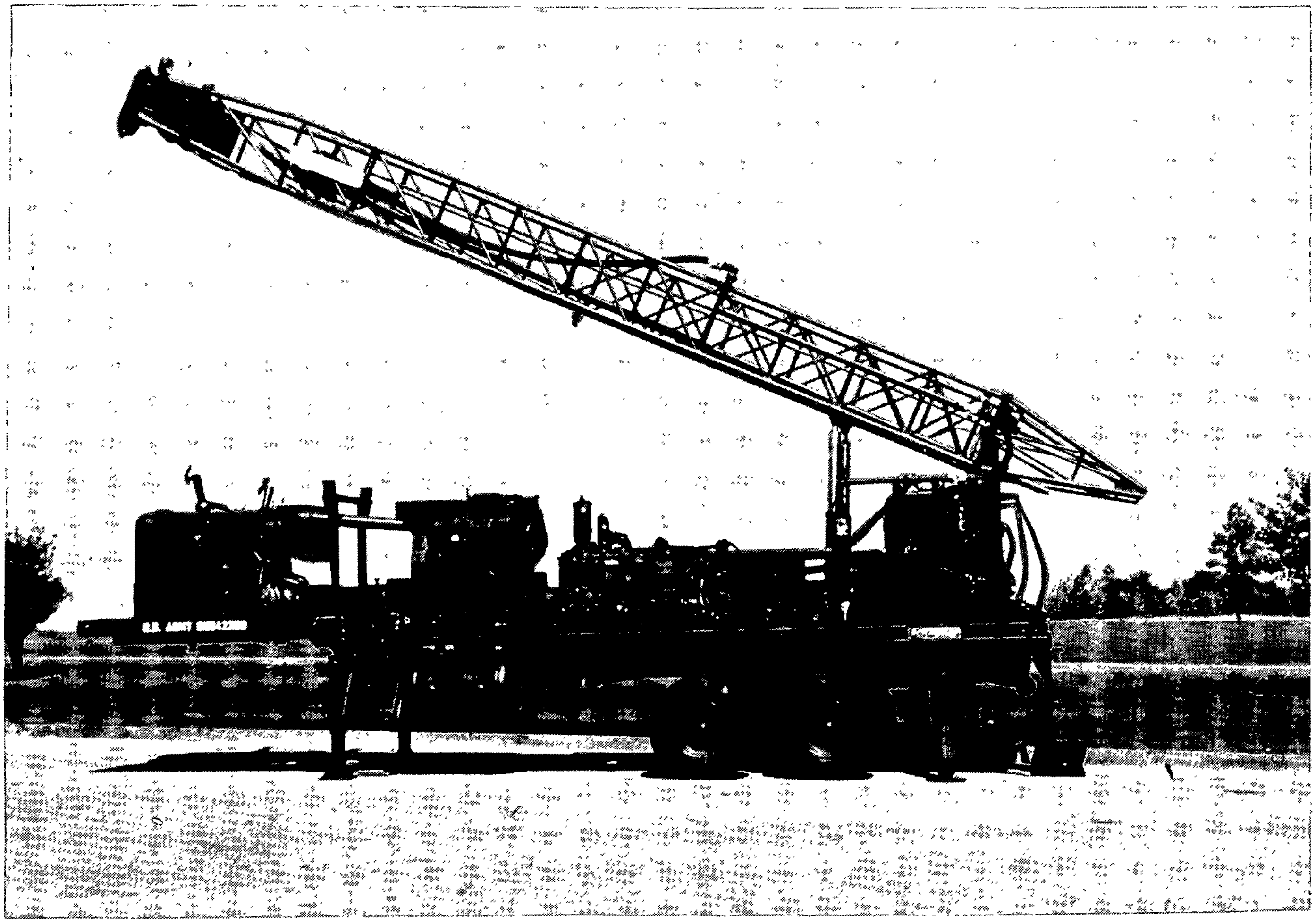


Figure 6-39. Reverse circulation drilling equipment-Portadrill.

CHAPTER 7

WELL DEVELOPMENT AND COMPLETION

Section I. INTRODUCTION

7–1. Elements of Well Completion

The operations described here as elements of well completion include those items of work that must be performed after the actual drilling operations to finish a well for use. The elements of well completion include the installation of casing, well screen, and gravel pack (if necessary), the cementing or grouting of the casing in the hole, sterilizing the well, and providing other sanitary protection.

7–2. Well Development

a. One of the most important operations in completing a well is the development of the water-bearing formation. To obtain maximum efficiency, a screened well is constructed to bring in a predetermined percentage of the finer soil particles for some distance around the well screen.

b. Development of a rock well opens up the fissures, crevices, and channels of the formation by removing the fine particles of sand and permitting the water to flow freely through the water-bearing formation. Well development is covered in paragraphs 7-9 through 7-14.

Section II. SETTING CASING

7–3. General

a. A well is cased (fig 7–1) to prevent collapse of the wall and to prevent surface drainage or polluted water from undesirable aquifers from getting into the well and contaminating it. The casing should extend at least 1 foot above the ground. The space between the outside of the casing and the inside of the hole must be tightly sealed.

b. When the well is being drilled by the rotary method (and sometimes by the jetting method), the casing is usually set in the hole after the drilling operation is completed. An exception to this is when a surface casing must be set through some of the upper formations before drilling can be continued to greater depths. This is sometimes necessary to prevent caving of the upper portion of the hole or to prevent the hole from being enlarged by the washing action of the drilling fluid. The procedure for handling casing and setting it in the hole is described in paragraph 4-33. Grouting and sealing of the casing in the drilled hole are described in detail in paragraphs 7-17 through 7-19.

Section III. WELL SCREENS

7–4. Well Screens and Fittings

a. Function. An intake device called a well screen must be installed when completing a well in a water-bearing sand and gravel formation, or aquifer. The well screen is a highly specialized and important piece of equipment used with any well which taps a sand and gravel formation. Proper selection and installation of the screen largely determines the efficiency of the completed well. The well screen supports the formation, prevents caving, and allows water to enter the well easily through closely spaced openings. The screens are made with openings of various sizes to fit the gradation of the water-bearing sand. The drive-well point, the continuous-slot screen, the wire-wrapped pipe-base screen, and the brass tubular screen are the types most commonly used.

b. Drive-Well Point. The drive-well point is designed to withstand the abuse involved in being driven through the soil to a position below the water table in the water-bearing sand. Intake area and screen efficiency are sacrificed, to some extent, to make the well point strong enough to withstand being driven. Details of well point construction and installation are discussed in paragraph 6–7.

c. Continuous-Slot Screen. The continuous-slot screen (fig 7–2) is the screen most commonly used by Army engineers. It may be lowered into a hole previously drilled into the water-bearing formation. When equipped with proper end fittings, the screen can be sunk a reasonable distance below the bottom of a drilled hole by a bailing-down operation or by jetting. The

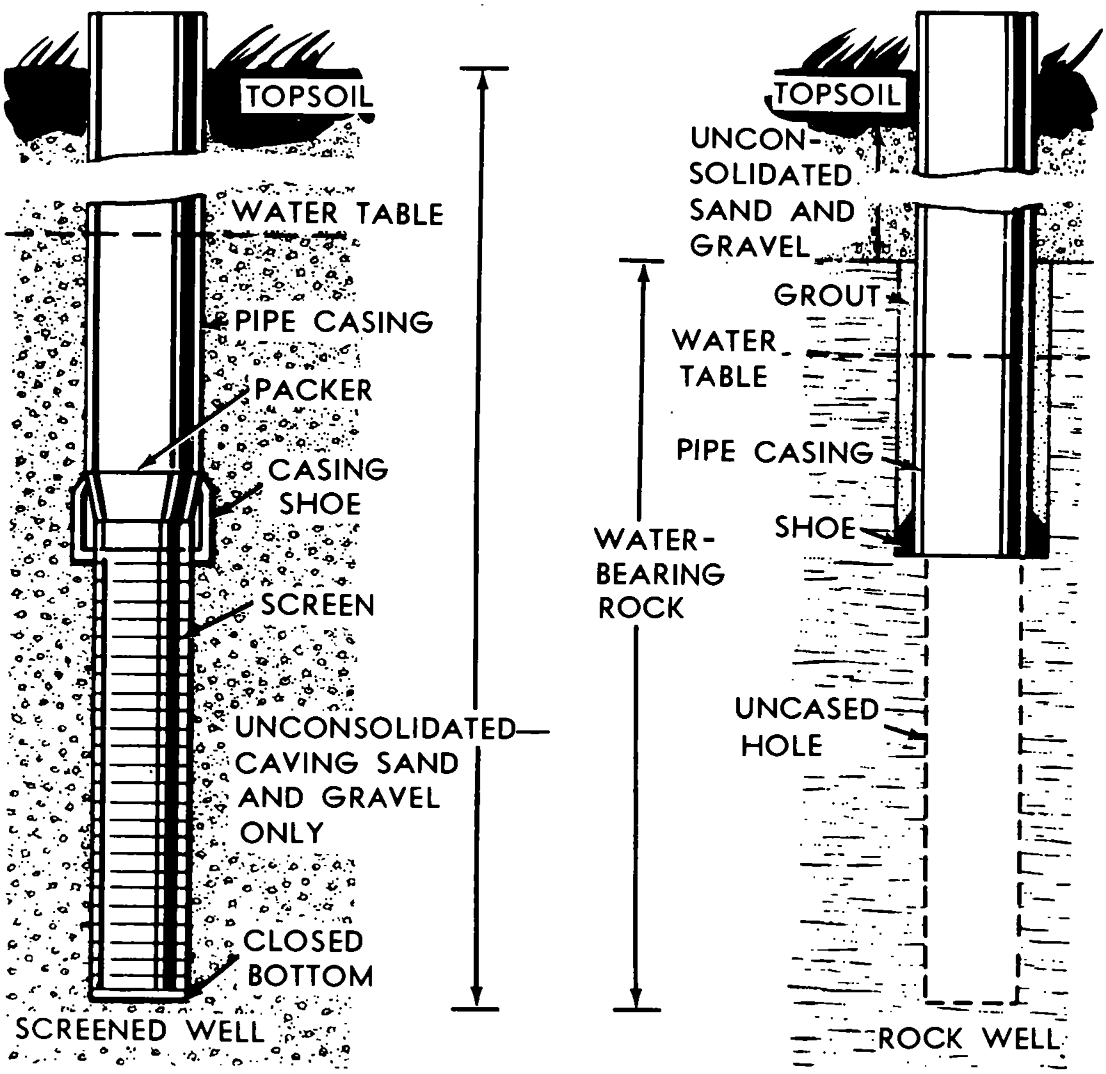


Figure 7-1. Well casing and well screen in place.

continuous-slot screen is made by winding cold-drawn wire, approximately triangular in cross section, spirally around a skeleton of longitudinal rods. The wire and rods are securely joined at each point where they cross. The wire and rods may be joined either by welding the wire to the rods at each intersection, thereby making the screen a strong, one-piece unit, or by calking the wire in notches cut in the rods. The screen openings are made by spacing the successive turns of the outer wire to form slot openings that are continuous around the entire circumference of the screen. This method of fabrication produces a screen with the greatest possible amount of open or intake area, coupled with adequate strength to withstand the forces which the screen must bear during and after installation. Each slot opening formed between adjacent wires is V-shaped in cross section, with sharp outer edges, which result from the special shape of the wire used. The V-shaped openings are narrowest at the outer face of the screen and widen inwardly. They are designed in this manner to make them nonclogging. Any grain of sand that will pass the sharp lips of the V-opening will easily pass through the screen without wedging in the opening.

(1) The screens normally stocked in Army supply points and depots are 4-inch and 6-inch nominal diameter. These screens have 3 3/4-inch and 5 5/8-inch outside diameters, respectively. The smaller size will telescope through 4-inch pipe casing and the larger size will telescope through 6-inch pipe casing. The screens are in 10-foot sections, but two or more sections may be assembled to form a longer screen when required. Some of the screens stocked have No. 16 (0.016-in.) openings, and are for use in medium sand

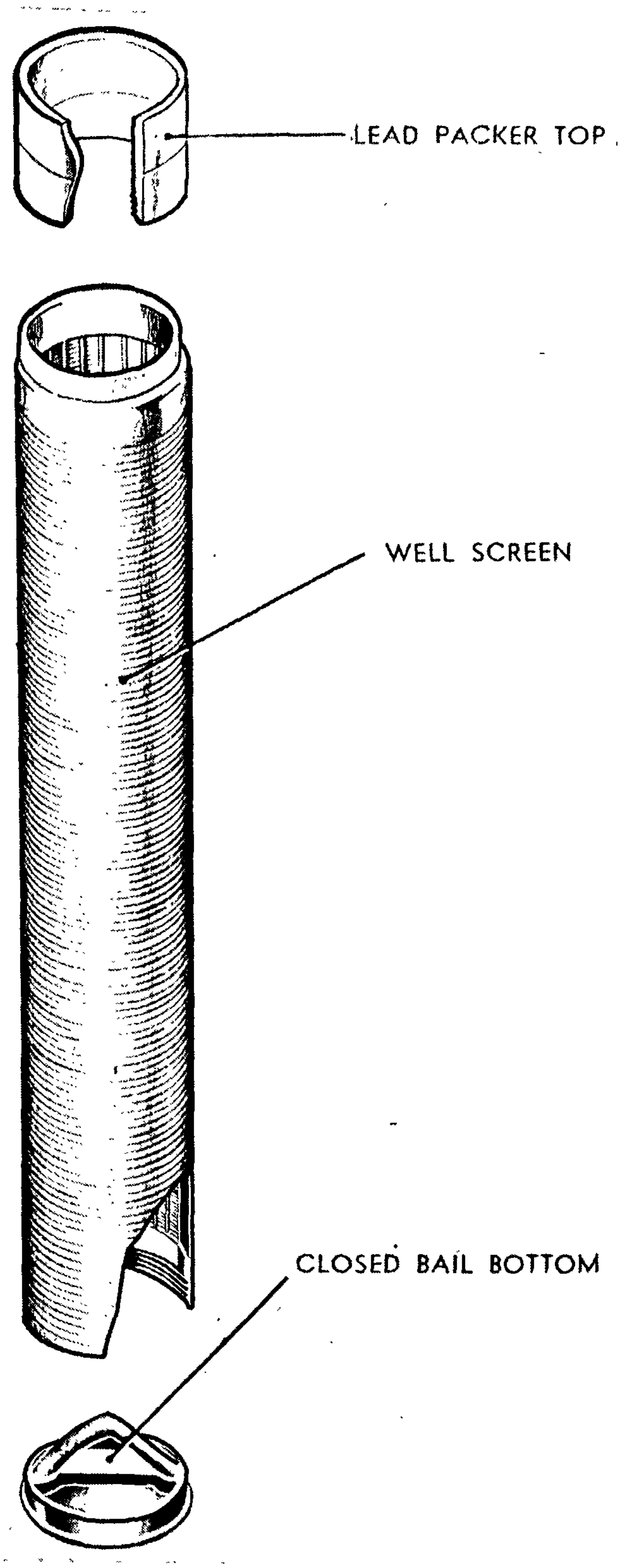


Figure 7-2. Continuous-slot well screen.

formations. Others have No. 40 (0.040-in.) openings, and are for use in coarser formations containing some gravel.

(2) These screens may be used in wells drilled by the rotary and jetting methods. Various types of end fittings are available for the screens to permit their installation by any of several different methods. Bottom and end fittings are illustrated in figures 7-3 and 7-4. The uses of the various fittings are described in the instructions on ways to install screens.

d. Pipe-Base Screen. The pipe-base screen (fig 7-5) is made by wrapping a trapezoidal shaped wire spirally around a pipe base which has been perforated first by drilling holes in it at regular intervals. This type of screen has two sets of openings. The outer openings are the spaces between adjacent turns of the wrapping wire; the inner openings are the holes drilled in the pipe base. The total area of the perforations in the pipe base is much less than the total of the slot openings formed by the outer wire, so the efficiency of the screen depends upon the percent of open area of the pipe base. This is usually quite low. For Army use these screens are furnished in two sizes, one with 3-inch pipe base and the other with 4-inch pipe base. The screens have 4-inch and 5 1/8-inch outside diameters, respectively. Screens with three different sizes of openings are stocked—No. 20 (0.020-in), No. 30 (0.030-in), and No. 40 (0.040-in) slot openings. Lead packers and other end fittings (fig 7-5), corresponding in size to 4-inch and 6-inch casings, are furnished. Figure 7-6 shows how the spring-loaded valve is assembled in a coupling at the lower end of the screen to make a self-closing bottom. The purpose of the wooden wash plug is also illustrated.

e. Brass Tubular Screen. Brass tubular well screens (fig 7-7) are made by milling horizontal slots in brass tubing. The slot openings are cut so they are narrowest at the outside and widen inwardly. This makes V-shaped openings that are nonclogging. Slot openings from 0.006 inch to 0.100 inch can be cut. Each slot is from 1 to 2 inches long depending on the diamater of the screen. The brass tubular screen has a satisfactory percentage of open area, but it is considerably less than the continuous-slot screen. Rather, thin-walled brass tubing is used in making this screen, so it is not as strong as the other types described. Various end fittings are provided for brass tubular screens to permit their installation by any of several methods.

7–5. Selection of Proper Well Screen

The selection of the well screen for a particular well involves the choice of length, diameter, and size of openings of the screen. The screen must be fabricated of metal that will resist the corrosive effects of the water. The total area of the openings

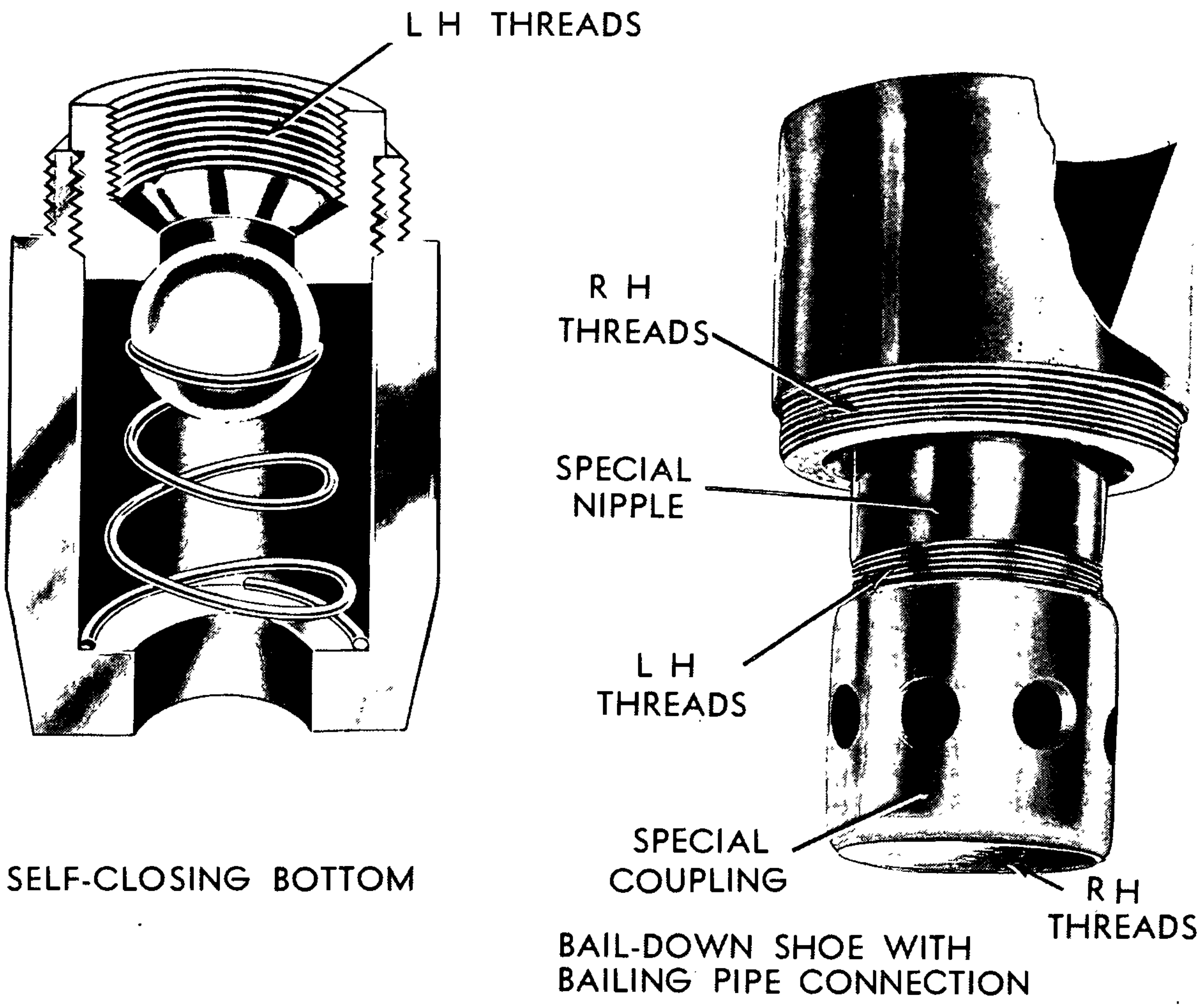


Figure 7-3. Two special bottom fittings.

varies with the length and diameter of the screen, and the size of the openings should limit the entrance velocity to 5 feet per minute.

a. The proper length of screen depends primarily on the thickness of the water-bearing sand formation. For a relatively thin layer, the length should be about equal to the thickness of the sand formation. For near-maximum well efficiency in a thick aquifer, the length of the screen should be about equal to one-half the thickness of the sand. This rule may be modified somewhat if the water-bearing formation consists of different strata, both fine and course. In such a case, the thickness of the coarser strata should be given more consideration than the finer portion in choosing the screen length. The screen should be set in the coarser strata in completing the well. The percent of open area, or intake area, of a well screen should also influence the choice of length.

b. The diameter of the well screen selected usually corresponds to the diameter of the well casing. Providing a large enough space for the pump that is to be installed in the well is usually the primary factor in choosing the diameter of the well casing. The yield or capacity of a well increases with an increase in screen diameter, other factors remaining the same. However, the increase in yield is not in the same proportion as the increase in diameter. *For example,* doubling the diameter of a well screen will, in theory, raise the capacity of the well only by bout 20 percent. As a rule, it is more important to use a larger diameter screen if the aquifer is thin. Where a long screen can be used in a thick water-bearing formation, a smaller diameter will operate efficiently. In general, if a thick aquifer is available, the yield of the well to be constructed will be increased more by increasing the length of the screen than by increasing its diameter.

c. The size of screen slot openings should be chosen to fit the gradation or grain sizes of the water-bearing sand or gravel. The proper selection of the size of openings is highly important in designing for maximum efficiency,

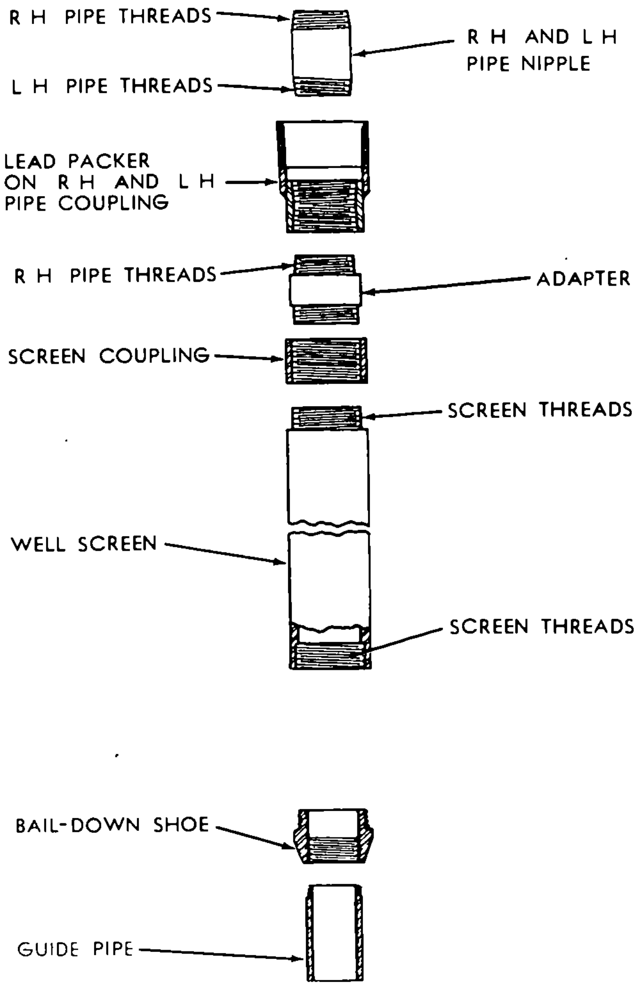


Figure 7-4. Various end fittings for well screens.

because the relation between the slot size and the grain sizes of the sand greatly affects the development of the formation around the screen. If the openings used are too small, the yield of the well will be limited by inadequate development. The small openings result in too high a velocity of the water passing through them. This may cause scale or incrustation to form in the sand just outside the screen over a period of time. If the openings are too large, too much development work may be necessary; and it may even be impossible to clear the well of sand. Obviously, the refinement in screen selection applied to civil works must be modified to some extent for military field operations, because it is not practical to stock screens in a complete range of slot openings.

(1) Tests and experience show that a screen slot size that will retain the coarsest one-third of sand or gravel in the formation in which the screen is to be installed is about right. The screen slot openings will then be large enough to let about two-thirds of the sand pass through. If the screen is to set in two strata, one fine and one coarse, each section of the screen must have openings of a different size. *For example,* the upper section of the screen may have small openings to fit fine or medium sand, and the lower section may have larger openings to fit a stratum of mixed sand and gravel.

(2) If the well screen is to be artificially gravel-packed, the screen slot openings should correspond to the size of the gravel used (para 7–15). Tests and experience show that screen openings which will retain from 3/4 to 9/10 of the gravel are best. Thus, only a few of the gravel particles will pass through the screen openings during the development operation, which is the desired condition for gravel-pack construction.

7–6. Setting Screens in Down-Hole Drilled Holes

Several ways to install well screens in wells drilled by the down-hole method are described below. The types of end fittings that are best suited to each method are indicated. Two tools used frequently when setting well screens are the screen hook and the swage block (fig 7–8). The hook engages the bail in the closed bail bottom of the screen and is used to suspend the screen on either the sandline or the hoist line when lowering it in the well. Do not try to pull a screen with the hook after the formation has closed in around the screen. The swage block is used to expand the lead packer to seal the top of the screen inside the well casing. To operate this tool, lower it in the well and seat the block in the lead packer. Raise and drop the sliding bar that runs through the center of the swage block several times, and the block will expand the packer as the result of these light blows. Do not raise the bar far enough to lift the block out of the packer while swaging. Only light taps are needed to deform the lead ring. The conditions encountered determine the method to be used for a particular well. Every method requires taking accurate and complete measurements of pipe length, screen length, cable length, and depth of hole. To avoid costly mistakes, measure; do not guess.

a. The simplest and best way to install a screen is by the pull-back method (fig 7–9). For this operation, sink the well casing to the full depth of the well and clean out the hole to the bottom of the pipe with the bailer. Assemble the closed bail plug in the bottom of the screen, and screw the lead packer fitting to its top. Lower the screen

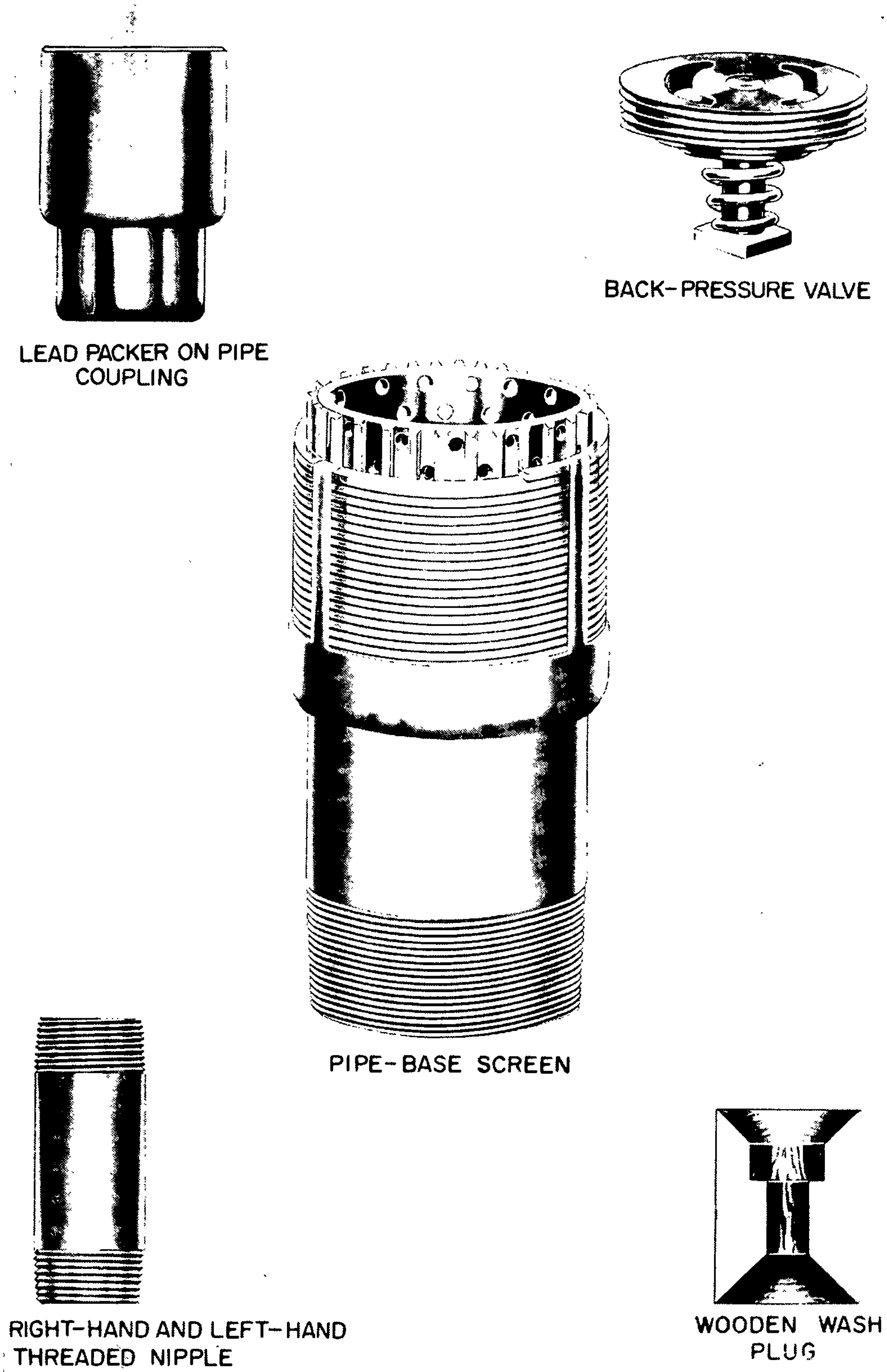


Figure 7-5. ① *Pipe-base screen and end fittings.*

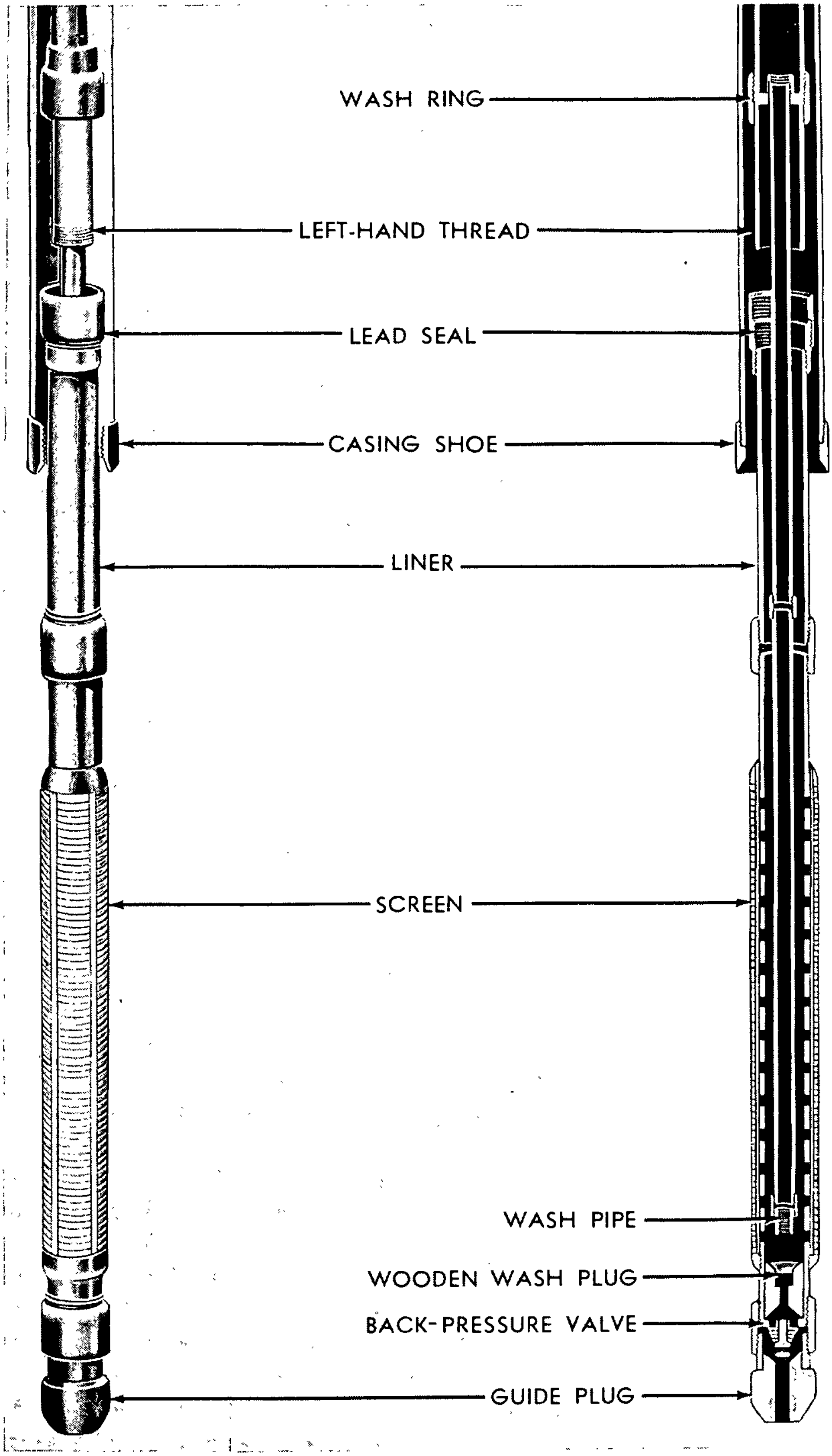


Figure 7-5. ② Pipe-base screen and end fittings. —Continued.

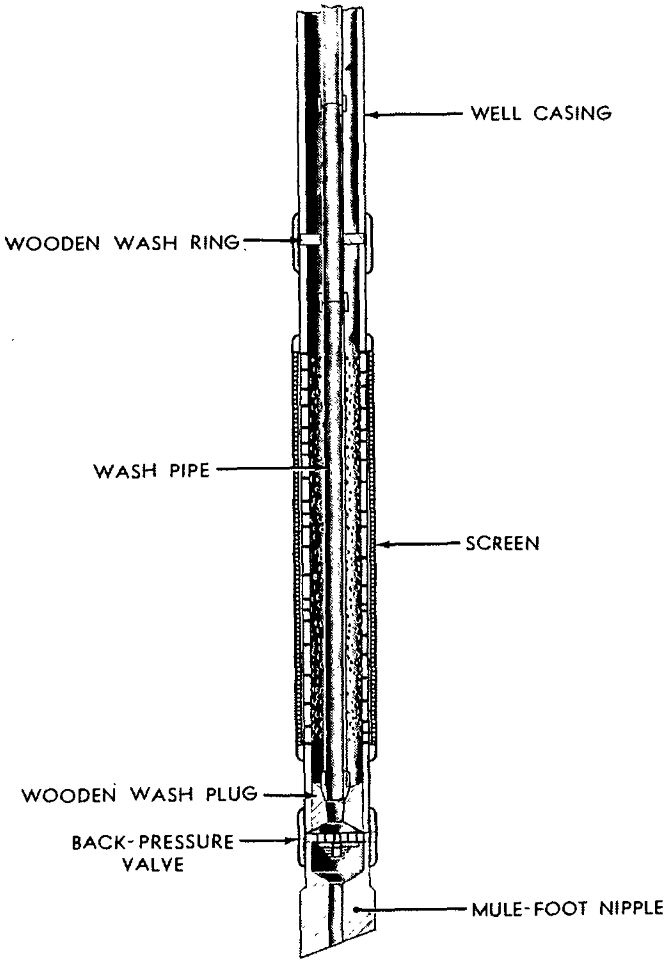


Figure 7-6. Single-string assembly of screen and casing with wash-down fittings.

inside the well casing, using the sandline. After setting the screen on the bottom, pull the casing back far enough to expose the screen in the water-bearing sand to a position in which the lead packer is still inside the pipe. Expand the lead packer to the inside wall of the pipe by a few light blows of the swage block to make a sand-tight seal, and then proceed with development of the formation. A casing ring and slips (fig 6–11), together with two hydraulic•jacks, are usually needed for pulling the pipe. If the screen moves upward as the pipe is pulled, lower the drill bit or other tool inside the screen to hold it down.

b. A second method of installation is to drill an open hole ahead of the casing to receive the screen. In this case, sink the well casing into the water-bearing sand to a depth a little below the desired position for the top of the well screen. Mix drilling mud and fill the casing with the fluid. Drill an open hole in the water-bearing sand beyond the end of the casing to make room for the length of well screen to be exposed below the casing. Lower the screen in position, making sure that the lead packer remains inside the casing near its lower end when the screen is on bottom. If the hole is too deep, drop gravel into it to fill it to the correct height. When the screen is in proper position, expand the lead packer to the inside wall of the casing and proceed with development work. The end fittings used with the screen in this method are the closed bail plug and the lead-packer top (fig 7–2). The drilling mud must be

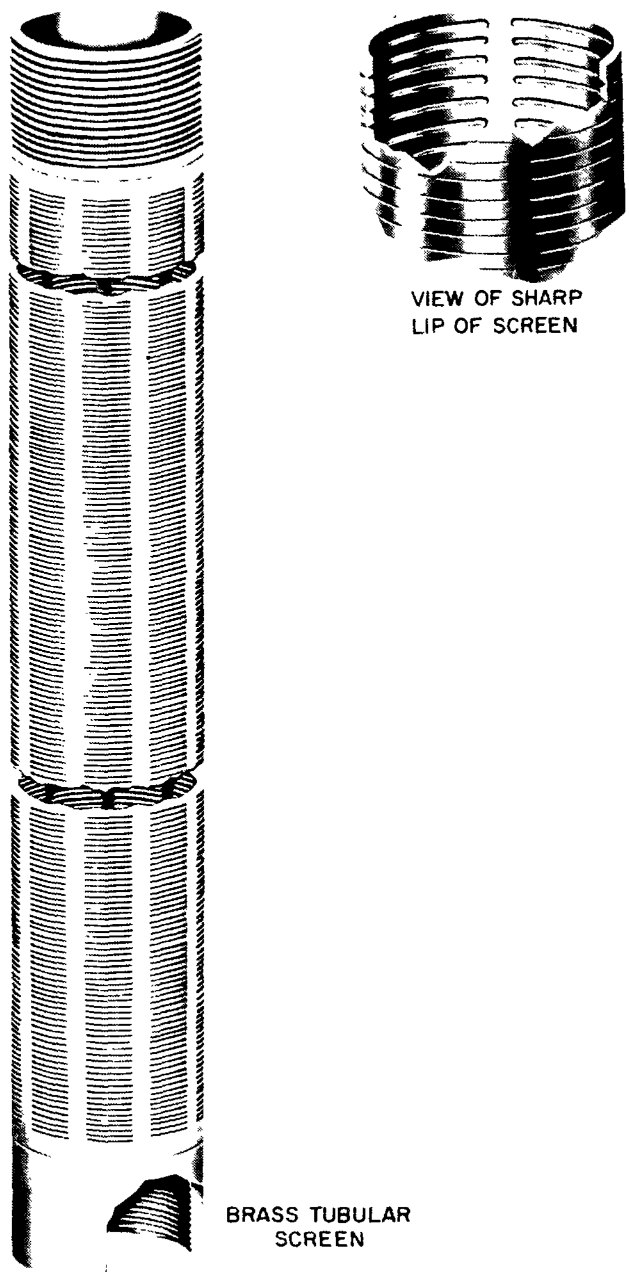


Figure 7-7. Brass tubular well screen.

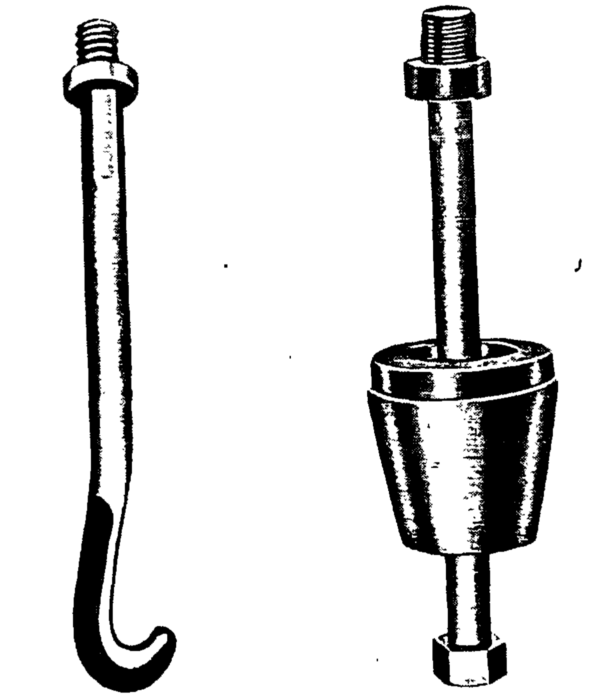


Figure 7-8. Screen tools.

heavy and thick enough to prevent the open hole from caving. During the following development, the drilling mud must be completely removed from the water-bearing sand.

c. A third method of setting a well screen is by a bailing-down operation. For this method, special end fittings for the screen are required. Figure 7–10 shows how one type of bail-down shoe, with a special nipple having right- and left-hand threads and a coupling with right- and left-hand threads, is assembled in the bottom of the screen. Another type of shoe with a guide pipe, which extends below the screen, is shown in figure 7–11. The bailing-down operation is started after the well casing is sunk to its permanent position, with its lower end a little below where the top of the screen will be after it is bailed down to the desired depth. Assemble the bail-down shoe, special nipple, and special coupling in the bottom of the screen. Screw a length of the proper size pipe into the right-hand half of the special coupling. This pipe, which will extend up through the screen, is called the bailing pipe or conductor pipe. Screw a lead-packer fitting to the top of the screen. Lift the whole assembly by the bailing pipe and lower the screen inside the well casing, adding lengths of bailing pipe as the screen descends, until it reaches the bottom of the hole. Mark off the length of the screen on the bailing pipe that projects above the casing, using the top of the casing as the reference measuring point. Run a bailer or sand pump inside the bailing pipe and start bailing sand from below the screen.

(1) As sand is removed from below the shoe by the bailer, the combined weight of the screen and the string of bailing pipe will cause the screen to move downward. If necessary, atach additional weights to the bailing pipe. Watch the progress of the work carefully and stop the operation when the screen is sunk to the desired depth. At this point the lead packer should be near the lower end of the casing but still inside the casing. Accurate measurements will avoid sinking the screen too far. The next step is to drop a weighted and tapered wooden plug (fig 7–12) through the bailing pipe to plug the special nipple on the bail-down shoe. With this plug in place, unscrew the left-hand threaded joint at the upper end of the nipple by turning the entire string of bailing pipe to the right. Remove the bailing pipe, expand the lead packer with a swage block, and proceed with the development of the formation.

(2) If a different type of bail-down show is used, the left-hand threaded connection for the bailing pipe may be in the opening in the shoe itself, or it may be in the lead-packer fitting at the top of the screen. In either case, the operations of bailing down, plugging the bottom, and removing the bailing pipe are done as described above.

d. Under favorable conditions, a well screen can be bailed down into place without using a bail-down shoe. In this case, the bailing pipe is not connected to the screen. Its lower end is fitted with a flange or coupling large enough to press upon the lead packer at the top of the screen. The weight of the bailing pipe, then, simply rests on the screen. The lower end of the screen is fitted with an open ring or a short piece of pipe. In using this bail-down method, considerable care is advisable because the screen is not connected to the bailing pipe, and its movement cannot be controlled from the ground surface. Careful measurements will prevent sinking the screen too far. Use of this method should be limited to bailing down fairly short screens. Plug the bottom of the screen by putting a small bag of dry concrete mix in the bottom and tamping the concrete lightly with the drill bit or other tool.

7–7. Setting Screens in Rotary Drilled Holes

a. The pullback method may be used in rotary drilled holes and is one of the best ways to install a well screen. Set casing in the hole to its full depth. Use the bailer to remove any sand in the bottom of the casing. Install the screen and pull

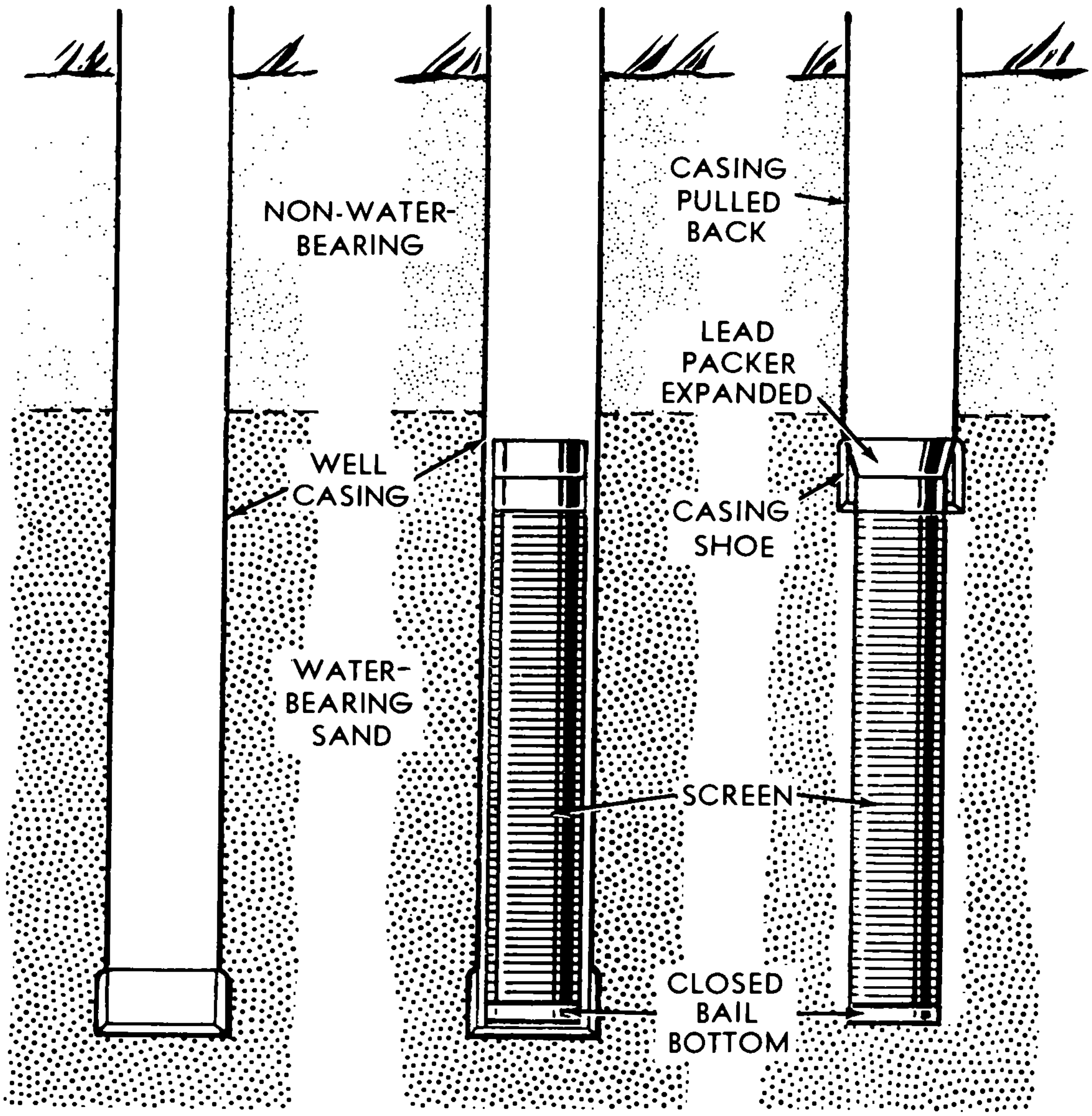


Figure 7-9. Pull-back method of setting well screens.

the casing to expose the screen as described in paragraph 7-6*a*. When the casing is pulled to its permanent position, it must be held by pipe clamps until the hole caves around it to grip the pipe or until grout can be placed around it and allowed to set. Drilling mud should be bailed out of the well so that the sand and gravel of the formation will close in around the screen. Development of the well can then be started.

b. The method of installation described in paragraph 7-6*b* can be used where the depth and thickness of the water-bearing sand have been determined first from a test hole. Then drill a hole of the proper size and depth for the casing. Set the casing and fix it by grouting or other means (para 7-17). Using a bit that will pass through the casing, drill an open hole in the water-bearing sand to receive the screen. Notice that the diameter of the screen must be smaller than the casing, since the hole drilled for the screen will be no larger than the inside diameter of the casing. Install the screen as described in paragraph 7-6*b*. Be sure that the lead-packer fitting at the top of the screen is the proper size to expand and seal inside the casing.

c. Another method of setting a well screen in a rotary hole is called the washdown method. The screen fittings required are a lead-packer top and a washdown or self-closing bottom. Two types of self-closing bottoms are shown in figures 7-5 and 7-6. The type shown in figure 7-5 is used when the screen is telescoped through the casing.

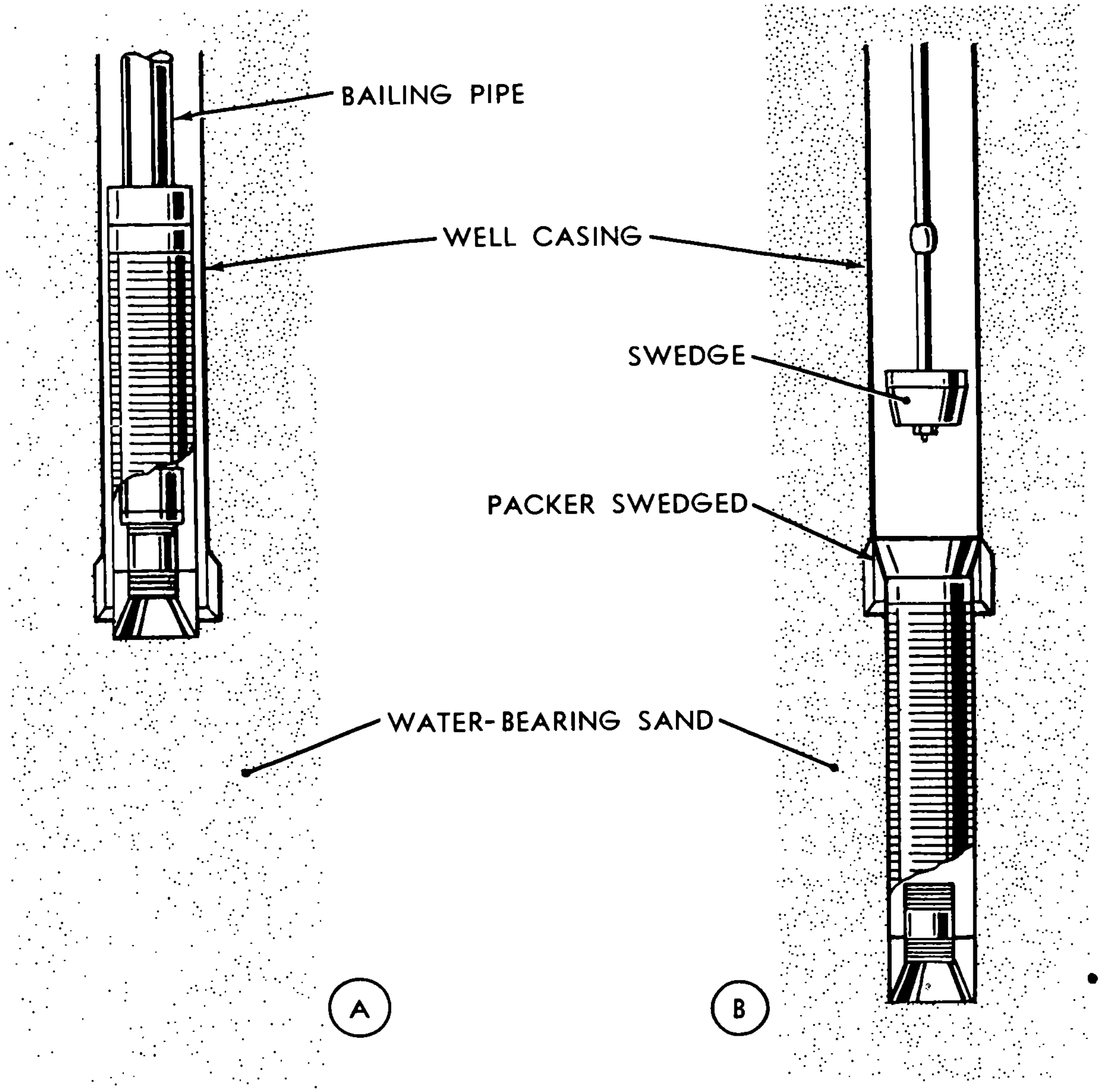


Figure 7-10. Bail-down method of installing well screen.

The first step is to set the casing from the ground surface to a depth a little below the point where the top of the screen will be when it is in place. Screw a section of wash pipe into the left-hand female thread of the self-closing bottom and attach the bottom to the screen with the wash pipe projecting through the screen. The rotary drill pipe may be used as the wash pipe if it is not too large. Attach the lead packer to the top of the screen. Lift the whole assembly by the wash pipe and lower the screen inside the casing. Add sections of wash pipe as required until the bottom of the screen is near the lower end of the casing. Connect the top of the wash pipe to the kelly and start the mud pump. Circulate water, not drilling mud, down the wash pipe. Let the screen move down as circulation is continued and as material is washed from under it by the stream of water. Take measurements carefully and stop the descent of the screen when the lead packer is near the lower end of the casing. If there is still some drilling mud being washed out of the well, continue pumping water until most of the mud is displaced. After stopping the pump, allow time for the water-bearing sand to close in around the screen. When the formation develops enough friction on the outer surface of the screen to hold it, turn the entire string of wash pipe to the right to unscrew the left-hand joint at the bottom. When the wash pipe is free, additional water may

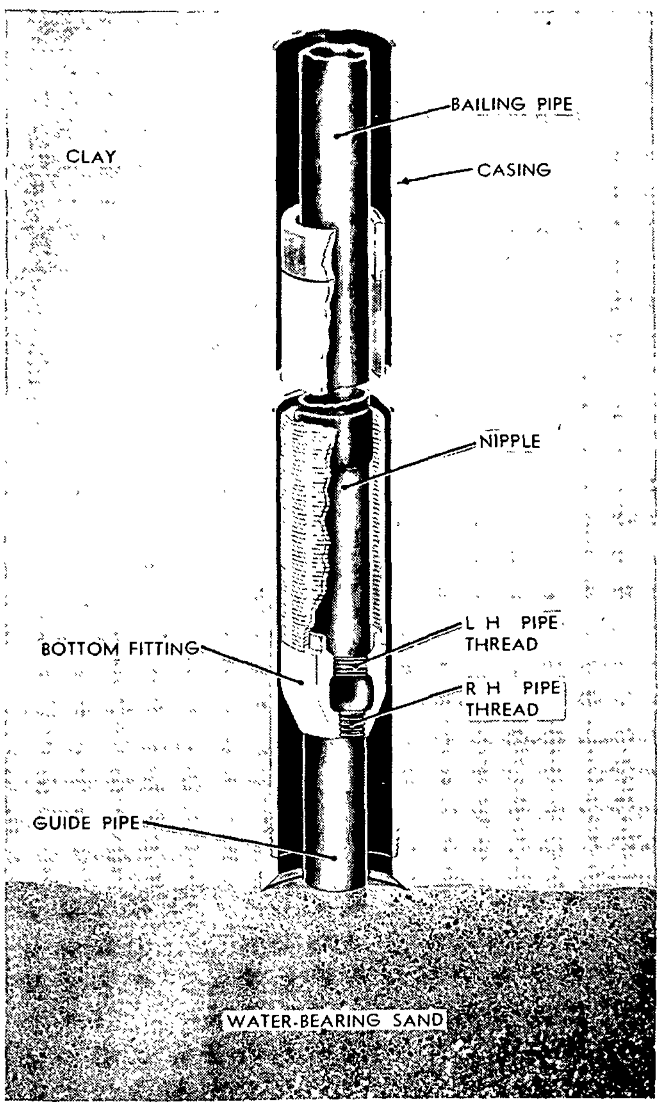


Figure 7-11. Screen in position to be bailed down.

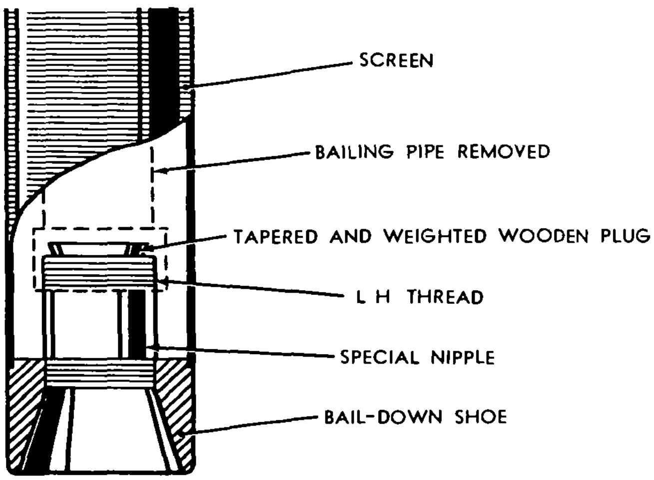


Figure 7-12. Nipple plugged and bailing pipe removed.

be pumped through it. Raise and lower it several times so that its lower end travels the full length of the screen. This will wash out more drilling mud and some fine sand from the formation, thus starting the development work. Remove the wash pipe, expand the lead packer, and continue the development work. This method of installation works best where the water-bearing formation is composed of fine to coarse sand with little or no gravel.

d. When using a screen with the type of self-closing bottom shown in figure 7-6, the screen must be coupled to the lower end of the casing, making the screen and casing a single-string assembly. The entire string is lowered in the hole at one time. Note that there is no way of holding the screen with the wash pipe alone, since the lower end of the pipe simply slips into the wooden wash plug and does not screw into the self-closing bottom.

e. The screen and casing can be made up in a single-string assembly and set in the drilled hole, omitting the washdown operation, if the hole is open to the bottom. The screen fittings required are a pipe-thread fitting at the top and a closed bottom. When the entire string has been run into the hole, pipe clamps should be used around the casing at the surface to carry all or most of the weight of the string until the formation closes in around the screen. With the string supported in this manner, run the drill pipe inside the casing to the bottom of the screen and pump water into the well to displace the drilling fluid. Raise and lower the drill pipe to wash the full length of the screen. Allow time for the formation to settle around the screen, then proceed with the development work. The single-string installation is suitable for shallow wells, up to 50 feet. For deeper wells, the telescope type of installation is much better for several reasons. It permits the grouting or cementing of the casing in the hole before the screen is installed. Proper grouting of the casing is impossible with the single-string installation and an outer casing of larger size must be used if grouting is required. The telescope method permits the screen to be removed and replaced when necessary. Furthermore, it avoids the bad construction practice of putting the weight of a long string of casing on top of a long screen. When the screen hits bottom it becomes a loaded column that is easily buckled because of its slenderness. It is always eccentrically loaded because a long screen adjusts itself to irregularities in alinement as it is lowered in the hole.

7–8. Recovering Screens by Sand Joint Method

a. General Considerations. A well screen can be readily removed from a well, when necessary, by a technique known as the sand joint method. The essential element of the operation is sand-locking a pipe in the screen solidly enough so that when the pipe is lifted, the screen will come with it without being damaged. Occasions for pulling a well screen may be the following:

(1) Recovery of a screen from a well that is to be abandoned, so that the screen can be used in another well.

(2) Removal of a screen that has been partially destroyed by corrosion, requiring replacement by a new screen.

(3) Removal of a screen for cleaning. Certain types of water cause scale or incrustation in the sand around the screen and in the screen openings. There are chemical treatments that will dissolve these deposits with the screen in place, but sometimes it is more effective to pull the screen, clean it, and then reinstall it by the baildown method.

b. Force Needed. Considerable force will almost certainly be needed to pull up the screen. The pulling pipe must be locked in the screen by the sand joint so that the grip is distributed over practically all of the inside surface of the screen. A lifting force of many tons can then be applied to the pulling pipe and transmitted to the screen without deforming the screen.

c. Proper Size of Pulling Pipe. The size of pulling pipe which should be used differs with the size of the well and the force which may be required. As a general rule, however, the size of pipe used is about one half the nominal size of the screen; *for example*, in pulling an 8-inch screen which has a clear inside opening of 6 5/8 inches, a line of 4-inch pipe is generally used. Table 7–1 gives sizes commonly used.

Table 7-1. Sizes of Pulling Pipe for Various Sizes of Screen

Size of screen (in)	Clear opening inside screen (in)	Size of pulling pipe (in)	Size of screen (in)	Clear opening inside screen (in)	Size of pulling pipe (in)
3	2	1	5	3 7/8	2 or 2 1/2
3 1/2	2 3/8	1 1/4	5 5/8	4 3/8	2 1/2
4	2 7/8	1 1/2	6	4 3/4	2 1/2 or 3
4 1/2	3 3/8	2	8	6 5/8	4

d. Type of Sand To Be Used. The type of sand used varies with the size of the screen and with the size of the pulling pipe. The sand must be clean, sharp material of reasonably uniform size. If it is not clean and free of clay, the sand joint may not hold on a heavy pull. In all smaller sizes of screens, medium to moderately fine sand is used. In larger sizes, coarse sand to fine gravel may be used; and in the very large sizes where the pulling pipe is considerably smaller than the screen, material as coarse as roofing gravel may be used.

e. Procedure. Figure 7–13 shows how the sand joint inside the screen should look. It is made as follows:

(1) Wire some sacking above a coupling screw to the lower end of the pulling pipe and cut the sacking in strips from 2 to 4 inches wide, depending on the size of the well. The sacking is to form a pocket to prevent the sand from washing out the bottom of the joint after it is formed. The narrow strips will adjust themselves inside the screen to make this pocket.

(2) Draw the ends of the strips of sacking up around the pipe as its lower end is put into the casing. Lay the strips over the top of the casing and arrange them evenly around the circumference. Lower the pulling pipe to the bottom of the well, taking care to keep it centered in the casing.

(3) Pour sand in the annular space between the pulling pipe and the casing. Pour it in slowly and evenly around the pipe. Move the pipe slightly at the top while pouring, to be sure the sand does not bridge above a coupling. A small stream of water can be used to wash down the sand and prevent bridging. Enough sand should be poured into the screen to fill it about two-thirds or more. Do not allow the level of the sand to rise above the screen. The proper amount can be calculated in advance by determining the space between the screen wall and the pulling pipe; or a string of small pipe may be used as a sounding rod to check the amount of sand in place. To prevent overfilling the screen, holes can be drilled in the pulling pipe just below the top of the screen.

(4) When the sand is in place, apply tension slowly to the pulling pipe by jacks working against clamps or against a casing ring with slips. The sand joint thus becomes set and cannot be broken loose without washing out the sand. If it becomes necessary to loosen the joint, wash out the sand by jetting or with compressed air.

(5) Apply tension slowly with the jacks. A reasonable pressure applied and maintained without change for a short time gives the tension in the pulling pipe a chance to transmit and maintain a force on the screen. The pressure should be increased gradually until the screen

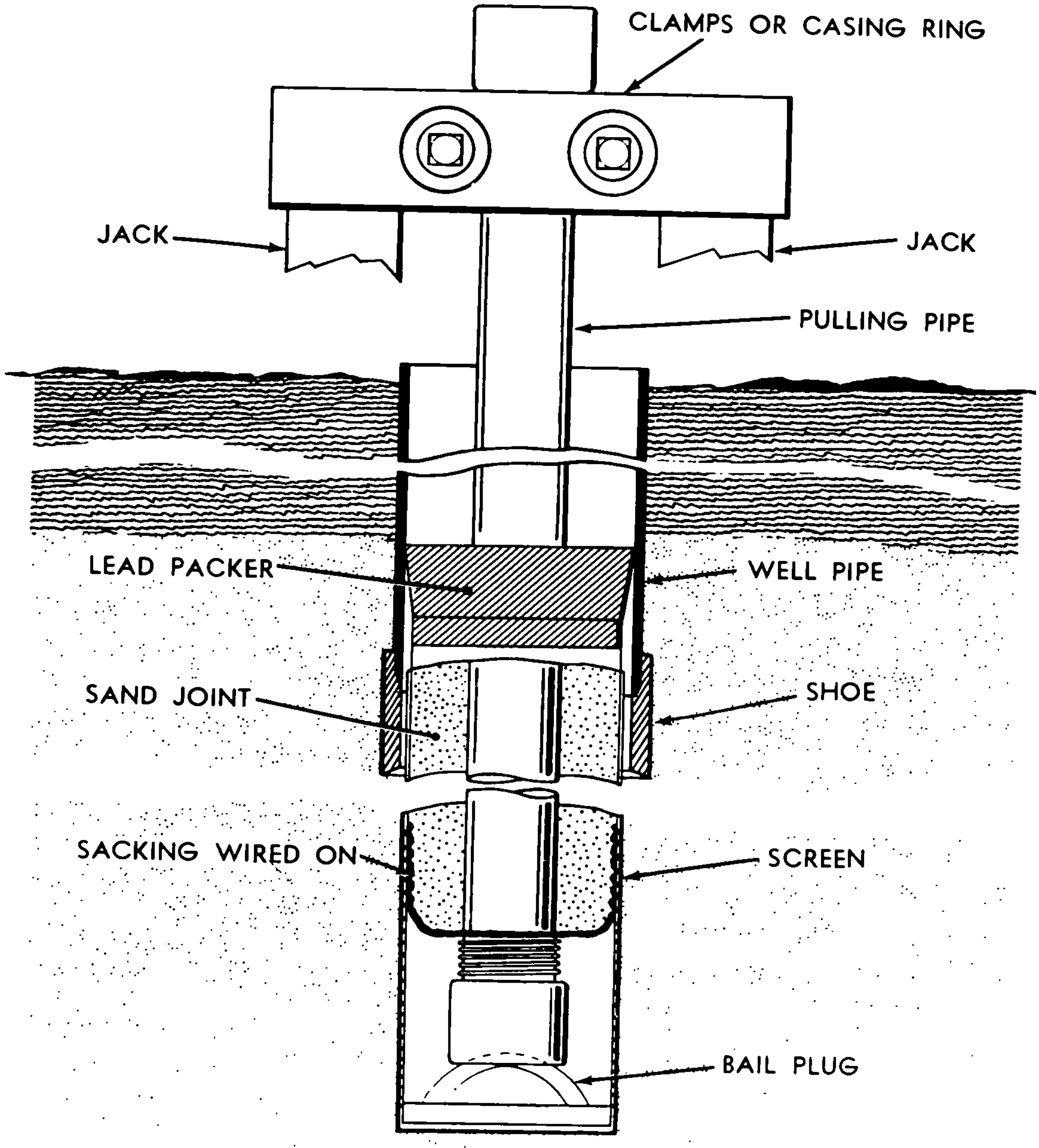


Figure 7-13. Diagram of sand joint.

begins to move, after which it may be pulled steadily without difficulty. There is much less chance of damaging the screen or breaking the pulling pipe in this way than if the force is applied rapidly. A heavy pressure applied quickly may bulge the screen.

(6) When the screen is out of the well, wash the sand joint loose with a stream of water or compressed air.

f. Acid Treatment Before Pulling. To avoid using an extremely high pulling force, which may break the pulling pipe, a light acid treatment should be used to loosen a screen in an old well. Fill the screen with a mixture of approximately 1/2 muriatic acid and 1/2 water, using a string of black pipe to carry the acid to the bottom of the well. Allow the acid to stand for several hours, or overnight if more convenient. Pump or bail the acid out of the well and start the pulling operations.

Section IV. WELL DEVELOPMENT

7–9. Development of Wells

a. Development work is most important in the completion of a screened well, because the uniformity of the grading of the sand or gravel around the screen is improved by removing the finer particles. The type of screen openings, the spacing between openings, and the size of the openings all affect the extent to which the development work can be carried out. The openings should be shaped so they will not clog. The sizes of the screen openings are deliberately chosen large enough so the desired proportion of the finer material in the water-bearing formation will pass through them (para 7–5*c*). The development work can then exhaust the finer material from the formation. When these finer particles are brought into the well by development, the coarser particles are held out by the screen envelope. The result is sometimes called "natural gravel packing" of the well, since the coarse and more permeable material left around the well screen is actually a part of the natural formation.

b. The uniformity of the sand or gravel is more important than the average size of the grains in its effect on the yield of the well. This will be discussed in chapter 8. In addition to improving the yield, proper development of a sand or gravel formation also stabilizes the formation in the vicinity of the screen so the well will always be sand free after it is completed. The natural gravel pack is coarsest next to the screen where all the fine particles have been pulled through the screen openings. A little farther out, some of the medium-sized grains remain mixed with the largest grains. Still farther outside this zone, more medium-sized sand and some fine sand remain. From this, it is seen that the whole envelope of material left around the screen grades gradually from the coarsest particles next to the screen to the unchanged natural formation at a distance outside the screen that is beyond the effective reach of the method of development employed (fig 7–14).

c. The methods of development and something about their relative effectiveness are discussed in the next few paragraphs. The fundamental purpose in each development operation is to induce alternate reversals of flow through the screen openings that will rearrange the formation particles, thus breaking down bridging of groups of particles. Figure 7–15 shows how small particles bridge between large particles and across screen openings when the flow of water through

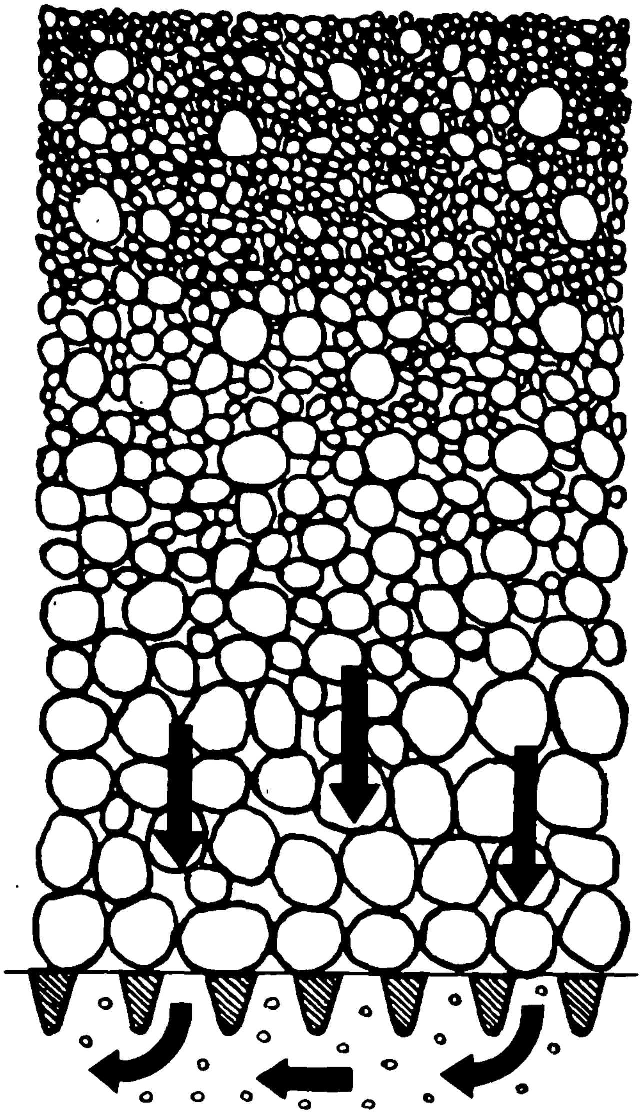


Figure 7-14. Results of development of a formation.

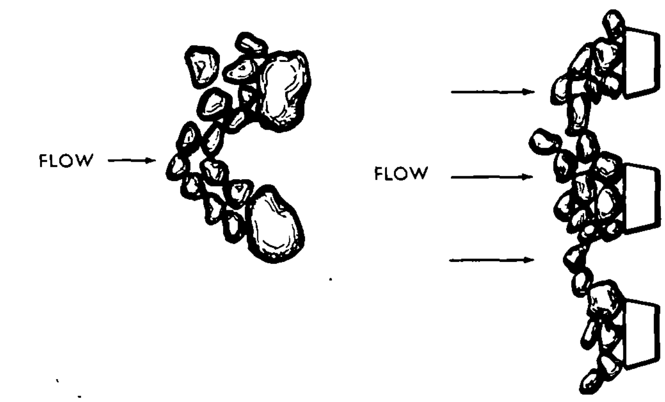


Figure 7-15. Bridging of sand grains.

the sand is in one direction only. In development, the direction of flow is alternately reversed by surging the well. The outflow portion of the surge cycle breaks down bridging, and the inflow portion then moves the fine material toward the screen and into the well.

7–10. Use of Surge Plungers

a. General Considerations. One of the most effective ways of surging water in a well to develop the water-bearing formation is to operate a plunger up and down in the casing like a piston in a pump cylinder. While there are other methods of surging, which have special advantages under certain conditions, most drillers prefer to use a surge plunger or surge block. Surge blocks can be classified into two general types: a solid plunger or swab (fig 4–17) and a plunger equipped with a valved opening (fig 7–16). The valve type plunger gives a lighter surging action than the solid type plunger. This is an advantage in developing tight formations since it is always best to start surging slowly and increase the force of the operation as the development proceeds. Plugging the valve of the plunger changes it to a solid type plunger which can be used when greater surging force is needed.

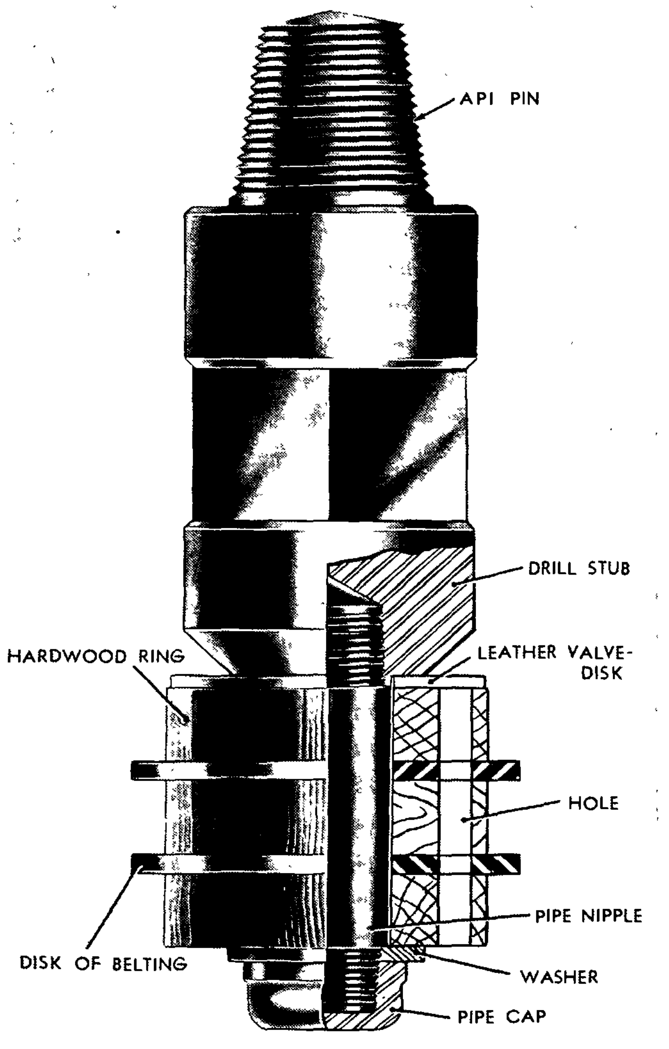


Figure 7-16. Surge block.

b. Weighting Plunger. Enough weight must be attached to the surge plunger to make it fall on the downstroke at about the same speed that the drilling machine lifts it on the upstroke. A common mistake in using a surge plunger is not having it weighted enough. The sinker bar shown in figure 4–17 provides extra weight for use with the swabs. The drill stem provides the weight required for the surge block. The surge block has an API pin joint that screws directly to the drill stem.

c. Operation.

(1) Lower the surge plunger in the well until it is in the water but above the top of the screen; keep the plunger a few feet above the screen so that it will not strike the lead packer while surging.

(2) Start surging slowly, gradually increasing the speed until the surge plunger rises and falls without letting the cable slacken. Work the plunger on a relatively long stroke. If the rotary rig is being used, lift the plunger 3 or 4 feet before dropping it. Control the movement by using the hoist brake and clutch if the sandline is being used.

(3) Continue surging for several minutes, then pull the plunger out of the well and lower the bailer or sand pump into the screen. When the bailer rests on the sand that has been pulled into the screen, check the depth of the sand in feet by measuring on the sandline. Bail all the sand out of the screen.

(4) Repeat the surging operation and compare the quantity of sand with that brought in the first time. Bail out the sand, and repeat surging and bailing until little or no sand can be pulled into the well.

(5) Lengthen the period of surging as the quantity of sand removed decreases. The total time for development may range from about 2 hours on small wells to 2 to 3 days on large wells with long screens.

7–11. Development With Compressed Air

The use of compressed air for development work is, under the proper conditions, a rapid and effective process. Two methods may be used—the open-well method or the closed-well method. The standard 250 or 600 cubic feet per minute (cfm) engineer compressor is adequate for developing most wells by either method. A pressure of at least 100 pounds per square inch should be used, and an even higher pressure is preferable. The 250 or 600 cfm compressor will pump water by airlift at from 100 to 150 gallons per minute depending upon the submergence and the size of the pipes used. Table 7-2 shows the recommended sizes of pipe and air lines to be used for various sizes of wells and rates of pumpage. Some variation from these sizes is permissible, but the combinations shown will give the best results.

Table 7-2. Sizes of Drop Pipes and Air Lines for Various Capacities

Pumping rate (gallons per minute)	Diameter of well casing (inches)	Diameter of drop pipe (inches)	Diameter of air line (inches)
30 to 60	4 or larger	2 1/2	3/4
61 to 100	5 or larger	3 1/2	1 1/4
101 to 150	6 or larger	4	1 1/2
151 to 250	8 or larger	5	1 1/2
251 to 400	8 or larger	6	2

a. Open-Well Method. The surging cycle is set up in this method by alternately pumping from the well with an airlift and dropping the air pipe suddenly to cut off the pumping. This discharges large bubbles of compressed air inside the screen.

(1) A ratio of submergence of at least 60 percent is required for successful development by this method. Submergence means the extent to which the air pipe is submerged in the water as compared to that part of the pipe between water level and ground level. The efficiency of the work drops off rapidly as the submergence becomes less than 60 percent. In deep wells with a considerable head of water above the bottom, even though the submergence is low, some effective work can be done by "shooting heads," which will be described later. If both the head and submergence are low, this method of development is of little value.

(2) Figure 7-17 shows the proper method of placing the drop pipe and air line in the well. The drop pipe may be conveniently handled with the hoist line. The air pipe should be suspended on the sandline. A tee at the top of the drop pipe is fitted with a short discharge pipe at the side outlet. A sack is wrapped around the air line where it enters the drop pipe to keep the water from spraying about the top of the well. The discharge from the compressed air tank to the well should be the full size of the air line in the well or the next larger size. A quick-opening valve must be connected in the line near the tank. A piece of pressure hose at least 15 feet long is required to allow for moving the drop pipe and air line up and down.

(3) At the start of development, lower the drop pipe to within about 2 feet of the bottom of the screen. Place the air line inside the drop pipe with its lower end 1 foot or more above the bottom of the drop pipe. Permit air to enter into the air line and pump the well in the manner of a regular airlift until the water appears to be free from sand. Close the valve between the tank and the air line, allowing the tank to be pumped full of air up to a pressure of from 100 to 150 pounds. In the meantime, lower the air line until it is 1 foot or so below the drop pipe. Throw open the quick-opening valve to permit the air in the tank to rush with great force into the well. A brief but forceful head of water will emerge or shoot from the casing and from the drop pipe. Pull the air line back into the drop pipe as soon as the first heavy load of air has been shot into the well. This will cause a strong reversal of flow in the drop pipe that will effectively agitate the water-bearing formation.

(4) Allow the well to pump as an airlift for a short time, and then shoot another head. Repeat this procedure until the absence of further sand shows that the development is complete at this point.

(5) Lift the drop pipe to a position 2 or 3 feet higher in the screen and follow the same procedure. This develops the entire length of the screen a few feet at a time. Return the drop pipe to its original position near the bottom of the well and shoot one or two more heads. To complete the development and thoroughly clean out any loose sand, pull the air line up into the drop pipe and use it as an airlift to pump the well.

b. Closed-Well Method. Another method of using compressed air for development is to close the top of the well with a cap and arrange the equipment so that air pressure can be built up inside the casing to force water out through the screen openings. Arrangement of the hookup is shown in figure 7-18. The valves and fittings required may not be available for military field operations. Because of this, the closed-well method is not used as often as the open-well method. Another disadvantage of this method is the danger of forcing water up around the outside of the casing when air pressure is built up inside it. These will loosen the casing and may ruin the well by bringing clay down into the formation.

(1) After arranging the equipment as shown in figure 7-18, turn the 3-way valve to deliver air down the air line, with the air cock preferably open. This will pump water out of the well through the discharge pipe. When the water comes clear, cut off the air and allow the water in the well to regain its static level as described in

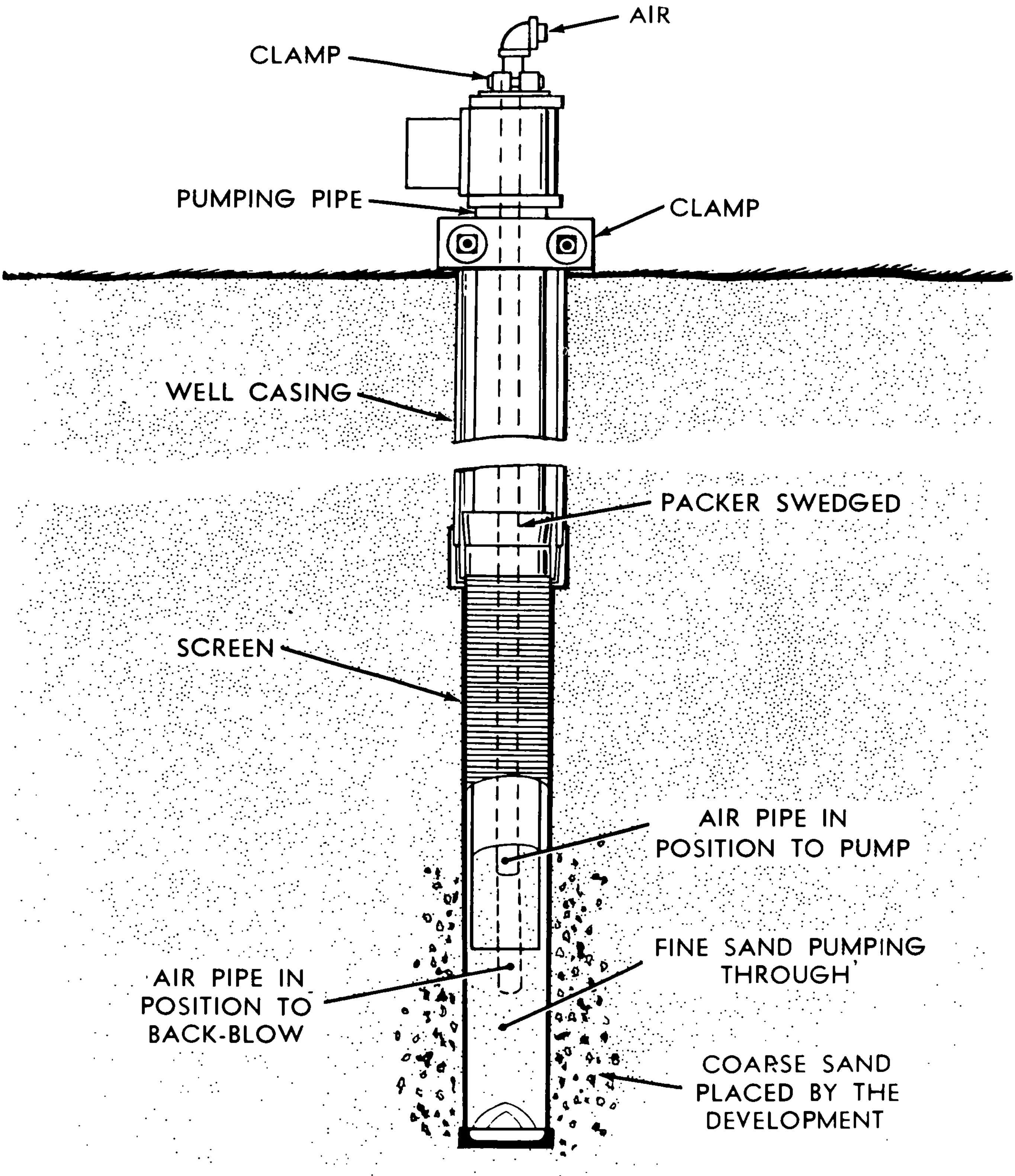


Figure 7-17. Hookup for developing well with compressed air by open- well surging method

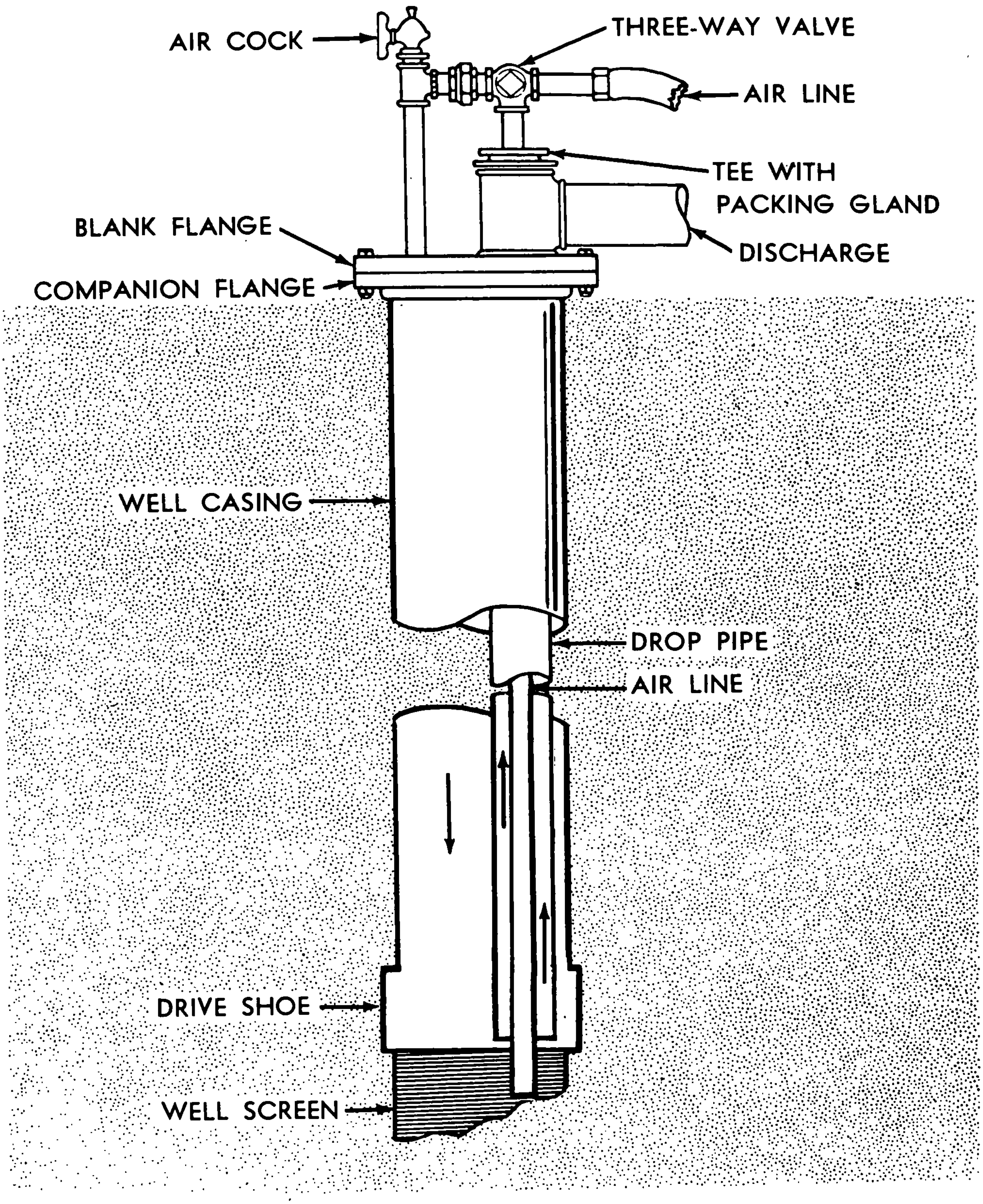


Figure 7-18. Hookup for closed-well method of developing wells with compressed air.

chapter 8. This can be determined by listening to the escape of the air through the air cock as the water rises in the casing. Close the air cock and turn the 3-way valve to direct the air supply down the bypass to the top of the well. This will force the water out of the casing and back through the screen, agitating the sand and breaking down the bridges of sand grains. When the water has been pushed down to the bottom of the drop pipe, air escapes through the drop pipe. If the drop pipe is kept above the screen, it will prevent air logging the formation.

(2) When the air is heard escaping out of the discharge pipe or when the pressure stops increasing, cut off the supply of air and reopen the air cock to allow the water to reach static level. Turn the 3-way valve and again direct the air supply down the air line to pump the well.

(3) Repeat this procedure until the well is thoroughly developed. It is seldom necessary to bail the well after this, because the velocity of the water usually cleans out the sand brought into it. However, if the well was not bailed thoroughly at first to remove the first large slugs of sand, these may be too heavy for this type of airlift to clean out properly, and bailing will be necessary.

7–12. Development by Backwashing

a. Three or four backwashing methods can produce the surging effect, or reversal of flow required to develop the formation. One of these methods consists of alternately lifting water to the surface by pumping and letting the water run back into the well through the pump-column pipe. About the only type of pump besides the airlift that can be used practically for this purpose is a deep-well turbine pump (para 9–6 and 9–7) without a foot valve. The pump is started, but as soon as water is lifted to the ground surface the pump is shut off. The water then falls back into the well through the column pipe. The pump is started and stopped as rapidly as the power unit and starting equipment will permit. The effect is to intermittently lower and raise the water level in the well which produces the inflow and outflow, respectively, through the screen openings. During the procedure, the well may be pumped to waste from time to time to remove the sand that has been brought in by the surging. After completing the surging, the pump must be removed and any material remaining in the screen must be bailed out.

b. Another method is to backwash by pouring water into the well as rapidly as possible, thus producing outflow through the screen openings. Inflow through the screen is then produced by bailing water out of the well as rapidly as possible. As can be seen, this is not a very rapid means of surging as the time required for a complete cycle will be several minutes under best conditions. If the static water level is high enough to permit pumping by suction lift, a small centrifugal pump can be used instead of the bailer and this will speed up the work. If there is room in the well casing, the discharge side of the pump can be connected to a string of small diameter pipe that is let down in the well. The water added is pumped down inside the screen, creating a turbulence which will help to develop the formation.

c. A third method that can be used if a rotary or jetting type drilling rig is available is to improvise a little jetting tool that can be operated inside the screen. To do this, screw a coupling to 1-, 1 1/2-, or 2-inch pipe and weld a plate over the open end of the coupling. Drill two or three 1/4-inch holes, located so they will pass through both the wall of the coupling and the pipe (fig 7–19). Lower this tool into the screen on a string of pipe. Connect the upper end of the pipe to the kelly or to the discharge side of the mud pump. Pump water into the screen and rotate the jetting tool very slowly so that the horizontal jets of water

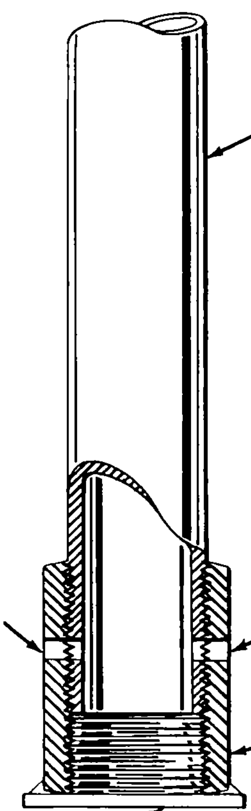


Figure 7-19. Improvised jetting tool.

will wash out through the screen openings. Raise the string of pipe little by little and continue rotating to backwash the entire surface of the screen. A pump pressure of 100 pounds per square inch should be used if possible. This method of backwashing is particularly effective in removing the cake of drilling mud that is plastered on the walls of holes drilled by the rotary or jetting method. Its disadvantage in military field operations is that it requires a large supply of water.

d. Occasionally, wells are backwashed by capping the casing and pumping water into the well under pressure. This is similar, as far as pushing water out through the screen openings is concerned, to the closed-well method of using compressed air for development. This method is not very efficient as it is almost impossible to produce a surging effect. As in using compressed air in the closed-well method, care must be taken to seal the casing very tightly in the hole and prevent water from being forced up around the outside of the casing.

7–13. Developing Rock Formations

All the methods already described for the development of sand and gravel formations apply to wells constructed in rock formations. The work is done to wash out fine cuttings, silt, and clay that have worked into the fissures, crevices, or pores of the rock during the drilling operations. Every opening that remains plugged means much less water running into the well. Enough development should be done to remove all the obstructing material. In civil work practice, acid is sometimes used in the development to dissolve lime-like cementing material and to open up more connections with additional joints or fissures beyond the actual wall of the borehole.

7–14. Redevelopment of Old Wells

a. In the discussion of the principles of screen selection in paragraph 7–5, it was pointed out that the ground water may be corrosive and that in such a case the screen should be made of a corrosion-resistant metal or alloy. Corrosive water attacks the metal of the well screen, casing, and pump, and eats it away. In contrast to this corrosive nature of some ground waters, many others have a somewhat opposite chemical tendency which makes them deposit some of their dissolved minerals in the area around a pumped well. Scale deposits build up on the sand or gravel particles around the screen and on the screen itself. This buildup of scale is called incrustation. Incrustation clogs the voids and pores in the water-bearing sand and may fill up the screen openings (fig 7–20). The scale deposits are caused by the reduction of pressure of water in the aquifer near the well, as represented by the drawdown; and the increased velocity of the water as it flows out of the aquifer and into the well. These two changes in the natural conditions in the aquifer, resulting from pumping the well, reduce the capacity of the natural water to keep in solution all of the minerals dissolved in it. The water, therefore, drops out part of its dissolved minerals similar to the way scale forms in a teakettle. The best ways to prevent serious incrustation are to keep the drawdown to a minimum by proper well construction, keep the velocity through the screen openings low by using a screen with maximum inlet area, and clean the well from time to time.

b. Cleaning a well that has dropped in capacity because of incrustation means the redevelopment of the well. Acid or other chemicals are often used to dissolve or otherwise assist in removing the cementing material that has clogged the pores of the formation and the screen openings. However, chemical treatment alone will not do this. One or more of the methods of development, or surging, described in paragraphs 7-9 through 7-12, must also be used to redevelop the formation and remove the incrusting materials in the same way the fines are pulled out of the formation in the development of a new well.

c. If the well screen is made of a metal that will withstand acid treatment for loosening the incrustation, enough muriatic acid may be brought into the bottom of the well, through a small diameter pipe, to fill the screen. The acid is allowed to remain in the screen for 1 to 2 hours; then the well is surged lightly for a few minutes and allowed to stand for 2 to 4 hours longer. The acid solution and any fine material that may have been brought into the screen are then bailed out. The well is surged again and bailed out. If there is some indication that the yield of the well has been improved, the procedure should be repeated, more surging being done the second time. A third treatment and considerable additional surging may be required to redevelop the well to its original capacity. The well should be pumped to waste for several hours after being acid-treated, to remove all the acid that may have been forced out into the formation. If the screen is of a metal that will not withstand acid treatment, it may have to be removed from the well and cleaned by mechanical means. The screen is then replaced in the well by bailing down.

d. In some cases, treating incrusted wells with a solution of sodium hexametaphosphate gives

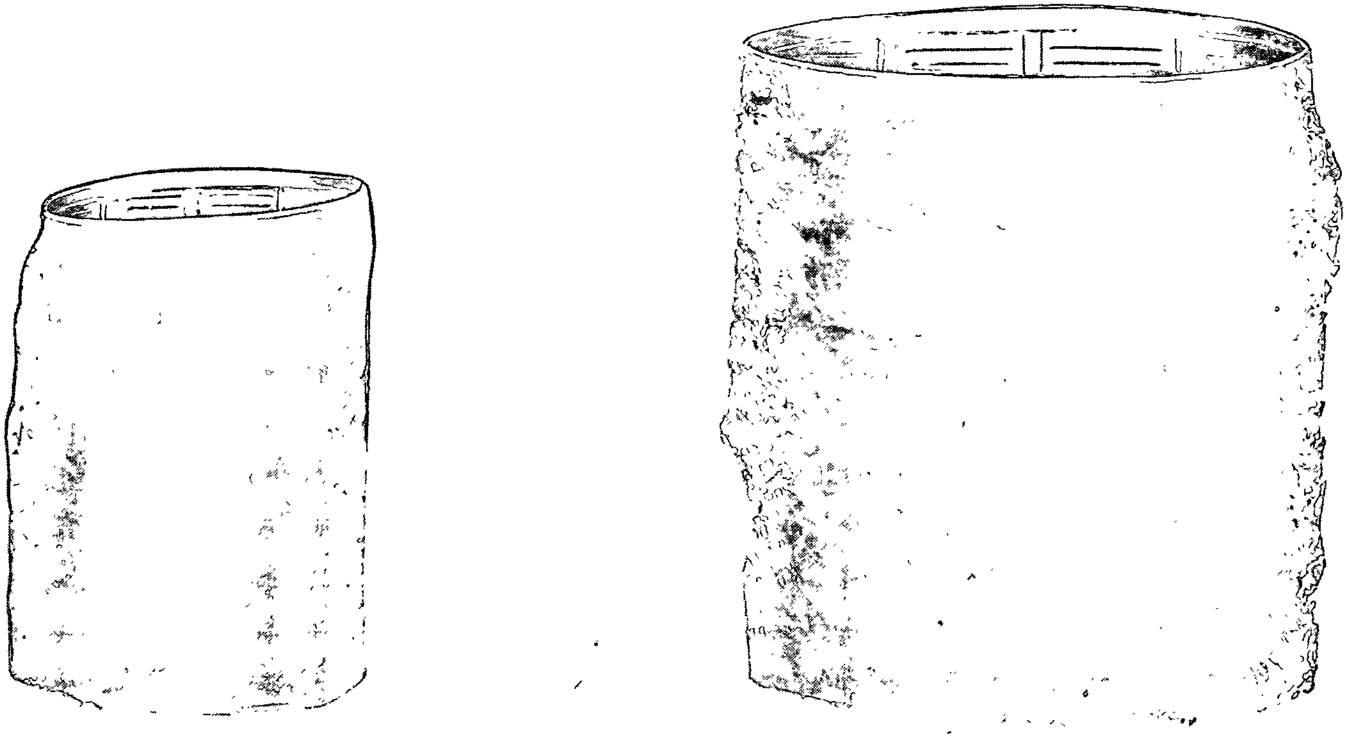


Figure 7-20. Short sections of well screens with sand cemented around them as a result of incrustation.

good results. Enough of the chemical should be mixed with water in a 50-gallon barrel so that when it is poured in the well and further mixed with the water in the well, the strength of the resulting solution will be about 3,000 to 5,000 parts per million by weight. This requires about 4 pounds of the chemical for each 100 gallons of water standing in the well. Enough calcium hypochlorite should be added to provide about 50 to 100 parts per million chlorine also. The chemicals are allowed to stand in the well for about 1 hour and are then surged vigorously for 2 or 3 hours. The well is then pumped or bailed out. The procedure is repeated, using the same amount of chemicals and extending the surging period. At least three, and sometimes four, repetitions of the treatment are required for best results.

e. There are many cases where redevelopment of the well alone, without the use of chemical treatment, will restore it to capacity. A small quantity of calcium hypochlorite should be used during redevelopment operations to keep the well disinfected (para 7-20). Certain types of bacteria are always present in the soil and may be sticking to tools used for surging and bailing. The chlorine kills these bacteria and prevents this source of contamination.

Section V. ARTIFICIAL GRAVEL TREATMENT OF WELLS

7–15. General

a. When the natural water-bearing sand does not contain any relatively coarse material to permit development and the formation of a natural gravel-pack around the screen, it is sometimes desirable to place the necessary coarse material artificially around the screen. Artificial gravel packing is of great value where the water-bearing formation is composed of fine sand in which the individual grains are uniform in size. Such a formation requires a screen with a firm slot to hold out the sand. Gravel packing will facilitate the use of a screen with large slots. The increased slot size will permit the maximum quantity of water to enter the well.

b. The most important feature of artificial gravel packing is the selection of the correct sizes of the gravel and the screen slot openings. The grading of the gravel should be in proper relation to the grading of the sand making up the water-bearing formation. The use of gravel that is too coarse can cause trouble. Figure 7-21 shows how fine sand may fill the voids in a coarse gravel-pack and reduce the yield of the well. Another result may be that sand will pass through the gravel-pack when the well is pumped, making the well a sand pumper. Coarse, uniformly graded filter sand, of about 1/8 inch maximum size, makes the best gravel-pack for most fine sand formations. Fine gravel up to 1/4 inch maximum size should be used to pack a formation consisting of medium or coarse sand. The screen to be used should have openings that will retain from 75 to 90 percent of the gravel.

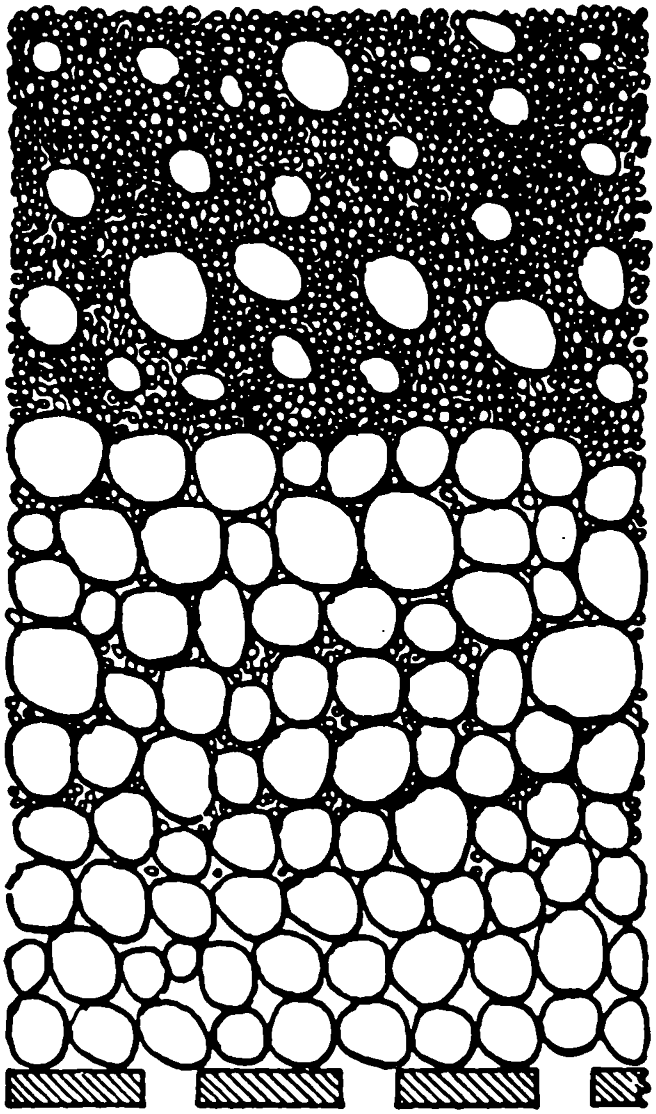


Figure 7-21. Fine sand moving into voids of coarse gravel.

c. There are two common methods of artificially gravel treating a well. One of these is to feed coarse material down around the screen as the screen is installed by the bail-down method. The bail-down shoe used in this case is made somewhat larger than the screen so that coarse sand or fine gravel being added will follow down around the screen as it sinks in the formation. Figure 7-22 shows how the operation is done.

d. Development work is an essential part of this method, just as it is in producing the natural gravel packing described in paragraph 7-9. The screen openings must be large compared to the grain size of the water-bearing sand to permit enough sand to be displaced and brought into the screen, so that an appreciable quantity of the coarse and/or fine gravel can take its place and inclose the screen.

e. The second method of gravel treatment is the most common and the one best suited for use in military field operations. The general procedure is to drill a large hole the full depth of the well, set a smaller diameter screen and casing carefully centered in the large hole, and fill the annular space around the screen with properly graded coarse sand or fine gravel. The hole may be drilled by either the down-hole percussion or the rotary method. Figure 7-23 shows the placement of the gravel where a temporary outer casing is used. This is pulled back as gravel is poured into the space. In a hole drilled by the rotary method, which is mudded up to prevent caving, the outer casing may not be necessary. In either case, the hole is filled with gravel to a considerable distance above the top of the screen. A supply of the coarse material will work down as the very fine sand and silt are removed from the formation around the gravel pack by subsequent development. After the gravel is in place, the well is developed by one or more of the methods described in paragraphs 7-9 through 7-12. The development work must be especially thorough when the hole has been drilled by the rotary method, because the mud cake on the wall of the hole is sandwiched between the gravel pack and the face of the formation. All of the mud cake must be broken up and brought through the gravel into the well. Any of it that is not removed reduces the efficiency and yield of the completed well. To assure complete removal of the mud cake, the thickness of the gravel envelope around the screen should be limited to a few inches. A common mistake is to drill the hole too large and use too small a screen, thus making the gravel thicker than it should be for best results.

f. The tremie method can be used in placing gravel pack materials to avoid separation of fine and coarse particles. A sand pumping well can result from such segregation of grain sizes. A string of 2-inch or larger pipe is lowered into the annular space between the inner and outer casings. The gravel is fed into a hopper provided

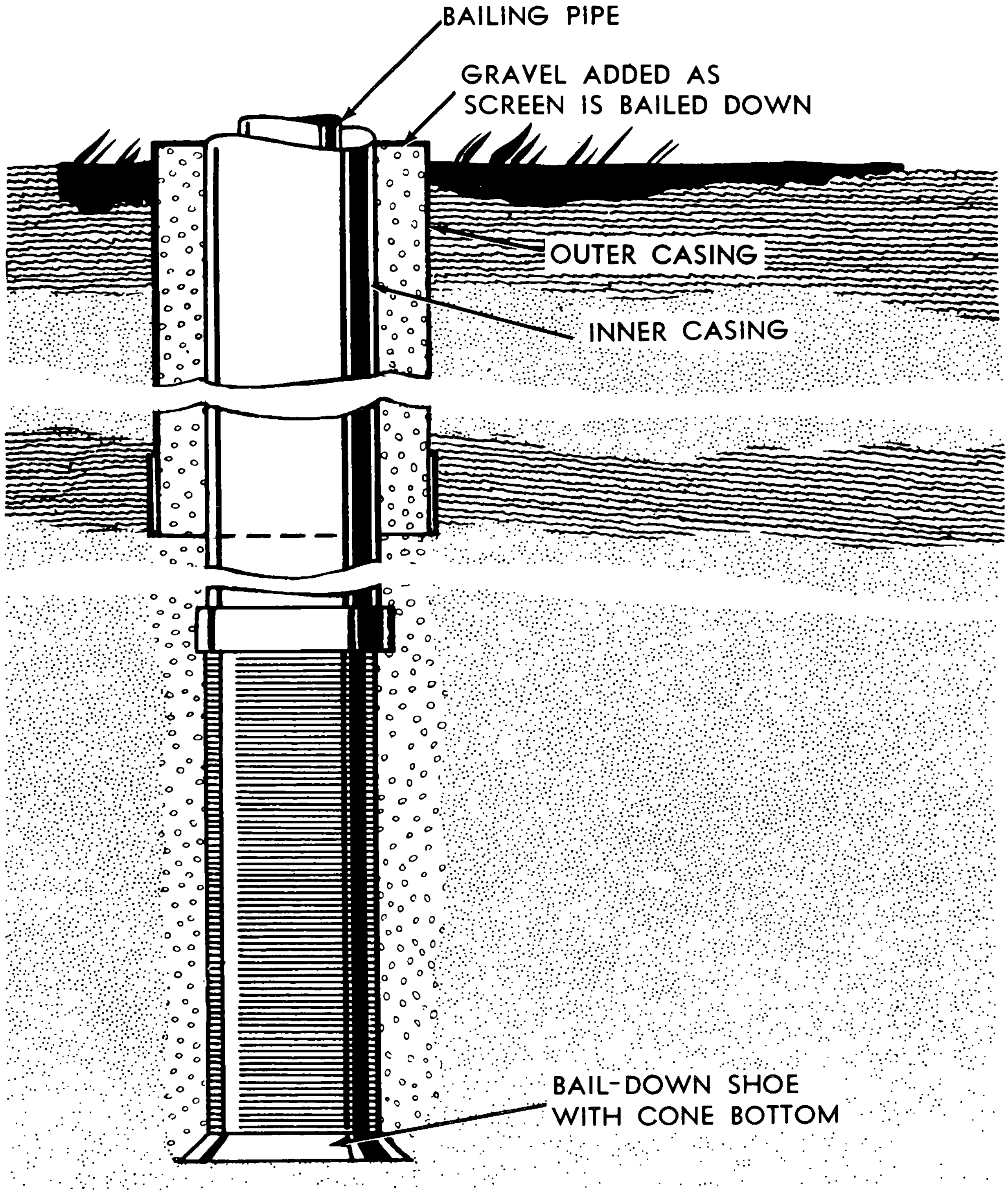


Figure 7-22. Gravel treatment.

at the top of the pipe. A good supply of water is usually fed into the pipe with the gravel to avoid bridging of the material in the pipe. The pipe is raised as the gravel builds up around the well screen, the depth to the material being measured by the string of pipe itself. The tremie system is practical for placing the gravel pack in shallow to moderately deep wells. Figure 7-24 shows the principle of the tremie method.

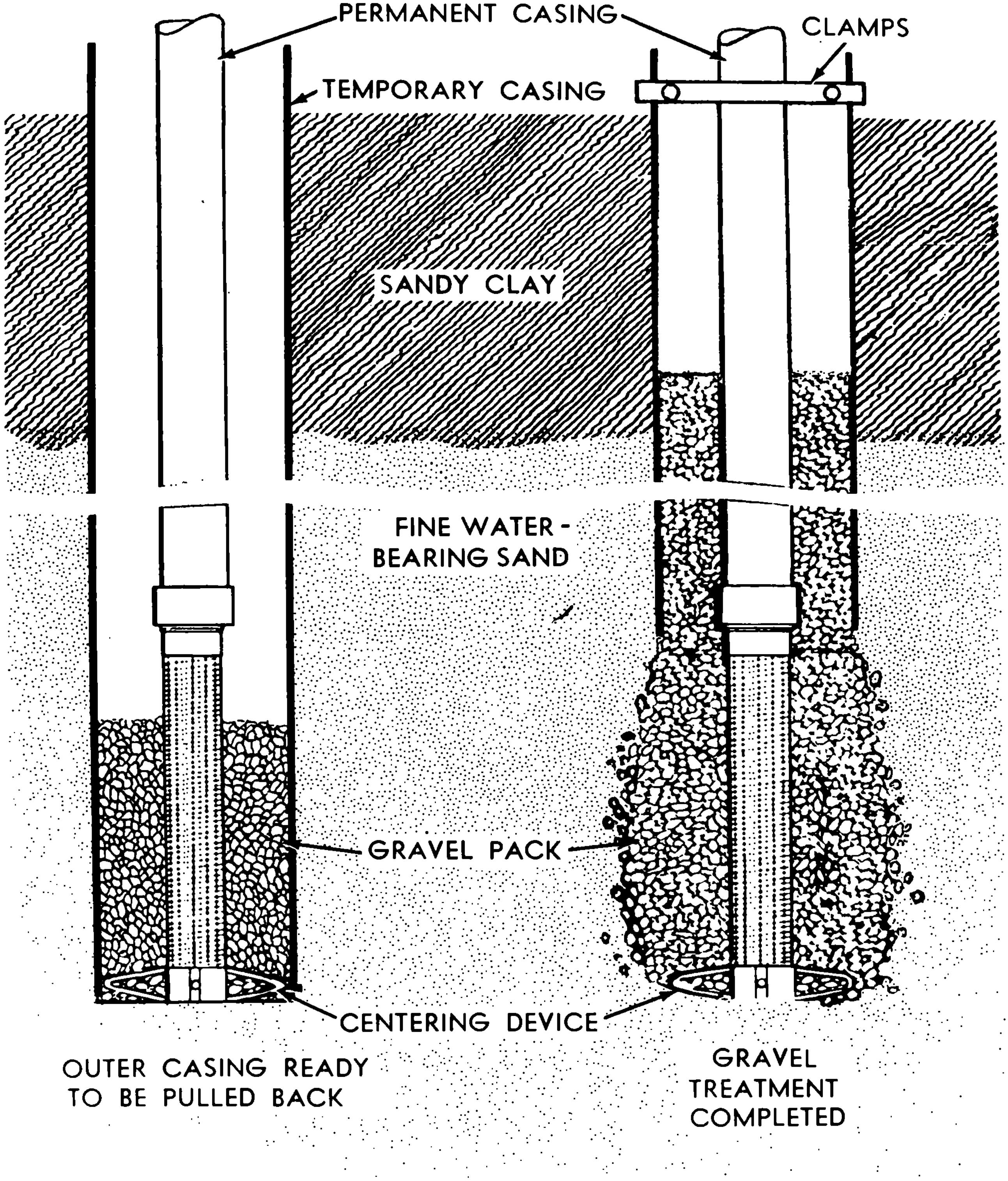


Figure 7-23. Positive method of gravel treatment.

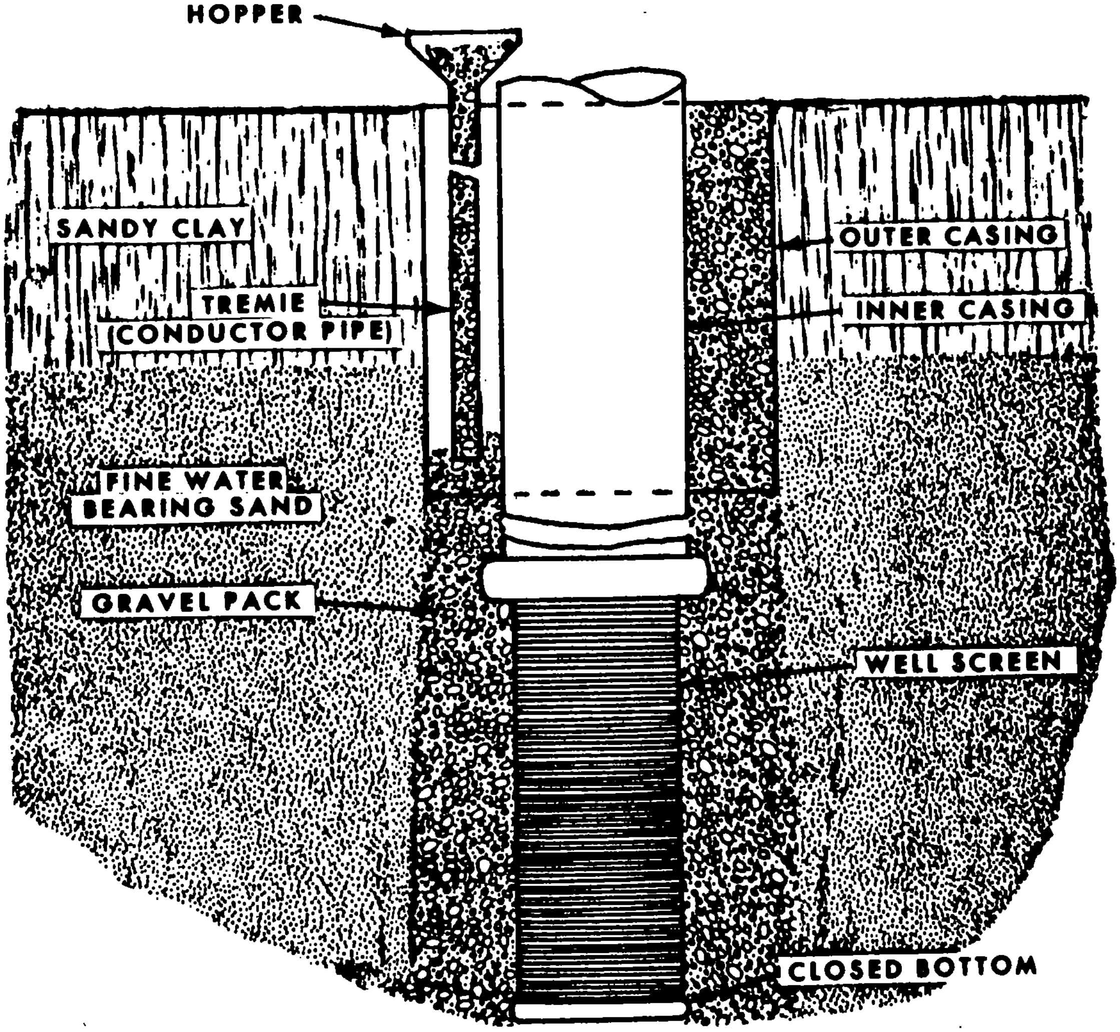


Figure 7-24. Tremie method of placing gravel pack.

Section VI. SANITARY PROTECTIVE MEASURES

7–16. Basic Considerations

A primary reason for constructing wells is to produce safe water. In selecting the well site, possible sources of contamination in surrounding areas should be considered and the construction practices described in this manual followed. Most contamination enters a well at the ground surface, either through the open top of the casing or around the outside of the casing. Sewage or other polluted liquids may percolate through relatively pervious upper layers of material down to the aquifer and contaminate an area around the source of pollution. Grouting and sealing the casing, completing the top of the well, and disinfecting the well are all operations performed to insure a safe well.

7–17. Grouting and Sealing Casing

a. Cementing or grouting the casing involves filling the annular space between the outside of the casing and the inside of the drilled hole with cement grout. When both an inner and outer casing are used, the grouting may be required between the two casings. The grout is a fluid mixture of cement and water of a consistency that can be forced through the grout pipes and placed as required. Grouting and sealing the casing in water wells is done for four reasons:

(1) To prevent seepage of polluted surface water down along the outside of the casing.

(2) To seal out water of unsuitable chemical quality in strata above the desirable water-bearing formation.

(3) To make the casing tight in a drilled hole that is larger than the pipe used.

(4) To make a protective sheath around the pipe, increasing its life by protecting it against exterior corrosion.

b. Figure 7–25 shows a rock well with the casing grouted from its lower end up to the ground surface. Figure 7–1 shows a rock well with only the lower portion grouted, the overburden being caving material that closes in around the casing tightly soon after the casing is set. Figure 7–26 shows grout placed between an inner and an outer casing, as well as around the inner casing in a portion of the drilled hole below the outer casing.

c. Equipment for mixing and placing cement grout need not be elaborate for average water well work, but it must be adequate. In planning the equipment to be used, the driller must remember that the grout mixture once prepared is starting to set. The most favorable time for placement is immediately after a thorough mixing. This means that freshly mixed material should be supplied in adequate amounts to meet the requirements throughout the grouting operation. Portland cement grout meets most requirements for grouting. However, quick-hardening cement is highly desirable and should be used to save time when it is available. Preferably about 5 gallons, and not more than 6 gallons, of water per 94-pound sack of cement should be used. Where a considerable volume of grout is needed, 1 cubic foot of fine or medium sand can be added for each sack of cement. A few pounds of bentonite (the clay used for drilling mud) added per sack of cement will make the mixture flow better. A small percentage of hydrated lime will also improve the flow property of the grout. For small jobs and where no other equipment is available, an ordinary 50-gallon steel barrel will serve as a mixing tank. Twenty gallons of water are put in the barrel and 4 bags of cement are sifted slowly while the water is stirred vigorously with a paddle. If a large quantity of grout is required, several barrels are used. This method of mixing by hand is rapid and fairly thorough. If a concrete mixer is available, a number of batches can be mixed and dumped into a storage vat from which the material is drawn as needed while mixing continues. The grout may be forced into place by suitable pumps, or by air or water pressure. Placement by gravity or by a dump bailer is practical and satisfactory in some cases. One or more strings of small diameter pipe are required for the tubing method of placement. Other equipment needed may include a mixing tank, suitable hoses, and a feed hopper.

d. The dump-bailer method of placing grout is probably the simplest and requires the least additional equipment. It works best for jobs like that shown in figure 7–1, where only the lower portion of the casing is to be grouted. The grouting is done with the hole drilled only slightly below the bottom of the casing. The drilling is completed after the grout is in place and firmly set.

(1) After running the casing in the hole, mix enough grout to fill the lower 20 to 40 feet of the hole. Place this grout inside the casing with a dump-bailer, which is a bailer arranged so that the bottom valve opens and dumps the load of grout at any place the operator wishes.

(2) When all the grout is in place, lift the string of casing 20 to 40 feet off the bottom, depending on the amount of grout placed. The lower end of the casing should be below the top of the grout.

(3) Fill the casing with water and cap the top of the pipe. Lower the pipe to the bottom of the hole and this will force most of the grout up the annular space around the outside of the casing. Do not uncap the top of the casing until the grout is set.

(4) When the grout is set, drill through the cement that has hardened in the lower end of the casing and continue drilling to the required depth.

(5) If it is expected that it will be difficult to fill the casing with water when it is lifted in the hole as described above, the water can be put in on top of the grout without lifting the casing. Calculate the volume of grout in the casing. Fill the casing to the top with water. Provide a connection to a pump so that additional water can be forced into the casing under pressure. Pump water into the casing, measuring the volume pumped, until a quantity equal to the volume of grout has been put in. This will force all or most of the grout out of the lower end of the casing. If desired, a wad of burlap may be put in on top of the grout before filling the casing with water, to separate the two fluids.

e. The inside-tubing method is another way of grouting a well. In this method the grout is placed in the bottom of the hole through a grout pipe set inside the casing. The grout may flow by gravity, or it may have to be pumped through the pipe. The grout pipe should be at least 1 inch in diameter. Once the grout has been placed in the hole to the desired depth, it is forced up into the space around the outside of the casing. The operation is continued until the grout appears at the ground surface around the casing. During the

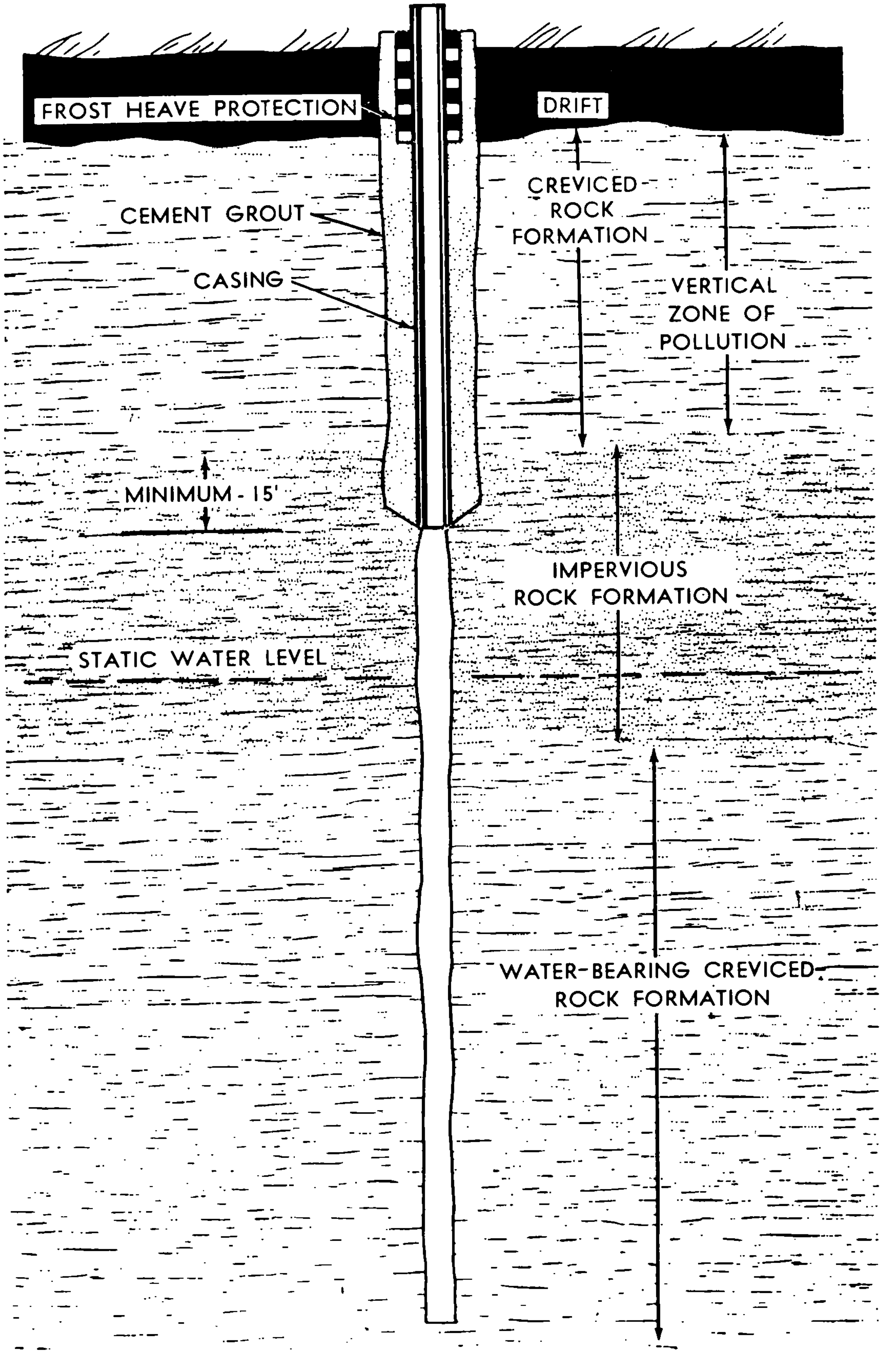


Figure 7-25. Construction of well with grouted casing pipe.

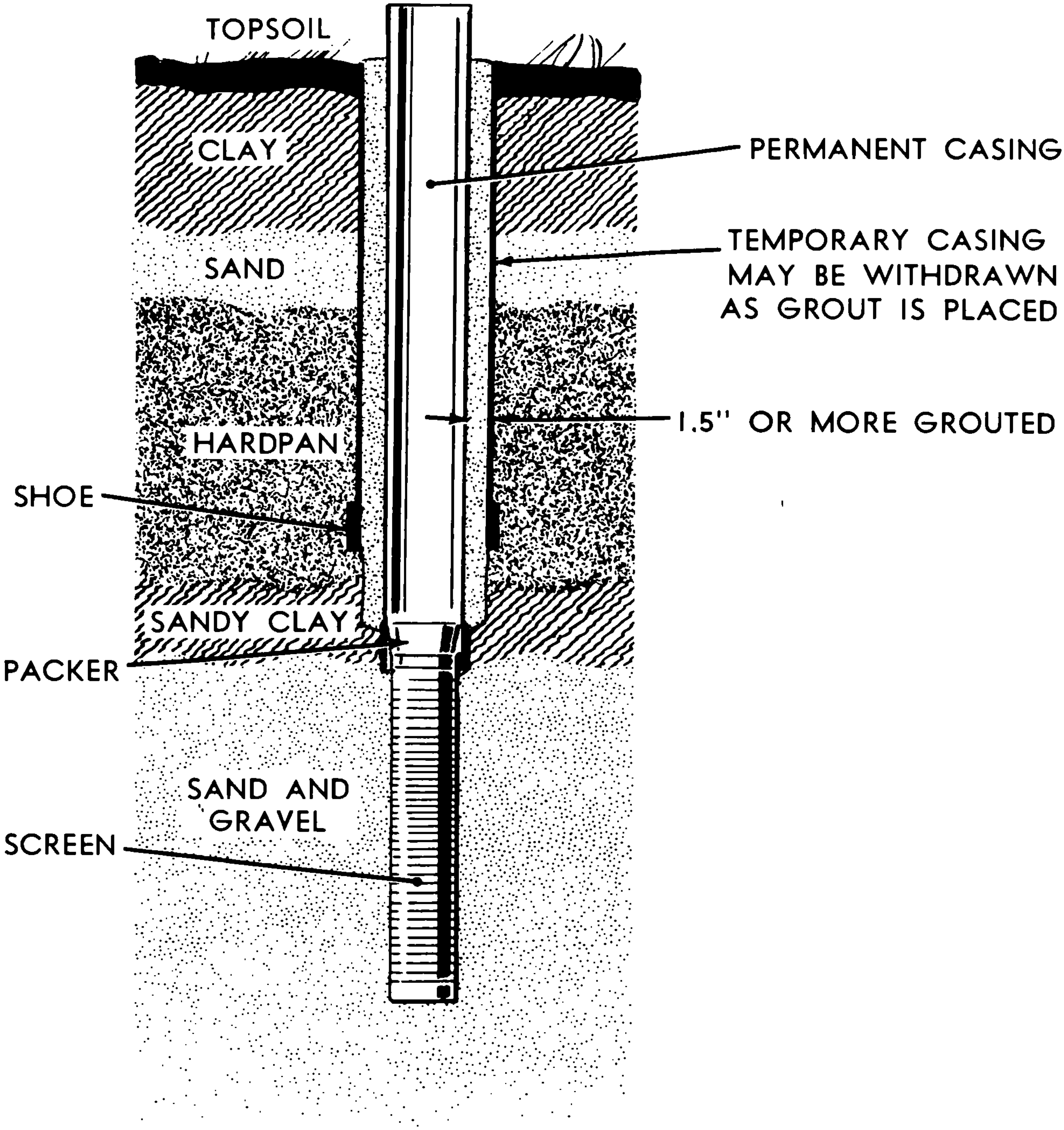


Figure 7-26. Grout placed between inner and outer casing.

grouting, the casing is suspended about 2 feet above the bottom of the hole. It is lowered and seated in its permanent position after the grout is in place. The grout pipe is then removed and cleaned, provision being made to prevent the grout from moving back into the casing. When the grout has set and hardened, which will be 24 to 72 hours later, depending on the type of cement used, the packer is drilled out, and drilling of the rest of the well below the grouted casing is continued. A useful precaution in this method and any other method where the grout is to be placed inside the casing is to be usre that water or drilling fluid will circulate up around the casing before grouting is started. To check this, cap the casing and pump water into it. If the water can be forced up to the surface outside the casing, grouting may be started. If water cannot be forced through the space around the casing, it is useless to try to grout this space.

f. If the space between the outside of the casing and the wall of the hole is large enough to contain a grout pipe of at least 1 inch standard size, the grout pipe may be lowered to the bottom of the hole in this space. Make sure that the lower end of the casing is tightly seated at the bottom of the hole. Mix the quantity of grout required and pump it through the grout pipe or let it run through by gravity (fig 7-27). As the grout is placed, lift the grout pipe little by little but keep the lower end submerged in the grout. It is good practice to fill the casing with water as the grout is placed to approximately balance the fluid pressure inside and outside the casing. This prevents leakage of the grout under the bottom of the casing. This method is not recommended for depths greater than 100 feet.

g. As an expedient, grouting of the casing near the surface can be done by simply dumping the grout in the hole around the casing and puddling it with lengths of pipe. Obviously this provides only a surface seal around the casing and cannot be compared with grouting and sealing done by the other methods described.

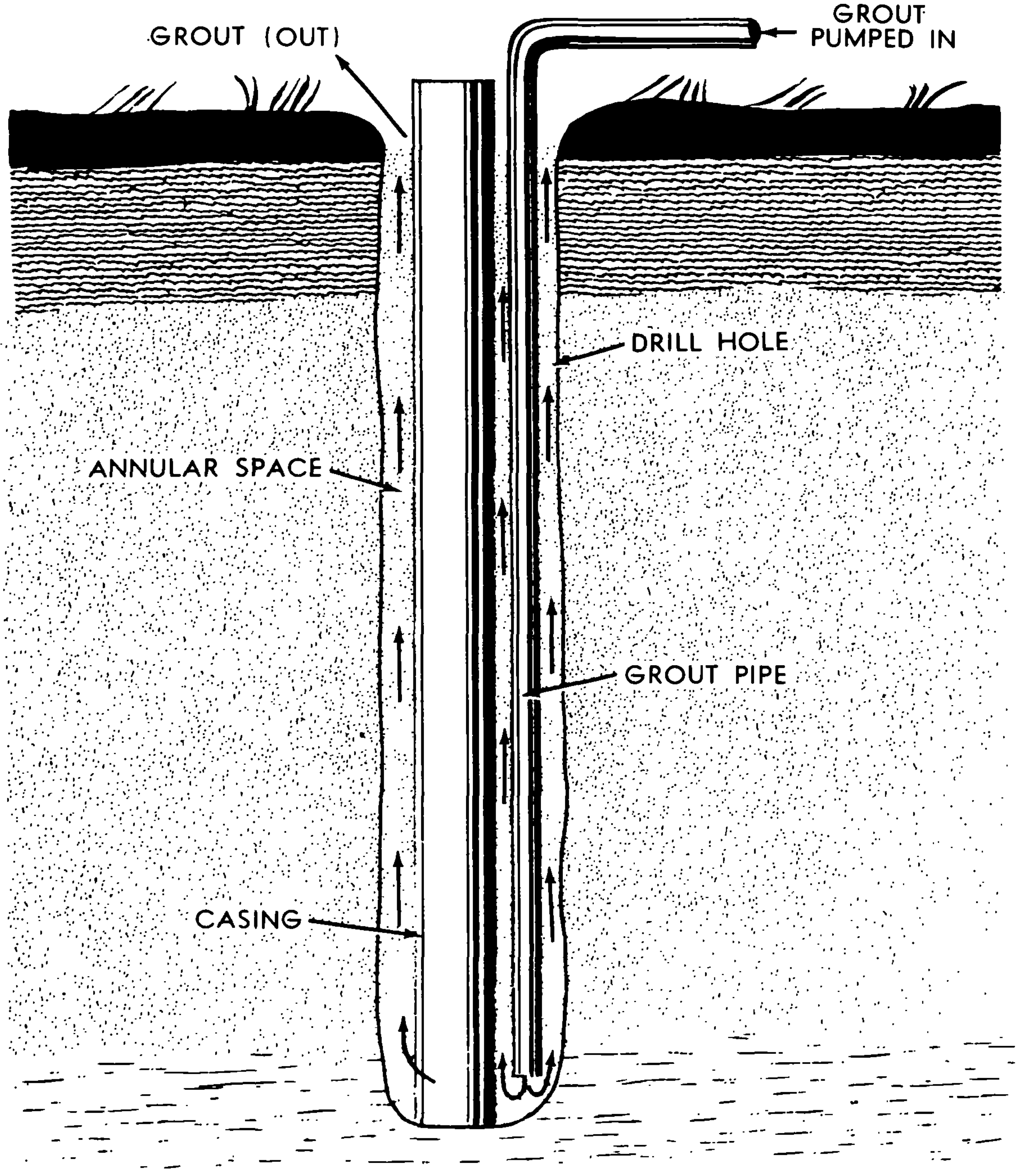


Figure 7-27. Grout pipe outside casing.

7–18. Plugging Wells

If a test hole or an old well is to be abandoned, it should be plugged properly so polluted water will not flow through it and contaminate the aquifer. Thick mud fluid or cement grout are the most effective materials for plugging wells. Sometimes a hole may have been drilled too deeply and it is desired to complete the well in a formation some distance above the bottom. In such a case, the bottom section of the hole must be carefully plugged from the bottom up. The methods described in paragraph 7-17 for placing grout may be used in plugging an open hole.

7–19. Completing Top of Well

The casing in any well should extend at least 1 foot above the general level of the surrounding surface. The space around the outside of the casing should be sealed securely as described in paragraph 7-17. When possible, a concrete platform should be poured around the casing at the ground surface. For an open dug well, a watertight cover must be provided over the curbing. A concrete cover is preferable. Wood covers cannot be kept watertight. A well with pipe casing should be provided with a sanitary well seal at the top that fills the space between the pump pipe and the well casing. This device consists of a bushing or packing gland that makes a watertight seal at the top of the casing.

7–20. Disinfection

a. Disinfection of wells is often neglected. Practically all newly constructed wells are contaminated from dirt sticking to the pipe and should be disinfected promptly after completion. The easiest way to do this is to prepare a chlorine solution as follows. Mix one heaping tablespoon of calcium hypochlorite with a little water to make a thin paste, being sure to break up all lumps. Stir this into 1 quart of water. Allow the mixture to stand a short time. Pour off the clear liquid. The chlorine strength of the solution is about 1 percent; 1 quart of the liquid is enough to disinfect 1,000 gallons of water. Larger quantities of the disinfecting solution may be prepared in the same proportion and, if placed in sealed containers (preferably glass), can be stored for several years without losing its effectiveness.

b. Estimate the volume of water in gallons standing in the well. Pour in 1 quart of the disinfecting solution for each 1,000 gallons of water in the well. No harm is done if too much solution is used, and it is better to use too much than too little. Agitate the water in the well thoroughly and let it stand for several hours, preferably overnight. Then flush the well to remove all of the disinfecting agent. The well casing can be disinfected by returning the water to the well during the first part of the flushing, thereby washing the walls of the well with chlorinated water.

CHAPTER 8

WELL HYDRAULICS AND TESTING

Section I. WELL HYDRAULICS

8–1. Drawdown

a. Before being pumped, the level of water in a well in an unconfined aquifer is the same as the level of the water table in the water-bearing formation in which the well is completed. This is called the *static level* in the well and in the formation. The depth from the ground surface to the static water level is measured and used to describe the level's position. Thus, if the water in the well is 25 feet below ground, the static water level is said to be 25 feet. Elevation of the static water level above mean sea level can also be used to describe its position.

b. When a well is pumped, the water level drops. After several hours of pumping at a constant rate, the level may stabilize in a lower position. This level is called the pumping level or *dynamic water level* for this rate of pumping.

c. The distance that the water is lowered by pumping is called the *drawdown.* It is the difference between the static level and the pumping level. The drawdown in the well, resulting from pumping, lowers the water pressure in the well and in the surrounding aquifer. In response to this change in pressure, water moves from the aquifer into the well.

d. The water-bearing formation does not give up its water all at once to the pumped well. The flow of water into the well is held back by the frictional resistance offered by the formation to the flow of water through its pores. This resistance affects *permeability* of the formation which is developed in direct proportion to the rate of movement or velocity of the water in the formation. It follows from this that the rate of flow resulting from a given pressure difference depends on the frictional resistance to flow developed in the formation.

e. To visualize what occurs when a well is pumped, consider the small voids, pores, and channels in the formation, through which the water passes, as a complex system of pipes, all of which are connected and leading to the main well. If a full stream of water were run through a single pipe with a device for measuring the head or pressure of the water placed at both ends of the pipe, there would be less pressure at the discharge end than at the intake end. The "rubbing" of the water against the pipe walls and the rubbing of the molecules of the water against each other cause friction, and it requires some pressure to make up for, or overcome, that friction. In a complex system of pipes or in a system of passageways like the openings in a sand formation, there are other causes of pressure loss, such as bends and contractions, in addition to simple friction. The property that is a measure of the total pressure loss in the formation is the permeability of the formation. It is the difference in pressure measured by the amount of drawdown or drop in head that moves the water through the water-bearing formation and into the well.

f. From *e* above it can be understood that the total pressure difference, represented by the drawdown in the well, distributes itself throughout the formation in every direction around the well. The water level in the formation slopes toward the well from every direction within the area of influence of the pumping well. The water table within this area takes the form of a depression, shaped like an inverted bell, which is called the *cone of depression.* At any point within the cone of depression, the distance that the water surface drops below the original static level is the drawdown at that point. This may be determined in an observation well at any desired location, just as the drawdown in the pumping well is measured. Figure 8–1 illustrates the drawdown at various distances from a pumping well. The shape and extent of the cone of depression vary with the rate of pumping and with the permeability of the aquifer.

g. For a particular type of well to be constructed, the yield of the well for any given drawdown is directly proportional to the permeability of the formation. This property of the formation varies through wide ranges, the value for a coarse sand stratum being several hundred times that of a fine sand stratum of the same thickness. As noted in paragraph 2–5, permeability is influenced by a number of factors. It increases with coarseness of the sand and decreases with the compactness of the material. It

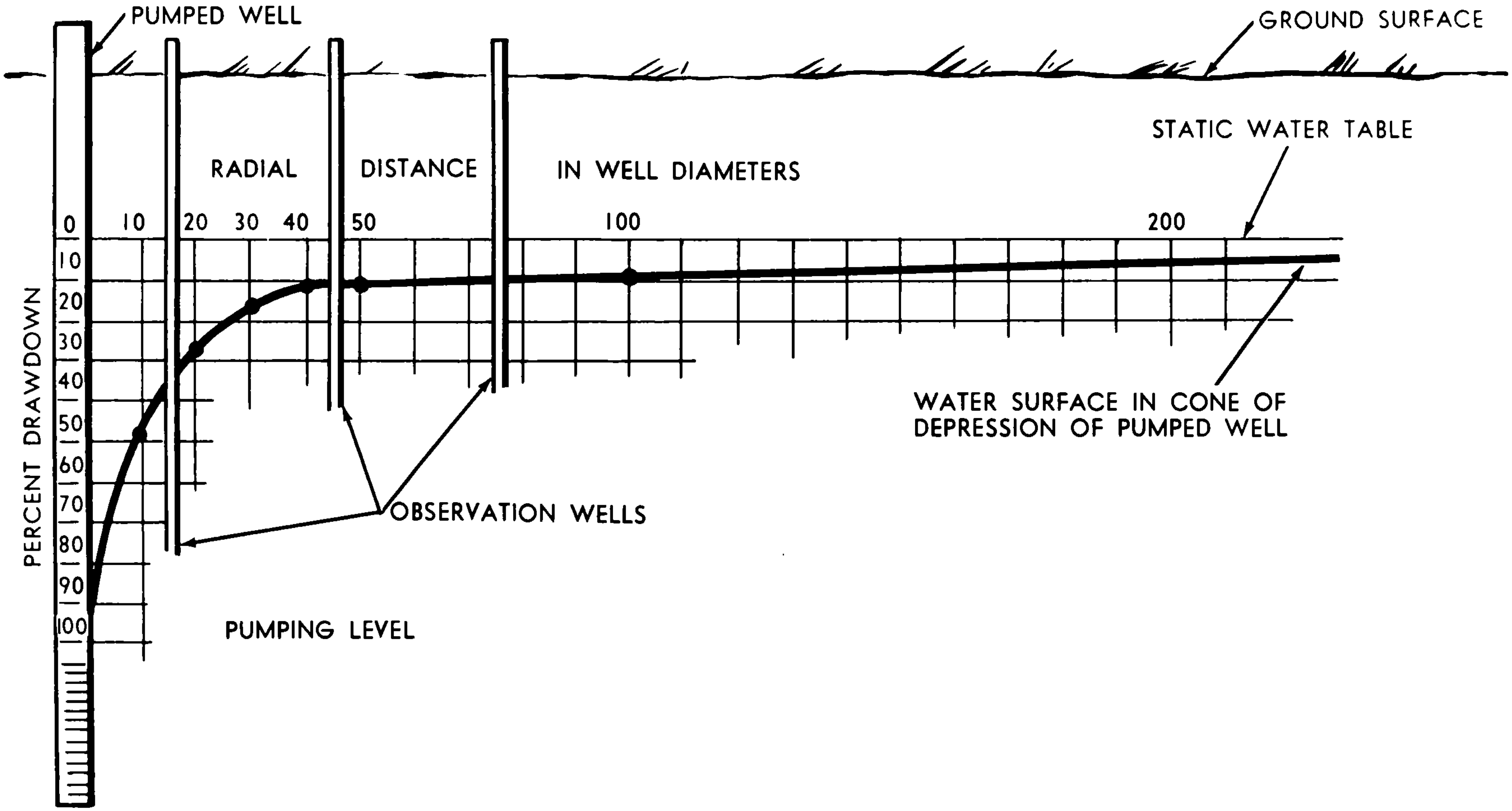


Figure 8-1. Curve showing drawdown at various distances from a pumped well.

increases where the sand grains are more nearly uniform in size. It decreases when fine sand and silt fill the voids between larger particles. The permeability of a rock formation, like limestone, varies with the number and size of the fractures, crevices, and solution channels.

h. The importance of the uniformity of sand in its effect on hydraulic properties is often overlooked. *For example*, if some large stones are found in a sand stratum, it is usually assumed that these particles improve the permeability of the formation. However, if these stones are seen as simply floating in the formation, each one completely embedded in the sand, it is obvious that the stones actually obstruct the flow, because water must move around them through the sand.

i. In wells where the casing penetrates the full depth of the water-bearing stratum, the water production capacity of the well is directly proportional to the thickness of this stratum if the drawdown and other conditions remain the same. The deeper the well is driven into a water-bearing stratum, the greater the discharge for a given drawdown. Where the water-bearing formations are thick, there is a tendency to limit the depth of wells due to the cost. This cost, however, usually is balanced by the savings in operation resulting from the decreased drawdown.

j. As noted in paragraph 2-5*a*, if the water-bearing stratum is confined under a tight, impervious layer of other material, such as clay, the water will usually be under some pressure in the formation so that when a well is drilled into it the water rises in the well above the top of the formation. In such cases, the water in the formation is said to be under artesian pressure. A well completed in such a formation is performing under artesian conditions, in contrast to nonartesian conditions where the water in the formation is not confined by an overlying impervious stratum. The relationship between drawdown and yield is somewhat different for each of these conditions, as indicated by the curves shown in figure 8-2. *For example*, under artesian conditions, 40 percent of the total available drawdown will develop 45 percent of the maximum yield of the well. Under nonartesian conditions, 40 percent of the total available drawdown will develop 64 percent of the maximum yield of the well. It is evident that yield increases almost in direct proportion to drawdown under artesian conditions throughout the whole range of available drawdown. Under nonartesian conditions, the yield increases about in direct proportion to drawdown up to the point where about 60 percent of the available drawdown has been utilized. Further drawdown beyond 60 percent will not give much additional yield. Further discussion of the use of these curves is given in paragraphs 8-2 through 8-7.

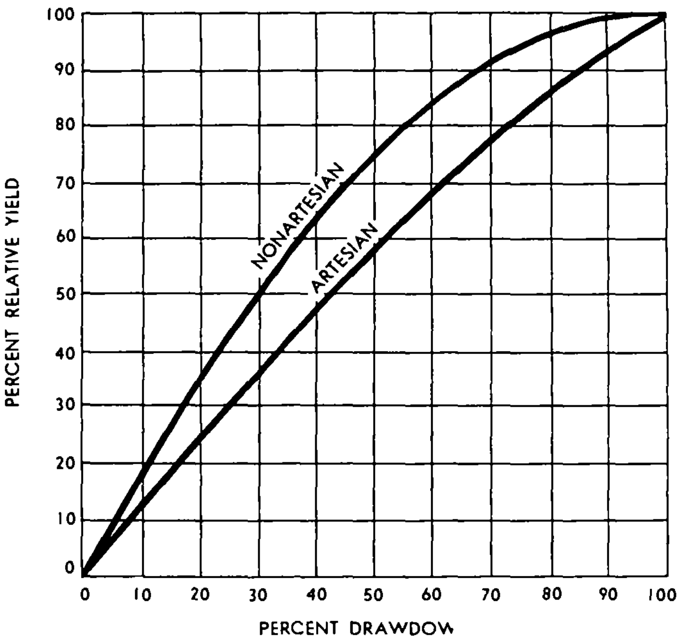


Figure 8-2. Ideal relation of drawdown to yield.

Section II. WELL TESTING

8-2. Purpose

Pumping tests are made on wells to determine the well's capacity and other hydraulic characteristics, and to secure information so permanent pumping equipment can be intelligently selected. Preliminary tests of wells drilled as test holes are sometimes made to compare the yielding ability of different water-bearing formations or different locations in the same formation. This information is then used to select the best site for a supply well and the aquifer in which is should be completed.

8-3. Measurements

The measurements that should be made in testing wells include the volume of water pumped per minute or per hour, the depth to the static water level before pumping is started, the depth to the pumping level at one or more constant rates of pumpage, the recovery of the water level after pumping is stopped, and the length of time the well is pumped at each rate during the testing procedure. For the definitions and the significance of some of the terms used here, refer to paragraph 8-1. The testing described in this chapter is essentially the measurement of the hydraulic characteristics of a particular well. An additional term called "specific capacity" needs to be defined here. The specific capacity of a well is its yield per foot of drawdown, usually expressed as gallons per minute per foot of drawdown. The specific capacity is not constant for all values of drawdown, but is nearly so for wells tapping very thick aquifers and wells operating under artesian conditions. Normally, the specific capacity of a well decreases with increased drawdown. Notwithstanding such variation, the specific capacity does indicate the relative yield of a well and is a term that is widely used.

8-4. Pumping Procedure

a. The pump and power unit used for testing a well should be capable of continuous operation at a constant rate of pumpage for several hours. The equipment should be in good condition for an accurate test, since it is undesirable to have a forced shutdown in the middle of the test. If possible, the test pump should be large enough to test the well beyond the capacity at which it will eventually be pumped, but this may not be practicable under field military operations. Pumping by airlift (para 9-9 and 9-10) will be a practical method in many cases. A rough idea of the yield of a small well can be gained by bailing water from the well rapidly, if no pump is available. Knowing the volume of water the bailer holds and counting the number of times per minute it is brought up full will give the gallons per minute removed from the well. No measurement of drawdown is possible, however, because the water level continuously fluctuates from the static level to a varying pumping level.

b. For a fairly complete test of a well, the pump should be operated first at a rate that will lower the water in the well about one-third of the maximum drawdown possible, or at about one-third of the capacity of the pump. Continue pumping at this rate until the pumping level remains about constant. This will require from 1 to 4 hours in most cases. After making the necessary measurements, change the rate of pumpage to produce two-thirds of the maximum drawdown or to two-thirds of the capacity of the pump. Repeat the measurements when the pumping level becomes about stable. Increase the rate of the pumpage to produce the maximum drawdown; or increase it to the capacity of the pump and make measurements a third time when the pumping level becomes about stable.

8-5. Measuring Rate of Pump Age

a. The simplest way to measure the water pumped is to catch it in a steel drum or other tank of known volume. The time required to fill the tank is determined as accurately as possible. The rate of pumpage in gallons per minute is then calculated. To get reasonable accuracy, the tank should be large enough to hold the water pumped during a period of at least 2 minutes. This limitation makes the method practical only for relatively small wells, since large tanks will not usually be available.

b. A circular-orifice meter (fig. 8-3) is the device that is most commonly used to measure rate of pumpage. It gives good results when used to measure the discharge of centrifugal and deep well turbine pumps. It is compact and easily installed. The device consists of a sharp-edged circular orifice at the end of a horizontal discharge pipe. The orifice is from one-half to three-fourths of the diameter of the pipe. The pipe must be smooth internally and free of any obstructions for a distance of at least 6 feet from the orifice. The discharge pipe is tapped with a small hole on one side and provided with a rubber tube connection, so that the pressure or head in the discharge pipe can be measured at a distance of 2 feet from the orifice as shown in figure 8-3. The length of hose

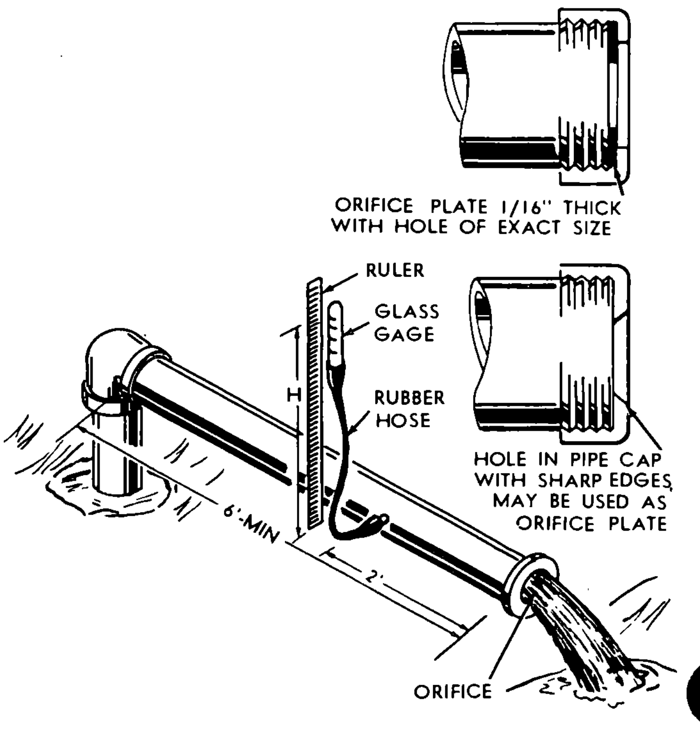


Figure 8-3. Circular-orifice meter.

and ruler will depend on pipe size as indicated in table 8–1. The discharge pipe must be horizontal and the stream must fall free from the orifice. The orifice must be vertical and centered in the discharge pipe. The combination of pipe and orifice diameters for a given test should be such that the head measured will be at least three times the diameter of the orifice.

c. Table 8–1 gives the discharge in gallons per minute through circular-orifice meters of various sizes corresponding to the heads observed in the manometer tube.

d. A triangular or V-notch weir is another convenient device for measuring the flow of water. The notch is cut in a plate that forms one end of a channel or box. The included angle of the V-notch should be 90°. The head on the weir is measured upstream from the weir at a distance at least 2 1/2 times the depth of the water flowing over the weir, as shown in figure 8–4. The flow through the box should be steady and free from waves. Table 8–2 gives rates of discharge through a 90° notch for various values of the measured head.

e. At times it is desirable to make a quick estimate of the flow from an open pipe. An approximate value of the discharge from a horizontal pipe, flowing full of water and with free fall from the end of the pipe, can be determined by measuring the distance from the end of the pipe to the point which is exactly 1 foot above the falling stream of water, as shown in figure 8–5. This distance in inches multiplied by the area of the pipe in square inches is approximately equal to the discharge in gallons per minute. Table 8–3 gives values of discharge for various sizes of pipe and various values of the horizontal distance (D).

8–6. Measuring Depth of Water

a. Chalked Tape Method. The most accurate way to measure depth to the static level and to the pumping level in a well is with a chalked tape. A steel tape with a weight to make it hang straight is chalked at the lower end with blue carpenter's chalk and lowered into the well until 1 or 2 feet of the chalked lower end is submerged. The proper length to lower may have to be determined by experiment the first time. The wetted length of the tape, which shows up very clearly on the chalked portion of the tape, is subtracted from the total length lowered below the reference point; this gives the depth to water.

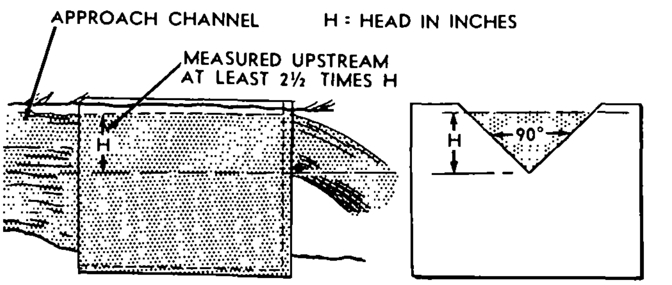


Figure 8-4. Triangular or V-notch weir.

Table 8-1. Discharge in Gallons per Minute from Circular-Orifice Meters

Head of water in tube above center of orifice (inches)	4-inch pipe, 2 1/2-inch opening (gpm)	4-inch pipe, 3-inch opening (gpm)	6-inch pipe, 3-inch opening (gpm)	6-inch pipe, 4-inch opening (gpm)	6-inch pipe, 5-inch opening (gpm)	8-inch pipe, 4-inch opening (gpm)	8-inch pipe, 5-inch opening (gpm)	8-inch pipe, 6-inch opening (gpm)
6	62	102						
7	66	110	88					
8	70	118	94	180	350	170	280	440
9	75	126	100	190	370	180	295	465
10	80	132	106	200	390	190	310	490
12	87	145	115	220	425	210	340	540
14	94	156	125	238	460	225	370	580
16	100	168	132	253	490	240	390	620
18	106	178	140	268	520	255	415	660
20	112	188	150	283	550	270	440	695
22	118	198	158	298	575	280	460	725
25	125	210	168	318	610	300	490	780
30	138	230	182	350	670	330	540	850
35	150	250	198	375	725	360	580	920
40	160	265	210	400	780	380	620	980
45	170	280	223	425	820	400	660	1,040
50	180	300	235	450	870	425	700	1,100
60	195	325	260	490	950	465	760	1,200

Table 8-2. Discharge over 90° Triangular Weir in Gallons per Minute

Head (in.)	Discharge (gpm)	Head (in.)	Discharge (gpm)	Head (in.)	Discharge (gpm)
1 1/2	6.6	3 3/4	64.0	8	416
1 3/4	9.8	4	75.0	8 1/2	485
2	13.6	4 1/2	100.0	9	556
2 1/4	18.0	5	130.0	9 1/2	635
2 1/2	23.5	5 1/2	165	10	721
2 3/4	30.0	6	204	10 1/2	813
3	37.0	6 1/2	249	11	913
3 1/4	45.0	7	299	11 1/2	1,020
3 1/2	54.0	7 1/2	355	12	1,131

Table 8-3. Approximate Flow from Pipe Running Full in Gallons per Minute

Diam pipe (in)	Horizontal distance (D) (inches)									
	12	14	16	18	20	22	24	26	28	30
2	41	48	55	61	68	75	82	89	96	102
3	90	105	120	135	150	165	180	195	210	225
4	150	181	207	232	258	284	310	336	361	387
6	352	410	470	528	587	645	705	762	821	880
8	610	712	813	915	1,017	1,119	1,221	1,322	1,425	1,527
10	960	1,120	1,280	1,440	1,600	1,760	1,930	2,080	2,240	2,400
12	1,378	1,607	1,835	2,032	2,286	2,521	2,760	2,980	3,210	3,430

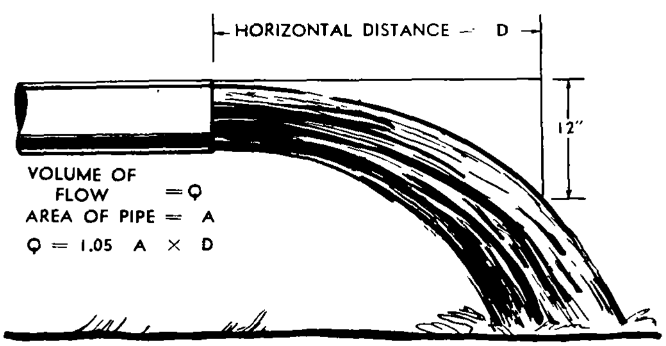


Figure 8-5. Method of estimating flow from horizontal pipe (full).

b. Air Line Indicator. Some deep well pumps are equipped with pressure gages and air lines of known lengths. The pressure in feet of water required to force all the water out of the air line subtracted from the length of the air line gives the depth to water (fig 8-6). The air line must be airtight to obtain correct readings. Air must be pumped into the line until the maximum pressure is reached. The bottom of the air line should be about 10 feet above or below the suction of the pump. This is especially true of turbine installations where high velocities will affect the readings. Normally the air line is full of water up to the level of the water in the well (static or pumping level). When air is forced into the line, it creates a pressure which forces all of the water out of the lower end, filling the line with air. If more air is then pumped in, air instead of water is expelled, and further increase of pressure is not possible. The head of water above the lower end of the air line maintains this pressure, and the gage shows the pressure or head required to balance the water pressure. If the gage is graduated in feet of water (altitude gage), it registers directly the amount of air line that is submerged. This reading subtracted from the length of the line gives the water level (static or pumping). If the gage is graduated in pounds per square inch, the reading must be multiplied by 2.31 to give the submergence in feet. Then, as above, the submergence is subtracted from the total length of the line to give the water level.

8-7. Calculations

a. The drawdown observed during a well test is the difference in feet between the pumping level and the static water level before pumping was started. The specific capacity of the well is the yield or discharge in gallons per minute divided by the drawdown in feet.

b. If desired, the yield of a well at some value of drawdown beyond the limit of the actual pumping test can be estimated by using the pumping test data and the curves shown in figure 8-2. In using the curves, the maximum possible

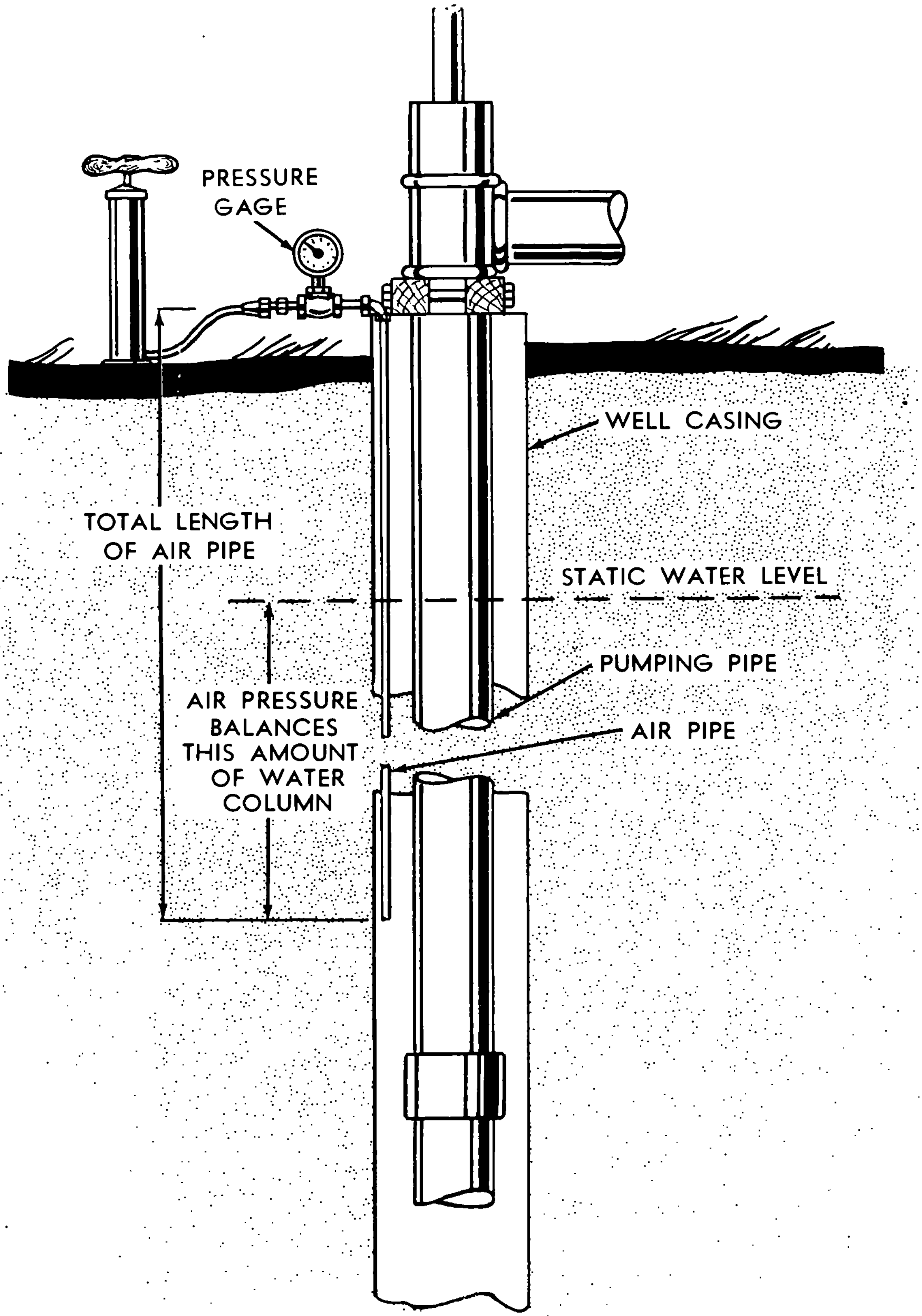


Figure 8-6. Air line water level indicator.

drawdown is considered as being from the static level to the bottom of the well. In other words, 100 percent drawdown equals the depth of water in the well before pumping. *As an example,* assume a well contains 100 feet of water and that the well is under a nonartesian condition. If the drawdown is 25 feet for a pumping rate of 80 gallons per minute, this is the yield corresponding to 25 percent drawdown. Looking at the curve, it will be seen that 25 percent drawdown will develop about 45 percent of the maximum yield of the well, which in this example equals 80 gallons per minute. Following along the curve to 50 percent drawdown, it is seen that the yield would increase to 75 percent of maximum at a drawdown of 50 feet. The yield for this drawdown would then be:

$\frac{75 \text{ percent}}{45 \text{ percent}} \times 80 \text{ gpm} = 133 \text{ gpm}$. Any other combination of drawdown and yield can be estimated by similar calculations. Theoretically, the maximum yield of this well would be:

$$\frac{100\%}{45\%} \text{ X } 80 \text{ gpm} = 178 \text{ gpm}.$$

CHAPTER 9

PUMPS

Section I. INTRODUCTION

9–1. Selection Criteria

a. The selection of the pump for a water well depends on the size of the well, the quantity of water to be pumped, the drawdown and pumping level when pumping at the desired rate, and the type of power unit that is available. There are two general types of pump installation. One type is set above ground, either on top of the well casing or near the top of the well. The other type is installed inside the well casing at the required depth below the ground surface for proper operating conditions. The pumps available for field military use can thus be grouped in two classes to simplify descriptions of their characteristics and limitations.

b. In this chapter the well pumps that are normally installed above ground are referred to as suction-lift pumps. This designation is used to distinguish such pumps from others called deep-well pumps which can be lowered inside the well casing to the desired depth. The lowest pumping level at which a suction-lift will operate is at a distance below the center of the pump equal to the maximum suction lift of the pump. At sea level, the practical limit of suction is 22 to 25 feet. Suction lift pumps can be used, therefore, only where the pumping level in the well will be within the limit of suction lift, or 22 to 25 feet below the position of the pump. This restricts the maximum drawdown to a few feet in most cases and limits the maximum pumpage to the yield of the well corresponding to this drawdown, regardless of the size of the pump used.

9–2. Suction Lift

The suction-lift pump does not lift water mechanically through the intake line in the sense that it pushes water out through the discharge line. Actually, the pump exhausts air from the suction or intake line, thus creating a partial vacuum by lowering the pressure on the intake side below atmospheric pressure. Atmospheric pressure on the water in the well then forces the water up through the suction line into the pump itself. The only force available, then, to lift water to the pump is the atmospheric pressure, which at sea level is 14.7 pounds per square inch, or the equivalent of 34 feet of water. This theoretical maximum cannot be reached in practice, which accounts for the limit of 22 to 25 feet given in paragraph 9-1. At 5,000 feet above sea level, the practical limit of suction lift is only about 20 feet. Since a suction-lift pump must create a partial vacuum in the suction line, the line must be absolutely airtight if the pump is to function properly. Threaded joints must be carefully sealed with pipe compound, and all connections to the pump must be tight.

Section II. SUCTION LIFT PUMPS

9–3. Pitcher-Spout Pump

a. This pump gets its name from the shape of the discharge spout (fig. 9–1). It has a hand-operated plunger that works in a cylinder designed to be set on top of the well casing. The suction pipe screws into the bottom of the cylinder. The plunger has a simple ball valve which opens on the downstroke and closes on the upstroke. Usually, there is a check valve at the lower end of the cylinder which opens on the upstroke of the pump and closes on the downstroke. The check valve is made so that it will tilt when the plunger is forced down on top of it by lifting the pump handle as high as possible. The tilting of the check valve allows the pump and suction line to drain. To reprime the pump after draining, put water into the cylinder from the top. Most pitcher pumps are open at the top and, for this reason, they are not an entirely sanitary piece of well equipment.

b. The maintenance for this type of pump consists of renewing the plunger and check valve leathers, and cleaning the suction pipe. Renewal of the leathers is a simple task. Cleaning the suction pipe is necessary when it becomes clogged with sand, gravel, or other material. This condition can be easily detected because the operation of the pump becomes noisy and the handle of the pump is likely to fly up when it is released during the downstroke.

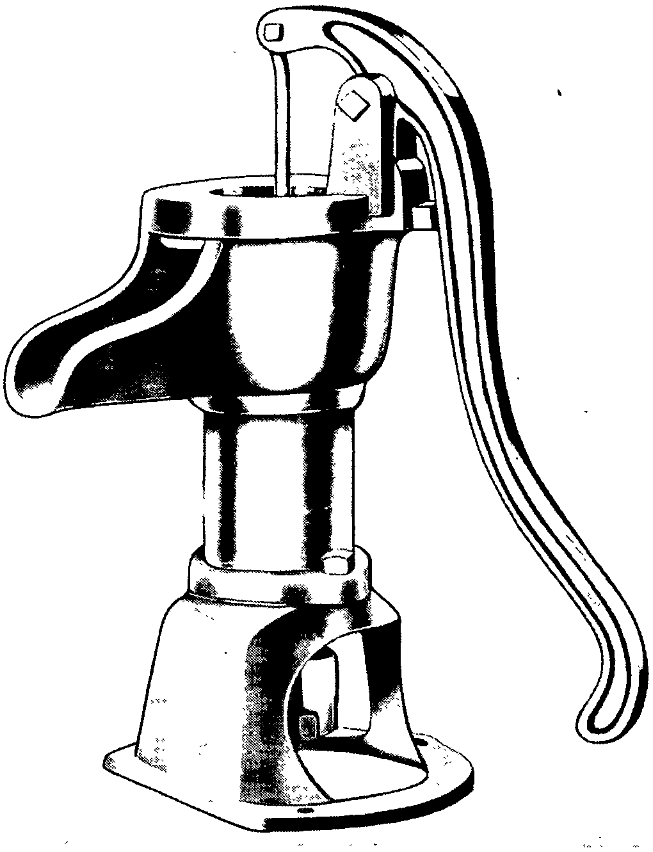


Figure 9-1. Pitcher-spout pump.

9–4. Centrifugal Pump

a. Description. A centrifugal pump (fig. 9–2) is one in which the water is moved by the centrifugal force transmitted to it in properly designed channels of a rotating impeller. The water enters the pump at the center of the impeller and is thrown outward by the centrifugal force. A closed case, with a discharge opening suitably located, surrounds the impeller. The essential parts, then, are the rotating impeller with a number of backward-bent blades fastened to a hub or mounted on a horizontal shaft, and the stationary case. The case has a volute or snail-shaped channel for the water, which increases in cross section in the direction of flow toward the outlet opening. As the water passes into the gradually widening channel, the speed decreases and the pressure increases. The hydraulic characteristics of the pump depend on the dimensions and shape of the water passages of both the impeller and the case.

b. Starting. The pump and the suction pipe must be filled with water before starting. A foot valve on the suction line is provided to permit filling the pipe. When the impeller starts rotating, the water is thrown outward from the center by centrifugal force. This forces the water already in the casing out through the discharge pipe, producing a partial vacuum in the center. Atmospheric pressure, acting upon the surface of the water source, immediately forces more water up the suction pipe and into the impeller to replace the water that has been expelled. This action is steady and continuous.

c. Effect of Increasing Head. Head is the pressure or force exerted by a column of fluid measured at its lower point. The head capacity of the pump is the pressure it must produce to overcome the pressure of the fluid. If the head against which the pump must work is increased and the speed is unchanged, the amount of water discharged will decrease and vice versa. If the head is increased beyond the head capacity of the pump (shutoff head), no water will be pumped. The impeller only churns the water inside the case and the energy expended heats the water and pump.

d. Two Pumps Connected in Series and in Parallel. If two centrifugal pumps are connected in series, that is, with the discharge of the first connected to the suction of the second, the pump capacity is that of the first pump, but the head is the sum of the discharge heads of both pumps. The same effect is obtained by placing two or more impellers in one casing (multistage pump). If the two pumps are connected in parallel, that is, if both suctions are connected to the source and both discharges connected to the discharge line, the head is the same as that of the individual pumps, but the capacity is the sum of the capacities of the two pumps.

e. Two-inch, 125-gpm, Self-Priming Pump Set. The centrifugal pumps issued for general use and for utility service with water supply equipment are of the self-priming type. They are rated at 125 gallons per minute (gpm) at 50-foot head. Each pump has a priming chamber that makes repriming unnecessary when the pump is stopped for any reason, unless the priming chamber is deliberately drained. The pump is mounted on a frame with and driven by a two-cylinder, 3-horsepower military standard engine (fig 9-3). The unit is close-coupled, and the impeller in the pump is secured to an adapter shaft which is fastened and keyed to the engine stub shaft. A self-adjusting mechanical seal prevents leakage of water between the pump and the engine. This type of pump performs at its best with a suction lift of 10 feet. It will operate at greater suction lifts, but the capacity and efficiency of the unit are reduced in proportion.

(1) *Installation.* Install the pump as close to the source of water supply as possible, to

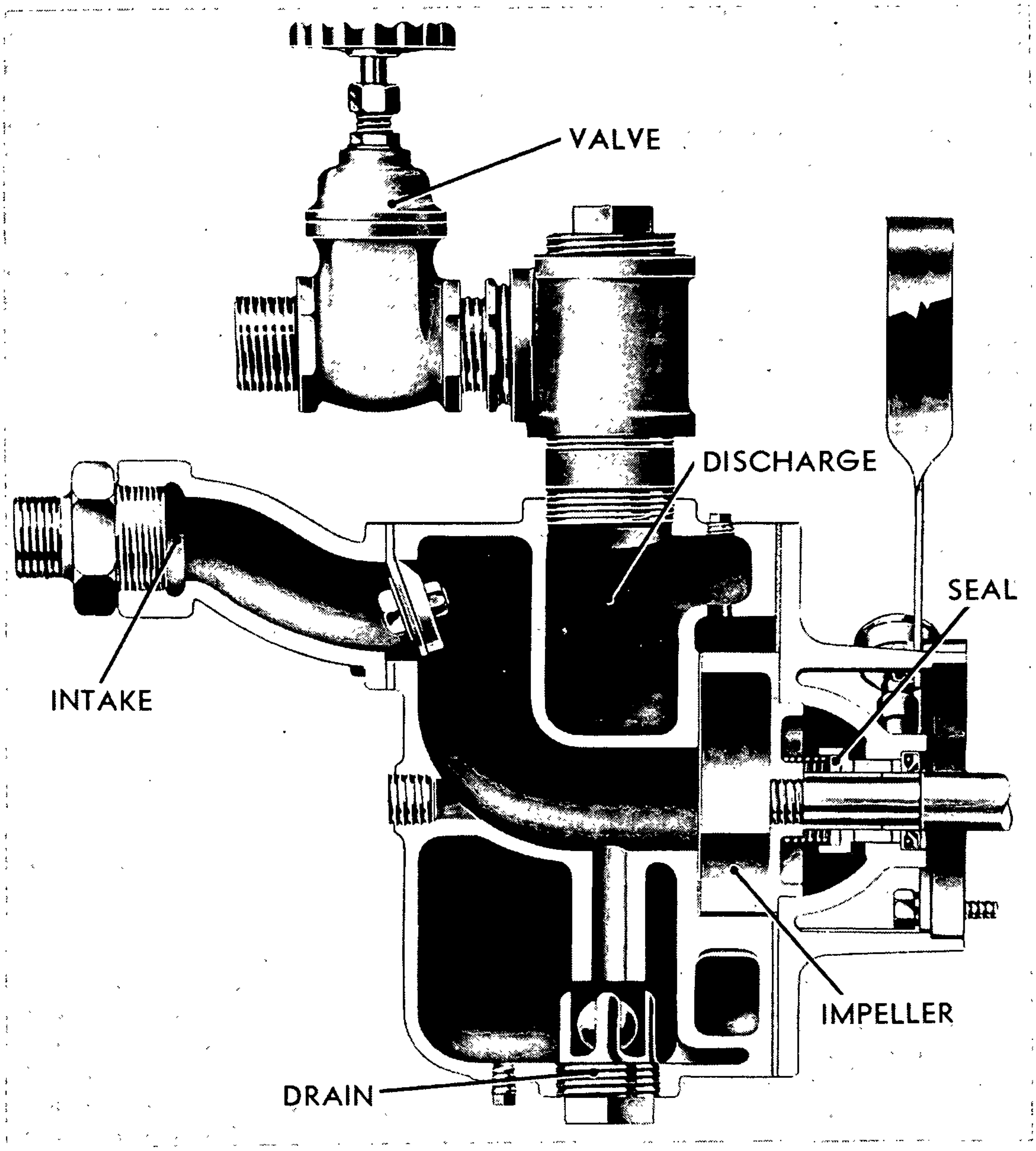


Figure 9-2. Centrifugal pump.

eliminate excess suction lift. Install full-sized suction piping with as few elbows or bends as possible, to cut down pipe friction. Suction piping must slope gradually upward from the source of water supply to the pump, to eliminate air pockets. Be sure there are no leaky joints in the suction pipe. Use pipe cement or teflon tape on all joints. If suction hose is used, make certain it is as airtight as possible throughout its length. If the suction or discharge piping or hose is to be removed frequently, the connections should be made through unions to reduce wear on the pump housing.

(2) *Priming pump.* To prime the pump, remove the priming plug on top of the pumping case, and pour water in the pump case until the case is full to the level of the discharge opening. Failure to fill the priming chamber may prevent priming. If the pump takes longer than 5 minutes to prime, there is something mechanically wrong. This pump normally attains its prime from a 10-foot suction lift in 2 minutes or less, depending on the length and size of the suction pipe. If a valve is used in the discharge line, it must be wide open during priming.

(3) *Possible causes of trouble.* If the pump fails to prime, look for—

(*a*) Plugged priming hole.

(*b*) Air leak in suction pipe or hose.

(c) Collapse of lining of suction hose.

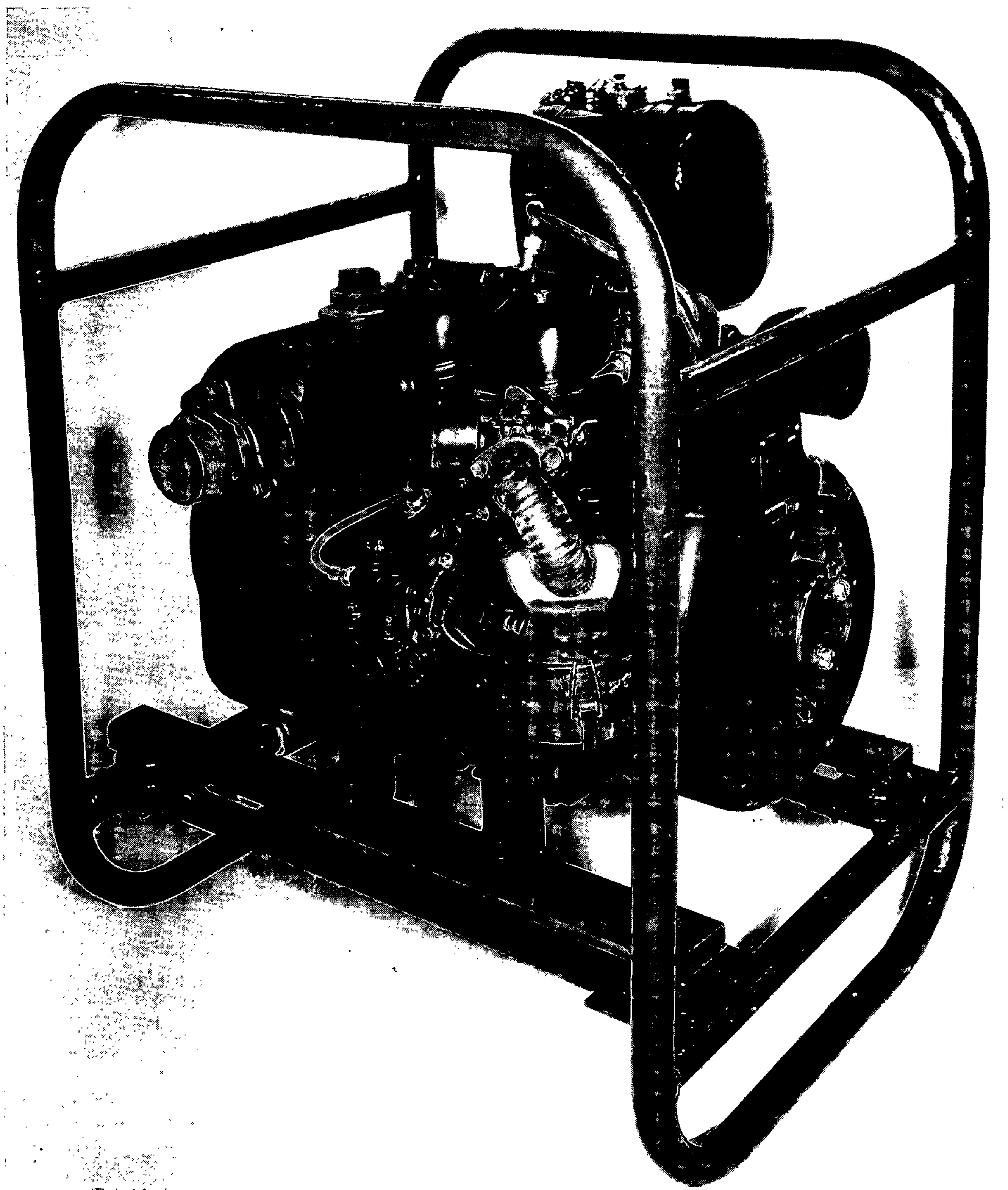


Figure 9-3. Standard 125-gpm centrifugal pump.

(*d*) Plugged end of suction pipe or suction strainer.

(*e*) Lack of water in housing of pump.

(*f*) Clogged, wornout, or broken impeller.

(g) Seal worn or damaged.

f. Submersible Pump. The submersible pump is a centrifugal pump closely coupled with an electric motor which can operate underwater. The motor is usually located directly below the intake of the pump. The main advantage of submersible pumps is that they do not need the long drive shafts and bearing assemblies required by conventional vertical turbine pumps with a power unit at the upper ground surface.

9–5. Rotary Gear Pump

a. A typical rotary gear pump (fig 9-4) consists of two moving parts shaped like gears. These gears rotate in an accurately fitted case, and close tolerances increase efficiency. Abrasion by sand or silt in the water can quickly damage this type of pump. The teeth of the pumping gears moving away from each other pass the inlet port and produce a partial vacuum, expelling the air from the suction line. This causes the water to rise in the suction pipe and into the pump, where it is carried between the teeth of the pumping gears around both sides of the pump case. The action of the teeth meshing displaces water and results in a condition similar to that set up by a piston, forming a seal that forces the water into the discharge line.

b. In a rotary gear pump, the flow of water is continuous and steady with only very small pulsations. The quantity of liquid pumped per hour is determined by the size of the pump and the speed at which the pump shaft rotates.

c. All internal parts, including the bearings, are lubricated by the flow of water. The rotary gear pump is suitable for 22 to 25 feet of suction, and will deliver any pressure the equipment can stand since it is a positive displacement type of pump.

9–6. Deep Well Turbines

A deep well turbine pump is essentially a vertical shaft centrifugal pump. It is hung in the well at the lower end of a string of pipe called the column pipe. The shaft runs through the column pipe to the top of the well. One or more impellers are mounted on the shaft in the pump. Water flows into the bottom of the housing or bowl that surrounds the impeller. The rotating impeller throws the water outward and then upward through the pipe to the surface. The pressure developed depends on the speed, diameter, and number of the impellers. Additional impellers and bowls may be added to provide enough pressure to raise water from any desired depth. Each impeller with its housing is called a stage; and pumps built up with several impellers, one above another, are called multistage pumps.

a. Model 6–M Turbine. Various turbine pumps used by the Army are all essentially the same. The Peerless Model 6–M turbine pump (fig 9–5) described below is typical. Designed for wells of at least 6 inches inside diameter, this pump supplies 200 gallons of water per minute with the

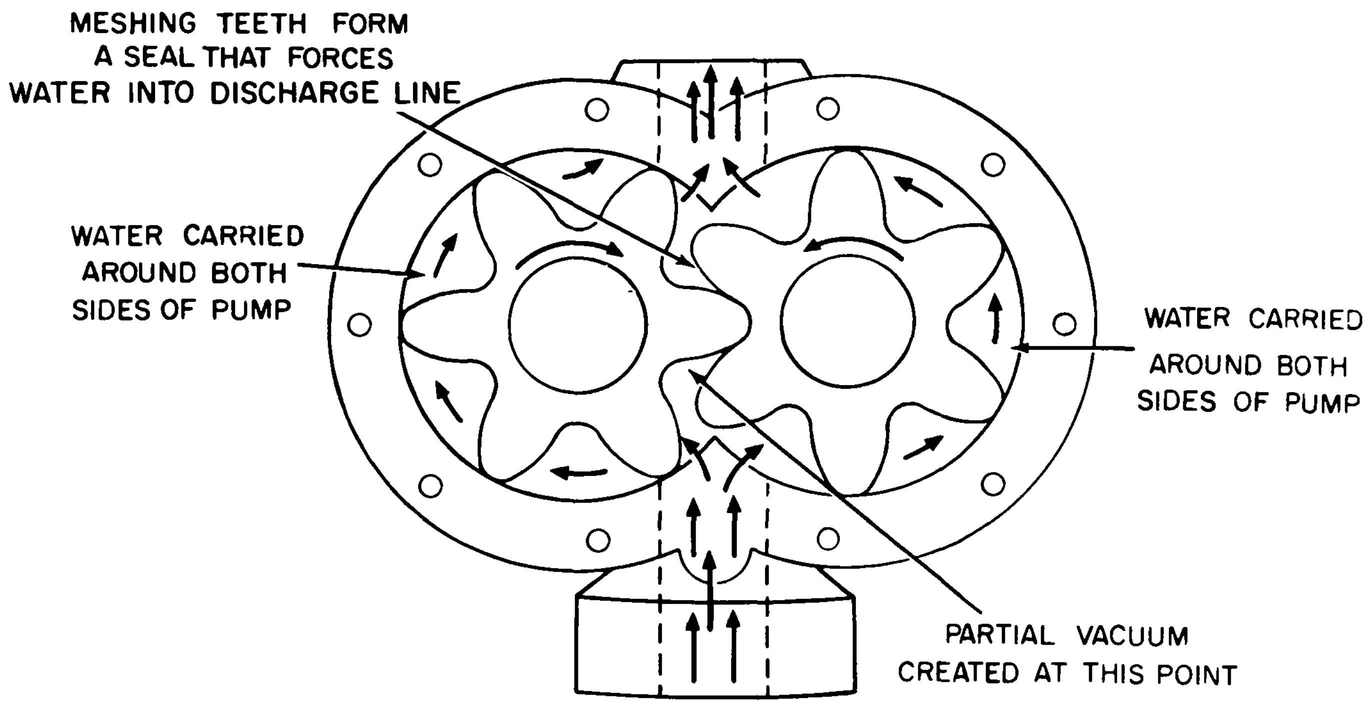


Figure 9-4. Rotary pump.

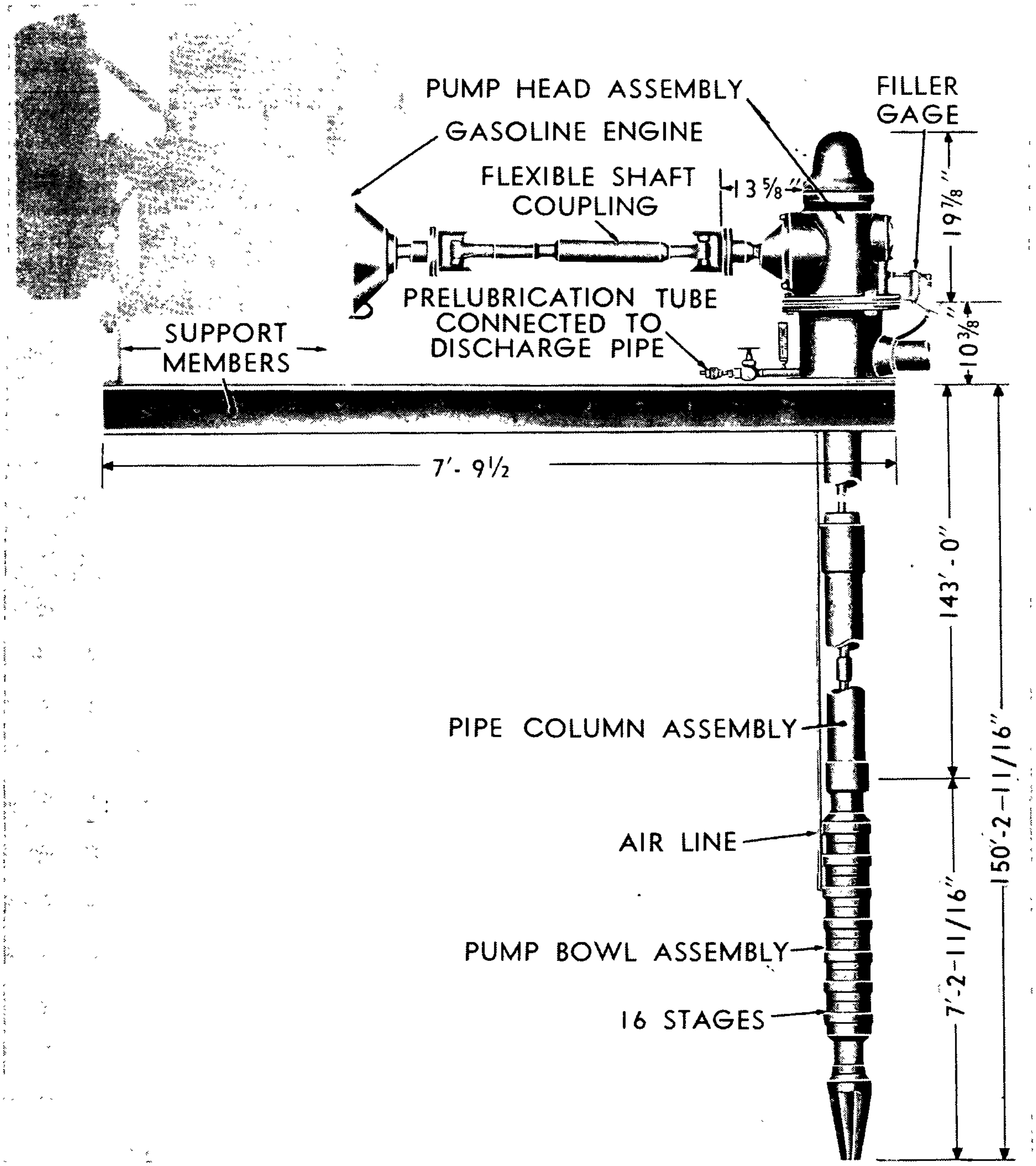


Figure 9-5. General assembly of 6-M deep well turbine pump.

pump bowls set at 150 feet, and will operate against a 200-foot head. The pump is designed to work at 3,600 rpm.

b. Pump Head Assembly. The pump head (fig 9-6) is an iron casting supporting the pump and column in the well. It also supports the gear drive above ground and furnishes a means for connecting the column pipe to the discharge piping. A packing gland prevents water leakage around the shaft. The discharge casting (fig 9-7) has a connection for manual prelubrication.

c. Right Angle Gear Drive. The right angle gear drive (fig 9-8) is used to couple the vertical pump shaft to the horizontal drive shaft. Heat-treated, hardened, and ground nickel-alloy spiral-bevel gears are used in the head. An annealed, one-piece main-body casting insures permanently correct gear mesh. Lubrication is by a centrifugal type oil pressure pump which constantly circulates cooled oil to the gears and the bearings. The pump shaft is protected against engine reversal by an antireverse ratchet. The gear head is designed for long and continuous full-load duty.

d. Column Pipe, Shaft, and Bearings.

(1) The column is 4-inch black steel pipe with a taper thread. When the column pipe ends butt

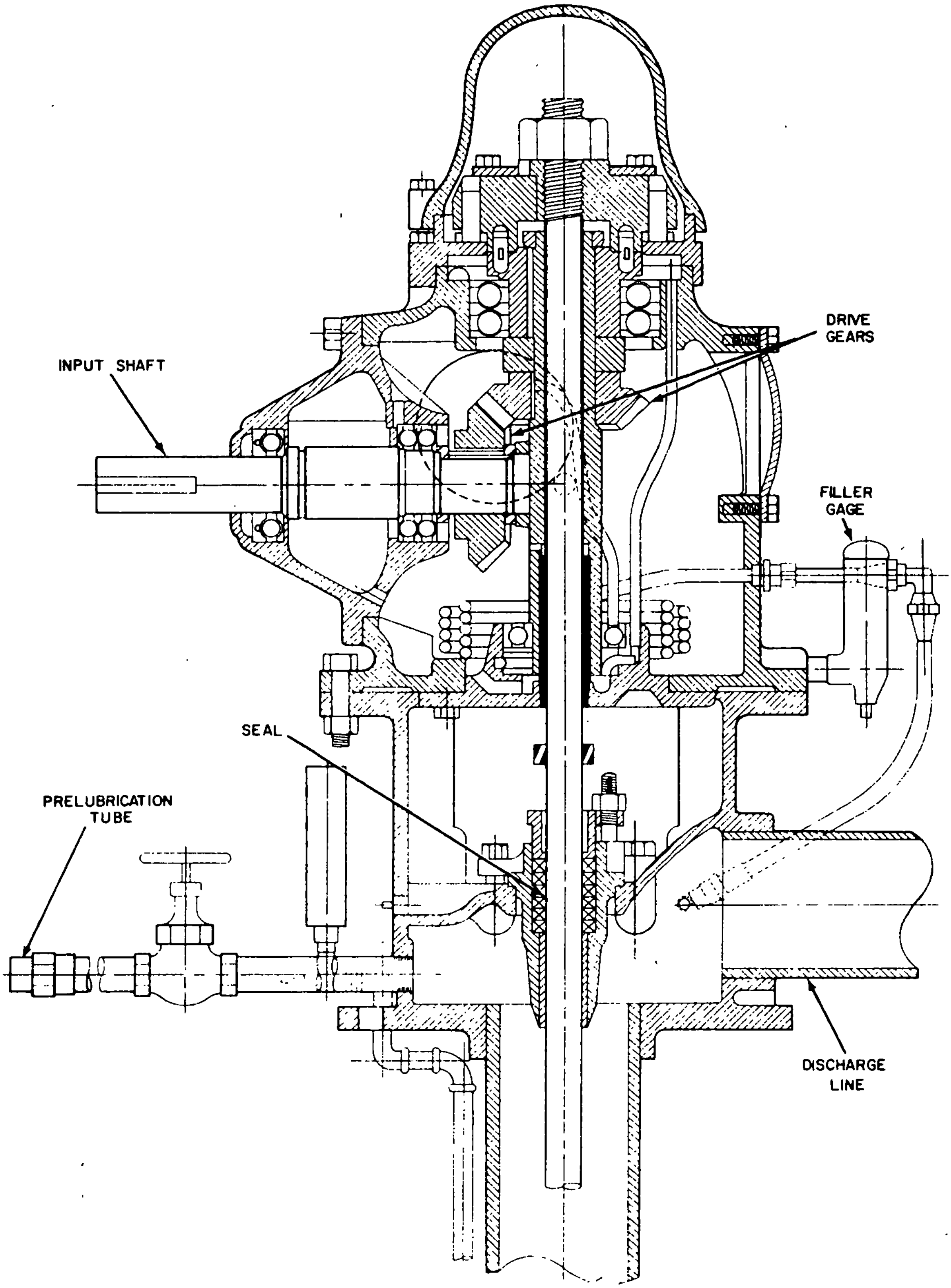


Figure 9-6. Turbine pump head assembly.

against the spider ring in the coupling, the threads also are tight.

(2) The vertical shaft is a ground and polished steel rod, 1 inch in diameter. The shafting is accurately threaded and faced, and the central portion of each end is counterbored so that

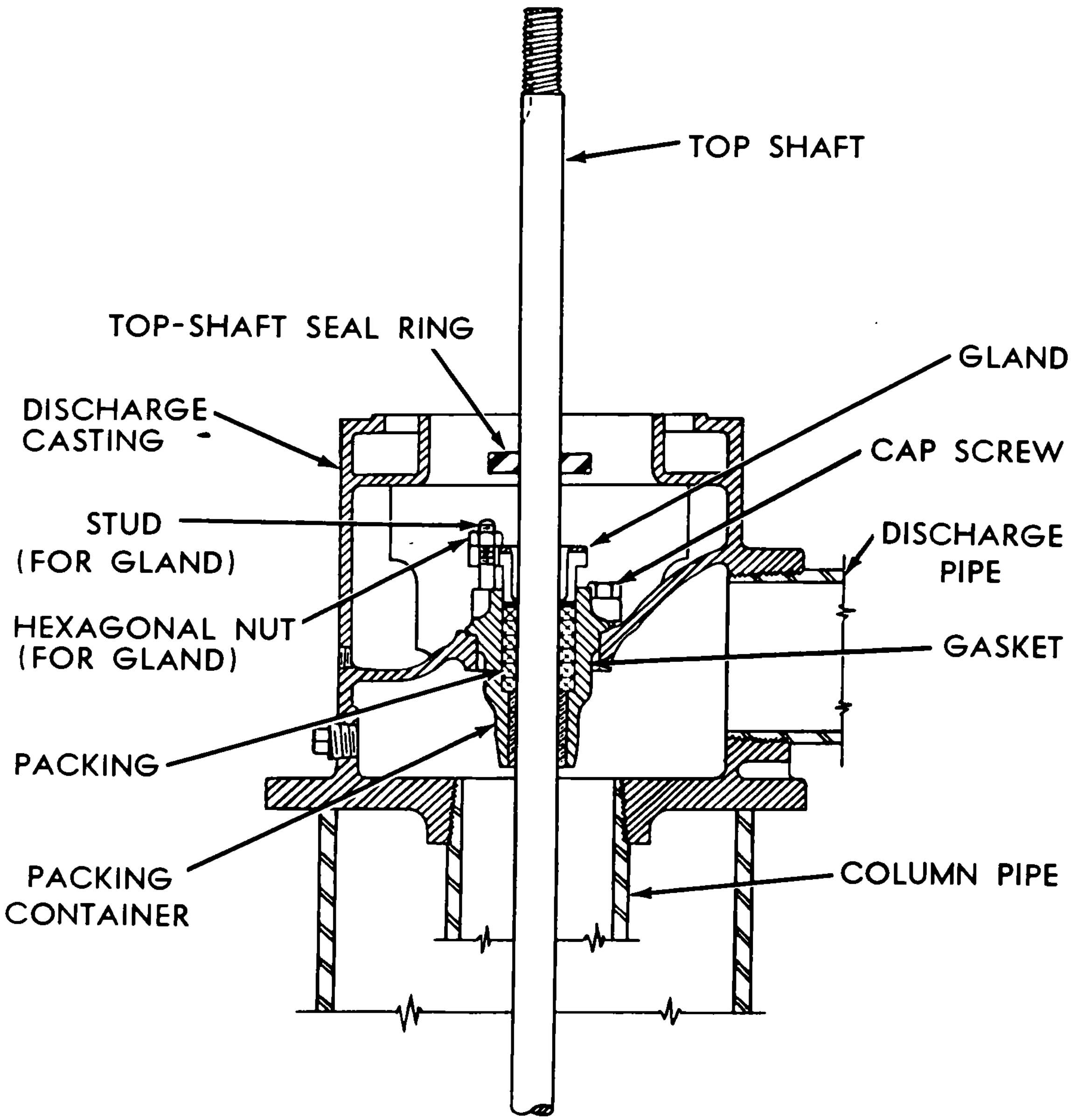


Figure 9-7. Discharge casting for Hi-Lift and turbine pumps.

when the shaft ends butt in the center of the coupling, they remain true and concentric. The shaft couplings are machined from solid stock for added strength and accuracy. An air-relief hole in the center of the coupling allows escape of air, when butting two shaft ends in the center.

(3) The shaft bearings are cutless fluted rubber, mounted in bronze spiders held in place between the ends of lengths of column pipe at each joint (fig 9–9). The first bearing is 3 feet to 5 feet below the pump head. Bearings are spaced at 10-foot intervals along the column except immediately above the bowls, where there are bearings 5 and 10 feet above the top of the bowl. Close operating clearance is maintained between the shaft and rubber bearings, and the bearings are rigidly fixed in the bronze spider to eliminate gyration and vibration. The rubber bearings are lubricated by the water flowing up the column pipe.

e. Pump Stages. The pump bowls (fig 9–10) of close grained cast iron are at the bottom of the column. The one-piece, bronze, fully inclosed impellers, when used with resilient double-seal rings, compensate for wear by endwise adjustment. A special tapered steel lock fits the impeller to the shaft, avoiding the necessity of key-seating the impeller shaft. This insures that each impeller adjusts exactly to its individual bowl case and provides a full-strength shaft throughout the entire pumping element. Long, closely spaced rubber and bronze bowl bushings

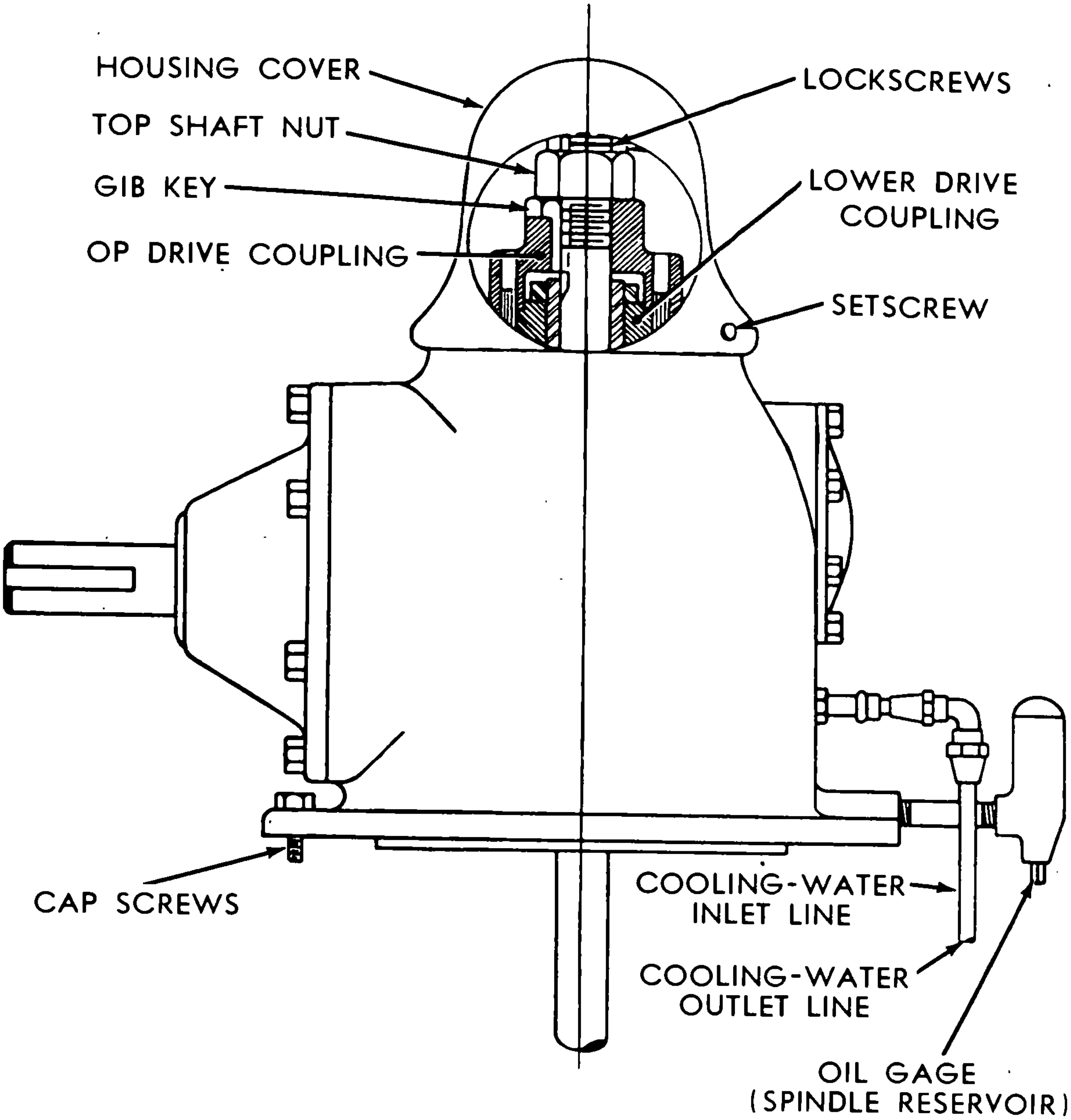


Figure 9-8. Right angle gear drive.

and bottom manifold bushings furnish maximum bearing support for the impeller shaft.

f. Flexible Shaft. The flexible shaft used to couple the engine and gear head on this unit consists of two universal joints with connections to the gear and engine. It is of simple construction with needle-bearing joints at each end for flexibility. A tubular connecting shaft carries the torque load, and a splined slip connection accommodates endwise movement. It functions with a complete and universal flexibility in both horizontal and vertical planes, with free end float under all conditions.

g. Engine. The power unit is an air-cooled gasoline engine with clutch and power takeoff, fuel tank, muffler, and oversized radiator. It is equipped for magneto ignition and handcrank starting.

9–7. Turbine Pump Installation

a. Tools and Equipment Required. The following tools and equipment ordinarily are required to install a deep well pump:

(1) A permanent derrick or a tripod. If the pump is set as the well is finished, the rig is used.

(2) A winch, cable, and blocks for raising and lowering the pump section in the well.

(3) Two pairs of chain tongs with enough

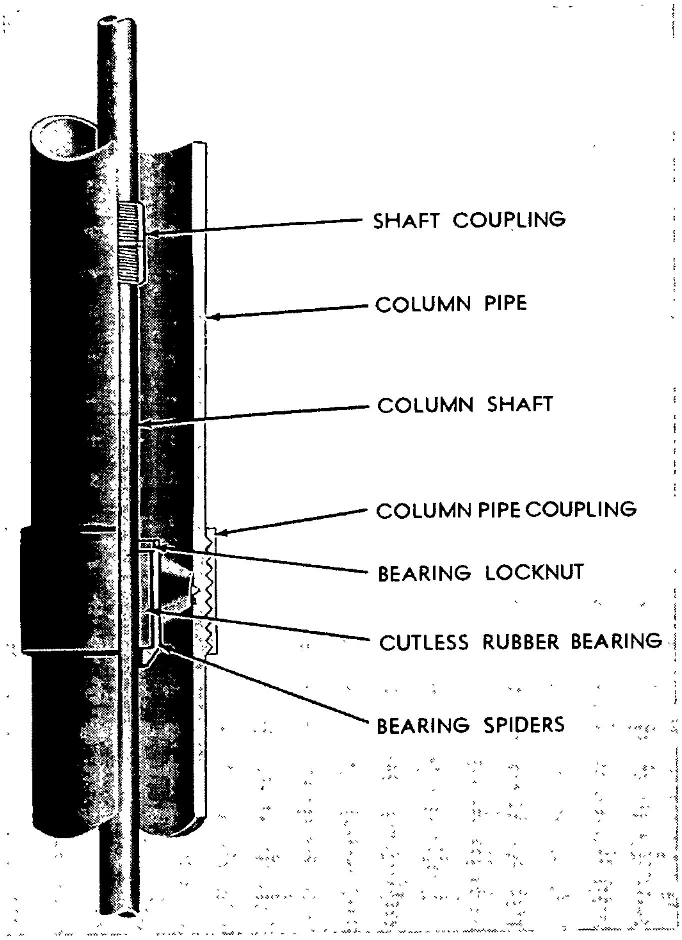


Figure 9-9. Pump column with open-line shaft as used with the Hi-Lift and turbine pumps.

chain to reach around the pump and column.

(4) Two pipe wrenches.

(5) Miscellaneous tools, including hammer, chisel, hacksaw, screwdriver, end wrenches, a wire brush for cleaning threads, and wiping rags.

(6) Two pairs of elevators or clamps to fit the outside diameter of the water column.

(7) Wire rope sling long enough to allow the hoist hook to clear the top of the shaft extension when lifting the column.

(8) White lead and machine oil or teflon tape to use on the column threads.

b. Preparation of Pump and Well. A substantial concrete pump foundation should be built around the well extending several inches beyond the pump base on all sides. The area of the bottom of the concrete foundation must be large enough to transfer the total weight of the pump and engine safely to the sustaining soil. I-beams of sufficient length and weight may be placed on either side of the well, or heavy timbers may be used, instead of the concrete foundation. If the ground will hold the weight of the pump and engine, using the structural steel subbase supplied, no other foundation is required, but the subbase must not be allowed to settle and throw the equipment out of alinement.

c. Unloading and Preparation of Pump Parts. Pump parts are carefully removed from the truck at the well site. Parts too heavy to be lifted should be skidded to the ground to avoid breakage or bending the shafts. A bent shaft always causes trouble. Thread protectors are not removed from column pipe until each joint is ready for use, and planks are used to keep pump parts from dragging on the ground. For detailed directions for installing the pump, refer to the instruction manual furnished with each unit.

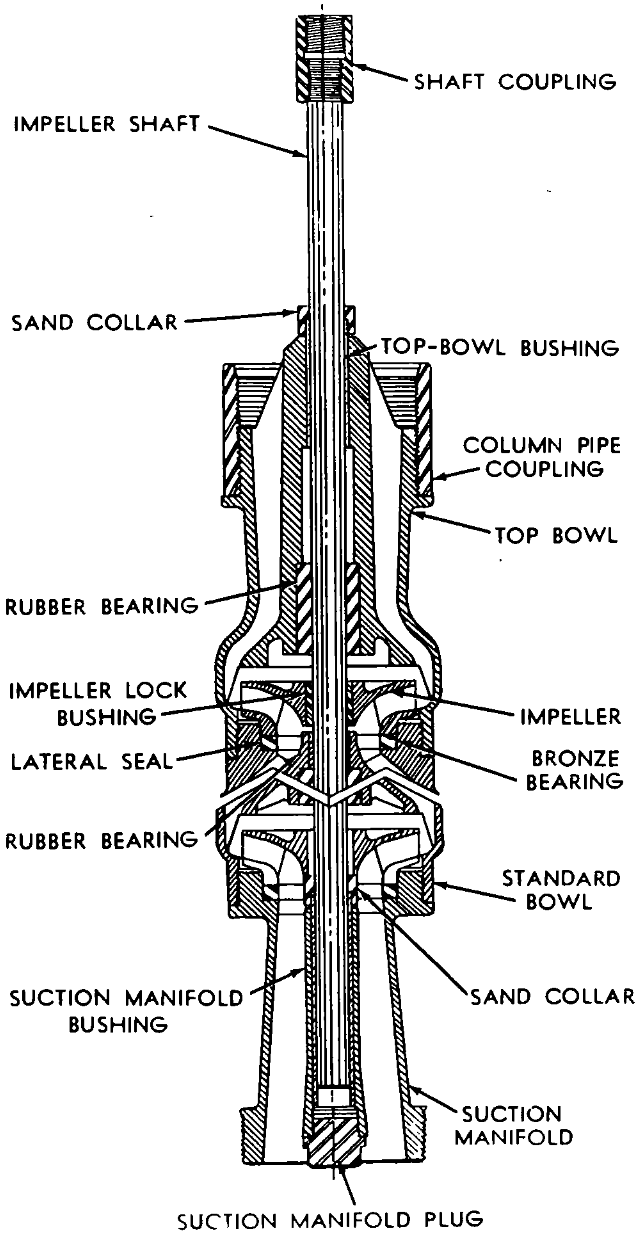


Figure 9-10. Top and bottom bowls of turbine pump.

9–8. Peerless Hi-Lift Pump

a. Description. This pump (fig 9–11) is especially designed for relatively low capacities and for installation in 4-inch or larger cased wells. The pump has three essential parts. The cross-sectional drawing in figure 9–12 shows that the pumping element consists of a main body known as a stator and a rotor, both of helical form, and a driveshaft assembly. The helices are worm threads, the stator having a double thread and the rotor a corresponding single thread. The pump is a positive displacement type. As the rotor rolls on the inner surface of the stator, liquid is squeezed ahead of the rolling action. The continuous rolling action of the rotor and the constant displacement cross section give a uniform flow. To resist corrosion and abrasion, the spiral-shaped rotor is made of heat-treated stainless steel with a hard chrome surface. The stator is cutless rubber, and is highly resistant to abrasive action. Grit momentarily depressed into the rubber when the rotor passes over it is washed away by the water when released.

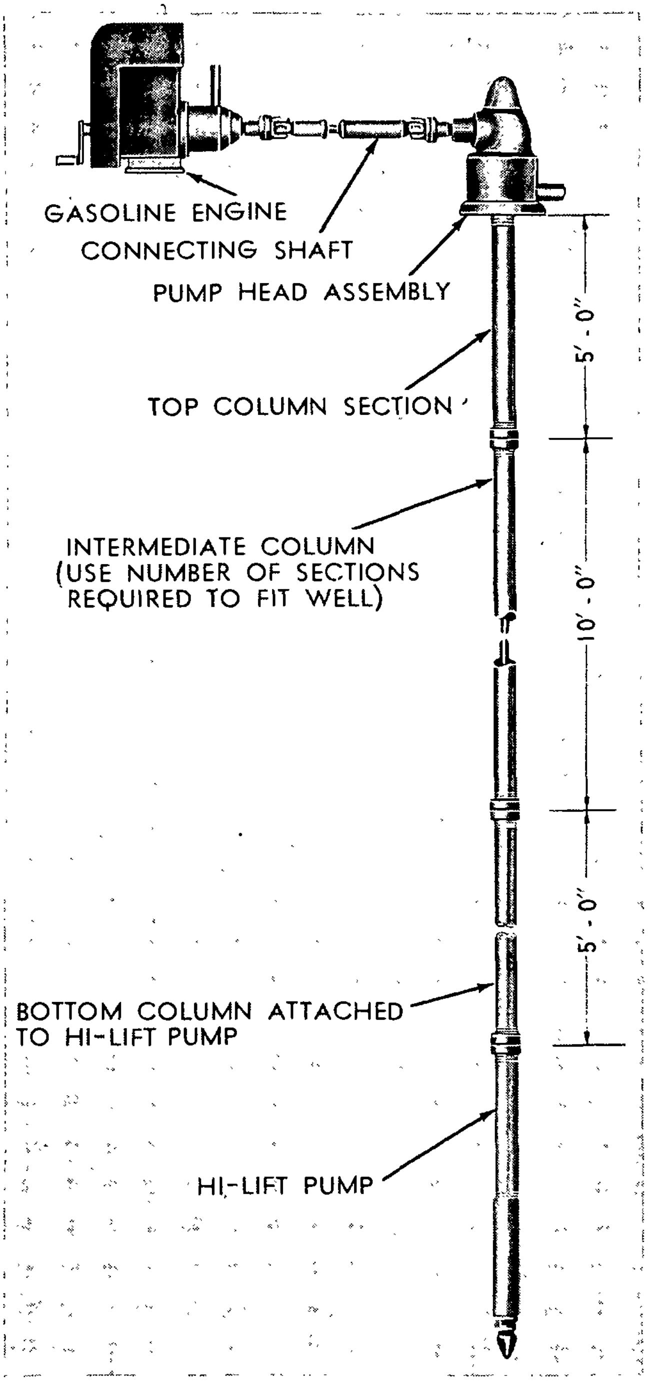


Figure 9-11. General assembly of the Hi-Lift pump.

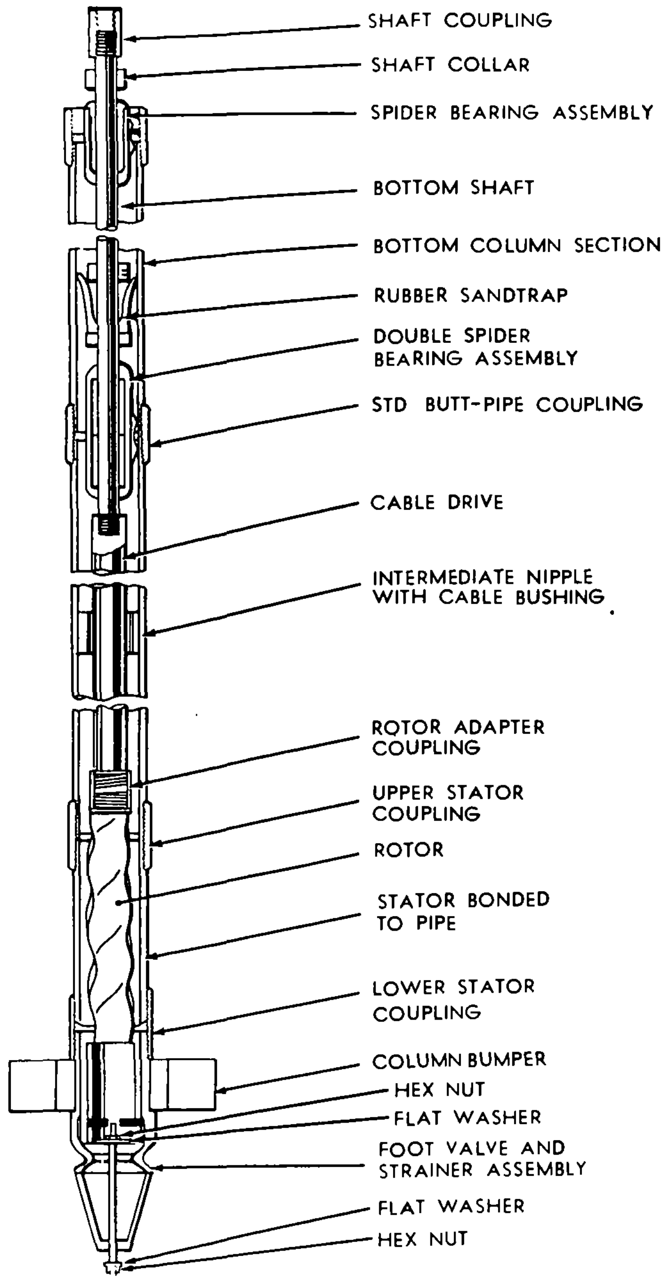


Figure 9-12. Hi-Lift pumping assembly.

b. Pump Head. The pump head consists of a discharge base (fig 9–7) on which is mounted the right-angle gear drive (fig. 9–8).

c. Column Pipe and Shaft. The column pipe is standard weight. It is made in 10-foot sections, except for the first section below the pump head and the first section above the pumping element, which are 5 feet long. Each end of each piece of pipe is faced and butted in the coupling. The column shaft is turned and polished precision steel. The shafting is in lengths the same as the column pipe. Long, cutless rubber bearings are located at each pipe joint. They are firmly supported in the column pipe, and are lubricated by the water being pumped. The pump column assembly is illustrated in figures 9–11 and 9–12.

d. Pumping Element.

(1) The pumping element consists of a hard, heat-treated, chrome-plated, stainless steel, helical-contoured rotor, revolving at relatively slow speed, usually 1,800 rpm, inside a cutless rubber, helical-contoured stator, creating a positive displacement pumping action.

(2) The pumping element and the column pipe must be full of water at all times to protect the rubber bearings. Attached to the stator is a combination bronze strainer and dual seated foot valve. The strainer prevents large particles from entering the pump.

(3) The Hi-Lift pump is furnished in one size rated at 50 gpm at 250-foot head.

e. Settings of Hi-Lift Pump. The Hi-Lift pump is furnished with 250 feet of column and shafting for a setting of 250 feet. The pump can be set at 400 feet without any speed change or any modification other than the addition of extra column and shafting. The capacity is approximately the same at the deeper settings.

f. Details of Installation. For detailed instructions for installing the Hi-Lift pump, see the directions furnished with each unit.

9–9. Airlift Pumping

a. Water can be readily pumped from a well by using an airlift pump. There are no airlift pumps in the Army supply system, but one can be improvised in the field by using compressed air and the proper piping arrangement. This assembly, which is called an airlift, consists of a vertical discharge pipe (or eductor pipe) and a smaller air pipe, both submerged in the water in a well below the pumping level for about two-thirds of their length. The compressed air is led through the air pipe to within a few feet of the bottom of the eductor pipe and is released inside the eductor pipe at that point. A mixture of air bubbles and water is formed inside the eductor pipe, resulting in a fluid that is lighter in weight than the water outside the pipe. This mixture of air and water flows upward and out the top of the eductor pipe. The driving force, causing water to rise continuously as long as compressed air is supplied is the difference in hydrostatic pressures inside and outside the pipe resulting from the lowered specific gravity of the mixed column of water and air bubbles. The energy operating the airlift is that which is contained in the compressed air released in the form of bubbles in the water. The operating principle of the airlift is shown in figure 9–13.

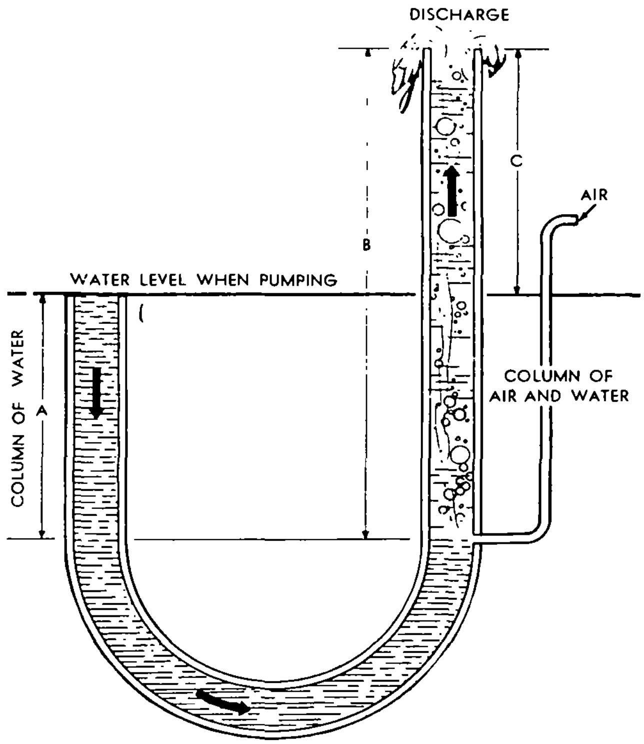


Figure 9–13. Diagram illustrating the principle of the airlift.

b. It is usual practice to arrange an airlift for pumping a well with the air pipe inside the eductor pipe, as shown in figure 9–14. Such an arrangement is commonly used for test-pumping wells and for well development (para 7-11). The well casing itself can be used for the eductor pipe if desired. This is a practical way to pump sand and mud from the bottom of a well during completion of the well and incidental to the development work. It is better to use a separate pipe when test pumping, however, since the pumping level can then be measured and the drawdown determined.

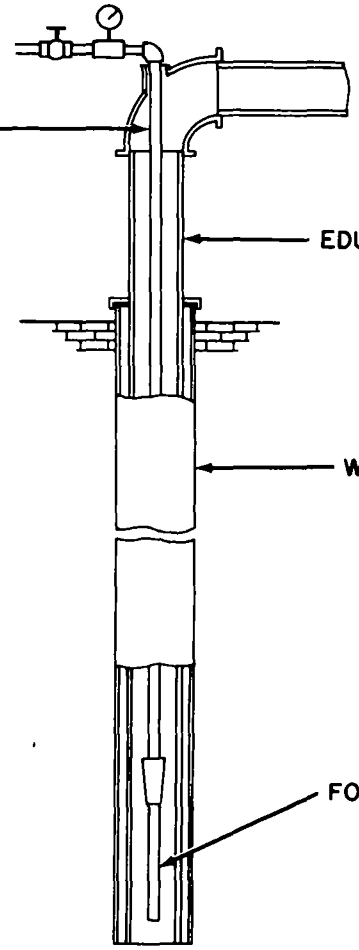


Figure 9-14. Airlift pump.

9–10. Design of Airlift Installation

a. Submergence. This is an important term connected with airlift pumping and needs definition. Submergence is expressed as the proportion or the percentage of the length of the air pipe that is submerged below the pumping level. Specifically, it is the length of air pipe submerged below the pumping level divided by the sum of the submerged length and the lift, the quotient being multiplied by 100 to give the result as a percentage. The lift is the vertical distance from the pumping level to the point of discharge of the water. To be strictly accurate, the frictional loss in the eductor pipe should be added to the lift in making the calculation of submergence, but usually it is neglected. In figure 9–15, the lift is the distance from A to D, and the length of air pipe submerged is the distance from D to E. If A to E is 200 feet, and the lift, D to A, is 80 feet, then the submerged length of air pipe is 120 feet. The percent submergence is:

$$\frac{120}{200} \times 100 = 60$$

percent. It is important to remember that the percent of submergence is calculated on the basis of the pumping level in the well, rather than the static level.

b. Air Pressure Required for Starting. The length of air pipe submerged below the static level is significant only for calculating the air pressure required to start the airlift. In figure 9–15, the water pressure represented by the column, C to E, is the starting air pressure. The number of feet of water column divided by 2.31 gives the required air pressure in pounds per square inch.

c. Performance and Efficiency of Airlift. The performance and efficiency of an airlift vary greatly with the percent submergence and with the amount of lift. Generally, a submergence of 60 percent or more is desirable, but in wells where the depth of the pumping level is considerable, lesser submergence must be used. If the submergence is too low, the airlift will not operate. Table 9–1 gives actual performance data for airlift pumps corresponding to various conditions of submergence and for different lifts. The figures are for properly proportioned air and eductor pipes with minimum frictional losses. The efficiencies indicated in terms of gallons of water per cubic foot of air probably cannot be fully attained in military field operations.

d. Use of Footpiece. For best efficiency, the air pipe should end in a footpiece (fig 9–14). This is simply a device for breaking the air into small streams so that the bubbles formed will be as small as possible. A footpiece can be improvised by drilling a number of small holes in a short section of pipe.

e. Length of Discharge Pipe. The length of the discharge pipe can be approximated from table 9–1. Lower submergences than those shown result in a lower pumping efficiency. Hence, the planned rate of pumpage must not cause an excessive drop in the water level, reducing the submergence. There are two chief losses in the discharge pipe: the slippage of the air through the water, and the friction of the water in the discharge line. As the velocity of discharge increases, the slippage decreases and the friction increases. There is an entrance loss at the lower end of the pipe due to friction and to the energy required to accelerate the flow of water into the pipe.

f. Importance of Correct Amount of Air. From the standpoint of efficiency, the compressor must deliver the correct amount of air. Too much air causes excessive friction in the pipe lines, and waste of air from imcomplete expansion in the discharge pipe. Too little air results in a reduced yield and in a surging, intermittent discharge.

Table 9-1. Airlift Performance Corresponding to Various Conditions of Submergence

Lift in feet	Submergence (percent)	Lift (percent)	Rating	Submergence (ft)	Starting air pressure (lb per sq in)	Gallons water per cu ft air	Cubic feet of air per gal water	Total length of air line (ft)
25	54	46	Minimum	29	13	4.55	0.22	54
	68	32	Best	53	23	8.34	.12	78
	76	24	Maximum	79	34	14.30	.07	104
50	51	49	Minimum	52	23	2.50	.40	102
	65	35	Best	93	40	4.35	.23	143
	72	28	Maximum	129	56	6.57	.15	179
100	47	53	Minimum	89	38	1.43	.70	189
	60	40	Best	150	65	2.70	.37	250
	67	33	Maximum	203	88	3.70	.27	303
150	43	57	Minimum	113	49	1.05	.95	263
	55	45	Best	183	79	2.04	.49	333
	62	38	Maximum	245	106	2.70	.37	395
200	41	59	Minimum	139	60	.85	1.18	339
	52	48	Best	216	94	1.54	.65	416
	59	41	Maximum	288	125	1.89	.53	488
250	39	61	Minimum	160	69	.71	1.41	410
	49	51	Best	240	104	1.21	.83	490
	56	44	Maximum	318	138	1.45	.69	568
300	37	63	Minimum	176	76	.60	1.67	476
	47	53	Best	266	115	.96	1.04	566
	53	47	Maximum	339	147	1.18	.85	639
350	36	64	Minimum	197	85	.53	1.88	547
	46	55	Best	287	124	.80	1.25	637
	50	50	Maximum	350	151	.94	1.06	700
400	35	65	Minimum	215	93	.48	2.07	615
	43	57	Best	302	130	.69	1.45	702
	48	52	Maximum	369	160	.79	1.26	769
450	34	66	Minimum	232	100	0.44	2.27	682
	42	58	Best	326	141	.61	1.65	776
	47	53	Maximum	399	173	.68	1.48	849
500	34	66	Minimum	258	112	.41	2.46	758
	41	59	Best	348	150	.54	1.85	848
	46	54	Maximum	426	184	.60	1.66	926
550	34	66	Minimum	283	123	.38	2.65	833
	40	60	Best	367	159	.49	2.05	917
	45	55	Maximum	450	195	.54	1.86	1,000
600	33	67	Minimum	296	128	.36	2.81	896
	40	60	Best	400	173	.45	2.25	1,000
	44	56	Maximum	471	204	.49	2.06	1,071
650	33	67	Minimum	320	139	.34	2.94	962
	39	61	Best	416	180	.42	2.40	1,066
	43	57	Maximum	490	212	.44	2.26	1.140
700	33	67	Minimum	345	149	.33	3.00	1.045
	39	61	Best	448	194	.39	2.55	1,148
	43	57	Maximum	528	228	.42	2.40	1,228

g. Compressors Used. The standard engineer 250 or 600 cfm compressor serves very well for operating an airlift. With a submergence of 60 percent, a lift not exceeding 50 feet, and the compressor delivering 250 or 600 cubic feet of air per minute, a well can be pumped at over 200 gallons per minute. If more air is needed, two compressors can be operated in parallel. The maximum pressure that the compressor will produce is 100 pounds per square inch, which is enough to start an airlift with about 276 feet of air pipe submerged.

h. Semitrailer Mounted Rotary Rig. The semitrailer mounted rotary rig has a 650 cfm, 125 psi compressor to supply air for down-hole drilling operation when using the air hammer.

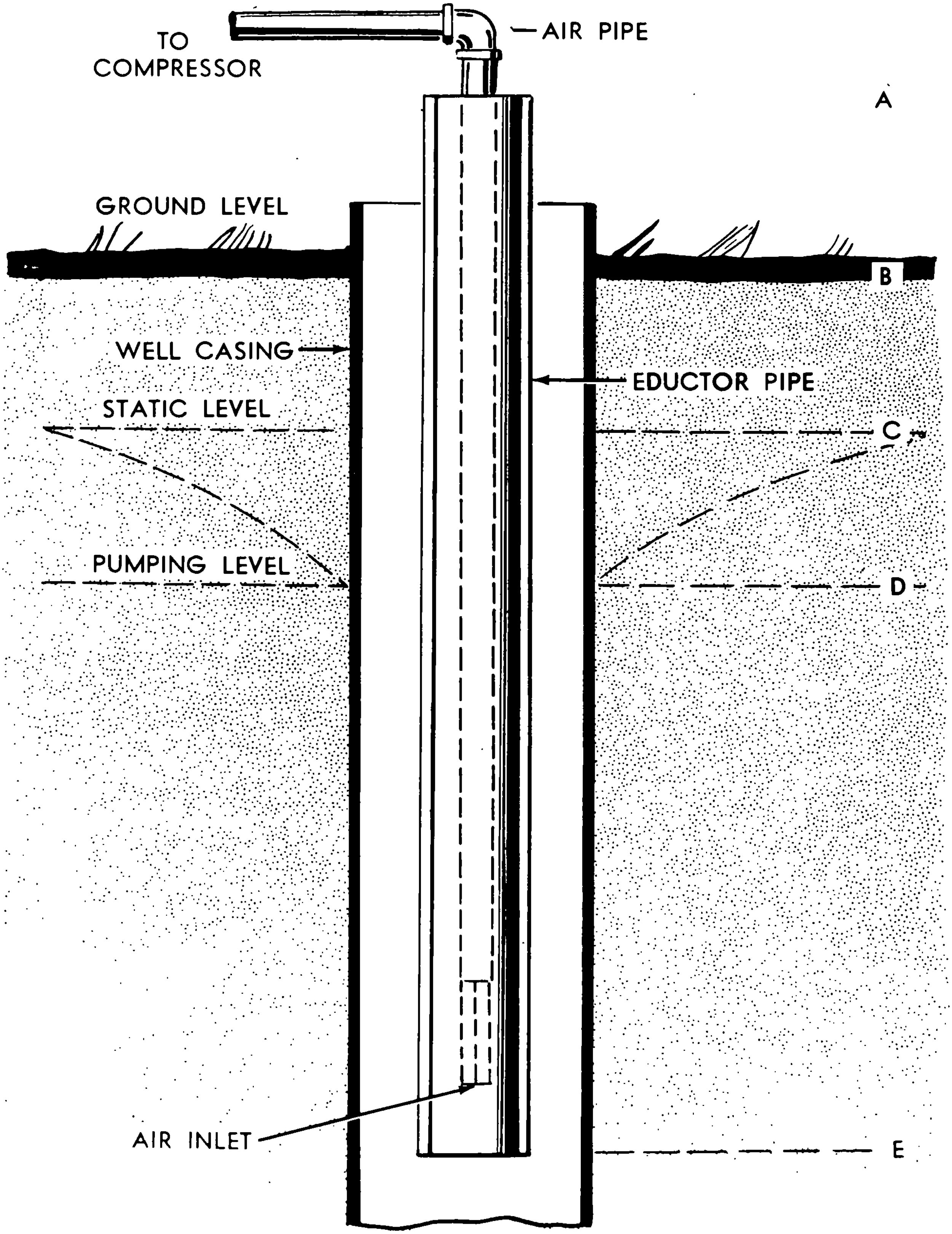


Figure 9-15. Diagram of well with airlift.

CHAPTER 10

ARCTIC WELL CONSTRUCTION

Section I. INTRODUCTION

10–1. Occurrence of Water in Cold Regions

Water supply is one of the most difficult problems of military or civilian operations in cold regions. For the purposes of this manual, cold regions are defined as the Arctic, Subarctic, and Antarctic. It may become necessary to obtain water in any of three widely varying situations which occur in cold regions. These are: permafrost, glaciers and ice caps, and sea ice and ice islands (fig 10–1 and 10–2).

a. In areas of discontinuous permafrost water may be obtained from many surface sources in summer, and in winter from deeper lakes and rivers which do not freeze. Year-round supplies of subsurface water may also be available by development of wells in unfrozen zones (taliks) (① fig 10–1) and from beneath the thin (tens of feet to a few hundred feet) permafrost bodies. In areas of thick, continuous permafrost (② fig 10–1) water will usually be readily available in summer from numerous surface sources, but in winter surface water can only be obtained from beneath considerable thickness (up to 6 ft) of ice in the larger lakes and rivers. Subsurface water is available only from wells which penetrate the permafrost, which will be from a few hundred to as much as 2,000 feet thick. Most of the Arctic North America is an arid region and receives little precipitation. Therefore, melting snow should not be considered as a source of water except as a temporary and emergency source for very small detachments in winter only.

b. The only water generally available at the surface of glaciers and ice caps, such as the Greenland and Antarctic ice caps, will be in the form of snow which must be gathered and melted. In summer, at the margins of the ice caps and on the lower reaches of valley glaciers sufficient thawing may occur to expose bare ice which is preferred to snow as a water source. Usually in the melt zone and thawing season water will be abundantly available directly from streams running on the surface of the ice.

c. On perennial sea ice (fig 10–2) or "old pack ice" fresh water may be pumped directly from melt pools in summer and potable ice may be harvested from pressure ridges and mounds in winter. It will be rarely, if ever, necessary to melt snow during operations on perennial sea ice. "Ice islands" are preferred as bases for operations in the Arctic Ocean because of their permanence and stability. This, in turn, is due to their origin as large fragments of polar glaciers which have essentially become flat icebergs. The glacier ice just beneath the surface may be harvested in winter and meltwater pools should be used in summer. Fresh snow would also be available for melting.

10–2. Occurrence and Development of Ground and Surface Water Sources in Permafrost

Substantial amounts of permanently frozen rock and soil may be encountered in the Arctic north of 50° N. latitude (fig 10–2). This condition will restrict obtaining subsurface water simply because some of the ground water is permanently frozen and, therefore, not available. In addition, since the frozen zones which vary in thickness from a few feet to 2,000 feet are impermeable (aquicludes), they inhibit the upward movement of unfrozen ground water that may be below them. Generally, the difficulty of obtaining water will increase as one proceeds north (fig 10–2) as the permafrost thickens and becomes colder and more continuous.

a. Discontinuous Permafrost. Thorough consideration should be given to obtaining water from surface sources before considering drilling and developing wells in the discontinuous permafrost zone. In fact, the existence of a good year-round source of water at the surface in the discontinuous zone will generally indicate that the ground is not frozen beneath it. Several indicators of water sources are listed below.

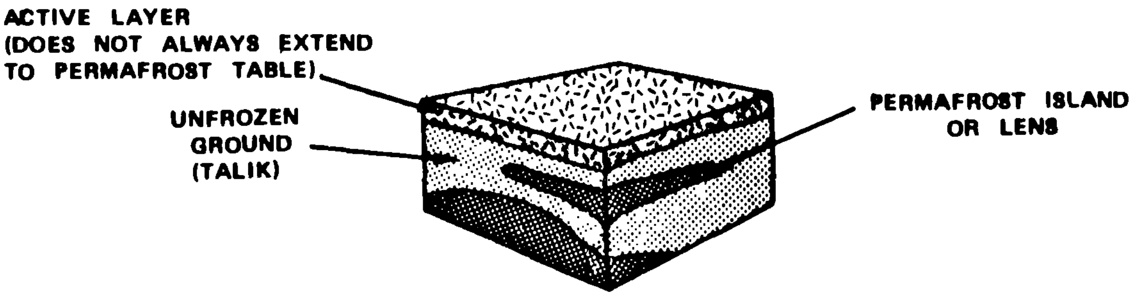
(1) Year-round springs which will appear as icings in winter, larger streams, and lakes can serve as water sources. Even if they are unusable (unpotable), they indicate "windows" in the permafrost where dug, driven, jetted, or drilled wells may be located.

(2) Vegetation may sometimes be used as a general guide to indicate the presence and thickness of permafrost. However, since the roots of most trees rarely exceed a depth of 3 feet, the presence of large trees may indicate only that the top of the permafrost during the thawing season is deeper than usual. On the other hand, large

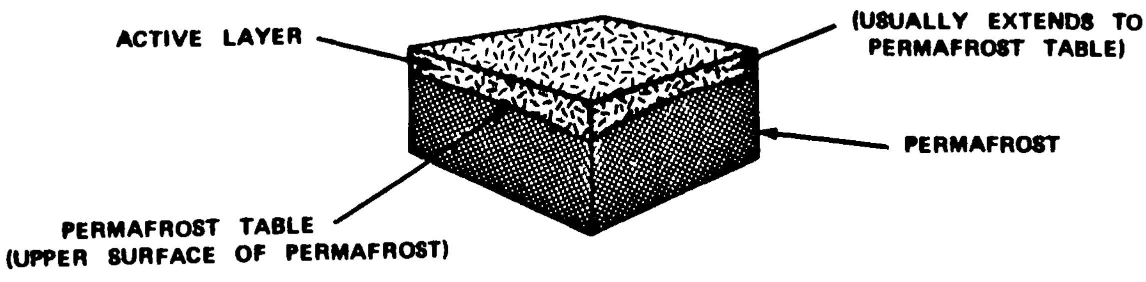
trees along a river would suggest that the top of the permafrost is depressed sufficiently to afford a limited supply of water or that permafrost may be entirely absent. The presence of pine and/or aspen (not willows) may indicate a similar depression of the permafrost table or possibly the complete absence of permanently frozen ground. The presence of willows (shrubs, not trees), peat and moss and/or stunted larch (tamarack) and birches, however, may indicate a thin zone of summer thawing (active zone) and the presence of cold, thick permafrost near the surface. These indicators will be seen more frequently in the zone of thick, continuous permafrost.

(3) In the discontinuous zone, permafrost will be thinner and may even be absent on the south slopes of hills, in valley bottoms containing permeable alluvial material (sands and gravels) and under surfaces that have been cleared of vegetation; for example, airport runways, farmlands, forest fire scars, and logging tracts. Local residents should be questioned regarding their knowledge of springs (and/or icings), existing wells, and unfrozen zones. They may also be able to identify which lakes and rivers freeze completely in winter and which do not. Sometimes northern people excavate caves in the permanently frozen ground to store meat; an examination of such caves may be of value.

b. Thick, Continuous Permafrost. Surface sources (larger streams and lakes) will generally have to be relied on here, since subsurface water will be available only by drilling deep (at least several hundred feet) wells through the



(1) DISCONTINUOUS PERMAFROST



(2) CONTINUOUS PERMAFROST

Figure 10-1. Typical profiles in permafrost region.

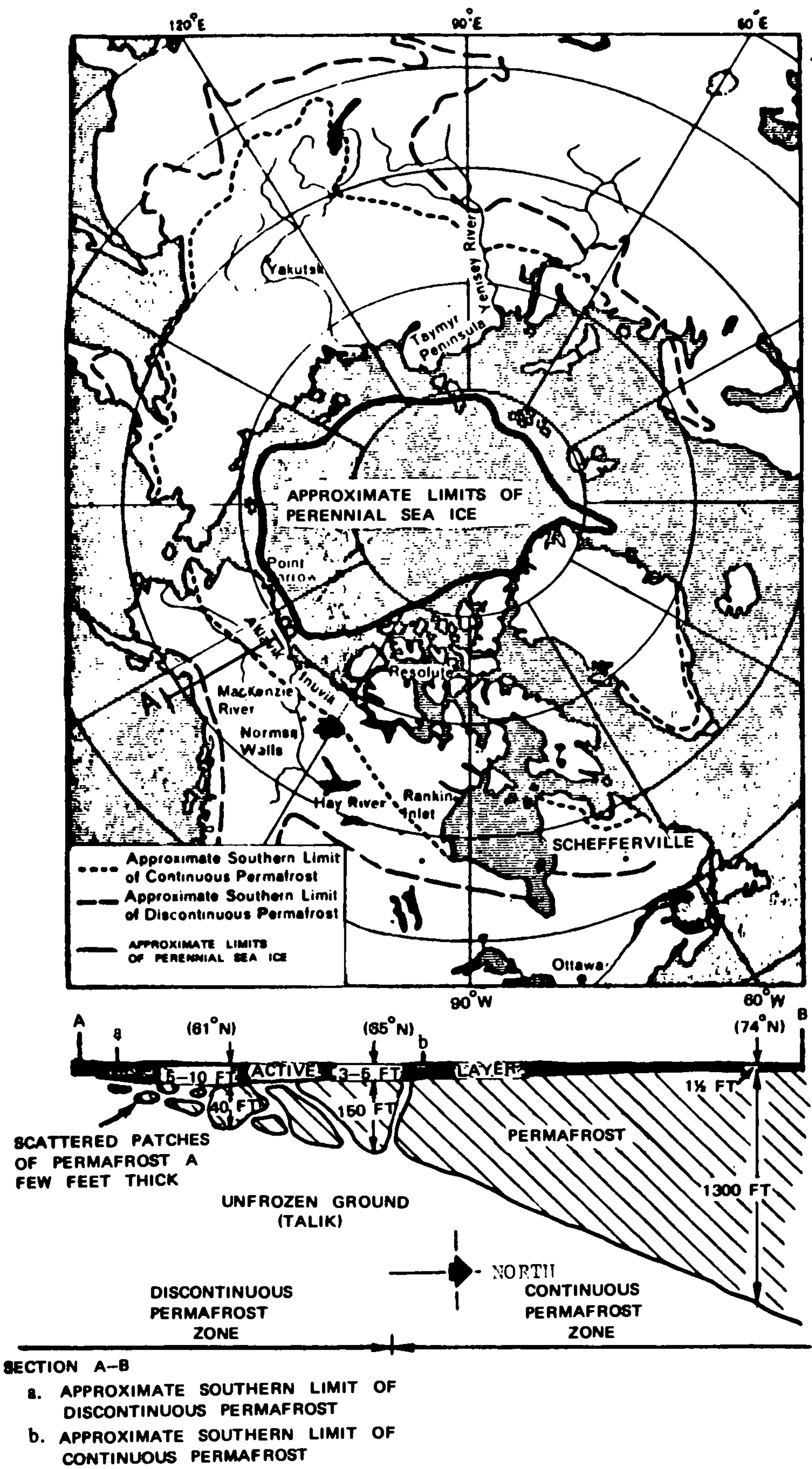


Figure 10-2. Distribution of permafrost in the northern hemisphere.

permafrost, a task which will probably be beyond the scope of military units.

10–3. Glaciers and Icecaps as Water-bearing Formations

The only source of water in glacial camps is the melt obtained from snow or ice. Either of two methods is used to obtain water from glacial ice—surface snow melting or steam drilling.

a. In the past, most of the water obtained from glaciers has been from melted snow. For production of large quantities of water, the surface snow melting method is inefficient, requires considerable manpower and machinery, and is practically impossible to maintain in operation under adverse winter weather conditions. Also, within the proximity of any glacial camp, the surface snow becomes contaminated. The quantity of water produced per day by the surface snow melting method depends upon the availability of manpower and the capacity of the snow melter.

b. The technique of using a steam drill to melt a hole into the subsurface ice of a glacier and developing a pond of water at the base of the hole has proven to be an effective method of establishing adequate water supplies. The hole or well established by this method can yield an estimated 10,000 gallons per day. However, very special equipment is required to accomplish steam drilling, and the concept has been tried only on a research basis. Hence, it should be considered for use in large, permanent or semipermanent installations.

Section II. EQUIPMENT AND APPLIANCES

10–4. Drilling Equipment

Drilling equipment for arctic well construction is the same as that described in previous chapters, except for additional accessories required as a result of adverse weather conditions. Heating devices must be provided to augment the well drilling equipment. Requirements for heating are twofold; first, heating for personnel and equipment on the construction site, which may be provided by a heater, duct-type, portable, gas, 2500,000 BTU or similar; and second, heating for storage and settling reservoirs, which can be provided by the use of immersion heaters, electrical or oil fired. Tentage or sheds are required to contain the heat and protect the operating personnel from cold winds or storms. Heavier drill rigs should be tracked for greater mobility.

Section III. METHODS OF ARCTIC WELL CONSTRUCTION

10–5. Rotary Drilling in the Arctic

In permafrost regions, the rotary drilling method of well construction is best used for deep drilling and large diameter holes, but is efficient also for shallow drilling and small holes. The procedure for rotary drilling in frigid climates remains essentially unchanged from that used in temperate climates except for temperature requirements of the drilling fluid. In adverse weather conditions, such as extremely low temperatures and snowstorms, shelters must be constructed to protect the rigs and to maintain comfortable working temperatures at all times. At temperatures below -20°F., generally no drilling is done. The mud used in rotary drilling operations in the Arctic should enter the drill stem at near-freezing temperatures to prevent thawing and caving of the hole; only enough heat should be applied to the mud to prevent freezing of the hole. The rig should be operated continuously to prevent freezing of the mud pump and accessories, bits, and casing during operations. If operations must be halted at night, it is preferable to remove the tools and let some ice form and drill it out in the morning. In addition, the rotary rig provides a means of circulating water in the finished well to prevent freezing until a pump can be installed.

10–6. Jet-Drive Drilling

Jet-drive drilling is another method of constructing small domestic wells in cold climates. It is a good, simple way of constructing wells in warm or discontinuous permafrost, but its applicability in colder permafrost is less certain. The wells constructed by this method are generally 2 inches in diameter and are drilled, in many cases, to a depth of 200 feet.

a. The procedure and equipment are essentially the same as those described in chapter 6. The equipment is simple and light and consists of a small derrick and a small engine with a cathead. Pipe is pushed down into the ground and advanced by manually dropping on it a small weight fastened to a line running over a sheave on the derrick to the cathead. The jet point is made from a reducer, which is ground into a bullet shape and attached to the end of the 2-inch pipe. Above the jet point a number of 1/4-inch holes are drilled for a distance of 1 to 2 feet. Through the head of the drive point a thaw-line pipe projects a maximum of 2 feet. A jet of water is pumped through the thaw-line pipe during drilling operations. This pipe is hung on a simple chain hoist and slowly moved up and down. This allows the thaw-line pipe to penetrate the sediments ahead of the jet point. When the thaw-line pipe is about 2 feet ahead of the jet point it is retracted, the casing is driven as far as it will go with ease, and the process is then repeated. Cold water at an optimum temperature of 40 °F. is used in this process. Jet-drive drilling proceeds about three times as fast in permafrost as in thawed ground. Figure 10–3 illustrates a typical jet-drive rig used in the Arctic. Shown in figure 10–4 is the typical jet-drive point used with this rig.

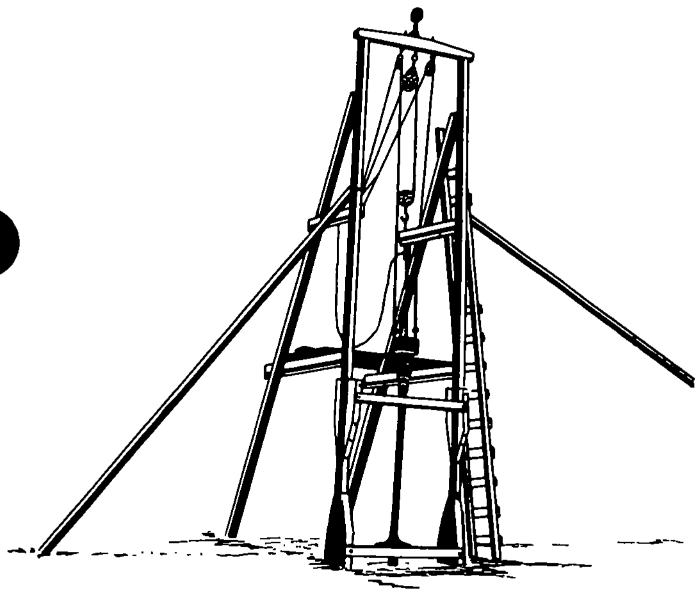


Figure 10-3. Jet-drive rig.

b. For depths of 100 feet or less, one man operating a rig can jet-drive an average of 28 feet per day in frozen ground. When thawing conditions are encountered, the footage of drill per day is reduced considerably. As much as 40 gallons of water per minute can be obtained by this method from 2-inch wells equipped with a suction pump with less than 20 feet drawdown. When the depth exceeds 100 feet during well construction, the jet-drive drilling process becomes rather slow and difficult. Hence, jet-drive drilling is probably best used in the southern portions of the permafrost zone.

10–7. Drilling Fluids

Drilling fluid used in permafrost drilling for ground water must meet two requirements; first, it must remain in a liquid state during the drilling operations; and second, it must not contaminate any possible sources of water. However, the latter effect may be eliminated by pumping.

a. When using mud as drilling fluid, provisions must be made to prevent the mud from freezing. The weight of the fluid can be increased by adding various commercial chemical agents such as aquagel, gel-flake, bariod, fibratex, smentex, micatex, and impermex. Care must be used to avoid excessive thawing of the permafrost, which will cause the hole to slough in during drilling. Therefore, the drilling fluid should not be artificially heated. An increase in the viscosity of the drill mud will result in a decrease in flow of the mud, eventually causing freezing or sticking of the drill bit.

b. Brine as a drilling fluid is less than ideal for permafrost areas because of the possibility of contamination and excessive thawing. It also causes corrosion of the drill string, rig, and pump; and it may cause skin rash on personnel. Hence, it should be used only sparingly when it is required. In water well drilling, the well is developed by pumping after drilling which also clears the well of brine. A suitable brine for drilling can be made by mixing 35 pounds of rock salt ($NaCl$) with a barrel of water (53 gallons). Experience in the Arctic has revealed that 100 pounds of rock salt is ample for drilling 15 to 20 feet of hole. Drilling equipment must be cleaned after using brine.

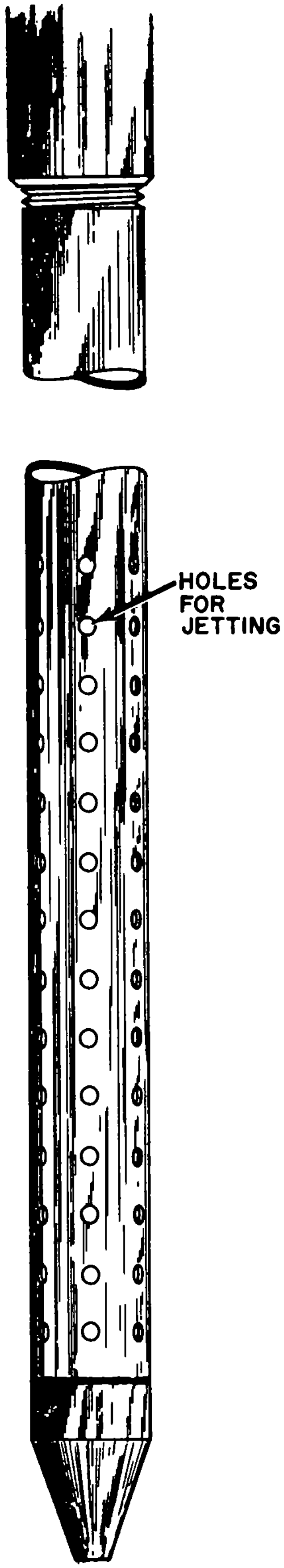


Figure 10-4. Jet-drive point.

CHAPTER 11

AUXILIARY USES OF WELL DRILLING EQUIPMENT

Section I. INTRODUCTION

11–1. Basic Considerations

Well drilling equipment is not limited to construction and development of water wells only. This equipment and its accessories are equally important in obtaining geological data, investigating soils for surface and subsurface structures, and furnishing support for emplacement of subsurface demolitions. The adaptability of standard well drilling equipment for uses other than water well construction depends on the nature of the information or data desired and the type of material to be penetrated during drilling. The two methods which adapt most readily to soil explorations and other drilling support are rotary and percussion drilling as described in previous chapters.

11–2. Responsibilities of Agencies Requiring Drilling Support

Present Army Engineer organization does not provide for specific units with personnel for performing the specialized tasks involved in exploratory drilling, coring and sampling, and special demolition drilling support. The agency requiring data or support for any of these operations will have to provide the specialist and project supervisory personnel to establish an efficient operation. The well driller can be expected to possess the skill necessary for collecting samples and for determining rates of penetration and any other data normally associated with the construction of a standard well. The succeeding sections in this chapter will provide the well driller with the basic procedures involved in providing drilling support for geology, soil exploration, and demolition emplacement. To assist the well driller, the agency requiring data must provide him with information on the type of data needed as to the nature, extent, and condition of soil layers. Typical considerations which may affect design, construction, demolition emplacement, and possible sources of construction materials are the position of the water table and the proximity of ledge rock. The well driller can collect data to fulfill the agency's requirements if the agency requiring the information provides him with special guidance.

Section II. EXPLORATORY DRILLING

11–3. Tools and Equipment

The tools and equipment for exploratory drilling are the same as for standard well drilling. However, the techniques involved in exploratory drilling differ somewhat from those of normal water well drilling, in that some of the accessory equipment is different and is used differently. Some of the tools standard to military well drilling equipment which may be used in exploratory drilling are the hand auger, power auger, and the core-barrel and crackerjack bit.

11–4. Methods of Explorations

a. The methods of soil exploration may be described as the removal and collection of soil samples from the earth by any of several means. Common military well drilling procedures use devices such as hand or power augers, core-barrels, wash casings, and bailers. All are effective in obtaining samples, although their usefulness for exploratory drilling varies with differing conditions. The hand and power augers are limited to obtaining samples at shallow depths. The samples they obtain are completely disturbed and are not suitable for strength determinations; but they can still provide useful data such as type of soil, water content, thickness of layer, changes in formation and possible occurrence of faults. Deep borings obtained by use of applicable equipment are required to determine soil conditions to depths beyond the range of the auger. Among the standard well drilling rigs, the one best suited for this is the rotary drilling rig. This rig can drill a hole to a desired depth; the sample may then be taken by a core-barrel and crackerjack bit.

b. The rotary or hammer drill can be used to investigate subterraneous material to obtain pertinent data for placement of bridge abutments and structures, and location, depths, and bearing stratum for other structures such as foundations, piles, dams, and underground facilities. These investigations may be made by drilling holes to reach desired materials which have good bearing capacity, to establish soil profiles for subsurface bedrock to support heavy structures, and to reveal flaws in rock formations. Standard well drilling procedures are followed in carrying out these tasks. During these drilling operations, particular attention must be given to the occurrence of water, and the places where drilling fluid loses circulation, as these frequently indicate flaws in the rock. The jetting method may be used to reveal the same information for shallow depths.

Section III. CORE DRILLING AND SAMPLING

11–5. Collection of Well Bore Cuttings and Well Cores

One of the most valuable sources of geologic and hydrologic information is in the collection of well bore cuttings and well cores. An actual determination of the type of rock penetrated may be made only by this means. Development of advanced techniques of well logging tends to minimize the importance of well samples; but these advanced techniques are only supplemental tools. Accurate determination of lithologic character is possible only with actual samples of a formation. The ideal situation in sampling is to collect representative samples from known depths, at intervals of such frequency as to obtain the complete lithologic character of the formations penetrated. This is best done by the coring method, by which a solid piece of the formation is obtained. A close approximation of ideal sampling can be achieved by the careful collection of well bore cuttings. Well bore sample cuttings are a representative part of the formation penetrated and are commonly collected at intervals of 5 to 10 feet, unless change of formation or other conditions justify a shorter interval.

11–6. Rotary Sampling

a. Well Bore Cuttings. A rotary driller should recognize changes in formations by the action or sound of his equipment, the action of the drill pipe, and the operating characteristics of the circulation pump. An examination of the drill cuttings deposited in the return ditch shows the type of material penetrated by the bit. When properly taken, rotary samples identify water-bearing formations in water well drilling. Samples are taken every 5 feet; more often if the occasion demands. After taking each sample, the bit is hoisted about 1 foot off the bottom and rotated slowly while the mud circulation is kept up to full volume. This is continued until the hole is washed free of drill cuttings. After this operation is completed, drilling is resumed for another 5 feet, after which the drill pipe is raised slightly and the hole circulated until it again is clean of drill cuttings. If this cycle is followed and the mud is screened carefully as it flows in the return ditch, samples usually can be caught with which to identify the different beds.

b. Contamination. Soft formations have a tendency to cave and account for a great amount of extraneous material entering into the drilling fluid. This material comes to the surface during the course of circulating the drilling mud, causing contamination of the sample. Material from the upper formation will also contaminate the sample when drilling mud is not heavy enough to cushion the impact of the drill pipe against the walls of the well. Much contamination can be eliminated if the mud pits are large enough to insure the settling of all the particles of the cuttings before the mud is recirculated into the hole. If an uncontaminated sample from the formation is desired, stop drilling and continue circulation until all cuttings are washed to the surface. Clean the ditch, proceed with drilling for a few inches, and catch all the cuttings that are washed out. This sample represents the material drilled, provided the fine sand and silt are not carried into the settling pit in the drilling mud. Samples are washed thoroughly and placed in canvas bags or on sample boards.

c. Accurate Determination of Depth of Sample. To determine accurately the depth from which a sample is taken, a measurement must be made of "lag time"—the time required for material to reach the surface after it is collected at depth. Lag time depends on: the size of the hole, the condition of the hole, the type of formation penetrated, the type and viscosity of the mud, and the actual depth. Lag time may be measured by placing easily identifiable substance, such as cut straw, into the intake drilling mud pipe, and recording the time it takes for this material to reach the surface again. Lag time may also be determined by the following procedure: stop the drill, circulate the mud until it is absolutely free of cuttings, resume drilling for a few inches, stop drilling, and measure the time required for the cuttings to reach the surface. This procedure also has the advantage of furnishing an accurate sample of the formation at the depth of the bit, and is generally used where the greatest accuracy of sampling is desired.

d. Powdering of the Sample. The powdering of a sample to a size which is too small for effective identification under a microscope is due largely to the use of mud of improper quality. A rigid control must be kept on the type and viscosity of the drilling mud so the particles of the sample are kept in suspension and brought to the surface without regrinding. On the other hand, the mud must not be so heavy that solid particles will fail to settle in the mud pit and will be carried through the system a second or third time. To insure this control, a geologist should work closely with the individual in charge of the drill mud.

e. Loss of Sample. When the drill penetrates areas or zones of high hydrostatic pressure, cuttings may be lost by being blown out of the hole. Samples may also be lost or partially lost when very thin bedded, fine or soft material is penetrated.

f. Well Cores. Conventional coring requires a core-barrel assembly fastened to the bottom of the drill string and consisting of a cutter head, outer barrel, floating inner barrel, and a finger-type catch which retains the core in the barrel when the assembly is raised. The drilling mud circulates down the drill pipe and between the two barrels to the cutting head. The type of cutter used depends entirely on the formation being cored. The length of core handled by this assembly is usually 21 feet. Using this method of coring, all of the drill stem must be removed each time to obtain the core. A large diameter core with a maximum percentage of recovery can be obtained by this method, and the effectiveness of this type of coring has been proven in all but the most abrasive formations.

Section IV. DEMOLITION DRILLING SUPPORT

11–7. Support Requirements

Demolition drilling support requirements are determined by the supported unit. A demolition specialist will be provided to give the driller specifications and guidance for preparing facilities for the emplacement of the demolition or munition. Standard well drilling equipment can be used in support of such operations.

11–8. Equipment

Among the well drilling equipment standard to the Army, the rotary drilling rig is best suited for providing support to demolition emplacement. The only additional equipment necessary is special bits, which may be obtained when needed. Detailed descriptions of techniques for handling the equipment and its accessories during demolition drilling support operations will be provided the well driller at the time the support is required. The well driller, however, must be prepared to reveal the occurrence of flaws in rock formations, as they may have adverse effects on the emplacement of the demolition.

APPENDIX A

REFERENCES

Department of The Army Publications

a. DA Pamphlets (DA Pam) and Army Regulations (AR)

DA Pam 108–1	Index of Army Motion Pictures and Related Audio-Visual Aids
DA Pam 310-series	Military Publications Indexes
AR 310–25	Dictionary of United States Army Terms

b. Field Manuals (FM)

FM 5–1	Engineer Troop Organizations and Operations
FM 5–20	Camouflage
FM 5–25	Explosives and Demolitions
FM 5–34	Engineer Field Data
FM 21–5	Military Training Management
FM 21–30	Military Symbols
FM 101–5	Staff Officers' Field Manual, Staff Organization and Procedure
FM 101–10–1	Staff Officers' Field Manual, Organizational, Technical, and Logistical Data

c. Technical Manuals (TM)

5–302–1	Army Facilities Components System Designs—Volume I.
5–302–2	Army Facilities Components System Designs—Volume II.
5–331B	Utilization of Engineer Construction Equipment, Volume B—Loading, Lifting, and Hauling Equipment.
5–331C	Utilization of Engineer Construction Equipment, Volume C—Rock Crushers, Air Compressors, and Pneumatic Tools.
5–349	Arctic Construction
5–545	Geology
5–660	Operation of Water Supply and Treatment Facilities at Fixed Army Installations
5–661	Inspection and Preventive Maintenance Services for Water Supply Systems at Fixed Installations
5–700	Field Water Supply
5–725	Rigging
5–813–1	Water Supply, General Considerations
5–813–2	Water Supply, Water Sources
5–813–3	Water Supply, Water Treatment
5–813–4	Water Supply, Water Storage
5–813–5	Water Supply, Water-Distribution Systems
5–884–2	Engineering and Design, Water Supply—Emergency Construction
5–3820–200–10	Operator's Manual: Auger, Earth, Skid Mounted; Gasoline Driven; 9 ft. Boring Depth
5–3820–238–15	Drilling Machine, Well, Percussion, Gasoline Engine Powered
5–3820–238–20P	Drilling Machine, Well, Percussion, Gasoline Engine Powered
5–4320-Series	Pumps
5–4610-Series	Water Purification Units
9–237	Welding Theory and Application

APPENDIX B

STANDARD CONVERSIONS

B–1. Length

1 millimeter	= .3937 inch
1 centimeter	= .3937 inch
1 meter	= 39.37 inches = 3.2808 feet
1 inch	= 2.54 centimeter
1 foot	= 0.30 meter
1 yard	= 0.91 meter
1 mile	= 5,280 feet
	= 1.60935 kilometers
	= .868 knots
	= 8 furlongs
Circumference of a circle	= 3.1416 x diameter

B–2. Area

1 acre	= 43,560 square feet
Area of a circle	$= 3.1416 \times \frac{D^2}{4}$
1 acre-foot	= 43,560 cubic feet
	= 325,900 gallons

B–3. Weight

1 gram	= 1 cubic centimeter of distilled water
	= 15.43 grains troy
	= .0353 ounce
1 kilogram	= 2.20462 pounds avoirdupois
1 metric ton	= 2204.6 pounds
1 cubic foot of concrete (1:2:4)	= 146 pounds
1 cubic foot of water	= 62.46 pounds
1 cubic foot of sea water	= 63.9 pounds
1 cubic inch of bronze	= .32 pound
1 cubic inch of cast iron	= .28 pound
1 cubic inch of steel	= .28 pound

B–4. Volume

1 cubic foot	= 7.4805 gallons
1 gallon	= 231 cubic inches
	= .8333 Imperial gallon
1,000,000 gallons	= 3.0689 acre feet
1 liter	= 61.023 cubic inches
	= .264 gallon
1 barrel	= 42 gallons
Volume of a sphere	$= 3.1416 \times \frac{D^3}{6}$

B–5. Temperature

Degrees C $\frac{5}{9} \times (F - 32)$

Degrees F $\frac{9}{5} C + 32$

B–6. Pressure

1 atmosphere	= 760 millimeters of mercury at 32 °F.
	14.7 pounds per square inch
	29.921 inches of mercury at 32 °F.
	2,116 pounds per square foot
	1.033 kilograms per square centimeter
	33.947 feet of water at 62 °F.
1 foot of air at 32 °F. and barometer 29.92	=.0761 pound per square foot
	0146 inch of water at 62 °F.
1 foot of water at 62 °F.	= .433 pound per square inch
	62.355 pounds per square foot
	.833 inch of mercury at 62 °F.
	821.2 feet of air at 62 °F. and barometer 29.92
1 inch of water 62 °F.	= .0361 pound per square inch
	5.196 pounds per square foot
	.5776 ounce per square inch
	.0735 inch of mercury at 62 °F.
	68.44 feet of air at 62 °F. and barometer 29.92
1 pound per square inch	= 2.0355 inches of mercury at 32 °F.
	2.0416 inches of mercury at 62 °F.
	2.309 feet of water at 62 °F.
	.07031 kilogram per square centimeter
	.06804 atmosphere
	51.7 millimeters of mercury at 32 °F.

B–7. Mechanical and Electrical Units

1 Btu	= 1,054 watt-seconds
	777.5 foot -pounds
	107.5 kilogram-meters
	.0003927 horsepower-hour
1 foot-pound	= 1.3558 joules
	13826 kilogram-meter
	.001286 Btu
	.03241 gram-calorie
	.000000505 horsepower-hour
1 horsepower	= 745.7 watts
	.7457 kilowatt
	33,000 foot-pounds per minute
	661,700 gram-calories per hour
	273,743 kilogram-meters per hour
	2,547 Btu per hour
1 joule	= 1 watt-second
	.10197 kilogram-meter
	.73756 foot-pound
	.239 gram-calorie
	.0009486 Btu

1 kilogram-meter	= 7.233 foot-pounds
	9.806 joules
	2.344 gram-calories
	.0093 Btu
1 kilowatt	= 1,000 watts
	1,341 horsepower
	2,665,200 foot-pounds per hour
	860,500 gram-calories per hour
	367,000 kilogram-meters per hour
	3,415 Btu per hour
	.102 boiler-horsepower

B–8. Hydraulic Equivalents—Miscellaneous

a. Specific gravity of water at 60 °F. =1.0.

b. Viscosity of water at 60 ° F. = 31.5 S.S.U. (seconds Sayboldt Universal).

c. Conversion factors—

Feet head X .434 X specific gravity	= pounds pressure per square inch
Pounds pressure X 2.31 X specific gravity	= feet head
Meters X 3.28	= feet head
1 acre-inch (quantity of water required to cover 1 acre to a depth of 1 inch)	= 27,152 gallons
1 acre-inch in 12 hours pumping	= 37.7 gallons per minute
Inches of mercury X 1.133	= feet-head of water
Barrels per day X 0.02917	= gallons per minute (if barrel has 42 gallons)

d. Velocity of flow formula—

Velocity of flow in a pipe in feet per second =

$$\frac{\text{gpm} \times .408}{(\text{diameter in inches})^2}$$

e. Doubling the diameter of a pipe increases its capacity four times.

f. Approximately every foot elevation of a column of water produces a pressure of 1/2 pound per square inch.

g. The gallons per minute which a pipe will deliver equals .0408 times the square of the diameter, multiplied by the velocity in feet per minute.

h. To find the capacity of a pipe or cylinder in gallons, multiply the square of the diameter in inches by the length in inches and by .0034.

i. The weight of water in any length pipe is obtained by multiplying the length in feet by the square of the diameter in inches and by .34.

j. To find the discharge from any pipe in cubic feet per minute, square the diameter and multiply by the velocity in feet per minute and .00545.

k. Flowing water—

1 cubic foot per minute	= 7.4805 gallons per minute
1 second foot	= 1 cubic foot per second
	= 448.83 gallons per minute
1 second-foot-day	= 2 acre-feet

l. Velocity head, sometimes called the head due to velocity, is the equivalent head in feet through which the water would have to fall to acquire the same velocity, or the head necessary to accelerate the water.

$$h = \frac{V^2}{2g}$$

Where: V	= velocity of the water through the pipe in feet per second
h	= head in feet (velocity head)
g	= 32.2 feet per second, acceleration due to gravity

m. Water horsepower is obtained from the formula:

$$\text{Water hp} = \frac{\text{gallons per minute} \times \text{head in feet} \times \text{specific gravity}}{3{,}690}$$

Note. The constant 3,690 is obtained by dividing the number of foot-pounds for 1 horsepower (33,000) by the weight of 1 gallon of water (8.33 pounds).

or

$$\frac{\text{gallons per minute} \times \text{head in pounds per square inch}}{1{,}714}$$

n. Brake horsepower is obtained from the formula:

$$\text{Brake hp} = \frac{\text{water hp}}{\text{efficiency of pump}}$$

o. Efficiency of water to water is obtained from the formula:

$$\text{Efficiency (water to water)} = \frac{\text{gpm} \times \text{total head in feet}}{3{,}960 \times \text{brake hp to pump}}$$

p. Field overall efficiency is obtained from the formula:

$$\text{Field overall efficiency} = \frac{\text{gpm} \times \text{total head in feet}}{3{,}960 \times \text{input hp to pump motor}}$$

B–9. Comparative Equivalents of Liquid Measures and Weights

Table B-1. Comparative Equivalents of Liquid Measures and Weights

Measures and weights for comparison	Measure and weight equivalents of items in first column.								
	U.S. gallons	Imperial gallons	Cubic inches	Cubic feet	Cubic meter	Liters	*Vedro	*Pood	Pounds
US gallon	1.	.833	231.	.1337	.00378	3.785	.308	.231	8.33
Imperial gallon	1.20	1.	277.27	.1604	.00454	4.542	.369	.277	10.
Cubic inch	.0043	.00358	1.	.00057	.000016	.0163	.00132	.001	.0358
Cubic foot	7.48	6.235	1728.	1.	.02827	28.312	2.304	1.728	62.355
Cubic meter	264.17	220.05	61023.	35.319	1.	1000.	81.364	61.023	2200.54
Liter	.26417	.2200	61.023	.0353	.001	1.	.08136	.06102	2.2005
*Vedro	3.249	2.706	750.1	.4344	.01228	12.29	1.	.7501	27.06
*Pood	4.328	3.607	1000.	.578	.01636	16.381	1.333	1.	36.07
Pound	.12	.1	27.72	.016	.00045	.454	.0369	.0277	1.

*Vedro and pood are a Russian measure and weight, respectively.

APPENDIX C

PERFORMANCE AND COMPUTATION TABLES

Table C-1. US Gallons in Round Tanks 1 Foot in Depth

Diameter of tanks (ft)	Number US gals	Cu ft and area in sq ft
1.0	5.87	.785
1.5	13.22	1.767
2.0	23.50	3.142
2.5	36.72	4.909
3.0	52.88	7.069
3.5	71.97	9.621
4.0	94.00	12.566
4.5	118.97	15.90
5.0	146.88	19.63
5.5	177.72	23.76
6.0	211.51	28.27
6.5	248.23	33.18
7.0	287.88	38.48
7.5	330.48	44.18
8.0	376.01	50.27
8.5	424.48	56.75
9.0	475.89	63.62
9.5	530.24	70.88
10.0	587.52	78.54
10.5	640.74	86.59
11.0	710.90	95.03
11.5	776.99	103.87
12.0	845.35	113.10
12.5	918.	122.72
13.0	992.91	132.73
13.5	1070.80	143.14
14.0	1151.50	153.94
14.5	1235.30	165.13
15.0	1321.90	176.71
15.5	1411.50	188.69
16.0	1504.10	201.06
16.5	1599.50	213.82
17.0	1697.90	226.98
17.5	1799.30	240.53
18.0	1903.60	254.47
18.5	2010.80	268.80
19.0	2120.90	283.53
19.5	2234.	298.65
20.0	2350.10	314.16

Notes:

[1]42 gallons = 1 barrel.

[2]To find the capacity of tanks greater than the largest given in the table, look in the table for a tank of one-half of the given size and multiply its capacity by 4, or a tank of one-third the given size and multiply its capacity by 9, etc.

Table C-2. Pressure in Pounds Per Square Inch with Equivalent Feet Head

Pressure in pound per square inch (tens)	0	1	2	3	4	5	6	7	8	9
	Equivalent feet head									
5	115.2	117.5	119.8	122.1	124.4	126.7	129.0	131.3	133.6	135.9
6	138.2	140.5	142.8	145.1	147.4	149.7	152.0	154.3	156.6	158.9
7	161.2	163.5	165.8	168.1	170.4	172.7	175.0	177.3	179.6	181.9
8	184.3	186.6	188.9	191.2	193.5	195.8	198.1	200.4	202.7	205.0
9	207.3	209.6	211.9	214.2	216.5	218.8	221.1	223.4	225.7	228.0
10	230.4	232.7	235.0	237.3	239.6	241.9	244.2	246.5	248.8	251.1
11	253.4	255.7	258.0	260.3	262.6	264.9	267.2	269.5	271.8	274.1
12	276.4	278.7	281.0	283.3	285.6	287.9	290.2	292.5	294.8	297.1
13	299.5	301.8	304.1	306.4	308.7	311.0	313.3	315.6	317.9	320.2
14	322.5	324.8	327.1	329.4	331.7	334.0	336.3	338.6	340.9	343.2
15	345.6	347.9	350.2	352.5	354.8	357.1	359.4	361.7	364.0	366.3
16	368.6	370.9	373.2	375.5	377.8	380.1	382.4	384.7	387.0	389.3
17	391.6	393.9	396.2	398.5	400.8	403.1	405.4	407.7	410.0	412.3
18	414.7	417.0	419.3	421.6	423.9	426.2	428.5	430.8	433.1	435.4
19	437.7	440.0	442.3	444.6	446.9	449.2	451.5	453.8	456.1	458.4
20	460.8	463.1	465.4	467.7	470.0	472.3	474.6	476.9	479.2	481.5
21	483.8	486.1	488.4	490.7	493.0	495.3	497.6	499.9	502.2	504.5
22	506.8	509.1	511.4	513.7	516.0	518.3	520.6	522.9	525.2	527.5
23	529.9	532.2	534.5	536.8	539.1	541.4	543.7	546.0	548.3	550.6
24	552.9	555.2	557.5	559.8	562.1	564.4	566.7	569.0	571.3	573.6
25	576.0	578.3	580.6	582.9	585.2	587.5	589.8	592.1	594.4	596.7
26	599.0	601.3	603.6	605.9	608.2	610.5	612.8	615.1	617.4	619.7
27	622.0	624.3	626.6	628.9	631.2	633.5	635.8	638.1	640.4	642.7
28	645.1	647.4	649.7	652.0	654.3	656.6	658.9	661.2	663.5	665.8
29	668.1	670.4	672.7	675.0	677.3	679.6	681.9	684.2	686.5	688.8

Example: In order to find the equivalent feet head for 136 pounds, follow down the first column to the figure 13, then across on the same horizontal line until under the figure 6, which gives 313.3 feet as the equivalent to 136 pounds pressure.

*Table C-3. Flow of Water in Gallons per Minute Through Smooth Bore Hose**

Hose (internal diameter inches)	Fluid pressure Pounds per square inch									
	20	30	40	50	60	70	80	90	100	125
1.00	23	28	33	37	40	43	46	49	52	58
1.25	40	50	57	64	70	76	81	86	90	101
1.50	64	78	90	101	111	120	128	135	143	159
2.00	130	159	184	206	227	242	262	275	292	326
2.50	226	278	322	358	394	425	455	482	509	566
3.00	356	437	504	570	620	665	715	755	800	890
4.00	745	910	1,055	1,180	1,292	1,395	1,492	1,582	1,670	1,850

*The above table is based on a 100-foot length of hose, laid in a straight line with open discharge end. For each set of couplings, deduct 5 percent.

Table C-4. Theoretical Discharge of Nozzles in U.S. Gallons per Minute

Head		Velocity of discharge (feet per sec)	Diameter of nozzle									
Pounds	Feet		1/16	1/8	3/16	1/4	3/8	1/2	5/8	3/4	7/8	1
10	23.1	38.6	0.37	1.48	3.32	5.91	13.3	23.6	36.9	53.1	72.4	94.5
15	34.6	47.25	0.45	1.81	4.06	7.24	16.3	28.9	45.2	65.0	88.5	116.
20	46.2	54.55	0.52	2.09	4.69	8.35	18.8	33.4	52.2	75.1	102.	134.
25	57.7	61.0	0.58	2.34	5.25	9.34	21.0	37.3	58.3	84.0	114.	149.
30	69.3	66.85	0.64	2.56	5.75	10.2	23.0	40.9	63.9	92.0	125.	164.
35	80.8	72.2	0.69	2.77	6.21	11.1	24.8	44.2	69.0	99.5	135.	177.
40	92.4	77.2	0.74	2.96	6.64	11.8	26.6	47.3	73.6	106.	145.	189.
45	103.9	81.8	0.78	3.13	7.03	12.5	28.2	50.1	78.2	113.	153.	200.
50	115.5	86.25	0.83	3.30	7.41	13.2	29.7	52.8	82.5	119.	162.	211.
55	127.0	90.4	0.87	3.46	7.77	13.8	31.1	55.3	86.4	125.	169.	221.
60	138.6	94.5	0.90	3.62	8.12	14.5	32.5	57.8	90.4	130.	177.	231.
65	150.1	98.3	0.94	3.77	8.45	15.1	33.8	60.2	94.0	136.	184.	241.
70	161.7	102.1	0.98	3.91	8.78	15.7	35.2	62.5	97.7	141.	191.	250.
75	173.2	105.7	1.01	4.05	9.08	16.2	36.4	64.7	101.	146.	198.	259.
80	184.8	109.1	1.05	4.18	9.39	16.7	37.6	66.8	104.	150.	205.	267.
85	196.3	112.5	1.08	4.31	9.67	17.3	38.8	68.9	108.	155.	211.	276.
90	207.9	115.8	1.11	4.43	9.95	17.7	39.9	70.8	111.	160.	217.	284.
95	219.4	119.0	1.14	4.56	10.2	18.2	41.0	72.8	114.	164.	223.	292.
100	230.9	122.0	1.17	4.67	10.5	18.7	42.1	74.7	117.	168.	229.	299.

Note. The actual quantities will vary from these figures, the amount of variation depending upon the shape of nozzle and size of pipe at the point where the pressure is determined. With smooth taper nozzles the actual discharge is about 94 percent of the figure given in the tables.

Table C-5. Suction Lift of Pumps at Various Altitudes

Altitude above sea level		Barometric pressure (pounds per sq in)	Equivalent head of water (feet)	Practical suction lift of pump (feet)
Feet	Miles			
0	0	14.70	33.95	25
1,320	1/4	14.02	32.38	24
2,640	1/2	13.33	30.79	23
3,960	3/4	12.66	29.24	21
5,280	1	12.02	27.76	20
6,600	1 1/4	11.42	26.38	19
7,920	1 1/3	10.88	25.13	18
10,560	2	9.88	22.82	17

Table C-6. Maximum Quantities of Water (in Gallons) Which May Be Pumped Through 100 Feet of Wrought Iron Pipe at Various Pressures

Pressure	Size pipe								
	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	4
17 lb	3.2	9.1	18.7	33.5	51.6	106	200	290	589
30 lb	5	14	28	52	78	160	308	436	885
40 lb	6	16	33	60	90	184	350	504	1,023
50 lb	6.5	17.5	37	70	101	206	390	564	1,143
60 lb	7	19.5	40	76	110	226	430	617	1,252
75 lb	7.5	22	45	85	123	253	480	690	1,400
100 lb	9	25	52	99	142	292	558	797	1,607

Table C-7. Relative Quantities of Water Delivered in 1 Minute, in 1 Hour, and in 24 Hours

Gal in 1 min	Gal in 1 hour	Gal in 24 hours
3.4	208	5,000
6.9	416	10,000
10.4	625	15,000
13.8	833	20,000
17.3	1,041	25,000
34.7	2,083	50,000
41.6	2,500	60,000
52.9	3,125	75,000
69.4	4,166	100,000
104.1	6,250	150,000
138.8	8,333	200,000
173.6	10,416	250,000
208.3	12,500	300,000
243.0	14,583	350,000
277.7	16,666	400,000
312.5	18,750	450,000
347.2	20,833	500,000
381.9	22,916	550,000
416.7	25,000	600,000
451.3	27,083	650,000
486.1	29,166	700,000
529.8	31,250	750,000
555.5	33,333	800,000
590.2	35,416	850,000
625.0	37,500	900,000
659.7	39,583	950,000
694.3	41,666	1,000,000
1,041.7	62,500	1,500,000
1,388.0	83,333	2,000,000
1,736.0	104,166	2,500,000

Table C-8. Standard Pipe Data

Butt Weld					
Diameters			Weight per Foot		
Size (inches)	External (inches)	Internal (inches)	Plain Ends (pounds)	Threads and Couplings (pounds)	Outside Diameter Couplings (inches)
1/8	0.405	0.265	0.244	0.245	0.562
1/4	.540	.360	.424	.425	.685
3/8	.675	.489	.567	.568	.848
1/2	.840	.618	.850	.852	1.024
3/4	1.050	.820	1.130	1.134	1.281
1	1.315	1.043	1.678	1.684	1.575
1 1/4	1.660	1.374	2.272	2.281	1.950
1 1/2	1.900	1.604	2.717	2.731	2.218
2	2.375	2.059	3.652	3.678	2.760
Lap Weld					
1 1/4	1.660	1.374	2.272	2.281	1.950
1 1/2	1.900	1.604	2.717	2.731	2.218
2	2.375	2.059	3.652	3.678	2.760
2 1/2	2.875	2.459	5.793	5.819	3.276
3	3.500	3.058	7.575	7.616	3.948
3 1/2	4.000	3.538	9.109	9.202	4.591
4	4.500	4.016	10.790	10.889	5.091
4 1/2	5.000	4.496	12.538	12.642	5.591
5	5.563	5.037	14.617	14.810	6.296
6	6.625	6.053	18.974	19.185	7.358

*Table C-9. Table of Velocities and Corresponding Velocity Heads**

Velocity (feet per second)	Velocity Head (feet)
1	0.02
2	.06
3	.14
4	.25
5	.39
6	.56
7	.76
8	1.01
9	1.25
10	1.55
11	1.87
12	2.24
13	2.62
14	3.05
15	3.50

*With centrifugal pumps, it is standard practice to give head in feet, not in pounds per square inch. For reciprocating pumps, head is always given in terms of pounds per square inch.

Table C-10. Horsepower Ratings and Maximum Lengths for Deep Well Turbine Shaftings
(Based on Turned, Ground and Polished Shaft)

Fpm of pump	Diameter of shaft (inches)						
	1	1 3/16	1 1/2	1 11/16	1 15/16	2 3/16	2 7/16
730	10	16	35	51	81	120	160
870	12	19	40	60	95	140	190
970	14	21	46	67	106	160	210
1,160	16	26	55	81	129	200	254
1,460	20	32	75	102	162	250	350
1,760	25	40	90	125	200	300	400
2,900	40	62	---	---	---	---	---
3,460	50	75	---	---	---	---	---
Maximum shaft length	400	450	550	600	650	675	700

Notes.
[1]Table based on a safety factor of 10.
[2]If horsepower ratings are increased. maximum shaft lengths must be decreased. Refer to the manufacturers for recommendations.
[3]For stainless steel shafting the horsepower ratings can be increased 40 percent.

Table C-11. Approximate Hydraulic Downthrust in Pounds per Foot of Pumping Head

Pump Diameter (inches)	Low Capacity (pounds)	Medium Capacity (pounds)	High Capacity (pounds)
6	2	3	4
7	3	4	6
8	3	5	8
10	4	5	9
12	6	11	15
14	8	14	18
16	9	18	24
18		25	34
20		29	41

Table C-12. Weight of Pump Shafting in Pounds per Foot

Diameter (inches)	Weight (pounds)
1	2.67
1 3/16	3.80
1 1/2	6.00
1 11/16	7.6
1 15/16	10.0
....	...
2 3/16	12.8
2 7/16	15.9

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