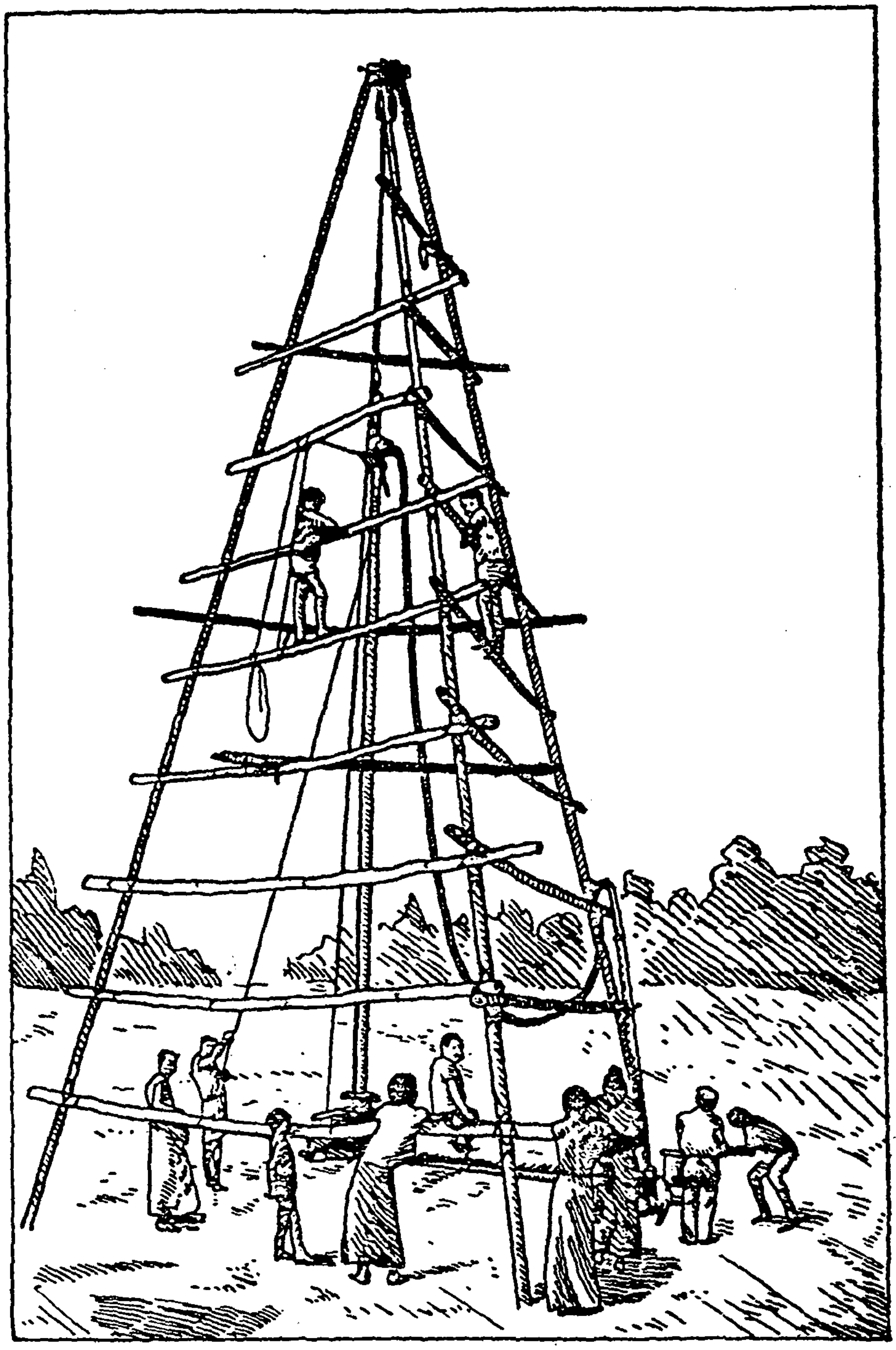

Appropriate well drilling technologies: a manual for developing countries.

Prepared by the National Water Well Association

APPROPRIATE WELL DRILLING TECHNOLOGIES:

A Manual for Developing Countries

A Report From

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Special credit goes to Bruce K. Dadisman and C. Mark Eberle for the numerous illustrations found throughout the text.

Cover: A manual rotary jetting rig; illustrated by Bruce K. Dadisman

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PREFACE AND EXECUTIVE SUMMARY

The economic and logistic difficulties of importing advanced technologies into developing countries are sufficient to make simple, locally producable alternatives attractive. Social and cultural factors, however, are equal, if not greater, obstacles to technology transfer; they must also be considered before appropriate technology can be selected.

This is particularly true for water well drilling. The techniques currently used for constructing water wells in developed countries were borrowed from the petroleum industry--an industry which evolved in an environment of readily available capital, abundant construction materials, and (by worldwide standards) a small, well-educated and expensive labor force. Thus, the water well drilling rigs presently used in developed countries are correspondingly expensive, massive, technically complex, and designed to be labor-saving. They are not suited for less developed countries, where equipment requirements are totally the opposite.

In spite of their complexity, "modern" drilling rigs operate according to basic excavating principles that have been practiced for thousands of years. To facilitate a more realistic kind of technology transfer, it seems fitting to reassess the evolution of drilling methods and to rediscover some of the diversity possible in the well construction process. Such is the spirit in which this literature survey has been undertaken.

Our effort is strictly limited to drilling (as opposed to digging) water wells, because definitive works on dug wells written with developing countries in mind have recently appeared. While scattered discussions of appropriate drilling technologies exist, the need for such information is crucial enough to merit a more comprehensive compilation of material.

The information in this report is presented in three sections: (1) discussion of historical accounts of drilling methods; (2) a survey of simple present-day techniques based on "historical" methods; and (3) a select annotated bibliography of related literature.

The historical discussion is an overview of several thousand years of drilling development worldwide. Particular attention is devoted to the remarkable engineering feats accomplished by the Chinese, to the relatively complex boring and hoisting machinery used in 16th Century Europe, and the simple but effective springpole method used by American settlers in the early 19th Century.

The second section is an illustrated historical outline of the drilling techniques used in recent years in either developing countries or areas too remote for large rigs. While low capital cost and portability of drilling systems are two primary criteria for inclusion in this inventory, equal or greater importance is given to the ease of maintaining the rig in countries where sophisticated technology is lacking. For this reason, the drilling rigs discussed are limited to those requiring no more complex a power source than a small gasoline engine, or the conversion of a conventional auto or truck engine. Particular attention is given to several important components of small portable rigs (i.e. drill bits, bailers, and support tripods).

The bibliography provides an annotated list of related materials. Information used in the preparation of this report, as well as references to sources that appear relevant, are included.

A Note on the Sources

The reference material for Section One is taken primarily from three sources. In order of increasing importance, they are: "The Evolution of Drilling Rigs" by R. B. Woodworth (AIME Transactions, Vol. 54, 1916), "Well Drilling Methods" by Isaiah Bowman (USGS Water-Supply Paper 257, 1911), and The History of Oil Well Drilling by J. E. Brantly (Gulf Publishing Co., 1971). The Woodworth and Bowman papers are both state-of-the-art reports written at the turn of the century, a time when mechanized drilling processes were relatively new, and animal and human powered rigs were still used in the more remote areas of the United States. Brantly's history is an impressive display of scholarship devoting 150 pages of the 1500 page total to early methods of water well drilling.

Because Brantly is frequently cited in Section One, the more concise numerical reference system used in Section Two has been abandoned and reference to his work is by name and page number.

SECTION I - HISTORICAL SURVEY

It is uncertain how long mankind has engaged in well construction. If the term "well" is used in its broadest sense, then well construction may actually antedate Homo Sapiens; digging for water in dry stream beds during drought periods, for example, is primarily an instinctive activity requiring less than human intelligence. Archeological records show that dug well technology achieved a remarkable degree of sophistication several thousand years before the Christian era. Wells of considerable depth were constructed throughout the Middle East in ancient times. Most likely picks and shovel-like tools were used for digging and windlass hoists for removing material from the bore.

As civilizations became more advanced, excavation needs became more diverse. Smaller and deeper holes in a wider variety of earth material were necessary for quarrying operations, and for constructing brine wells. Rotary and percussion drilling techniques developed in response to these emerging construction problems. These two basic techniques are still in use today for water well construction.

Percussion Systems

The principle behind percussion drilling systems is that a heavy, sharp object when successively lifted and dropped will progressively bore through earth. This action penetrates hard soils and rock that could not be efficiently hand-dug. Percussion methods were known worldwide prior to the mid 1800s. Despite their separate evolution in different areas of the world, most percussion downhole tools are remarkably similar in form. Actual cutting is effected by a chisel-shaped, flat metal bit. Typically the length is five times the width of the cutting face (Figure 1). Some sort of "sinker bar," or weight, is attached directly above the bit. The sinkers eventually were constructed as sliding linkages (known as "jars" in the U.S.). The sharp impact as the linkages open and close provides extra force to the bit on the downstroke and a corresponding blow on the upstroke freeing the bit, which otherwise may become stuck at the bottom of a deep hole. The drill string (bit, jars, and any other weights added to that assembly) is securely

Figure 1

Cable Tool Bit

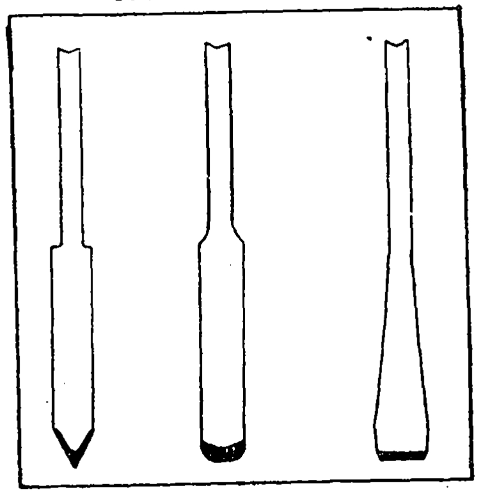
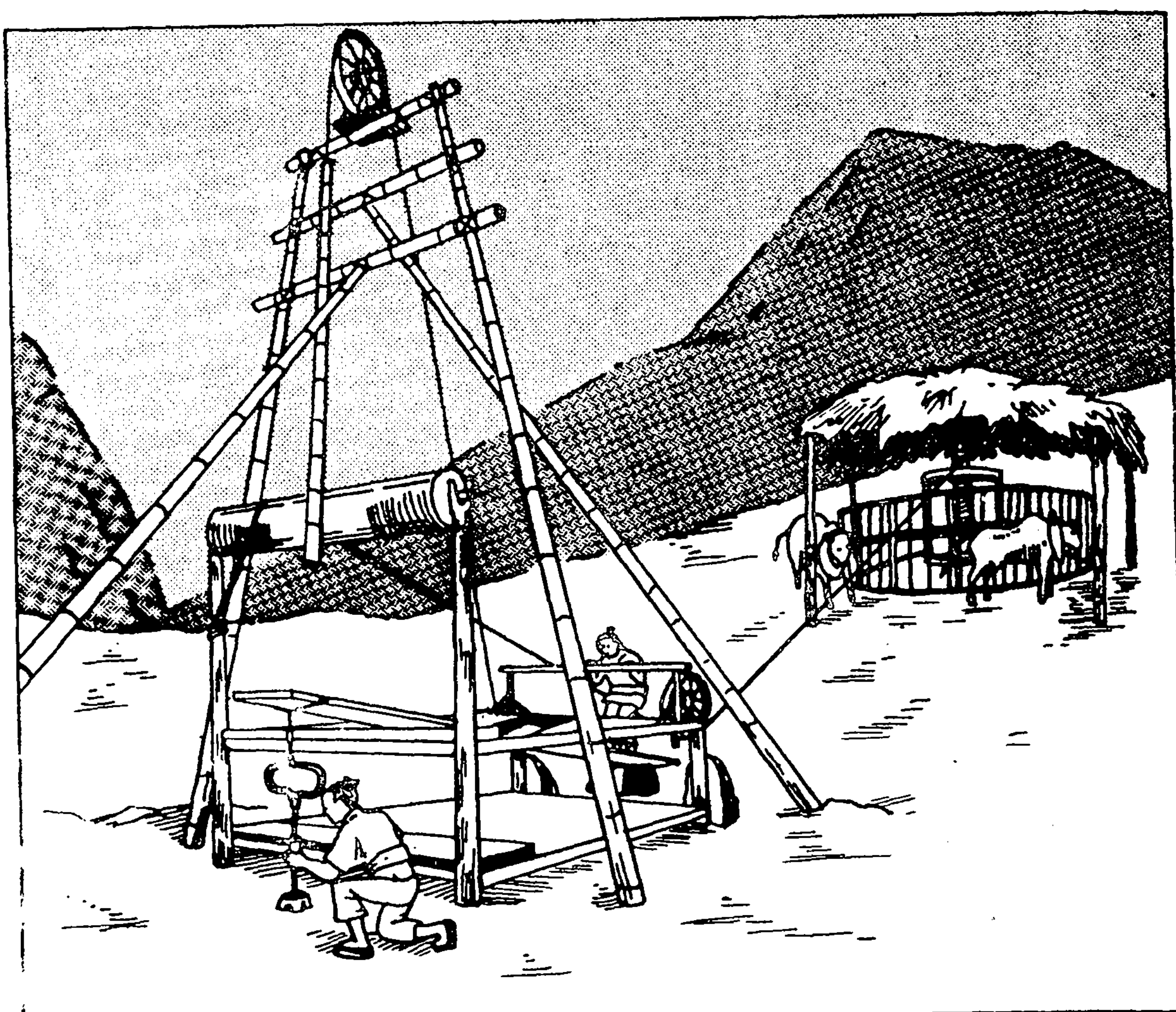


Figure 2

Chinese Brine Well Drilling Rig



attached to a drilling "line" of rope-like material or rigid rods, which in turn run to the surface and transmit the up and down motion.

The major difference between early percussion drilling systems is the means by which the reciprocating motion of the drill string was produced. Three basic "power sources" were used: the springboard, the springpole, and the walking beam. The first was primarily a Chinese drilling technique, while the latter two were used in the United States. The following examples serve to clarify each.

CHINESE SPRINGBOARD DRILLING

According to Brantly, (pp. 41-47) the earliest records of drilled wells in China go back as far as 1122 B.C. These early wells were drilled to obtain supplies of brine to supply salt to the vast Chinese inland areas. As late as the 1940s, the methods used for drilling deep wells for brine and natural gas in remote Chinese provinces were still labor-intensive, almost totally unmechanized, and based on the availability of bamboo as a major component of the rig.

As can be seen in Figure 2, the derrick consisted of a two-legged tower which carried a crown block. Two bracing legs were used as support. A line for raising and lowering the drill string ran over a pulley and back to a large horizontal spool turned by oxen walking in a circle. The reciprocal percussion motion was produced by human power. A long, rigid, horizontal plank served as a lever with drilling tools lashed to the short side of the fulcrum; a crew of laborers took turns raising the drill string by jumping onto the opposite end of the plank. When the laborers jumped off, the tools dropped to the bottom of the borehole under their own weight. A small team of properly synchronized jumpers could drill at a rate of twenty to forty strokes per minute.

The drilling line was made of pliable strips of bamboo about 40 feet (12 meters) long. The strips were notched and lashed together with strong hemp cord and rawhide. A single strip was sufficiently strong to support tools down to 1500 feet (457 meters). Multiple strips were used for drilling beyond that point. Bamboo rope, though used in the field for many other purposes, could not be employed as drilling line due to excessive stretching.

Deep drilling by this method was definitely a long-term project, and rather costly. Completion of a 4,000-foot (1219 meter) brine well took about four years and was estimated to have cost the equivalent of $17,000 in 1923 (probably ten times that amount at today's dollar value).

American Springpole Method

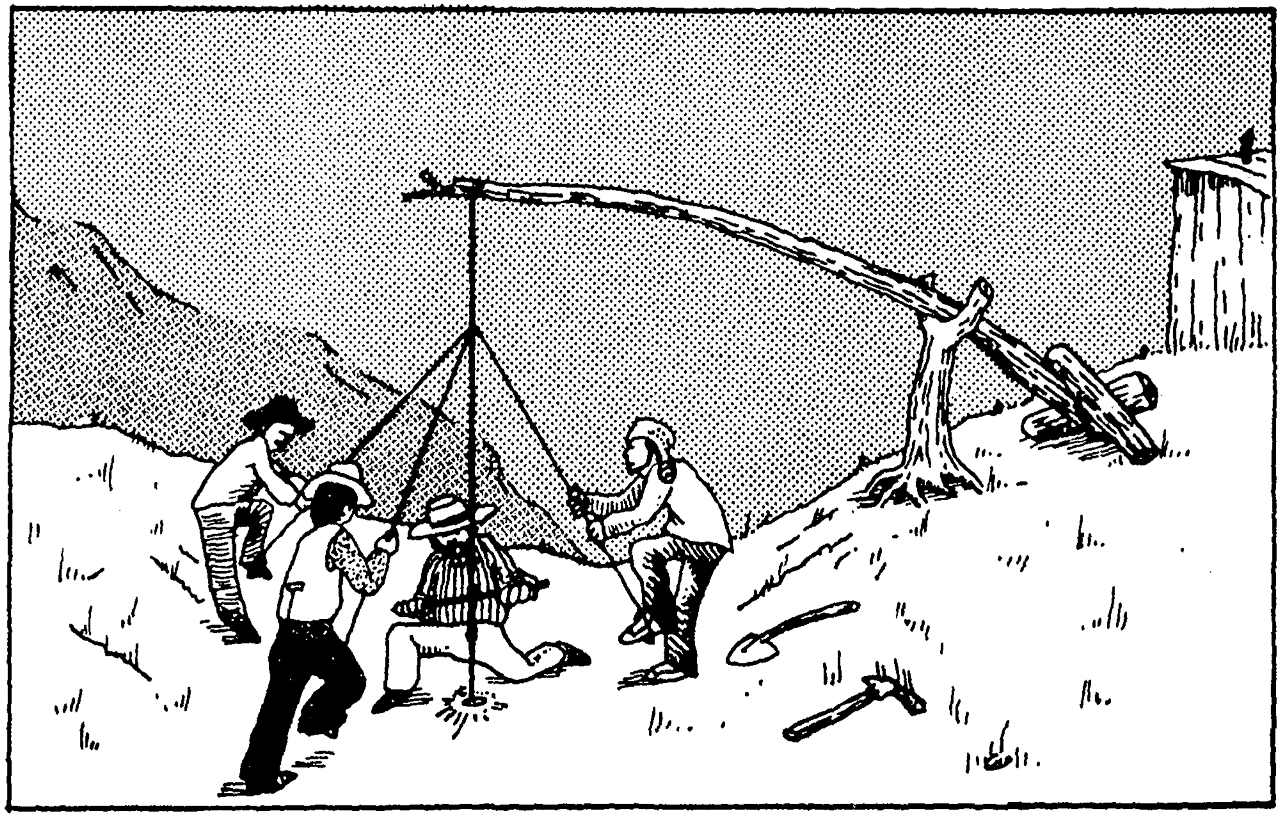
At the beginning of the 19th Century, one of the world's simplest and cheapest methods of well drilling was developed and widely used in the U.S. The springpole method, as it came to be called, was invented in 1807 by David and Joseph Ruffner. In seeking to augment the flow of a salt spring which supplied their commercial salt factory in Kanawha County, West Virginia, the Ruffner brothers devised an apparatus capable of imparting a reciprocal motion to a heavy chisel-type bit (Figure 3). This apparatus consisted of very few parts. The most important piece was a long, straight pole of such diameter that adequate support for the tools was possible while maintaining sufficient flexibility to generate a lifting/dropping motion. The pole was heavily weighted on the butt end by logs or boulders, and was supported at some point in the middle by a forked log fulcrum with a larger diameter than the springpole itself. The tools (a 2 1/2" (6.4 centimeter) steel chisel bit, and later, steel extension shanks welded to the bit) were connectd by a manila line to the narrow end of the pole. A stirrup device was attached near the drilling line by which two or three men could "kick down" on the pole to initiate and continue the reciprocal percussive motion. A small tripod was erected above the borehole to facilitate pulling the tools out of the hole and to operate a bailing device for hole cleaning (the exact type of bailer and/or swab is not known).

The Ruffner brothers drilled about 60 feet (18 meters) below the earlier hand-digging limit when they struck an ample flow of strong brine and halted the drilling operation. The time required for this 60 feet (18 meters) of drilling was 18 months.

Salt being a scarce and valuable commodity in the interior of the U.S. at that time, the economic incentive for the entrepreneur in the salt business was great and the climate for technology transfer was extremely favorable. Whether by hearsay or independent discovery, knowledge of

Figure 3

Springpole Device



the springpole technique traveled rapidly through the Ohio Valley and Western Appalachia following the Ruffners' success. Although documentation is scarce, one report indicates that by 1810, brine wells were being drilled 200 to 400 feet (61 to 122 meters) deep in Cumberland, Lewis, and Perry Counties in Kentucky, a remarkable spread of knowledge in only a couple of years (Brantly, pp. 75-6).

Springpole Experiment

Intrigued by historical accounts of springpole methods, J. E. Brantly conducted a springpole drilling experiment in April, 1964. Enlisting the aid of a "crew of two-220-lb. (99 kg.) mountain lads of the same stock as those who drilled the early 1800's wells," Brantly constructed a device capable of drilling the types of wells described for those times. Specifications are summarized in Table 1.

Different combinations of the concrete weights ranging from 60 to 360 lbs. (27 to 162 kg.) were tested on the springpole rig to assess drilling rate and rig capacity. For nearly all weights tested, the natural stroke length was in the neighborhood of 14 inches (35.5 centimeters) for the fulcrum position described. As the weight increased from 60 to 360 pounds (27 to 162 kg.), the number of strokes per minute decreased from 65 to 40.

Brantly's further experimentation with alternate fulcrum positions and his calculations for the differences between modern rods and manila line as drill string material yielded some interesting data which are too detailed to bear repetition here. Suffice it to say that with a springpole rig of the size described, holes 200 to 250 feet (61 to 76 meters) deep could have been drilled if the driller were lucky enough to escape problems with caving formations, sticky clays or quicksand. Brantly suggested that if a springpole of twice that strength were used, then small holes to depths approaching 1,000 feet (305 meters) could have been drilled (and conceivably were) in the early 19th Century.

Evolution of the Walking Beam

By the mid 1800's, the springpole method was already beginning to die out in the U.S., Canada and Europe. It was suceeded by the introduction of steam as a prime mover and the development of the portable drilling machine for shallow

TABLE 1

SPRINGPOLE	Hemlock; 30 feet (9 meters) long; 8 inches (20 centimeters) diameter at bottom tapering to 4 inches (10 cm) at top.
FULCRUM	Oak; 10 inches (25 centimeters) diameter at ground with fork 8 feet (2.5 meters) above ground. Was trimmed to a 6 foot (1.8 meter) length under the fork. Fork itself had 12 inch (30 centimeter) prongs. Set 9 feet (2.7 meters) from butt end of springpole.
SPRINGPOLE WEIGHTS	30 inch (76 centimeter) diameter chestnut log served as the primary anchor. Two additional 6 foot (1.8 meter) oak poles 4 inches (10 centimeters) in diameter were used to help keep the butt end in position.
HOISTING TRIPOD	Three 14 foot (4.5 meter) poles lashed together with 12 feet (3.6 meters) of log chain.
"TOOLS"	Concrete weights, to simulate weight of bit, shanks and line. Made in both 30-and 60-lb. (13.5 and 27 kg.) sizes.

wells. The reciprocal "springing" motion was now being provided by means of a rigid beam (walking beam) which was raised and lowered with mechanical (steam) power. The flexibility of the long, fixed wooden pole was no longer necessary, hence, rigs became more compact and portability was made possible. Figure 4 represents one of the first attempts at a walking beam apparatus. Figure 5 depicts one example of an early portable rig.

The success of these early mechanical rigs marked the beginning of a totally new approach to drilling. Well construction could now be undertaken with significantly less manpower. The percussion drilling technologies which evolved after this point were labor saving and capital intensive; therefore, they are outside the scope of this study.

Rotary Techniques

In contrast to the mechanics of the percussion techniques, drilling action in rotary techniques is the result of continuous circular scraping under constant pressure (in present-day terms, "rotary drilling" connotes methods in which the hole is cleaned by a stream of fluid or air; "rotary" is being used more broadly in this report to include drilling with augers). Rotary drilling techniques are at least as old, if not older, than percussion methods. Some form of core drilling was used as early as 3000 B.C. by the Egyptians in stone quarrying operations. Most of the basic gear, screw and hoisting devices which have been applied to rotary drilling in the Christian era had been invented and reported in Greek and Roman times (Brantly, pp. 36-40).

Well Boring in Europe

Published accounts of drilling methods in Europe prior to the 19th Century are sparse; however, what documents are available indicate that boring techniques, as opposed to percussion methods, were favored for large well projects on the continent. It is assumed that the vast majority of small ground water supplies came from shallow dug wells.

Rotary drilling was done predominantly with earth augers in a dryhole environment (i.e., the drilling action was not dependent on any kind of hydraulic circulation). Both "pod"

Figure 4

Thom Walking Beam System

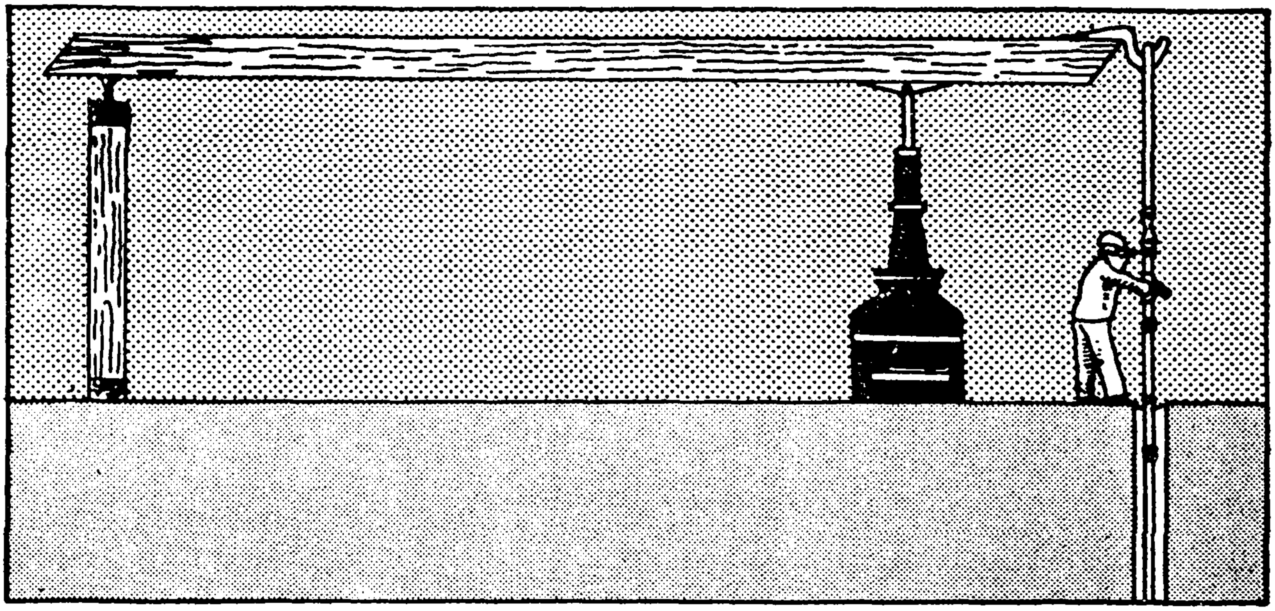
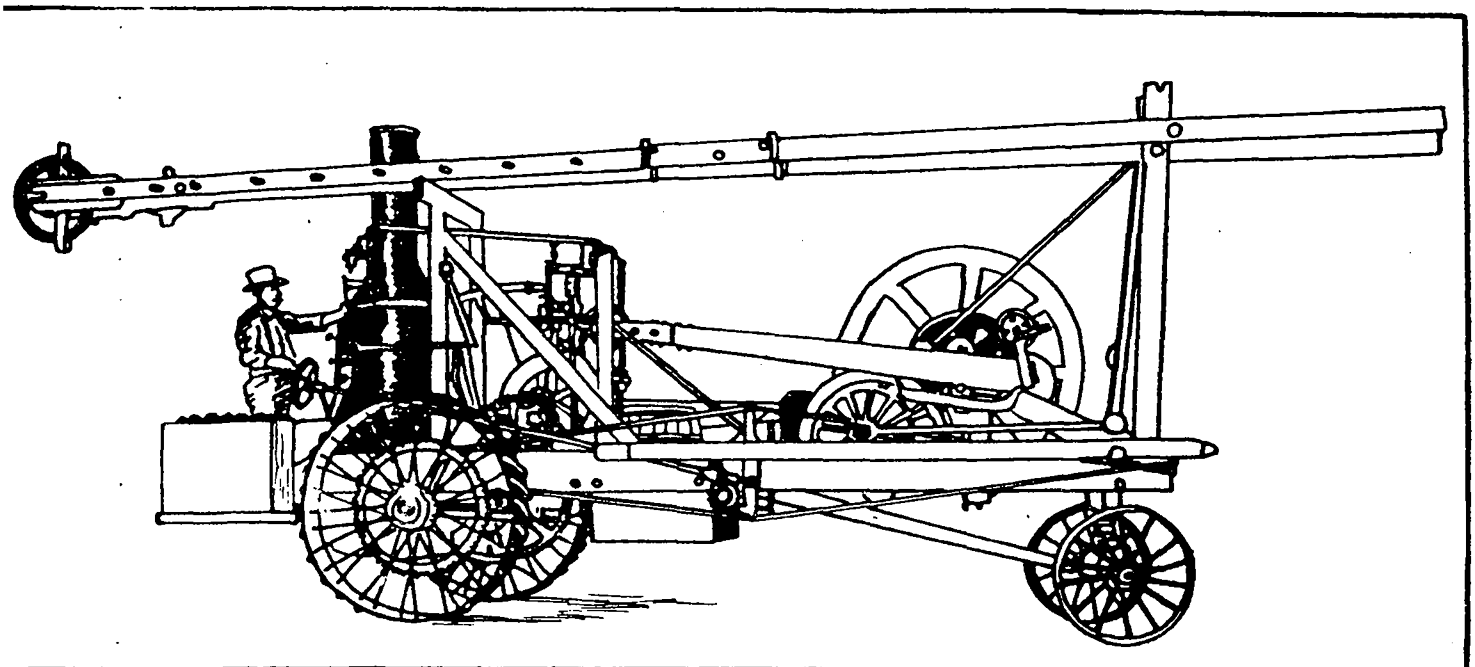


Figure 5

Portable Rig from the Early 1900's



and helical types of augers were used. The choice of auger type was based on their comparative efficiencies in various soil types. A string of connecting rods was attached to the bit piece by piece as the hole deepened and a simple scaffold or derrick arrangement with a hoisting device was used to raise and lower tools, as well as regulate downhole pressure in deeper bores.

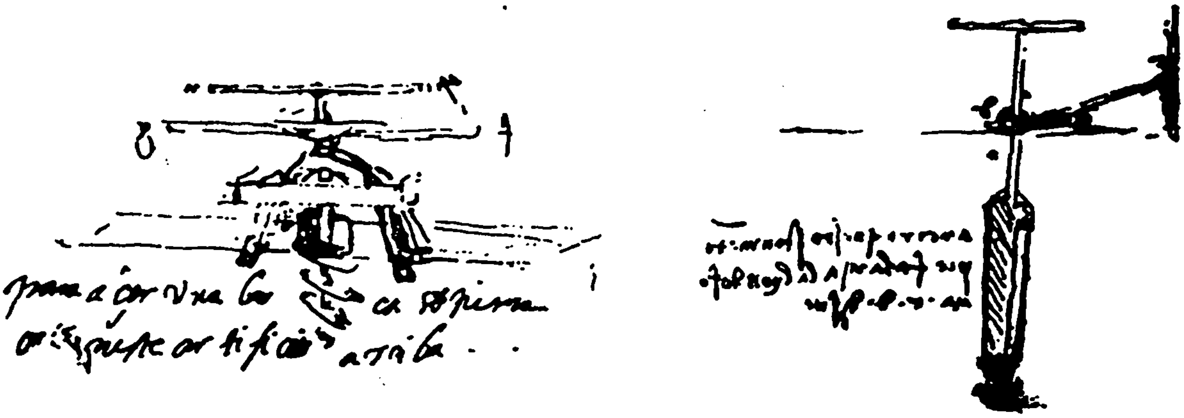
These early European rigs varied greatly in size and complexity. The Notebooks of Leonardo da Vinci and De Re Metallica by Georgius Agricola indicate the diversity already in existence during the 16th Century.

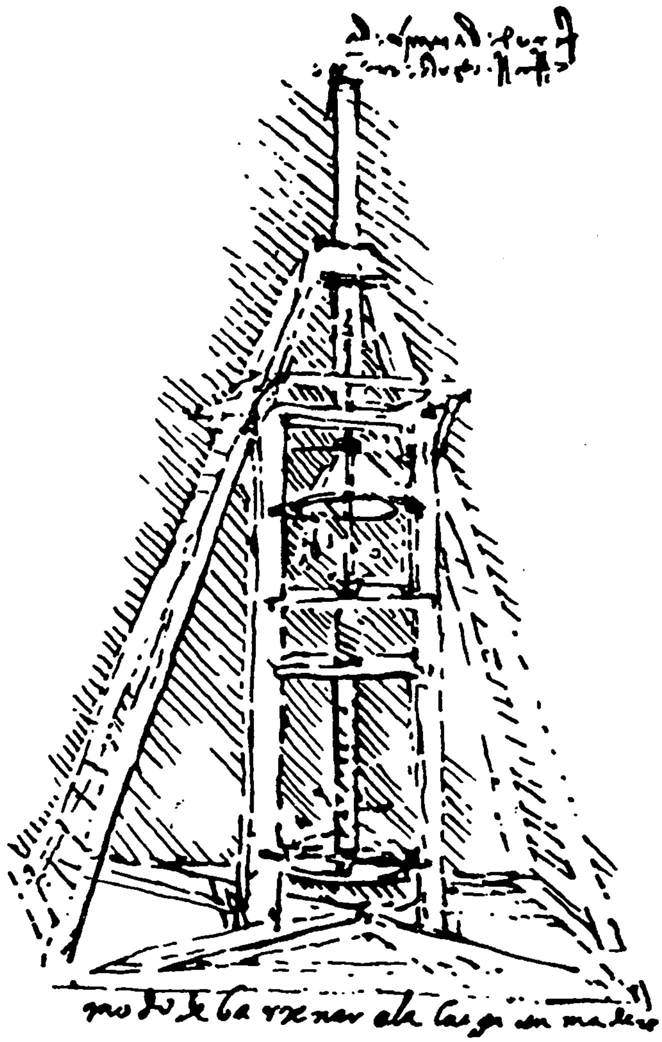
Figure 6 represents three of Leonardo's drilling machine designs. Figure 6b is a small pod type auger such as described earlier. Figure 6a shows a small boring machine equipped with a helical auger. The upper bar was attached to a vertical stem which was threaded to fit the inside hub of the lower bar. By rotating the upper handle, the auger was twisted into the earth to the desired depth. The lower handle was then turned to raise the stem and auger, thus cleaning the hole. This principle is still being used in modern post hole digging machines. A larger version of this machine also appears as an incomplete drawing in his notebooks. Rigs of this type were possibly used by Leonardo himself during a water supply project he directed in the valley of the Loire in the early 1500's. As with many of Leonardo's sketches, we are uncertain of the extent these designs were based on existing machines and what proportion was his own innovation.

The illustrations of Agricola indicate the degree of technical sophistication achieved in the mining and excavating fields during the mid-1500's. The work does not bear directly on water well drilling, however, various pieces of hoisting and horse-powered equipment, which would certainly have been useful in boring a large well, are shown in detail. None of the detailed engravings from De Re Metallica (which have been reproduced in several 20th Century facsimiles of the book) have been included here, as they primarily depict underground mine technology. An inspection of these engravings leaves no doubt that the power producing capabilities for deep well boring could easily have been met in the 16th Century, although the equipment itself would have been massive and by no means portable.

Figures 6a and 6b

Leonardo's Sketches of Drilling Devices





Drilling methods in Europe probably changed very little from the time of Leonardo and Agricola through 1800. Well records from the 17th and 18th Centuries frequently omitted mention of the exact method of construction, however, as late as 1841, machines with the same level of technical sophistication depicted in the 16th Century were still in use for large projects. Figure 7 shows the rig that was used on the Grenelle well in France, which was drilled to a depth of 1,771 feet (540 meters).

The simple hand auger coexisted with the larger rigs, and was still being used for smaller holes up to the early 20th Century. An illustration from Ernest Spon's 1875 drilling manual (28) shows a typical British application of the late 19th Century (See Figure 8).

Hydraulic Methods

The rotary methods previously discussed were "effective" in the sense that wells of considerable depth were completed, but these techniques were not efficient. Because all of the drilling action at the bit face was provided by mechanical means, the drilling tools themselves were heavy and awkward to handle. Removing drill cuttings from the bore under relatively dry hole conditions slowed operations even more. The previously mentioned Grenelle well (1772 feet) took eight years to construct.

Dramatic developments took place in the mid-1840's, when fluid circulation devices were invented in Britain and first used successfully in France. In July of 1844, Robert Beart of Godmanchester, England submitted patent drawings and specifications for a drilling aparatus which featured a water circulation system to flush cuttings from the hole. It was basically a rotary device with hollow iron rods for a drill string. Although not clearly specified in the patent description, it is assumed that a stream of water was sent down the annulus between the hole wall and the drill pipe, and was pumped back up to the surface through the pipe itself (a "reverse circulation" rig, to use current terms) (Brantly, pp 92-98).

Whether Beart actually built and operated such a device is unknown, however, a French gentleman by the name of Fauvelle reported the successful use of a similar appartus to drill a 558 foot (170 meter) artesian well in 1845. Fauvelle's rig was described as operating via "straight"

Figure 7

Grenelle Rig

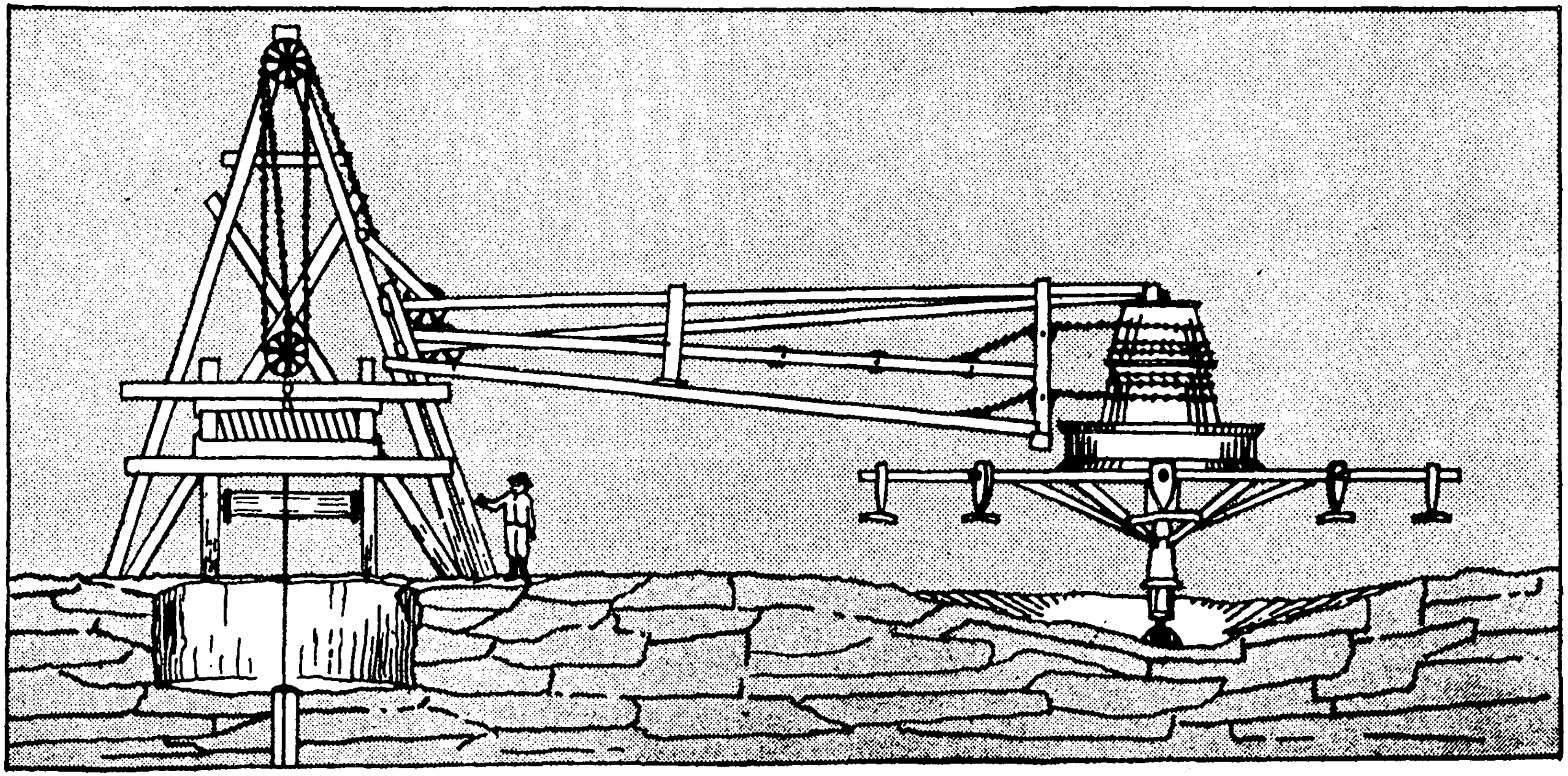
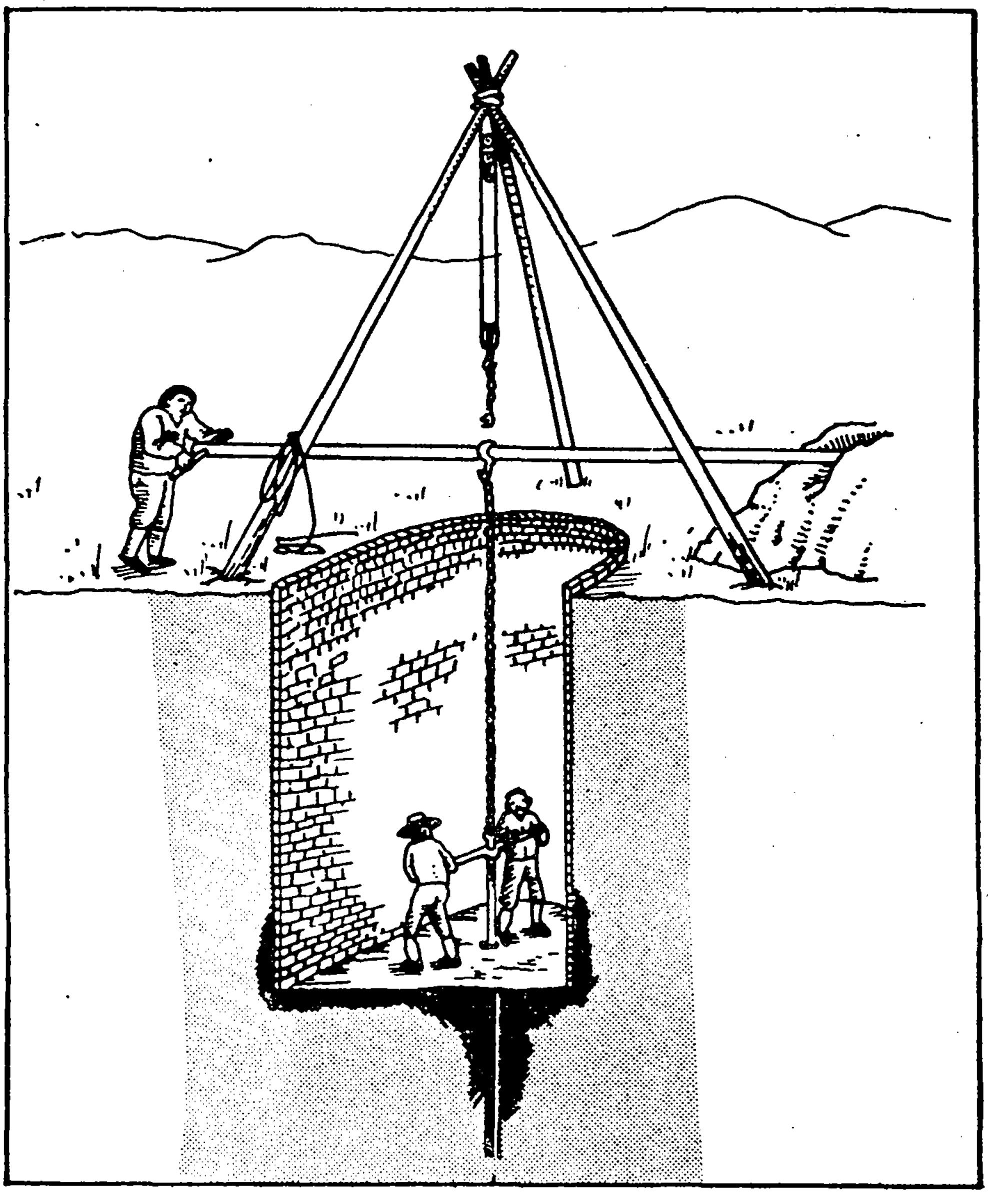


Figure 8

British Hand Auger System



circulation, the water being pumped down the pipe and returning the cuttings up the annulus. Supposedly, both rotary and percussion types of drilling were possible with his machine. Fauvelle also admitted that if hole stability were a problem, reverse circulation procedures would be preferable to his standard drilling method.

Between 1845 and 1900, French drillers began modernizing the methods used during the preceding 300 years. In conjunction with fluid circulation systems, percussion drilling systems became popular and eventually replaced the cumbersome dry hole, slow rotation rigs. By 1880, fluid circulation systems were just starting to be used in the United States.

The age of "primitive" rotary drilling methods came to an end around 1890, when the invention of the rotary table (described in Section 2.2.3) made mechanical powered rigs possible.

2. CURRENT DRILLING RIGS AND EQUIPMENT

2.1 Introduction

Experience shows that large, highly sophisticated and efficient drilling rigs can often drill a well faster and at a lower cost than manual drilling methods. However, the major portion of capital funds is consumed in amortization, plus the operation and maintenance costs of the drilling rig itself. When this occurs, very little money remains within the local economy. The use of low-cost, labor intensive drilling equipment reverses this economic cycle, giving developing communities the advantages of increased agricultural productivity and improved health standards while simultaneously creating additional employment, developing occupational skills, and recycling local financial resources.

For the previously stated reasons, the following descriptions of drilling equipment and techniques are limited to very fundamental methods which may be fabricated using basic woodworking, metalworking and blacksmithing skills. With the realization that simple (3 to 24 horsepower) gasoline/diesel engines are becoming more widespread as portable power units and that in many areas sufficient local technology is available for their maintenance and repair, a number of drilling rigs which utilize these engines are discussed.

The complexity and manufacturing skills required for larger engine driven equipment exceeds the objectives of this manual. Individuals who desire additional information on larger drilling equipment and supplies may consult the manufacturer bibliography at the back of this manual.

Regardless of drilling rig size, the type of drilling rig or equipment used within an area depends upon local geologic conditions. Some drilling equipment applies only to unconsolidated formations such as sand, silt, and clay while others may be effective in a wide variety of soil and bedrock conditions. Table 1 is designed as a guide for the comparison of drilling equipment described in the text.

2.2 Basic Drilling Rig Components and Power Sources

2.2.1 Tripods (for low cost drilling)

The tripod, a three legged derrick, represents the most widely used and locally manufacturable type of drilling support structure. Basic tripod construction materials may range from locally available timber, cut

Table 1

Comparison of Low-Cost, Labor Intensive Drilling Methods

Drilling Rigs	Geologic Conditions: sand silt and clay	Geologic Conditions: weathered or soft rock formations	Geologic Conditions: hard rock formations (limestone, granite, basalt)	Well Diameter	Average Well Depth	Manpower Requirements	Drilling Time	Fabrication Skills: woodworking	Fabrication Skills: metalworking	Fabrication Skills: blacksmith	Fabrication Skills: machine shop	Fabrication Skills: foundry	Cost of Equipment 1978 Dollars	Remarks
Dry Bucket	●			2-4 inches (5-10 cm)	64 feet (19.5 m)	2-4 men	3 hours	●	●	●			100 to 700	Excellent results in dry semi-cohesive sand and silt.
Bail Down	●			10 inches (25 cm)	140-200 feet (43-61 m)	8 men	4-6 weeks	●	●	●			500 to 800	Best applied to areas where caving or flowing sand prohibits the use of other drilling methods.
Cable Tool	●	●	●	4-6 inches (10-15 cm)	150 feet (45 m)	6-8 men	3-28 days	●	●	●			300 to 2,000	Best method for drilling in hard rock formations
Reverse Circulation Percussion (Sludger)	●			2-6 inches (5-15 cm)	50 feet (15 m)	4-6 men	4-9 hours	●	●	●			125	Excellent shallow depth drilling in unconsolidated material.
Well Point Driving	●			2-4 inches (5-10 cm)	25-50 feet (7.6-15 m)	1-2 men	3 hours	●	●	●	●		20 to 1,500	Excellent shallow depth drilling method for low volume wells.
Hand Auger	●	●		4-6 inches (10-15 cm)	50-80 feet (15-44 m)	4-6 men	1-5 days	●	●	●			125 to 1,700	Excellent shallow depth drilling mothod; best utilized in unconsolidated and alluvial river flood plain deposits.
Manual Jetting	●	●		2-4 inches (5-10 cm)	150 feet (45 m)	2-3 men	2 days	●	●				100 to 500	Expedient method for drilling deep wells in unconsolidated or soft rock materials. (Requires a water supply and pumping system.)
Manual Rotary Jetting	●			4-10 inches (10-25 cm)	195 feet (60 m)	8-15 men	2-4 days	●	●	●			500 to 2,500	
Hydra-Drill	●	●		2-4 inches (5-10 cm)	50-200 feet (15-61 m)	2-3 men	1-2 days		●				750	Rapid means for drilling small diameter supply and observation wells.
Truck Mounted Jetting-Driving	●	●		2-4 inches (5-10 cm)	100 feet (30 m)	4 men	2-3 days	●	●	●	●		1,000 to 2,500	Excellent field proven drilling rig. Equipment performs the best in unconsolidated sand, silt, and clay formations.
Walking Beam Jetting-Driving	●	●	●	2-4 inches (5-10 cm)	145 feet (44 m)	3-4 men	1-2 days	●	●	●	●		1,250 to 2,750	Drilling rig and equipment are well suited for drilling under all conditions.
Rotary- Percussion Exploration Drill	●	●	●	2-3 inches (5-7.6cm)	150 feet (45 m)	2 men	1-3 days		●	●	●	●	2,600	Excellent drilling rig for small diameter wells in all materials. Equipment may be disassembled and transported into remote areas by pack horse.
Hydraulic Rotary	●	●	●	3-6 inches (7.6-15 cm)	60-250 feet (19-76 m)	2-3 men	3 hours to 2 days		●	●	●	●	6,600 to 14,800	Highly diversified drilling rig which handles a wide variety of drilling tools and methods. Operation and maintenance costs for the rig are likely to average an annual rate which is 20% of the original purchase price.

lumber, or bamboo. More sophisticated tripods can be constructed from pipe or available scrap metal (Figure 9). Common methods for connecting the three legs to form a tripod configuration include lashing wood or bamboo timbers with rope, or boring a hole through each leg member and attaching them with a metal bolt.

When local timber or bamboo are plentiful, they represent the least costly material for tripod construction. If these materials are in short supply and several wells must be drilled using the same equipment, it is usually more economical to construct a metal "pipe" tripod which can be disassembled and transported from one drilling site to another.

The wood, bamboo, and simple pipe tripods may be constructed using simple hand tools. The height of a tripod is limited only by the strength of its support legs. If this height exceeds 4 meters it is best to use legs constructed from 3 or 4 inch (7.6 to 10 centimeters) pipe or construct either a heavy or reinforced pipe tripod (such as those at the bottom of Figure 9).

Construction of a reinforced pipe tripod requires the skills of an experienced metal worker and an electric arc or an oxygen-acetylene welding apparatus. The cost of a reinforced tripod will depend upon local materials and labor costs. Similar tripods referenced in the Peace Corps Program and Training Manual (1) list the 1974 average cost for materials and construction in Togo, a nation along Africa's Ivory Coast, at approximately $500. Complete construction details for wood and reinforced pipe tripods appear in the VITA Publication, Using Water Resources (33) and in the Peace Corps Program and Training Manual (1).

2.2.2 Methods for Producing Vertical Reciprocating Motion

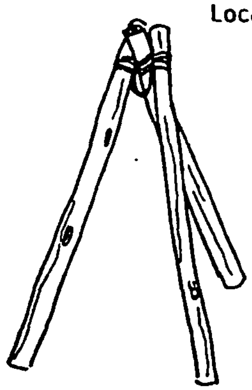
A number of drilling operations require a method of successively raising and dropping the drilling tools. This vertical motion is necessary for percussion drilling, sand bailing, setting or removing casing, and driving well points. The vertical reciprocating movement needed for these drilling methods is produced in several ways.

Manual Methods

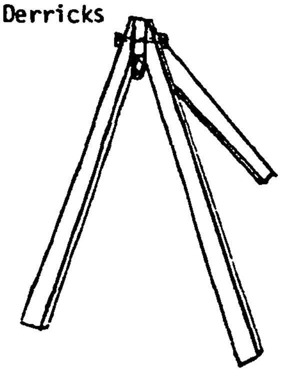
The more popular methods, including the spring pole technique, are discussed in the historical section of

Figure 9

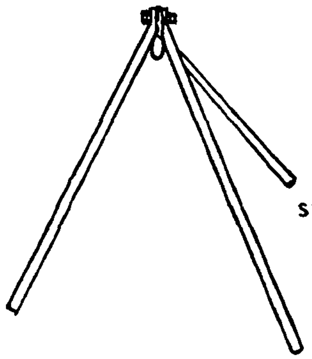
Locally Fabricated Tripod Derricks



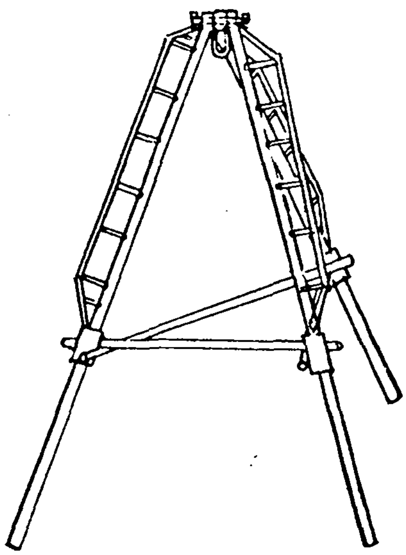
timber or bamboo lashed with rope



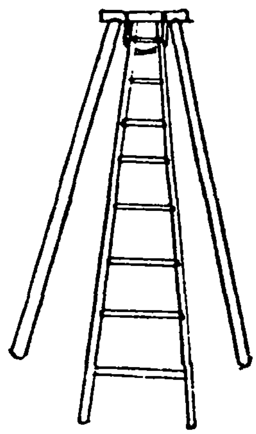
cut hard-wood lumber bolted together



simple pipe tripod bolted together



reinforced tripod with extension legs for added height



heavy-duty pipe tripod with access and equipment mounting ladder this manual. Whenever a suitable spring pole is not available, the drilling action can be produced by means of a lever or by alternately pulling and releasing a rope (Figure 10 a and b).

Mechanical Methods

In areas where manual labor is less cost effective, or when a great number of wells must be drilled in a limited amount of time; vertical motion may be produced by a motorized cathead or capstain. The cathead consists of a rotating metal spool powered by a gasoline engine, hydraulic motor, a rear wheel hub of a vehicle, or a power-take-off from a truck, tractor or land rover (Figures 11, 12, and 13).

To operate the cathead, several turns of the drilling rope are "set" around the rotating spool. As the free end of the rope is alternately pulled and released, friction between the cathead and rope supply the force necessary to lift even the heaviest weights with very little manual effort.

Self Powered Cathead

Figure 11 represents a diagramatic sketch of a motorized cathead run by a three or four horsepower gasoline engine. In the diagram, engine power is transferred through a fluid or centrifugal clutch to a main drive pully which then turns the cathead. The motorized cathead is designed to mount directly to a tripod leg. Alternate mounting locations include the chassis, frame, or bumper of a support vehicle.

Power-Take-Off Mounted Cathead

A cathead operating from a power-take-off (PTO) of a truck is a simple and low-cost addition to any field vehicle (Figure 12). Most manufacturers of 4-wheel drive vehicles, commercial trucks and farm equipment feature a PTO as either standard or optional equipment. The use of a PTO drive cathead for drilling is not widely publicized. However, the method is used by a substantial number of soils engineering firms to assist in test borings for soil sampling and in driving well points.

Hub-Mounted Cathead

Another location for mounting a cathead is directly to the rear hub of a support vehicle (Figure 13). This method is described in an account by McJunkin (21).

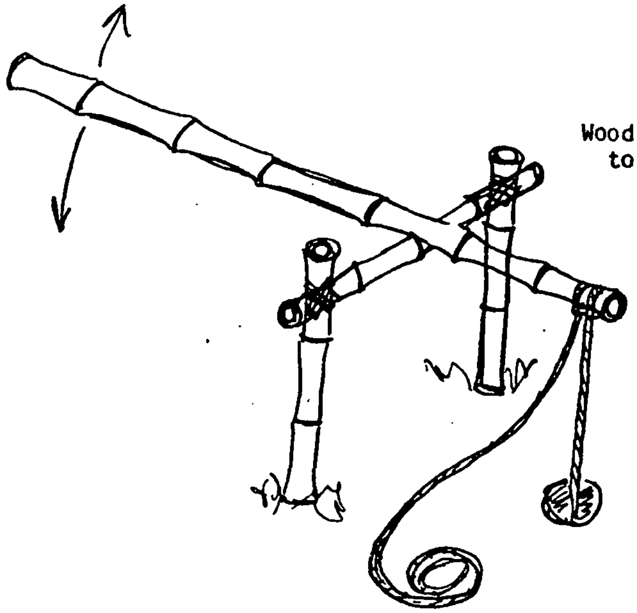


Figure 10a
Wood or Bamboo Lever and Fulcrum
to Produce Reciprocating Motion

Figure 10b
Pulling and Releasing a Rope to Produce Reciprocating Motion

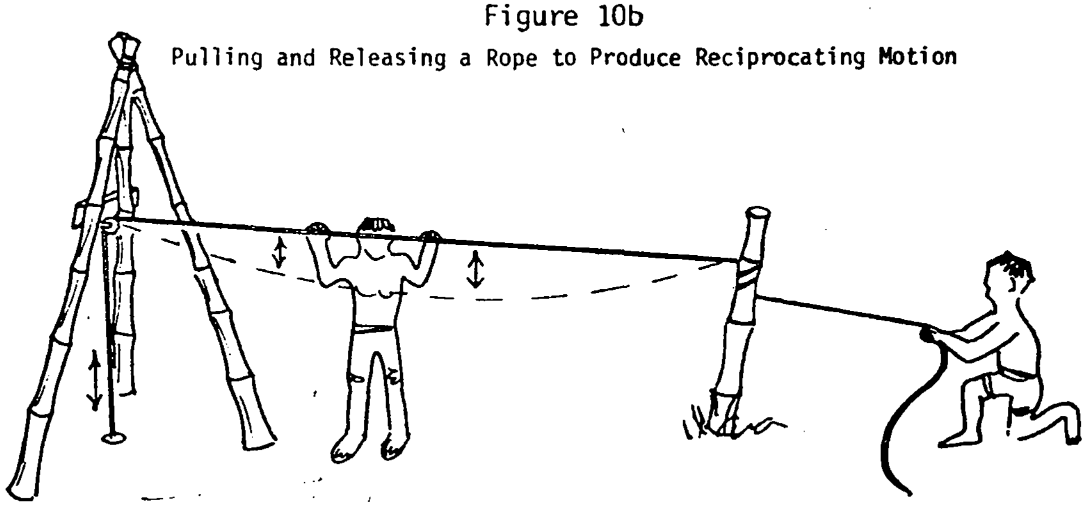


Figure 11

Motorized Cathead

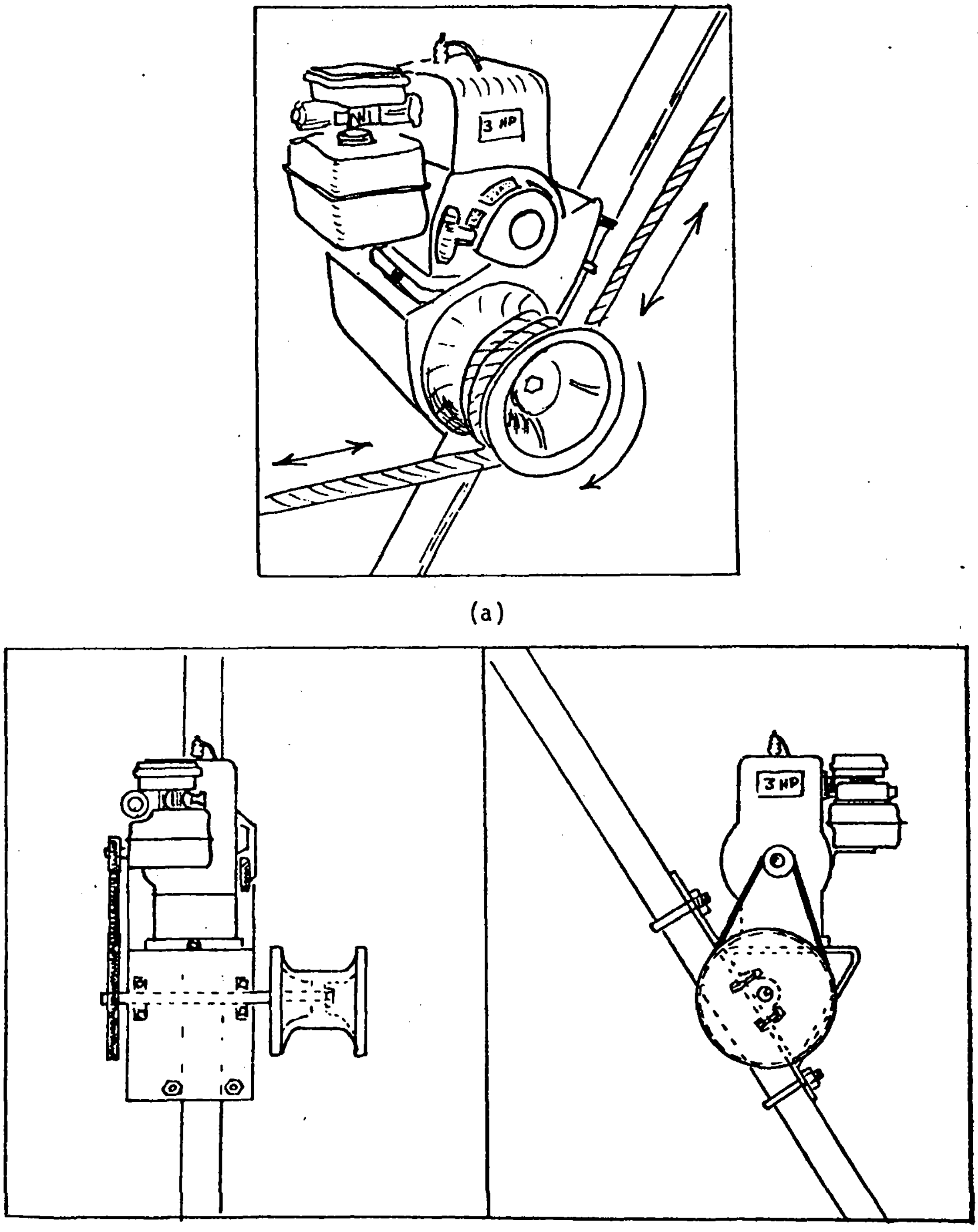
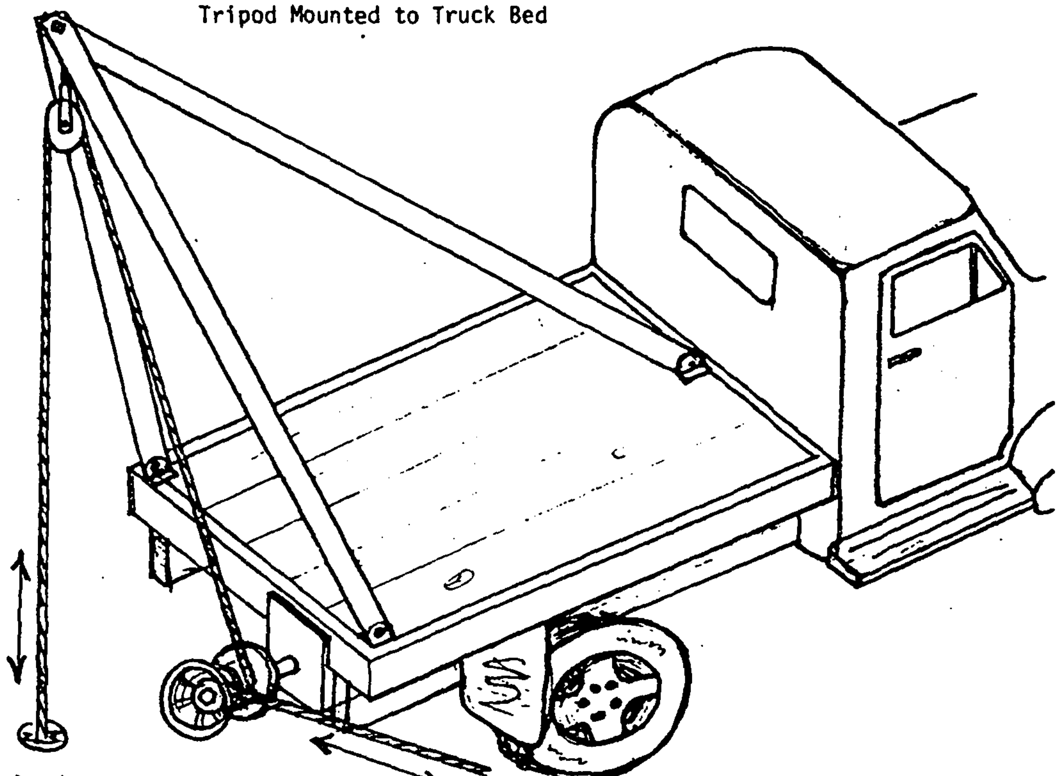
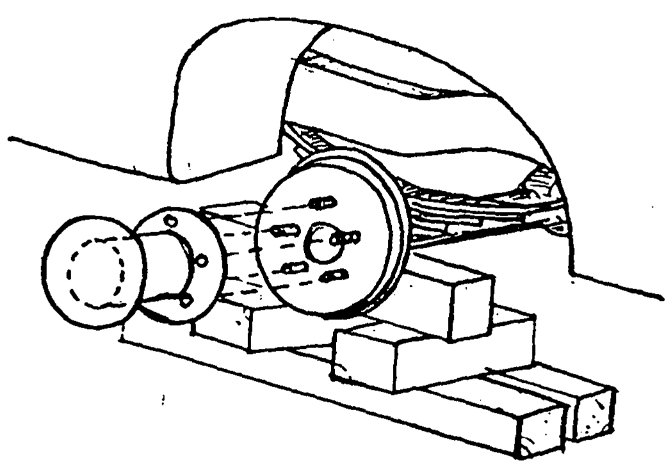


Figure 12
Tripod Mounted to Truck Bed



cathead bolted to a power-take-off

Figure 13
Locally Fabricated Cathead Mounted to a Rear Wheel Hub



The hub mounted cathead consists of a metal spool, welded together from a scrap section of well casing, and two steel rims, one of which is drilled and bolted to the hub of a support vehicle.

This cathead costs almost nothing to construct and can be fabricated in as little as one hour. However, two very important precautions are necessary for its use: first, all truck wheels must be chocked to prevent vehicular movement if the rope should "bind" or cause the opposing rear wheel to rotate, and second, care must be taken to avoid overloading the cathead which may cause unnecessary wear to the engine and drive train.

As mentioned earlier, a cathead may be fabricated from scrap materials. More refined catheads can be produced using simple sand casting and foundry techniques. The relative ease of fabrication using local skills should result in a cost considerably lower than the current U.S.A. value of $800 for a motorized cathead and approximately $90 for a replacement cathead.

2.2.3 Methods for Producing Rotary Motion

The rotation of an auger, drill bit, or well casing is required for almost all types of drilling. A wide variety of locally manufacturable methods are described in the following accounts.

Rod or Auger Handles

The most basic and labor intensive method for producing rotary motion utilizes an auger or drill rod handle. The handle, or clamp block is bolted around the drill rod as in Figure 14a. With this arrangement, rotary motion is achieved by one or more men turning or walking the handle in a circle. A standard rod handle can be fabricated at minimum cost using simple woodworking tools and two sections of hardwood lumber.

Chain Tongs

As drill pipe or casing size increase, wood handles become impractical and chain tongs represent a useful rotary tool. A chain tong utilizes leverage to tighten a link chain around the entire circumference of the casing. The link chain and attached tong are then used as a handle to rotate the casing. Large 10 to 20 inch (25.4 - 50.8 centimeters) casings may require two to three chain

Figure 14 a
Wood Rod Handle

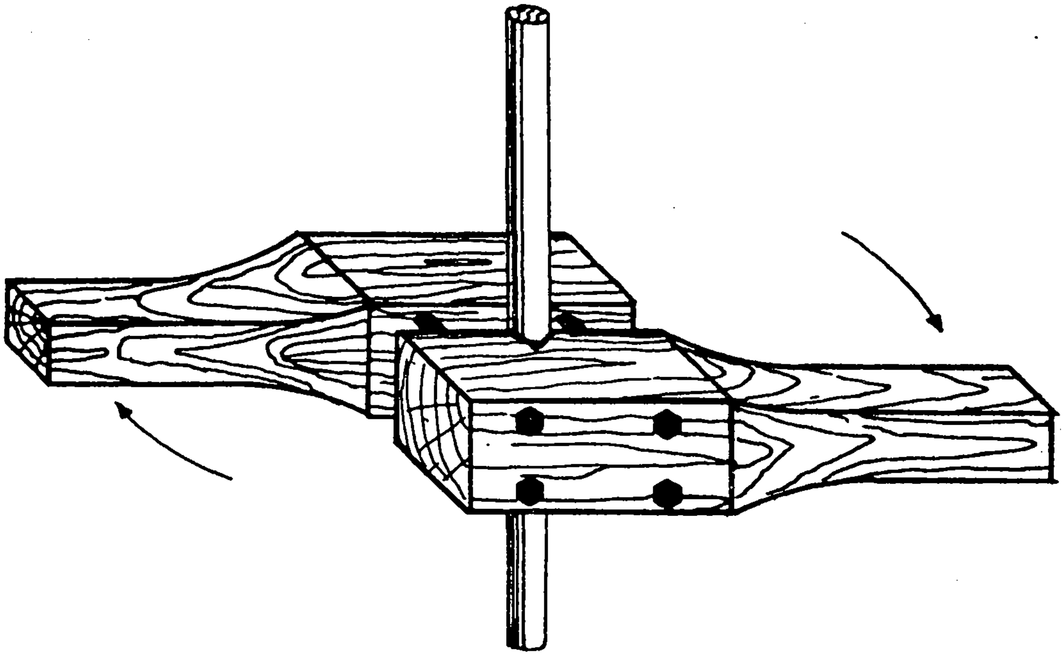
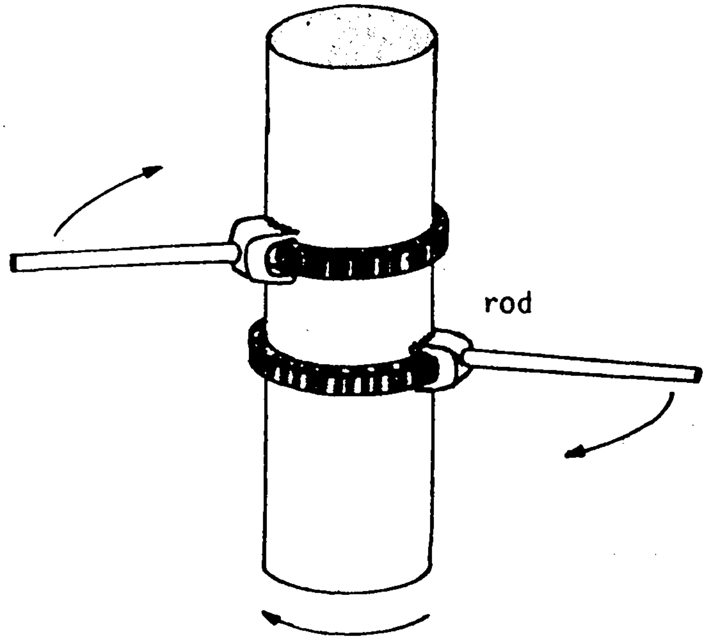


Figure 14 b
Chain Tongs (for large diameter well casing)



tongs and from four to nine men to rotate the casing (Figure 14b). The cost of commercially available chain tongs ranges up to $124. However, similar tongs could be easily fabricated in a local machine shop from sections of scrap pipe and chain.

Rotary Tables

The rotary table, developed in the early 1890's, revolutionized the well drilling industry. Early rotary tables, such as the one illustrated in Figure 15, employed the same rotary principles as do the highly sophisticated rotary tables of modern drilling rigs. These early models used a clamp, similar to a rod handle, which attached to the drill rod. The clamp and drill rod assembly were turned by two upright pipes attached to a large beveled gear or rotary table. As additional technological advancements were made, the rod clamp and vertical pipes were replaced by an assembly of lock rollers. These clamped the drill rod while still permitting unlimited vertical rod movement in and out of the drill hole (Figure 16).

The power required to operate a rotary table may be supplied by a farm animal, as in Figure 17, or by a steam, diesel, or gasoline engine. The primary advantage of a rotary table is its ability to produce a faster rotation and cutting rate than is normally possible with manual rotary methods.

Present day rotary tables, costing thousands of dollars, are designed principally for high production oil and gas well drilling. Relatively inexpensive rotary tables (see Figures 15, 16, and 17) powered by animals or small engines can be designed and fabricated using simple foundry and machine shop equipment. The cost for a locally fabricated rotary table is purely conjecture, but should not exceed $1,000.

Gasoline Engine

Mechanized techniques for producing rotary motion employ increasingly complex transmissions and gasoline engines to rotate a drill stem. In its most basic form, a small gasoline engine mounted as a conventional two-man post hole digger provides a very simple, portable rotary drilling power source. The gasoline engine powered drill is adaptable to a variety of augering and jet drilling methods.

Aside from the one or two man hand-held engines, the same units may be mounted on a sliding track or suspended in a rope harness from the apex of a tripod (Figures 18 and 19). Both track mounted and suspended versions can

Figure 15

Early Rotary Table with
Vertical Poles and Rod Clamp

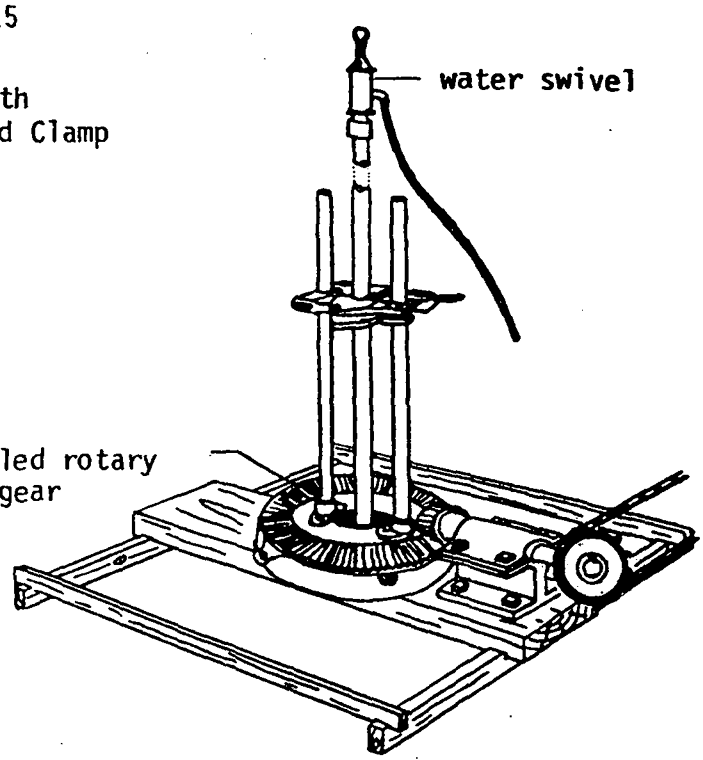
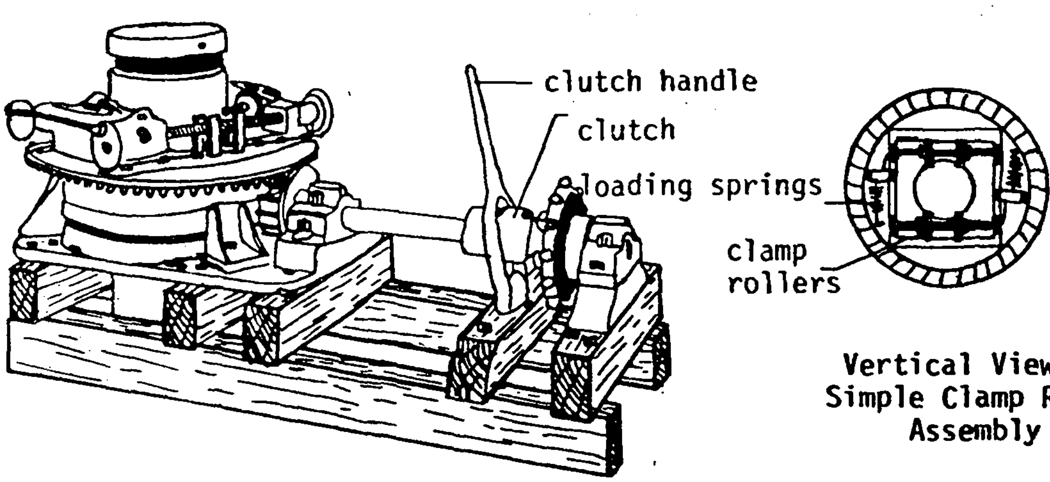


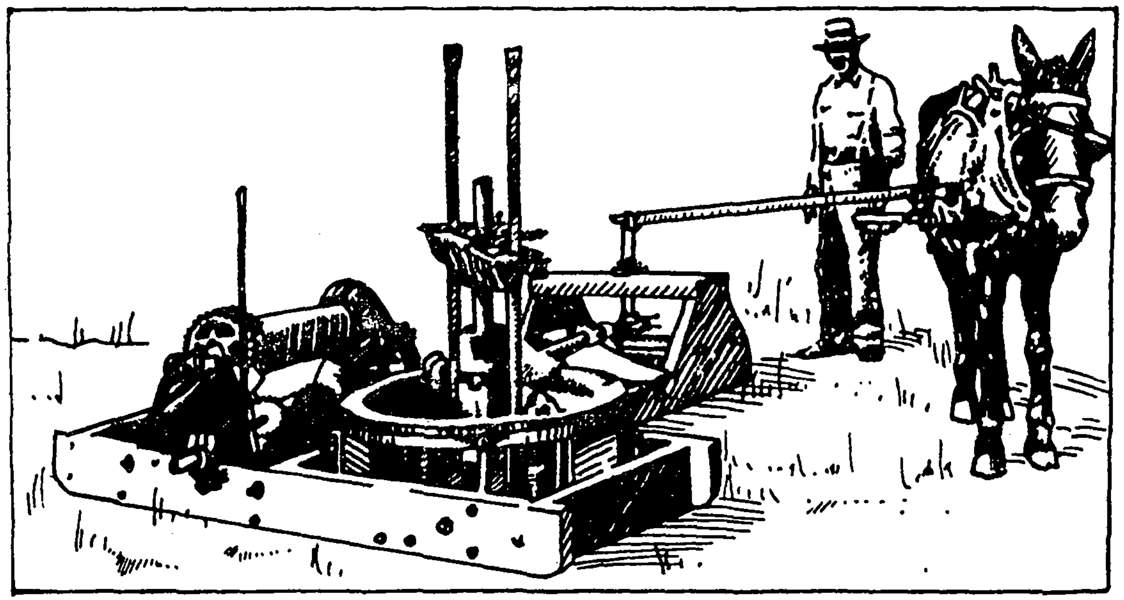
Figure 16

Rotary Table Equipped with Clamp Rollers



Vertical View of a
Simple Clamp Roller
Assembly

Figure 17
Animal Powered Rotary Table



Mule-power supplies the rotation for this rotary table. A drive shaft and an arrangement of gears transfer power from the turnstile to the rotary table. The drilling rate is controlled by bit weight, rotary gear ratio, and the speed or pace at which the turnstile operates.

reduce manual labor requirements and increase well drilling productivity by allowing more uniform and controlled drill bit cutting rates than is possible with a hand-held engine.

The cost for an individual one or two man hand-held rotary engine ranges from $200 for the Hydra-Drill (M-16) to as much as $500 (M-9, 30 and 35).

Hydraulic Motors

Hydraulic motors are often utilized as a rotary drilling power source. In this application, a high torque hydraulic motor is mounted on a sliding track. High pressure hydraulic fluid which operates the motor is supplied through a hydraulic pump driven by a twenty horsepower or higher gasoline or diesel engine (Figure 20). Hydraulic powered drilling equipment is relatively easy to maintain. The use of hydraulic lines and controls eliminates many of the drive shafts, open gears, chains, clutches and bearings which can create both maintenance problems and dangerous working conditions.

Very simple hydraulically operated drilling rigs are currently manufactured by the Southern Iowa Manufacturing Co. (M-36). The cost of a simple hydraulic rig ranges upwards from $6,600. A full set of continuous flight augers, drill rods, bits, drive hammer and assemblies, water pump and miscellaneous tools can increase the cost of a small, fully equipped hydraulic rig to $10,000 or more.

Rotary Kelly Bars

The larger and often more powerful rotary drilling rigs use a stationary drive engine and movable kelly bar to rotate the drilling rods. Most kelly bars are either square or hexagonal, and slide into a similarly shaped opening in a rotary table or gear box. The angular sides of the kelly and its matching drive gear permit much higher drilling torques than is possible with a simple rotary table.

Two types of kelly bars are in common use. The first is a solid steel kelly bar with a square cross section, to which drilling tools attach at its lower end. The second is the hexagonal, hollow shaft kelly bar which works similarly to a drill chuck (Figure 21). Unlike the solid shaft kelly bar which must be uncoupled each time a drill rod is advanced, the hollow shaft kelly bar allows considerable lengths of drill rod to be fed through the kelly in one continuous operation. This greatly improves drilling efficiency and precision. Equipment of this nature is relatively expensive ($15,000-$40,000) and is used almost exclusively for mineral exploration and diamond core drilling.

Figure 18

Rotary Engine Mounted on a Sliding Track

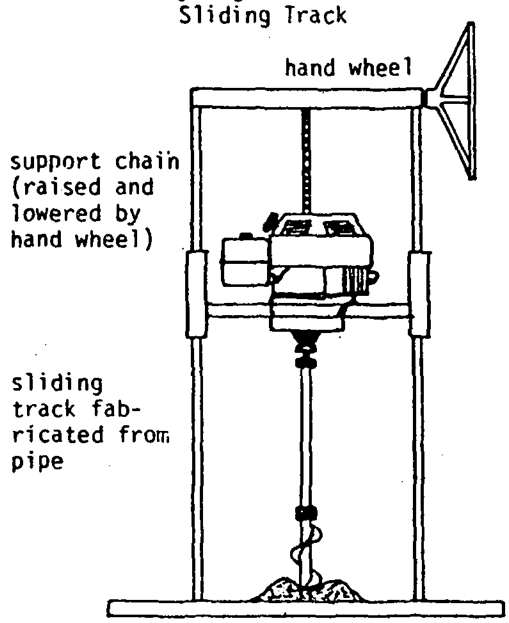


Figure 19

Rotary Engine Suspended from a Rope Sling

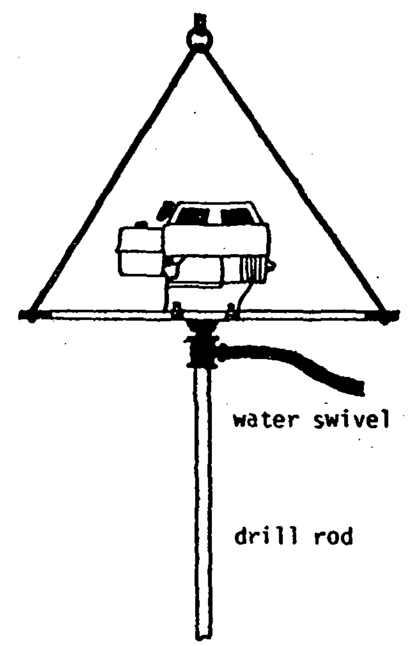


Figure 20

Schematic of a Hydraulic Rotary Drill

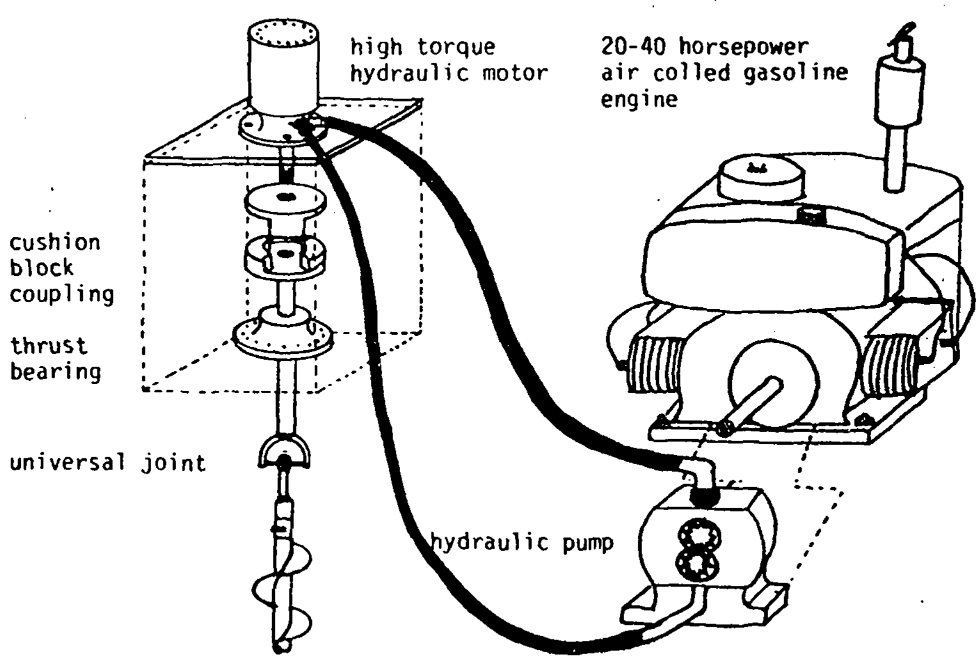
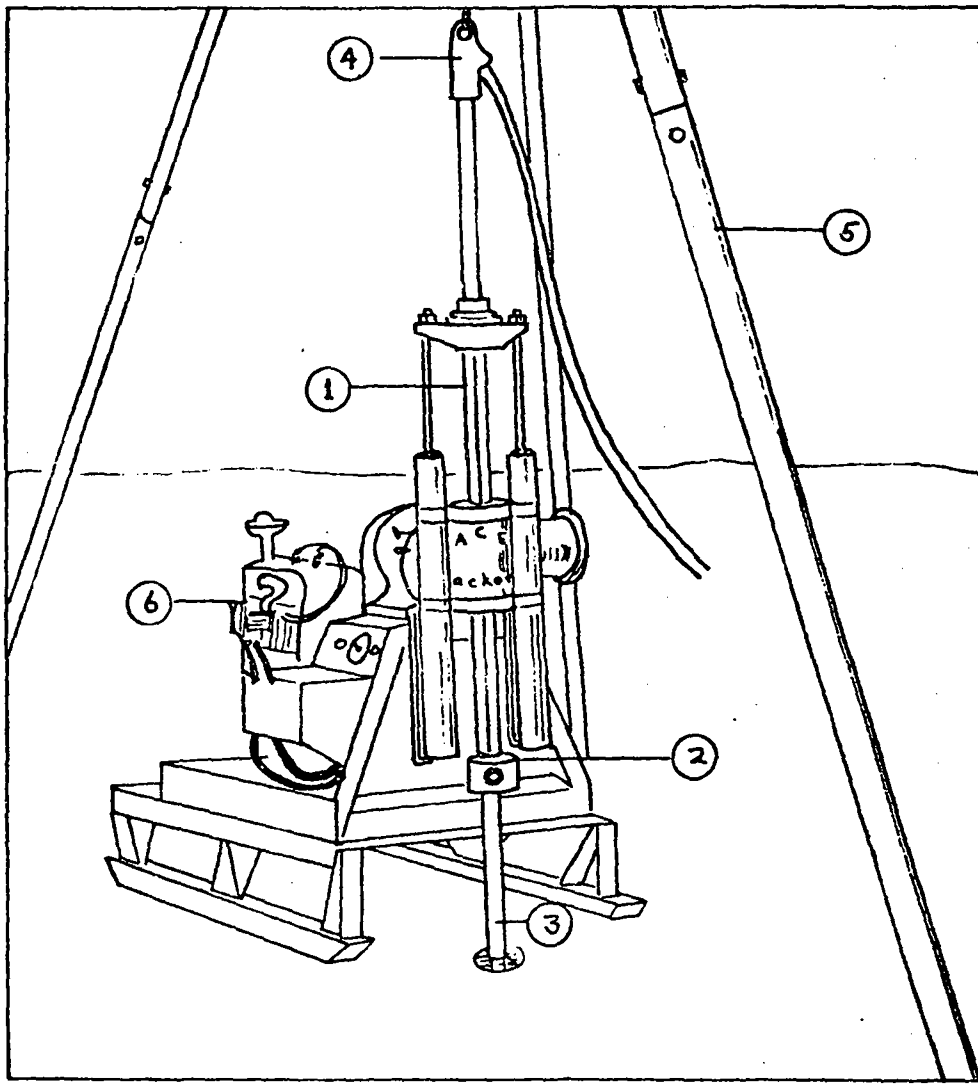


Figure 21

Small Portable Rotary Drilling Rig with Hollow Shaft Kelly Bar



1) hollow shaft kelly bar
2) drill chuck
3) drill rod
4) water swivel and water supply hose for wash boring
5) collapsabile aluminum tripod
6) 15 horsepower gasoline engine

Source: Acker Drill Co., Inc. (M-9)

2.3 Percussion Drilling Rigs and Equipment

2.3.1 Dry Bucket Drilling Rig

Equipment and Method

The dry bucket method is a simple and expedient method of drilling small 2 to 4 inch (5-10 centimeter) diameter wells. The basic components of a typical dry bucket rig or drilling kit include a tripod, rope, pulley, and a dry bucket (Figure 22). Whenever the well must be excavated through moist or wet soil, additional tools such as a temporary casing, sand bailer, or an auger are used.

In dry bucket drilling, the drill hole is advanced by successively lifting and dropping the dry bucket. Each impact forces additional soil upwards inside the bucket. As additional soil accumulates inside the bucket, penetration decreases. When this occurs, the bucket is drawn to the surface and emptied by tapping its side with a hammer or piece of iron. The drilling procedure continues until damp soil no longer adheres inside the bucket. At this point a temporary casing and a sand bailer or auger may be used to advance the well below water table.

Geological Applications

According to an account by J. Brelsford in the VITA Using Water Resources manual (33), the dry bucket method is best suited to small 2 to 4 inch (5-10 centimeter) diameter wells. Soil conditions should be dry and free of rocks. Under the above conditions, a two man crew operating a dry bucket rig (in northern Florida) drilled to a depth of 64 feet (19.5 meters) in less than 3 hours. Since then, 30 such wells have been drilled with equal success.

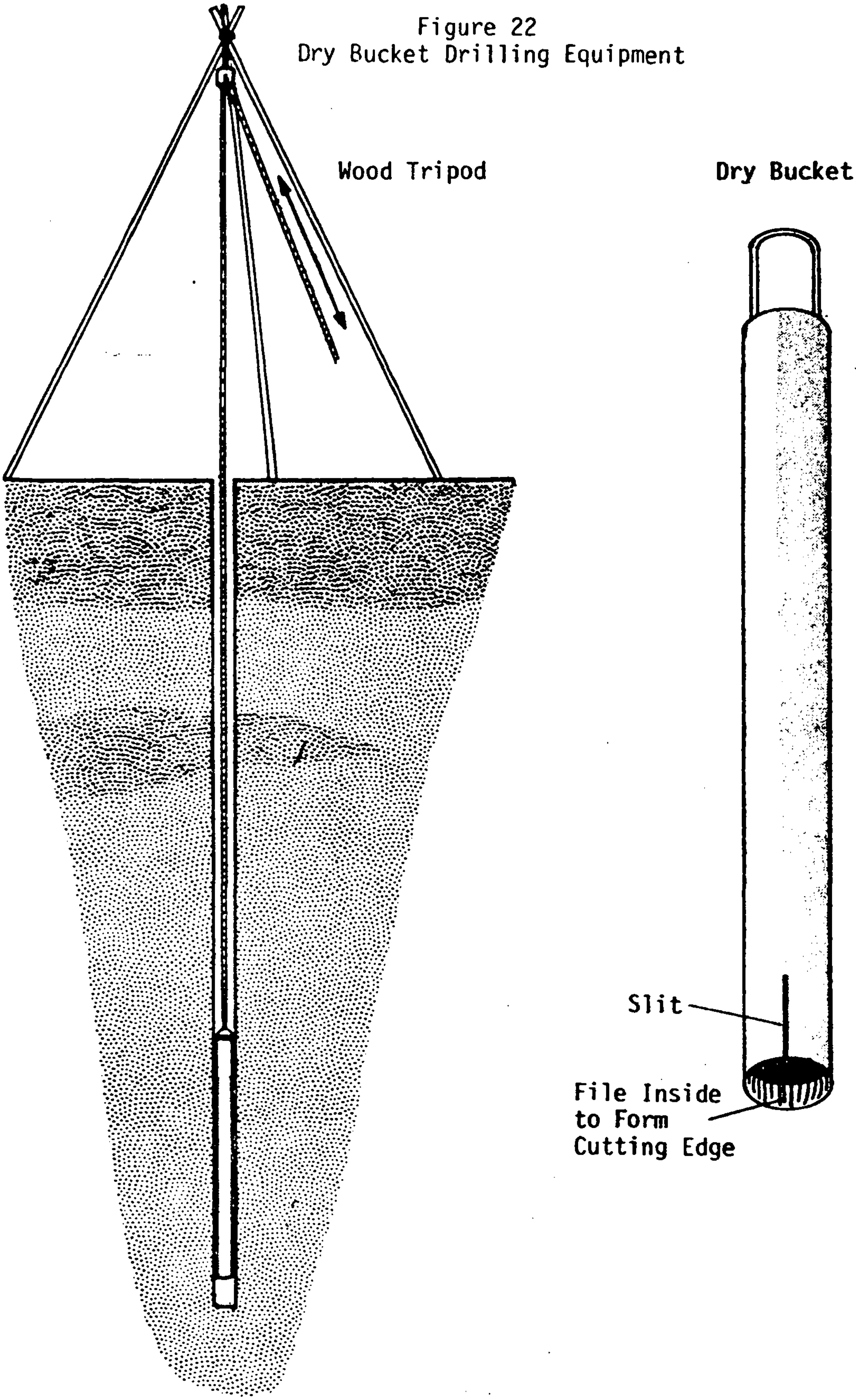
Labor Requirements

Shallow dry bucket rigs operate with a drilling crew of two to four men. Normal operation requires only two men at a time, with crews alternating periodically to avoid fatigue. Whenever a temporary casing is utilized, all four men may be required to manipulate and sink the casing. One member of the crew must have knowledge of appropriate drilling techniques while the remaining crew may consist of locally available unskilled labor.

Fabrication Skills

Dry bucket rig construction can be accomplished with a minimum of metalworking tools and skills. Principal

Figure 22
Dry Bucket Drilling Equipment



tools used in its construction are a hacksaw, file, and metal drill. The small size and relatively light working loads make low-cost tripod derricks (constructed from wood or bamboo), particularly adaptable to dry bucket drilling.

Cost of Equipment

Material and labor costs to fabricate and maintain a dry bucket drilling rig need not exceed the range of $100 to $200. As with other systems, the type of tripod used will influence the total rig cost, adding as much as $500 to the final cost.

2.3.2 Bail-Down Drilling Rig

Equipment and Method

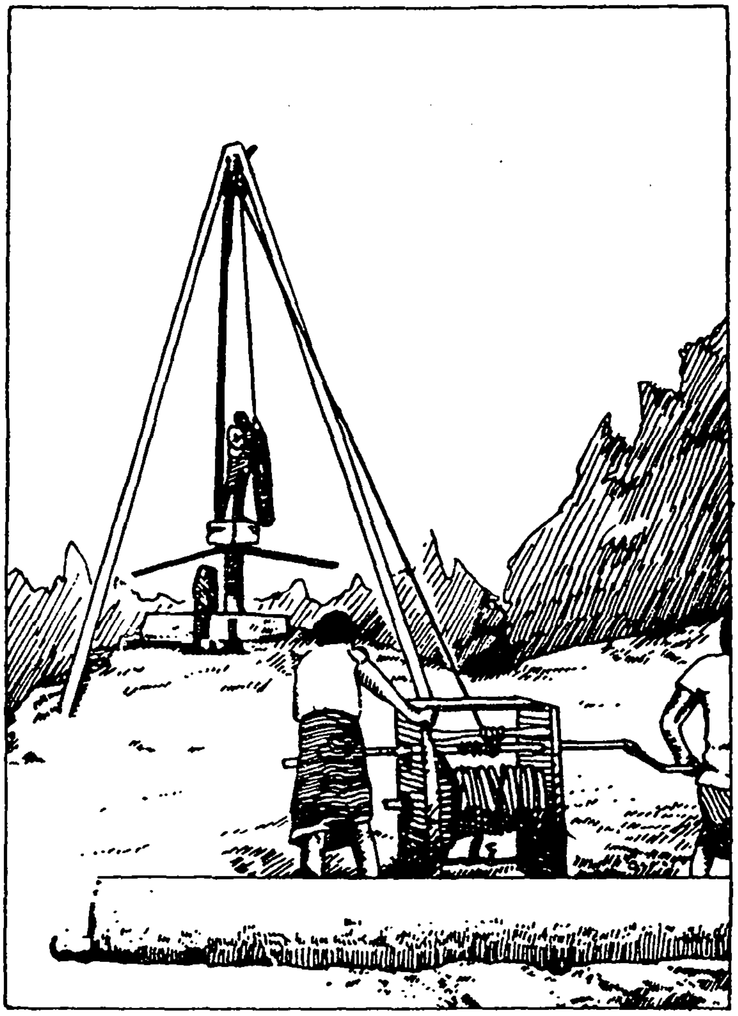
Bail-down drilling is very similar to dry bucket drilling. The principle difference is that the casing is filled with water, and a wet bailer is used to excavate the bore hole. Bail-down drilling involves the following basic procedure: stand the casing on end, add 2 to 3 feet (0.5-1 meters) of water to the casing, and repeatedly raise and drop a bailer to excavate and suspend soil in the drilling fluid (water). As the bailer fills with the muddy solution, it is hoisted to the surface and emptied. Additional fresh water is then added to the casing and the processes is repeated (Figure 23).

As the drill hole advances, a cavity is created by bailing soil from beneath the casing. This allows the casing to sink and to simultaneously case off all soil layers. The bail-down rig's unique ability to continually case a drill hole permits the construction of large diameter 10 inch (25.4 centimeter) wells in conditions where caving soil, flowing sand, or highly permeable formations would make alternate drilling methods difficult, if not impossible.

A wet bailer may be any one of three basic types: the flap valve bailer, the dart value bailer and the combination dart valve and sand pump bailer (Figure 25). All three bailers can be produced locally from sections of well casing and scrap metal (material for the flap valve or the plunger in a sand pump bailer is cut from a discarded tire innertube). Of the three types of bailers, the flap valve is best suited for bail-down drilling, the dart bailer for removing coarse cuttings from a percussion bit drill hole, and the combination dart valve and sand pump for bailing

Figure 23

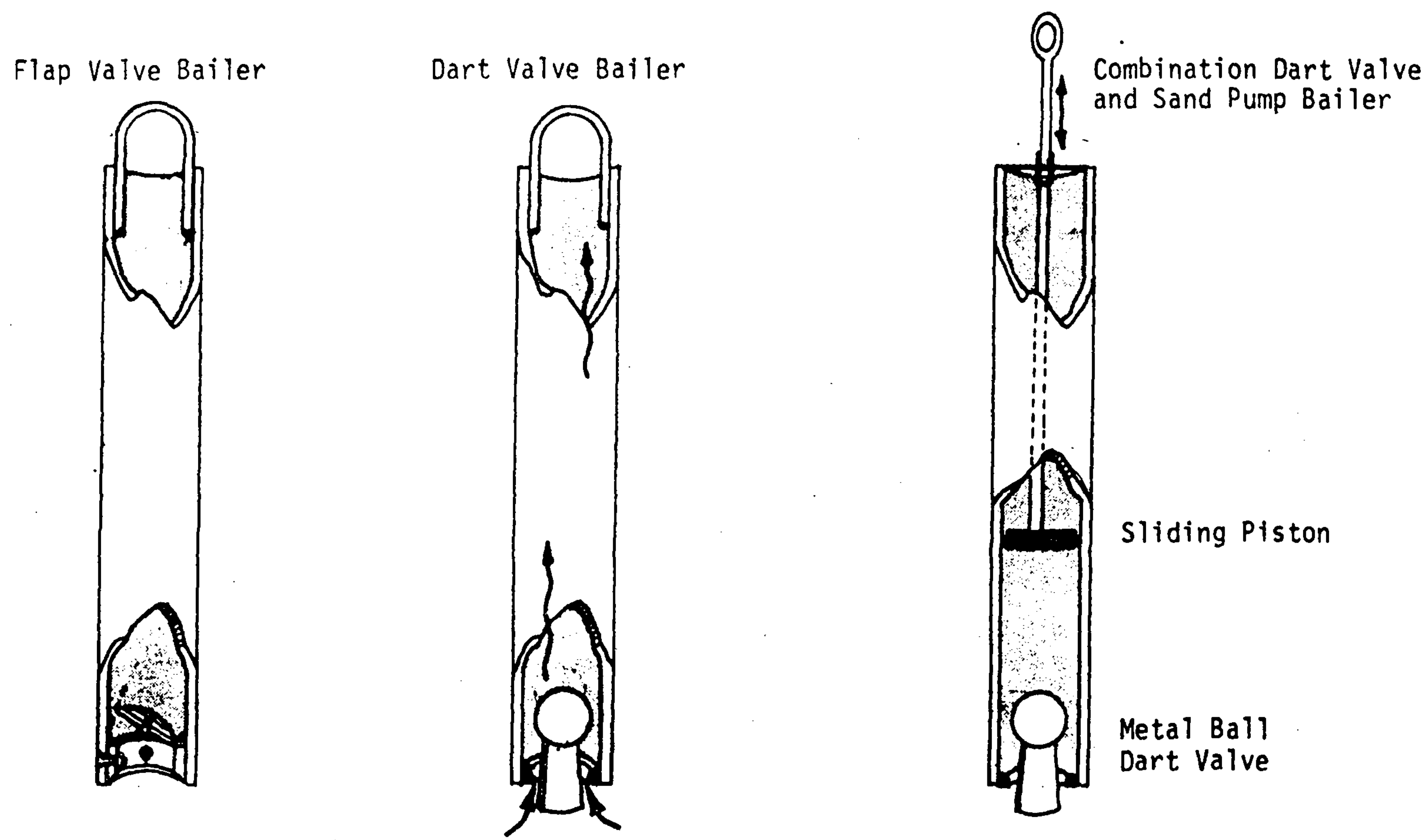
Bail-Down Drilling using a Hand Winch



Large diameter wells,such as this one, require the use of casing weights and chain tongs to help advance the casing.

Figure 24

Locally Fabricated Wet Bailers



large quantities of sand which may rapidly settle to the bottom of a well.

The use of bailers is not limited to bail-down drilling. Any one of these three bailers is a useful addition to any drilling procedure.

Bail-down rigs are capable of completing large diameter wells to depths up to 200 feet (61 m). In drilling deep wells, sections of casing are added as the well depth increases. To facilitate sinking the casing, sandbags and concrete or metal weights are suspended from casing clamps while the entire casing assembly is rotated with chain tongs.

Wells drilled by this method in the Dinajpur region of Bangladesh and in West Pakistan (6) utilized a strong reinforced tripod and a two man hand-powered winch. The reciprocating motion necessary to drill and to draw the muddy slurry into the bailer is supplied by a team of men jumping onto a taut bailer winch cable. When the desired well depth is reached a well screen and riser pipe are installed. Then, using screw jacks and a casing clamp, the temporary casing is slowly removed from the hole. At this time a mixture of fine gravel and coarse sand is tremied into the annular space between the well screen and the bottom of the casing. The end result is a high efficiency, gravel packed well suitable for large scale irrigation usage.

Geological Applications

The bail-down drilling method is best suited for large diameter wells in sandy formations. Drilling by this method is considerably slower in hard clay and becomes impossible when rocks or boulders are encountered.

This method was used (in the Dinajpur region) to successfully complete four 10 inch (25.4 centimeter) diameter wells. Although this method allowed the drilling crew to penetrate troublesome caving formations, the drilling rate was extremely slow, requiring an average of 4 to 6 weeks to complete a 150 foot (45 meter) well.

Labor Requirements

The bail-down process produces numerous jobs for unskilled individuals. For example, operation of the Dinajpur rig required a crew of eight unskilled men, a field supervisor, and a score of local individuals to carry water for the bail-down procedure.

Fabrication Skills

All components except the hand winch and screw jacks were produced by a local blacksmith. The hand winch and screw jacks were purchased or fabricated in a machine shop. The drilling rig and equipment proved to be highly reliable, requiring a minimum of on-site repair.

Cost of Equipment

Total equipment and fabrication costs for the bail-down rig are not available. However, their total value can be approximated in the range of $500 to $800. Although the initial equipment and fabrication costs are quite low, the cost per foot of drilling is extremely high in comparison to 10 inch diameter wells drilled by alternate methods. On the other hand, Kenneth Brown (6) reported that smaller, 4 to 8 inch (10-20 centimeter) diameter wells bailed down during the mid 1960's were more cost-effective than comparable wells drilled by motorized equipment. Therefore, in areas where labor costs are low, the small diameter 4 to 8 inch (10-20 centimeter) bail-down drilling rig may economically compete with sophisticated, mechanized drilling equipment.

2.3.3 Cable Tool Drilling

Equipment and Method

Cable tool drilling consists of repeatedly raising and dropping a chisel faced bit; this breaks and pulverizes material producing a slurry of water and cuttings in the borehole. Periodically the drill bit is raised to the surface and the slurry removed with a wet bailer. After bailing, additional water is added to the borehole and drilling is resumed. With manual methods, a vertical reciprocating motion is imparted to the drill bit through a simple tripod and pulley arrangement operated by four to six men (Figure 10b). Alternate methods of applying the vertical motion include the use of a cathead (Figures 11, 12, and 13) or through a walking beam arrangement (pictured in Figures 40 and 41 of the motorized jetting percussion drilling rigs). In all of the above cases, the basic tools required are a simple tripod capable of supporting a 40 to 80 kg. drill bit, a wet bailer, and a steel cable (rope may be used for percussion drilling but wears out quickly due to abrasion).

Typical drill bits may be fabricated locally from sections of steel bars, pipes, structural steel, an automotive axle, or a spud bar (Figure 25). Construction is relatively simple when compared to a full drill string used on modern high-capacity drilling rigs (Figure 26). Despite the large size of conventional bits, locally fabricated bits are just as effective when used with low-cost labor intensive drilling methods.

Geological Applications

The percussion method is among the most versatile of drilling methods. It is capable of drilling through almost any rock formation. The majority of manual percussion drill rigs create a 4 to 6 inch (10 to 15 centimeter) diameter well. Wells drilled by the manual rope-pull method for a UN Church World Services project in Peru (27) penetrated 100 to 120 feet (30 to 36 meters) of solid basalt to reach an underlying sandstone aquifer. Only three to four weeks were required to complete a well under these extremely difficult conditions. In unconsolidated sediments consisting of sand, gravel, silt, and clay, a manual percussion rig can complete a 150 foot (45 meter) deep well in as little as one to three days.

Labor Requirements

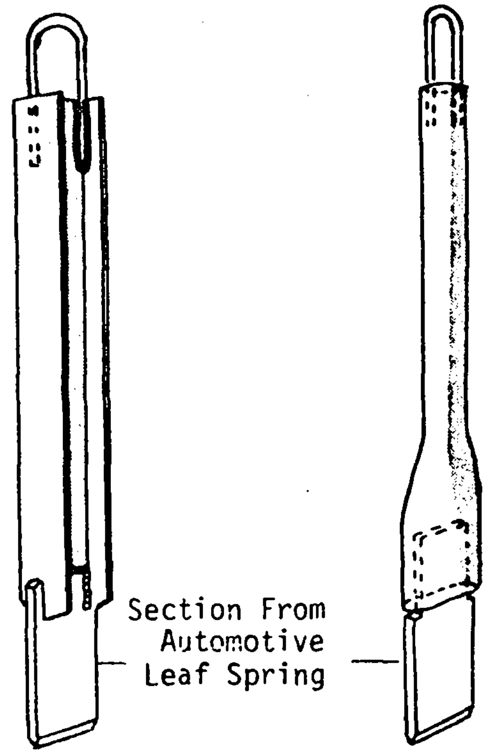
A minimum of five to seven men are required to transport, assemble and operate a manual percussion rig. Replacement crews may be used to help avoid worker fatigue. While a cathead or a walking beam to provide reciprocating motion may reduce the physical labor requirements, assembly and safe, efficient operation of the equipment still requires a crew of three to four men.

Fabrication Skills

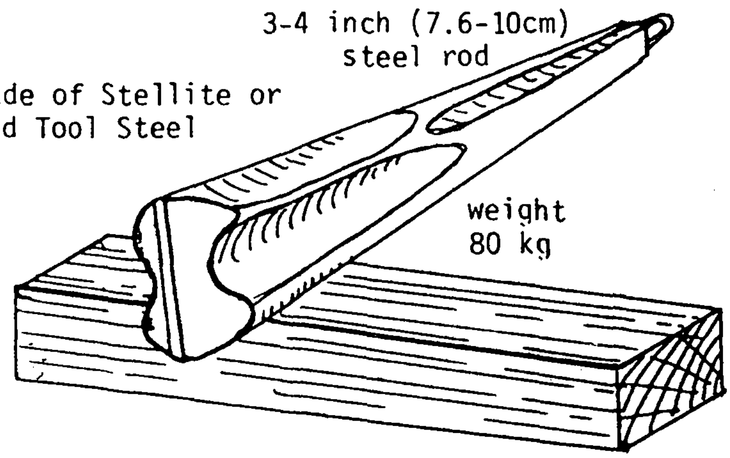
Blacksmithing represents the principal technical skill required for percussion drilling. Initial construction of a "quality" drill bit requires extensive reworking of a round steel bar to produce a fluted side which allows water to surge upwards around the bit. This flushing action removes cuttings from the bottom of the hole where they could cushion the bit's impact. In the field, a blacksmith's abilities and a forge are required to dress the bit and maintain a sharp cutting edge. This is especially true when drilling in hard rock, such as the Peruvian basalts reported by R. Chagnon (27). Approximately 70% of the total three to four weeks drilling time in that area was consumed in heating and dressing the bit.

Figure 25

Locally Fabricated Drill Bits



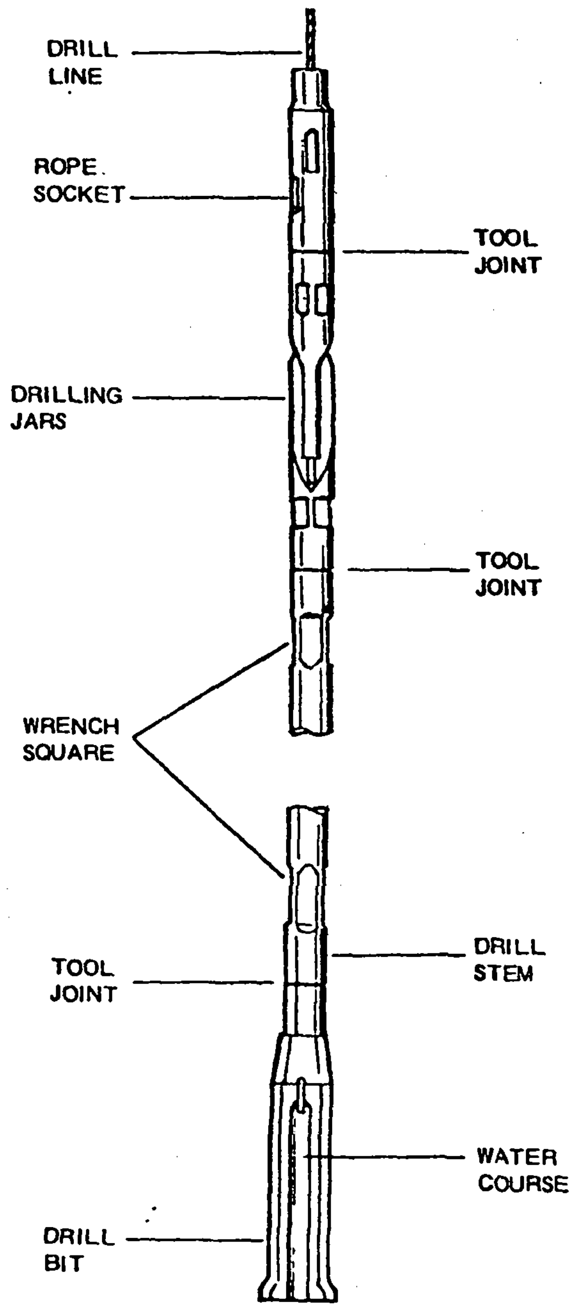
Simple drill bits constructed from structural steel, pipe, and scrap metal.



Locally Fabricated Bit for Drilling Hard Rock

Figure 26

Conventional Percussion Drill Bit and Assembly used on High Capacity Drilling Rigs



A highly recommended alternative to manually dressing a bit is to use an electric arc welder, a hard facing welding rod, and a hand grinder to resurface and build up the worn edges of a percussion bit.

Cost of Equipment

The percussion method is very versatile; it may even be utilized to penetrate hard rock formations which are impervious to other drilling methods. The design and the fabrication of a percussion bit (Figure 25), is relatively simple and should require no more than $150 in materials and labor. For these reasons, a percussion bit is useful in most drilling rigs and tripod designs. Respective costs for simple percussion rigs range from approximately $300 for a tripod, wet bailers, and rope or cable,; to as much as $2,000 for a reinforced tripod and simple motorized cathead or walking beam engine.

2.3.4 Manual "Reverse Circulation" Percussion Drilling (Sludger)

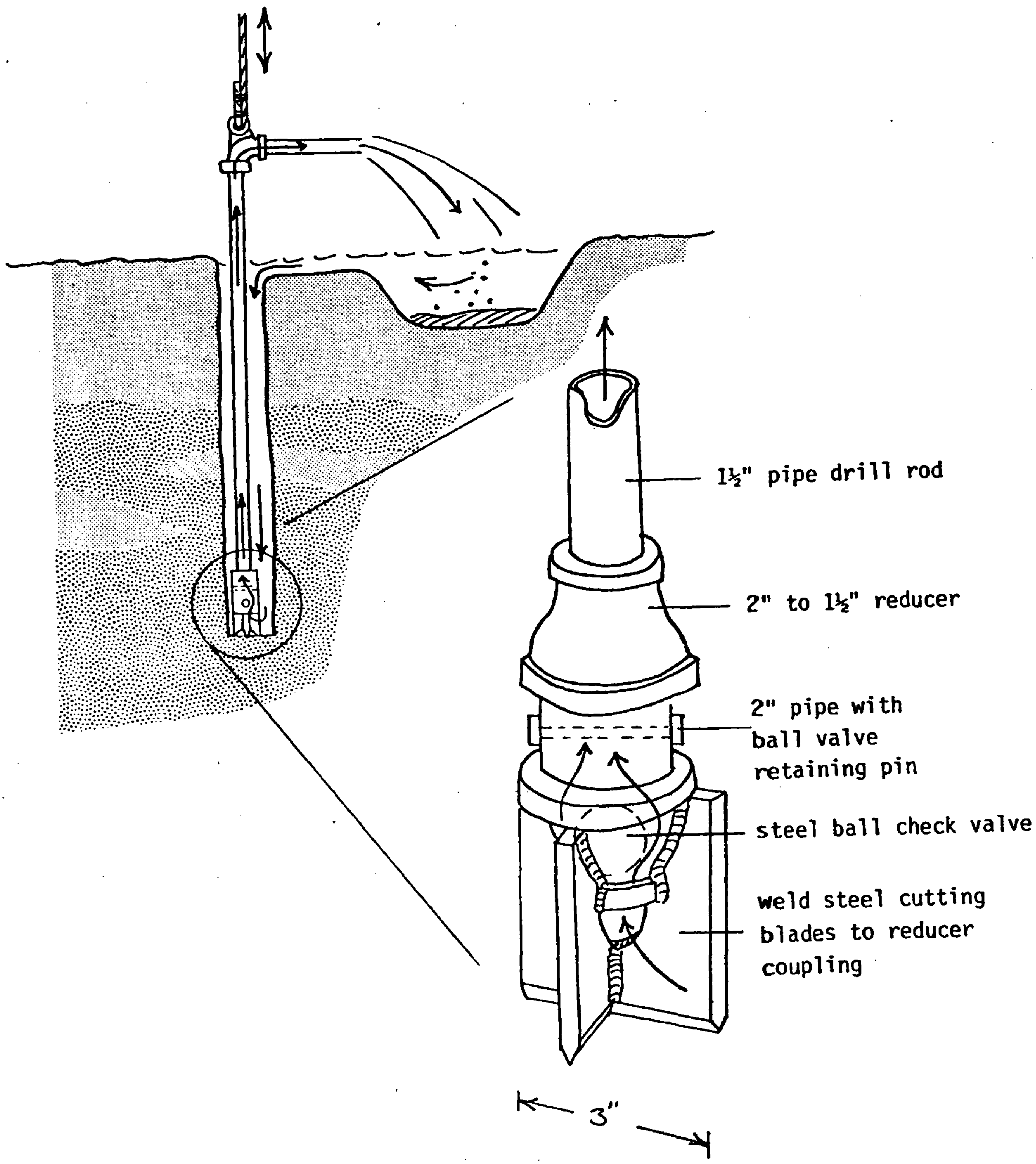
Equipment and Method

The reverse circulation drilling apparatus utilizes a one-way valve contained within the drill rods. As the rods are successively raised and dropped this valve produces a pumping action similar to that of a hand pitcher pump. Downward inertia of the drill rods allows the valve to open so that water laden with mud and drill cuttings can enter the rods. As the rods are raised, the valve closes, retaining the accumulated drilling fluid. Repeated reciprocating motion of the rods creates a continuous upward flow of mud-laden water inside the drill rods. This water then flows through a hose to a settling pit where the cuttings accumulate. A trench connecting the settling pit and the well allows water to circulate back to the well and the process repeats itself (Figure 27).

The reverse circulation technique is widely used throughout Asia (1, 12, and 19). Small diameter, shallow wells of 20 to 30 feet (6 to 9 m) in depth may be drilled by directly lifting and dropping the drill rods without the aid of a tripod or scaffold. When drilling in this manner, drill rods are added in 5 foot (1.5 meter) sections so as to minimize the weight and height of the drill rod assembly. Greater drilling depths are possible when the drill string is attached to a lever or tripod mechanism, as in Figures 10 a and b.

Figure 27

Reverse Circulation Percussion Drilling (Sludger Method)



A wide variety of materials and techniques are possible with the sludger method. When steel pipe and fittings such as those illustrated in Figure 27 are unavailable, a section of bamboo pipe may be used. The one-way valve action can also be supplied without need for outside materials. To do this, a drilling helper is positioned on an adjacent scaffold, then, using the palm of his hand as a one-way valve, he seals the top of the rods on the upstroke and removes his hand on the downstroke. This requires skill, as well as a certain sense of rhythm, but has proven highly successful when equipment and materials are limited. The principal complaint concerning this method is that everyone becomes soaked with slippery drilling mud. This problem can be significantly reduced if a section of hose or pipe is attached to the top of the drill rods directing the mud-laden drilling fluid away from the workers.

Geological Applications

The sludger method works well in alluvial deposits consisting of sand, silt, and clay, but it cannot contend with gravel, hard pan, or rocks. Typical well diameters are usually in the 2 to 4 inch (5 to 10 centimeter) range, but they may be as large as 6 inches (15 cm) in diameter. This method has proven highly successful in areas where water lies at depths of 280 feet (80 meters) or less. Average well depths of approximately 50 feet (20 meters) are easily attained by the sludger method in only four to nine hours of operation.

Labor Requirements

A crew of four to six unskilled workers can erect a scaffold (or platform) for the "valve" man and operate all equipment involved. An individual experienced in sludger drilling techniques is needed to identify drill cuttings and water bearing zones.

Fabrication Skills

Skills required for basic rig fabrication are minimal. All components are made from locally available timber or bamboo, and can be constructed in less than half a day. Drill bits with check valves can be easily constructed from scrap sections of pipe as in Figure 27.

Cost of Equipment

The major cost involved in simple sludger equipment is for the purchase of pipe used as a drill rod; this cost should not exceed $125.

2.3.5 Rig for Driven Wells

Equipment and Method

Whenever the water table lies at shallow depths (23 feet or 7 meters), a well screen equipped with a drive point may be driven through the overlying soil and into the water bearing formation. This method employs the reciprocating motion of a drive hammer. Three basic types of drive hammers are in common use: (1) the hand driver, consisting of a sliding weight and an attached pipe which fits over the riser pipe (Figure 28a); (2) an internal driving bar which strikes directly upon the driving point (Figure 28b); or (3) a sliding weight and drive stem or guide which attaches to the uppermost riser pipe coupling (Figure 29).

The basic equipment required for a driving rig ranges from a 4 foot (1.2 meter) section of oversized pipe (used as a sliding hand driver) to more elaborate systems requiring a tripod, pulley, rope, and driving bar or drive stem and sliding hammer. The driving rig will also require two or three pipe wrenches, and a shallow well hand pump to develop and remove soil debris from the well screen.

Geological Applications

Driven wells are generally one of the most efficient methods of drilling whenever the water table is within 23 feet (7 meters) of the surface and the soil consists principally of sand with minor quantities of silt and clay. Under ideal soil conditions a small diameter well point may be driven to a depth of 25 feet (7.6 meters) in 15 minutes. In heavy soils such as stiff clay or soils which contain numerous boulders, drilling with an auger or percussion bit is faster than driving with a well point.

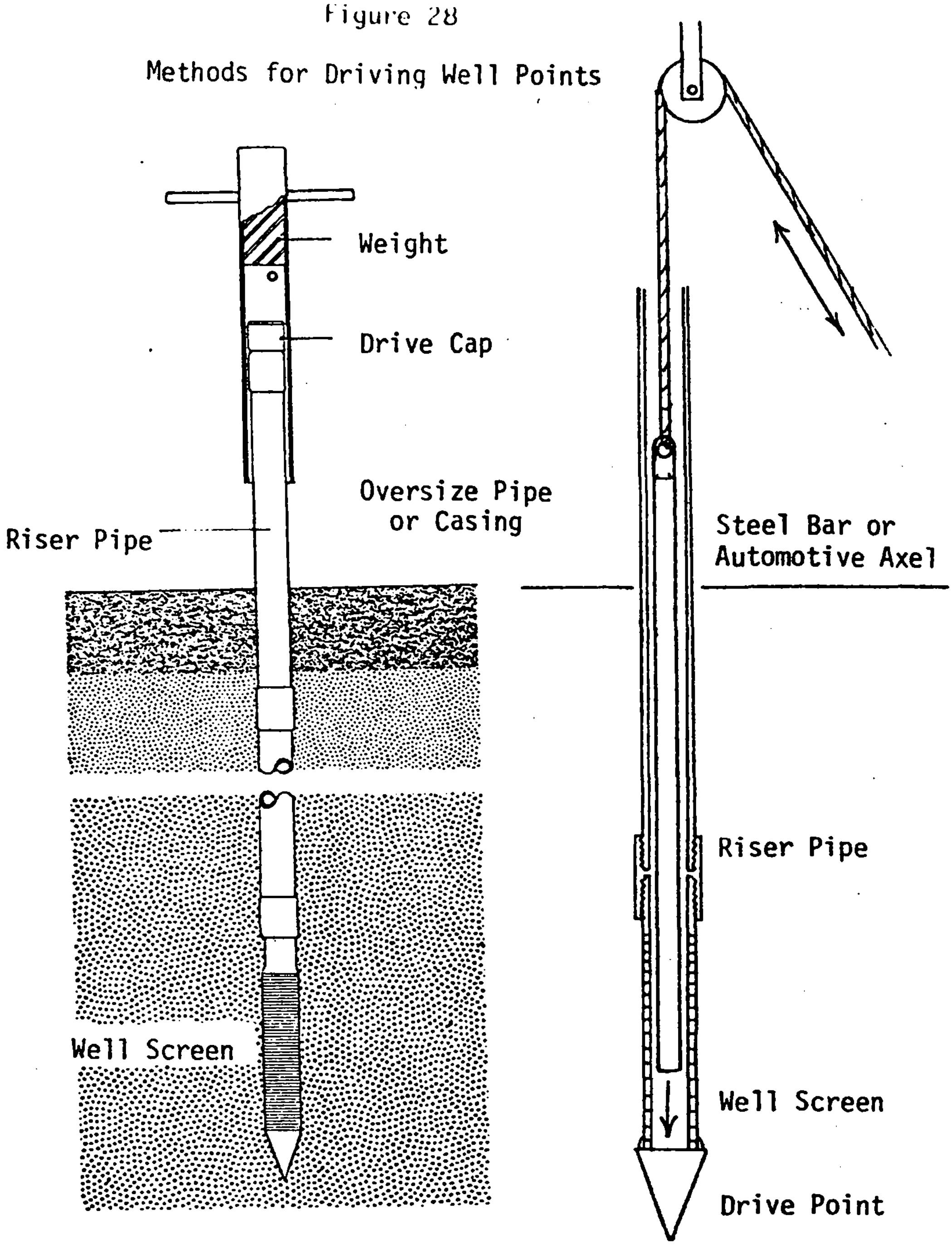
Hand driven well points of 1 1/4 to 2 inches (3 to 5 centimeters) in diameter can be driven up to 25 feet (7.6 meters). If heavy 100-300 lb. (45 to 135 kg) drive hammer assemblies are used, 4 inch (10 centimeters) well points and casings can be driven to depths of 33 to 49 feet (10 to 15 meters).

Labor Requirements

Given the proper soil and water table conditions small diameter driven wells may be completed by one to two unskilled men. Large diameter driven wells require a heavy-duty drive hammer and a tripod assembly. The crew necessary for operation of this equipment consists of six men for manual methods and two or three men for a motorized cathead system.

Figure 28

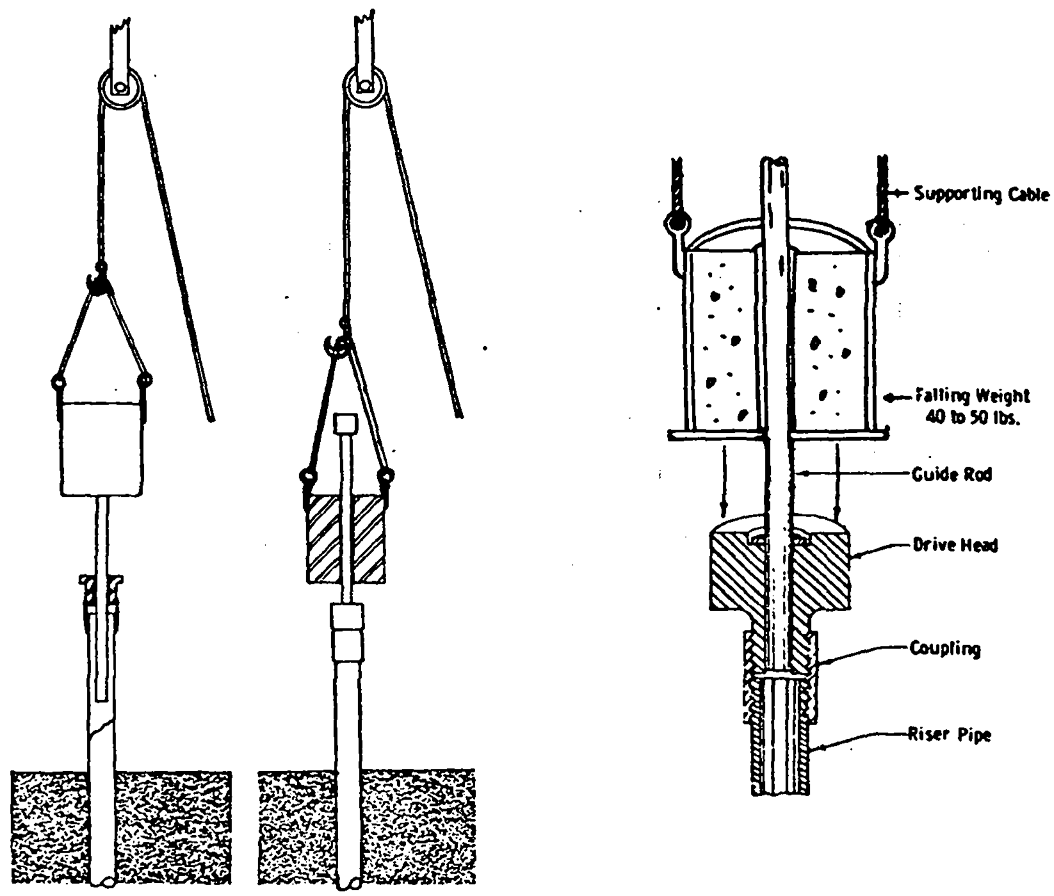
Methods for Driving Well Points



(a) Hand Driver (b) Internal Rod Driver

Figure 29

Heavy Duty Sliding Hammer
and Drive Stem Assemblies



internal guide drive hammer

drive stem with sliding hammer

cross-section of sliding hammer and drive stem

These assemblies provide an effective means for driving both well screens and casings.

Fabrication Skills

All well point driving equipment can be constructed easily from locally available scrap pipe or steel bars and standard pipe fittings. The fabrication of simple drive hammers requires basic metal working and blacksmith abilities. Construction of heavy-duty drive hammers, which weigh in excess of 50 lbs. (22.5 kg), will require the aid of an electric arc welder or basic metal casting techniques.

Cost of Equipment

Excluding the initial cost of a well screen, drive point, and riser pipe, a locally constructed hand drive system which requires no tripod should cost a maximum of $20. Heavy-duty systems may cost $50 for the fabrication of both drive hammer and drive stem, plus an additional $500 depending on the type of tripod used. If a driving rig incorporates a motorized cathead the system price could increase by another $800. A hub driven cathead (Figure 13) would cost considerably less but would require a support vehicle.

2.4 Rotary Drilling Rigs and Equipment

2.4.1 Hand Auger Rig

Equipment and Method

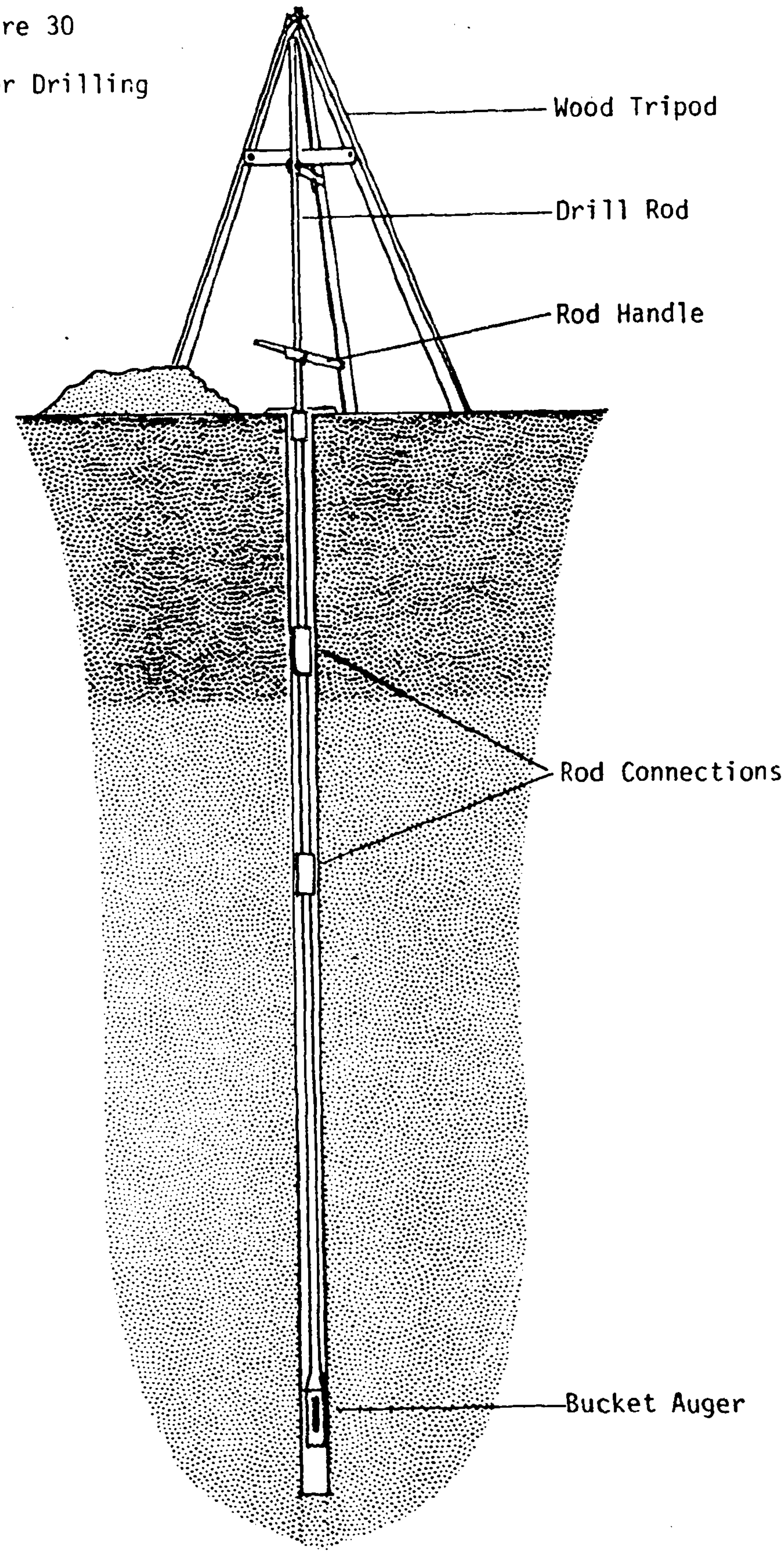
The hand auger method of drilling is one of the oldest and one of the most basic forms of low-cost labor intensive well drilling. In hand augering the drilling action is applied by manually rotating a cutting blade or auger (Figure 30). As drilling progresses, the auger fills with soil and must be periodically lifted to the surface and emptied. Drilling by this method is fairly rapid for the first 20 feet (6 m). Thereafter, the number of drill rod sections which must be coupled and uncoupled each time the auger is brought to the surface add considerably to the drilling time.

The basic components of a hand auger rig are:

(1) support tripod
(2) drill rod, fork and auger handle
(3) auger
(4) rope and pulley
(5) sand bailer
(6) temporary casing - to case hole through caving soil
(7) drill bit - to break up hard soil and boulders

Figure 30

Hand Auger Drilling



The support tripod may use any of the designs discussed in the section on tripod derricks. However, most light duty hand auger drilling systems utilize an inexpensive wood or pipe tripod.

Drill rods are constructed from locally available 3/4 inch (2 centimeters) galvanized or black iron pipe. All connections between drill rods and augers are of box and pin type construction (Figure 31). Joining pins for the connections are made from either toggle bolts or from standard nut and bolt assemblies. Both pin systems have proven highly reliable.

To avoid dropping a disconnected section of drill rod down the borehole, a rod fork or auger fork is slid under a coupling to support and retain lower sections of the drill stem (Figure 32). This rod fork may be constructed from a 1/4 inch (6 millimeter) steel plate or from a notched hard-wood board. In either case the notch must be wide enough to slide around the drill rod but narrow enough to retain a coupling.

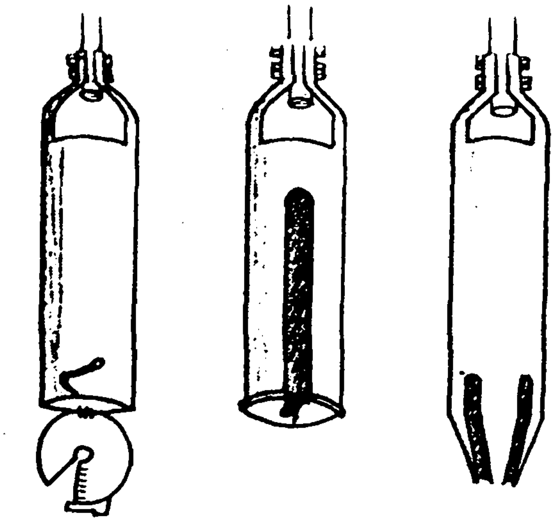
An auger handle is constructed by clamping two hardwood handle sections around the drill rod (Figure 14a). As the borehole advances, the bolts are loosened and the handle is relocated to a more convenient height.

Auger construction falls into two main catagories, those for use in cohesive soils and those for noncohesive soils. The cohesive soil augers (Figure 31 b), are designed for use in soils which adhere or stick together. These soils commonly contain a mixture of sand, silt, and clay. Augers designed for use in noncohesive soils (Figure 31a) are best suited to loose sand and gravel formations.

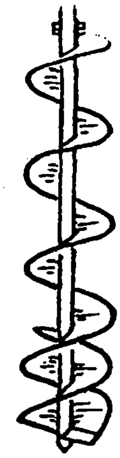
Each type of auger can be produced locally using discarded sections of casing, pipe, sheet metal, or perhaps the tubular section of an automobile drive shaft. Local soil types determine the type of construction used. In general, the best performance in soft cohesive soils can be obtained with an open blade or helical auger. Hard clay soils may be excavated with the bucket auger. In noncohesive soil, the tapered tube auger is most effective (Figure 31a).

In addition to a tripod, rope and pulley are also primary components of the drilling equipment. On a hand auger rig, a rope and pulley are often used to handle the drill rods when a long pull of 20 or more feet (6 meters) is necessary to raise the auger. This long pull saves time and eliminates the need for disconnecting numerous drill rods.

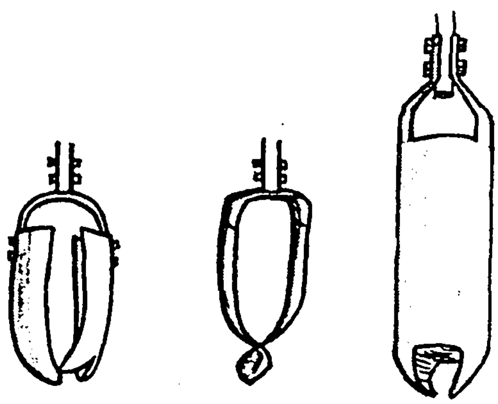
Figure 31



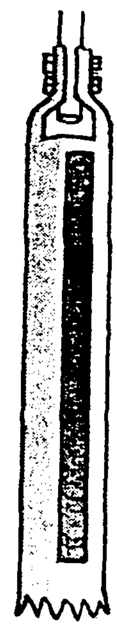
(a) Sand Augers for Non-Cohesive Soils



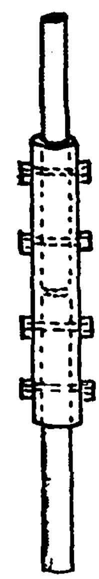
Helical Auger



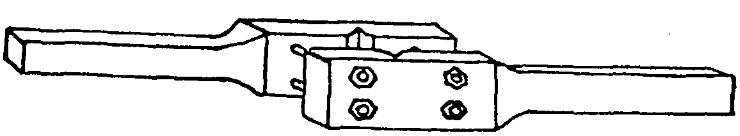
(b) Cohesive Soil Augers



Bucket Auger



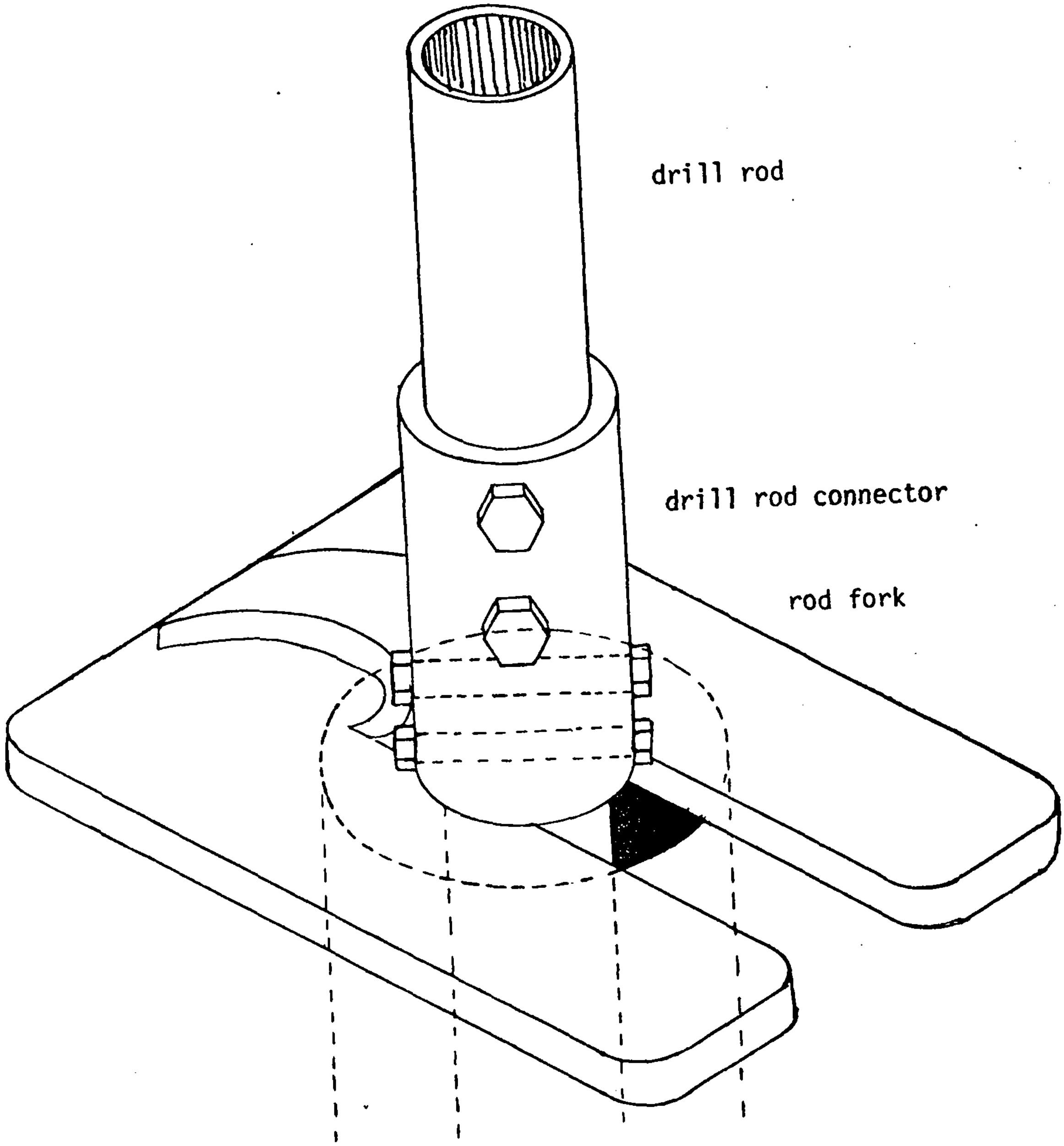
Typical Drill Rod Connection



Hard-Wood Rod Handle

Figure 32

Rod or Auger Fork Locally Fabricated from
a Section of ¼ inch (6mm) Steel Plate



When placed around a drill rod or auger, the fork acts as a support for the drilling tools. In this manner, rods and augers may be added or removed from the drill string with little danger of droping sections down the bore hole.

A rope and pulley are also necessary to handle other drilling equipment such as well casings and wet bailers and percussion bits. These accessories provide a useful means for continuing the well when water saturated or hard-pan formation are encountered.

The most frequently used wet bailer on a hand auger rig is the flap valve bailer, also used in bail-down drilling. A complete description of various bailers can be found under Bail-Down Drilling (Section 2.3.2).

A percussion drill bit is also commonly used in conjunction with hand auger equipment. Its ability to break up and loosen hard soil and boulders which cannot be excavated with a hand auger permits drilling under a wide variety of conditions. The design and construction of these locally fabricated bits is discussed in Cable Tool Drilling (section 2.3.3).

Geological Applications

Hand augered wells are particularly well adapted to alluvial deposits, consisting primarily of silt, clay, sand, and limited quantities of gravel. Maximum depths for hand augered wells range up to 400 feet (122 meters); however, normal hand augering is best suited to maximum depths ranging from 49 to 80 feet (15 to 25 meters). Hand auger wells of these depths were used for an extensive hydrological survey of specific community well sites in Tanzania (9). Other significant hand auger well projects include wells in the following locations: Western Pakistan (6), Vietnam (33), Sri Lanka, India (15), Togo and the Ivory Coast Region of Africa (1), and in Ecuador (16).

Labor Requirements

The operation of a hand auger rig requires a minimum crew of four to five men. One member of the crew must be trained in basic well drilling as well as development techniques. The remainder of the crew may be unskilled local labor. Under ideal conditions, inexperienced crews have drilled to depths of 49 feet (15 meters) in a single morning. However, greater drilling depths will require a considerably longer period due to the time and effort spent in removing and emptying the auger.

Fabrication Skills

All hand auger tools and equipment are easily produced using locally available sheet metal and pipe.

TABLE 2: TOGO BOREHOLE PROJECT

Equipment for one well rig

A. Drilling Tools

Qt.	Item	Dimensions	Materials
1	Earth Auger	1300 x 115 mm	black pipe 6 mm
1	Rock Hammer	1100x100 mm	solid steel bar round
2	Rock Hammers	1300x80 mm	solid steel round bar
1	Sand Bailer	1300x115 mm	black pipe 6 mm
1	Sand Bailer	1300x90 mm	black pipe 6 mm
5	Drill Stem	6000x42 mm	Galv. pipe 33x42 mm
1	Tripod	9000 mm	Galv. pipe 50x60 mm
4	Galv. pipe (casing)	6100x115 mm	Galv. pipe 10x115 mm
11	Pipe couplings	4" 102x115 mm	
1	Pipe clamp for 4" casing	515x70 mm	flat iron bar 70x10 mm
2	Sliding handles for drill stem	1000x100 mm	flat iron bar 100x8 mm and galv. pipe 33x42
1	Safety notched board	500x300 mm	Plank 50 mm
2	Platform boards	2000x300 mm	Plank 50 mm
2	Pulleys	25x90 mm	Steel
1	Vice with bench capacity	130 mm jaw width	150 mm steel
2	Rope	35000 x 16 mm	manila rope
1	Fishing tool	3 m long	20 mm rod

B. Small Tools and Other Equipment

Qt.	Item	Dimensions	Materials
2	Hydraulic jacks	6 to 8 ton cap.	
1	Spade		
1	Expanding double meter measure		
1	Water pump pliers	20 in.	
1	Pliers 6 in.		
10	Metric end wrenches	8 mm to 28 mm	
1	Adjustable wrench	12 in.	
1	Vice grip pliers	12 in.	
2	Chain tongs	4 in. cap.	
1	Trowel	8 in. (200 mm)	
1	Heavy Hammer 10 lbs.		
1	Light hammer 3 lbs.		
1	Magnet		
1	Pipe wrench	No. 813	
1	Pipe wrench	14 in.	
1	Oiler can	18 in.	
1	Screen box	600x800 mm	Metal screen 2 mm
1	Screen box	500x700 mm	Metal scren 5 mm
1	Screen box	500x800 mm	Metal screen 1 mm
1	Small measuring cord	50 m	
1	Tube plastic joint glue		
1	Can thread sealing compound		

Qt.	Item	Dimensions	Materials
1	Pipe vice	3 inch cap.	
1	Hack saw with 3 blades		
1	Wood saw		
1	Center punch		
1	Metal brush		
4	Steel files, flat, half round, round (2)		
1	Wood file		
2	Metal box with hasp	400x300x650 mm	Metal
2	Padlocks		
1	Screw driver		
1	Phillips screw driver		
1	Metal hand drill		
10	Steel bits	6 to 16 mm	
1	Wood brace		
3	Wood bits	11, 12, 14 mm	
1	Pr. tin cutters		
roll	Wire galv.	No. 10	
roll	Wire galv.	No. 15	
1	Cold Chisel	6 in.	
1	Pipe threader	1 to 2 in. cap.	
1	Rod threader	10 and 12 mm cap.	
1	Tool box with handles	300x500x80 mm inch wood	

Typical construction requires the use of basic metalworking and hand tools. When available, a blacksmith's forge, an oxygen-acetylene cutting torch, and an electric arc welding machine can reduce both the overall construction time and labor costs. These items are essential, and should be available to fabricate, maintain and repair equipment for any project in which several drilling crews are operating.

Costs of Equipment

Local materials and fabrication costs for a hand auger rig range from $125 to $1,700. Rigs in the $100 to $200 range generally incorporate inexpensive wood tripods and tool selection limited to a hand auger, several drill rods, an auger handle, sand bailer, rope and pulley, temporary casing and a limited assortment of small hand tools. Hand auger rigs that cost in the range of $700 to $1,700 are fully equipped to handle a wide variety of drilling conditions. In addition to the basic hand auger tools, these rigs usually incorporate a reinforced pipe tripod, a complete assortment of necessay hand tools and one to two support vehicles to transport equipment between drilling sites.

Table 2 adapted from the Togo Small Bore Well Program (1) lists the basic drilling tools, their dimensions, and material specifications, for a fully equipped rig. The cost of materials and fabrication for a tripod and basic tools was approximately $800. A complete assortment of hand tools adds another $900 for a total 1974 cost of $1,700 per rig. Operation and maintenance costs were relatively minor considering the size and adaptability of the rig. Actual on-site repairs plus shop maintenance averaged 42 cents per meter or roughly $6.30 per 15 meter (49 foot) well.

2.4.2 Jet Drilling

Equipment and Method

The jetting method of well construction utilizes the force of a high pressure stream of water to help loosen and wash material upward and out of the borehole. Water under pressure at 40-50 psi (2.8 to 3.5 kg/cm^2) is pumped downward inside the drill rods. The actual drilling action is accomplished by the combined chopping (or scraping) of a drill bit and the high pressure water jet which issues from ports surrounding the bit. Continuous circulation of the water suspends the drill cuttings and carries them out of the hole to a settling pit. The success of this method does not depend on bulky drilling equipment. The techniques are relatively simple and excellent results are obtainable entirely with hand tools.

Basic tools necessary for jet drilling are: (1) a manual or motorized pressure pump; (2) drill rod with standard pipe couplings; (3) a drill bit; (4) barrel or other source of supply water; and (5) a small assortment of pipe wrenches. These components and hand tools have proven extremely effective. 2 inch (5 centimeter) diameter wells as deep as 149 feet (45 meters) have been drilled by one man in as little as two days. This represents the maximum depth obtainable by manually handling a 3/4 inch (2 centimeters) drill rod pipe. In addition to the basic tools, jetting rigs for large diameter 4-10 inch (10 to 25 centimeters) wells incorporate a tripod or derrick to suspended the drill string and a water swivel to permit continuous rotation of the drill bit.

Drill bits used in jet drilling vary in their design and function. The four basic bit forms are the expansion bit, straight bit, side bit and the "Z" bit (Figure 33). The expansion bit has moveable blades which can collapse to fit inside a casing and then expand while drilling, thus cutting a hole of sufficient diameter for the casing to easily follow the bit. The straight jetting bit is used with a chopping action and is effective in weathered to moderately hard bedrock. When sharp, the straight bit can drill through boulders and limited quantities of hard bedrock. The side bit is specifically designed to trim boulders or hard zones of rock from the sides of a hole. This is essential when casing must advance through hard zones. The "Z" bit and a variation called the "T" bit are best suited for cohesive silts and clays.

Although these bits represent commercially manufactured items; basic jetting bits may be constructed by flattening the end of a pipe and drilling a water port hole on each leading bit face (Figure 34). This locally fabricated bit is highly effective and operates efficiently in unconsolidated formations.

Jet drilling does not require tremendous bit pull down forces and is therefore particularly well adapted to manually operated rotary equipment. Manual drive methods include the use of rod handles, chain tongs, and rotary tables. Motorized drive methods include an equally wide variety of systems (described in section 2.2.3).

Geological Applications

Jetting rigs are particularly well adapted to cohesive sandy soils. Under these conditions, drilling rates may be as high as 40 feet (12 meters) per hour. The

Figure 33
Common Bits for Jet Drilling

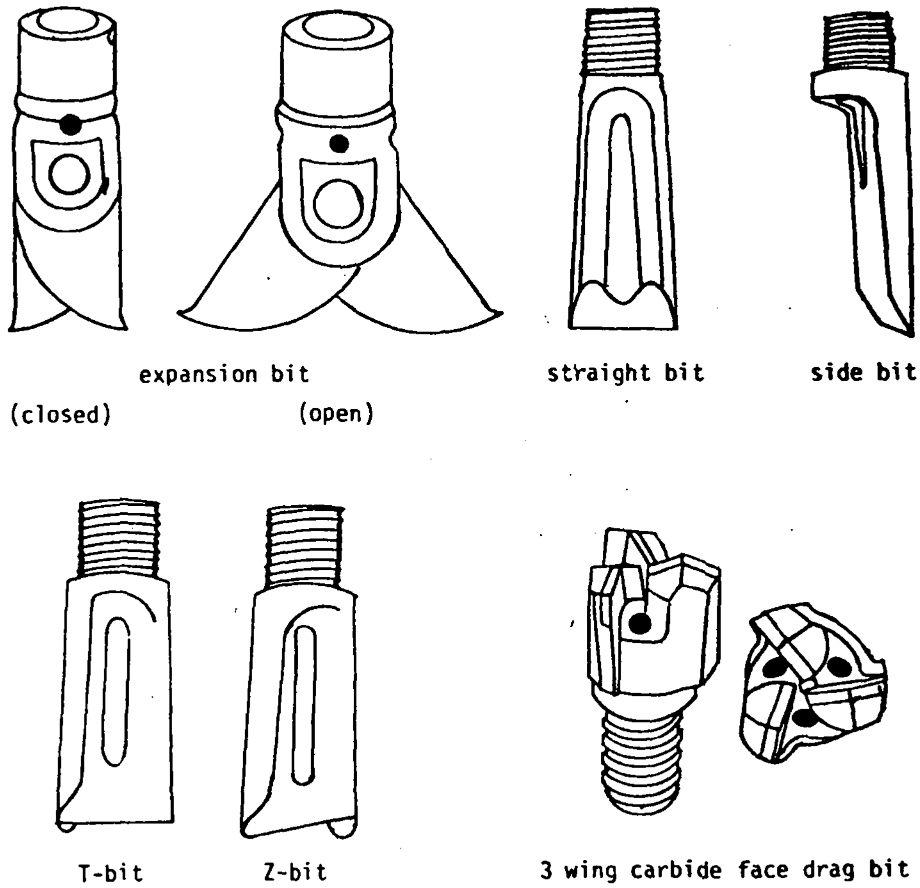
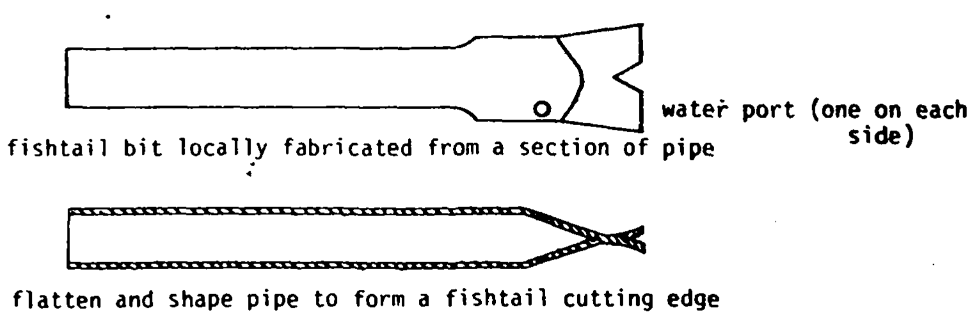


Figure 34
Locally Fabricated Jetting Bit



sharp bit and combined chopping and jetting action permit jet drilling in sandstone, limestone and weathered granite. When drilling in these materials well depths as great as 200 feet (60 meters) can be easily attained in one half to one fourth the amount of time required for other manual drilling methods.

A full description of every conceivable type of jetting rig is beyond the scope of this manual. However, the following subsections describe several types of manual and simple mechanical rotary jetting equipment which are locally manufacturable and have been proven lowcost labor intensive water development projects.

2.4.3 One or Two Man Jetting Rig

Equipment and Method

The one or two man jetting rig requires only the basic jetting tools. The rotary cutting motion is supplied by manually rotating the drill rods. Water pressure required to flush cuttings from the drill hole is supplied by a hand pump or by a 3 horsepower gasoline engine water pump. The jetting procedure is quick, simple, and when a settling pit is dug to receive and settle drill cuttings, the same water may be reused through the pumping system (Figure 35).

Geological Applications

The one or two man jetting rig is best suited to small diameter 2-3 inch (5-8 centimeter) wells. When equipped with a locally made cutting bit, the hand operated jetting rig can penetrate sand, clay, silt, fine gravel, and soft weathered rock formations to depths ranging from 50 to 150 feet (15 to 45 meters).

The method is particularly useful for constructing domestic wells and for developing temporary water supplies which are often required for operation of larger drilling rigs.

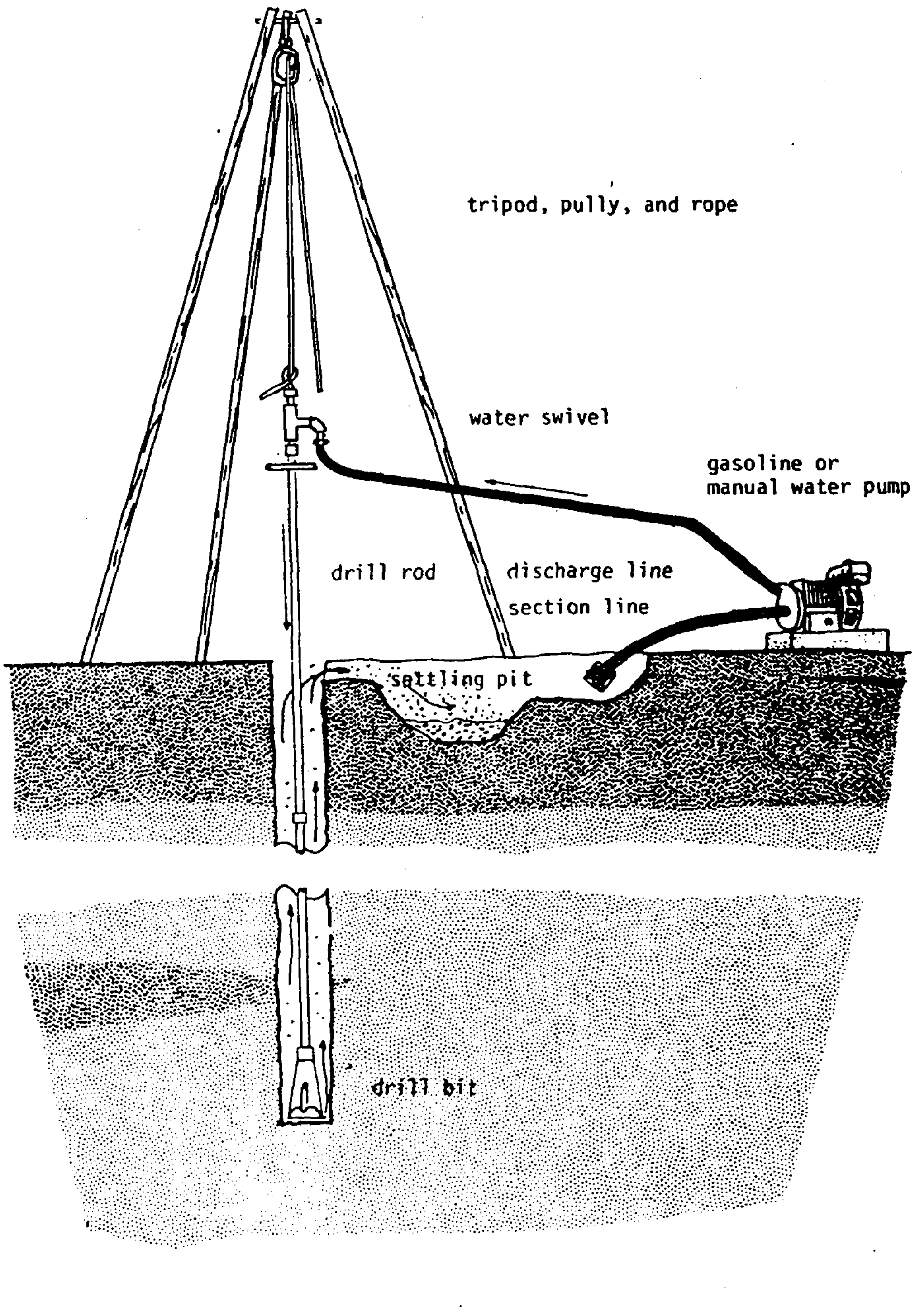
Labor Requirements

Minimal skilled labor is required to operate a hand jetting rig. Two men can easily keep the unit operating. However, a supervisory person is necessary to locate proposed drilling locations and monitor drilling operations.

Fabrication Skills

Fabrication skills for a basic jetting rig are extremely simple. The most basic rig may be easily constructed from scrap pipe which is fashioned into both drill rods and drill bits. Only a water pump must be fabricated in a machine shop or purchased through outside sources.

Figure 35
Manual Jetting Equipment



Cost of Equipment

A complete hand jetting rig including water swivel, 50 feet (15 meters) of drill rods, bit, rod handle, and portable gasoline engine water pump can be purchased in the U.S.A. for less than $550 (M-16). The simplicity of all jetting rig components indicates that a resourceful individual using a pre-existing water pump, can probably fabricate an entire one man jetting rig for as little as $100.

2.4.4 Manual Rotary Jetting Rig

Equipment and Method

This type of rig was used to drill a total of 16 large diameter 7 to 10 inch (18 to 25 centimeters) wells in Jalchatra, Dinajpur and Kazir Simla, Bangladesh (12). The rig shown in Figure 36, consists of a 40 foot (12 meters) reinforced tripod derrick constructed from 3 inch (7.6 centimeters) pipe. Drill rods were 3 inch (7.6 centimeters) galvanized iron pipe and the drill bit resembles an arrow shaped drag bit. Chain tongs are attached to the drill rod and the entire drill string rotates as members of the drilling crew walk around the well pushing on the tongs. Both the drill rods and the attached water swivel are suspended from the tripod and lowered by means of a two man hand winch. The drilling fluid used to wash cuttings from the drill hole is pumped from a series of settling pits by means of a hand powered donkey pump. Later in the program, the donkey pump was replaced by a 6 inch (15 centimeters) Ebara 1 3/4 cusec (approximately 300 gpm) pump operated by a Yanmar diesel engine. Water delivered by the diesel powered pump greatly increased the effective drilling depth and produced a faster drilling and cutting removal rate than was possible with the donkey pump.

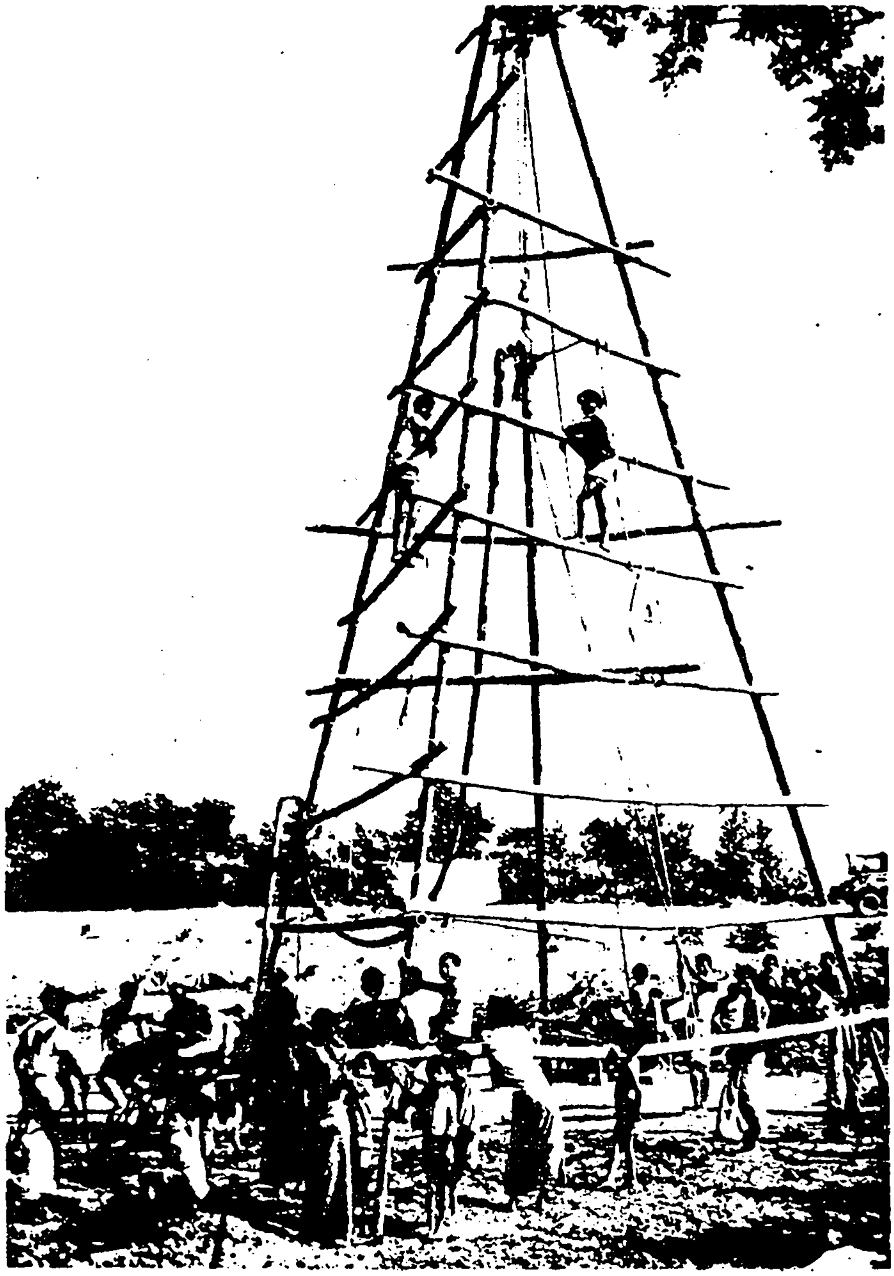
Geological Applications

The manual jetting method works exceedingly well for large diameter wells in moderately cohesive sand and clay formations. Average drilling time for the rotary jetting rig is less than 24 hours for 150 feet (45 meters). Maximum depths attained with the rig reached 195 feet (58 meters) for a 10 inch (25 centimeters) diameter well at Kazir Simla.

Labor Requirements

The manual rotary jetting method is extremely labor intensive and requires twelve to fifteen unskilled

Figure 36
Jet Drilling a Large Diameter Well in Bangladesh



Local villagers gather around the derrick as drilling on a 10 inch (25.4cm) diameter well progresses. Sections of bamboo lashed to the derrick serve as a scaffold for overhead workers who keep the drill rod in vertical alignment.

Bruce Eaton JICCP (12)

laborers to keep it operating continuously. At least one skilled driller is required to contend with caving sand and the drilling fluid mud mixtures.

Compared to other manual drilling methods the large diameter well jetting rig is especially cost-effective for large labor intensive water development projects. The total time required for completion of a 150 to 200 foot (45-61 meters) well is approximately four to five days, of which, two days are required for assembly and dismantling the drilling rig, pumping station, and mud pits. When disassembled, the entire rig and diesel pump can be transported from site to site on several oxcarts or a large truck.

Fabrication Skills

Fabrication of a manual jetting rig requires basic metalworking skills. The hand winch and water pumps are the only components which must be fabricated in a local machine shop or purchased.

Cost of Equipment

Cost statements for the jetting rig are not available. Estimates based upon construction and equipment indicate that the tripod, drill rod and tools would cost approximately $500 for materials and fabrication. The two man hand winch ranges from approximately $250 to $500. The diesel engine powered centrifugal pump may cost as much as $1,500. This brings the total rig cost for large diameter 7 to 10 inch (18 to 25 centimeter) wells to approximately $2,500.

Use of a locally available hand winch or block and tackle significantly reduces the cost of a large jetting rig. Smaller jetting rigs can utilize hand pumps, but larger diameter wells will require the purchase or rental of a large motorized water pump.

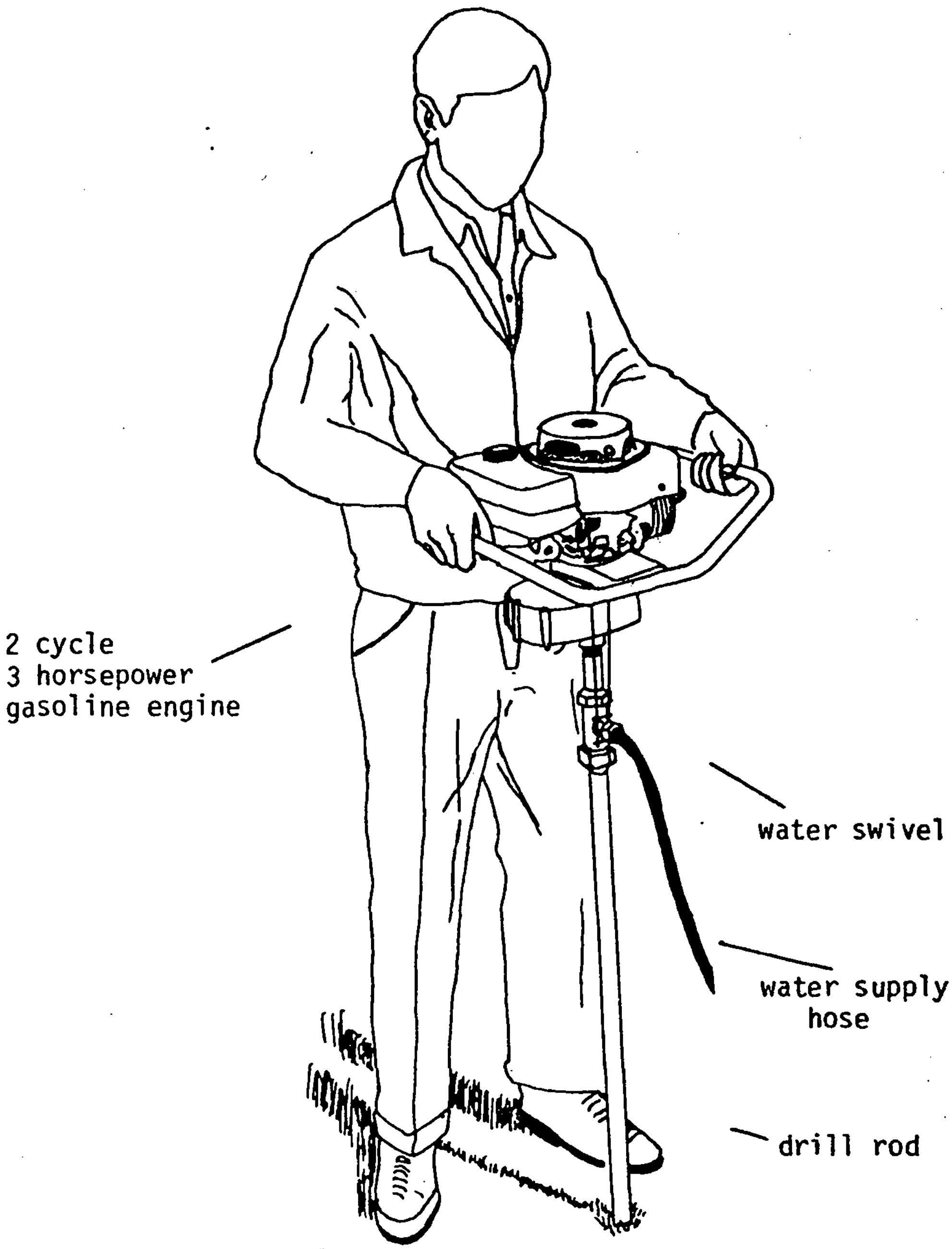
2.4.5 "Hydra-Drill" Rotary Jet Drilling

Equipment and Method

This is a very light weight one to two man motorized drilling machine. The machine uses the jet-rotary method of drilling and is powered by a three horsepower two cycle gasoline engine (Figure 37). The engine, which runs at approximately 3,500 rpm is geared down to apply power to the drill rods through a 100 to 1 reduction gear box. Ordinary 5 foot (1.5 meter) lengths of 3/4 inch (2 centimeter) pipe serve as the drill rods. Drilling fluid

Figure 37

Hydra-Drill



One man may operate this equipment to depths of 50 feet (15m). Greater depths may be attained when the engine and drill rods are suspended from a tripod.

(water) circulation is attained by attaching a hose from a water swivel, below the gear box, to a small centrifugal pump driven by a three hoursepower, four cycle gasoline engine. Mud laden drilling fluid flows from the drill hole to a settling pit, the heavier materials settle out and the fluid, minus the heavy cuttings, is recirculated to the pump.

Geologic Applications

The Hydra-Drill (M-16) is best suited to small diameter, 2 to 4 inch (5 to 10 centimeters) wells with depths to 200 feet (61 meters) in unconsolidated and soft to moderately hard formations. Best results are attained in alluvial deposits consisting of sand, silt and clay. Although drilling is slower, the Hydra-Drill can also penetrate some soft or weathered bedrock formations.

In Bangladesh, the Hydra-Drill was used in the Joint Christian Catholic Irrigation Project (JCCIP) (12) for sinking observation wells and for drilling experimental wells.

Labor Requirements

One man trained to operate the two cycle engine can effectively drill to a depth of 50 feet (15 meters). Beyond this depth drilling becomes increasingly difficult. This difficulty can be overcome by erecting a small tripod and using a block and tackle to suspend the engine and drill string. With this arrangement, wells up to 200 feet (69 meters) can be successfully and economically drilled using as few as two or three men.

Fabrication Skills

The Hydra-Drill, used in Bangladesh, was purchased as a fully equipped unit and required only the fabrication of a simple wood tripod. Additional drill rods and bits for the Hydra-Drill were easily fashioned from local materials.

Agencies wishing to fabricate or assemble their own rotary drilling units might consider using a four cycle gasoline engine rather than the two cycle engine mentioned above. The two cycle engine runs best when the proper type of oil (outboard motor oil) is mixed with its gasoline; it runs less effectively when ordinary oil is used. Since outboard motor oil is practically unobtainable in many less developed countries, sufficient quantities should be imported for use with any two cycle engine. A four cycle gasoline engine does not require a gasoline - oil mixture and therefore eliminates many of these problems.

Cost of Equipment

The Hydra-Drill unit complete with water swivel, 50 feet (15 meters) of drill rod, bit and hole reamer costs less than $500. A three horsepower high pressure centrifugal water pump will add approximately $250, increasing the total rig cost to $750.

2.5 Combination Rotary - Percussion Drilling Equipment

2.5.1 Truck Mounted Jetting - Driving Rig

Equipment and Method

The plans for this drilling rig appear in a 1967 article by Frederick McJunkin (21). The equipment was first developed and utilized in 1961 by Marvin E. Miller, a USAID Well Drilling Advisor in Cambodia. The rig (Figures 38 and 39) is constructed to perform both jet and drive drilling operations. The chassis for the rig is a Dodge Power Wagon or similar truck to which a locally fabricated folding steel mast is attached. The rear wheel is removed and replaced by a cathead which provides the necessary power source for driving well points with a 90 pound (40 kilogram) hammer. An eccentric wheel also attached to the hub can be utilized to transfer reciprocating action to the jet drilling tools. An illustration of this apparatus is shown on the design plans in Figure 38 and 39. Water for the jetting process is supplied by a small three horsepower centrifugal gasoline pump. Drill rods are constructed from a steel pipe to which a chisel bit (fashioned from a section of hardened steel automotive spring) is welded.

Geological Applications

The combined jetting-driving rig is suitable for drilling in alluvial soils consisting of sand, silt, and clay. It cannot drill through rock or other exceedingly hard formations. During the early 1960's the rig proved to be highly successful and was used to drill several hundred two inch (5 centimeter) diameter wells in Cambodia. The depth of an average well was 100 feet (30 meters) and required two to three days to complete.

Labor Requirements

A crew of four men is required for the safe and efficient operation of this drilling rig. All crew members must be familiar with rig operation and safety practices. An experienced crew chief knowledgable in well construction

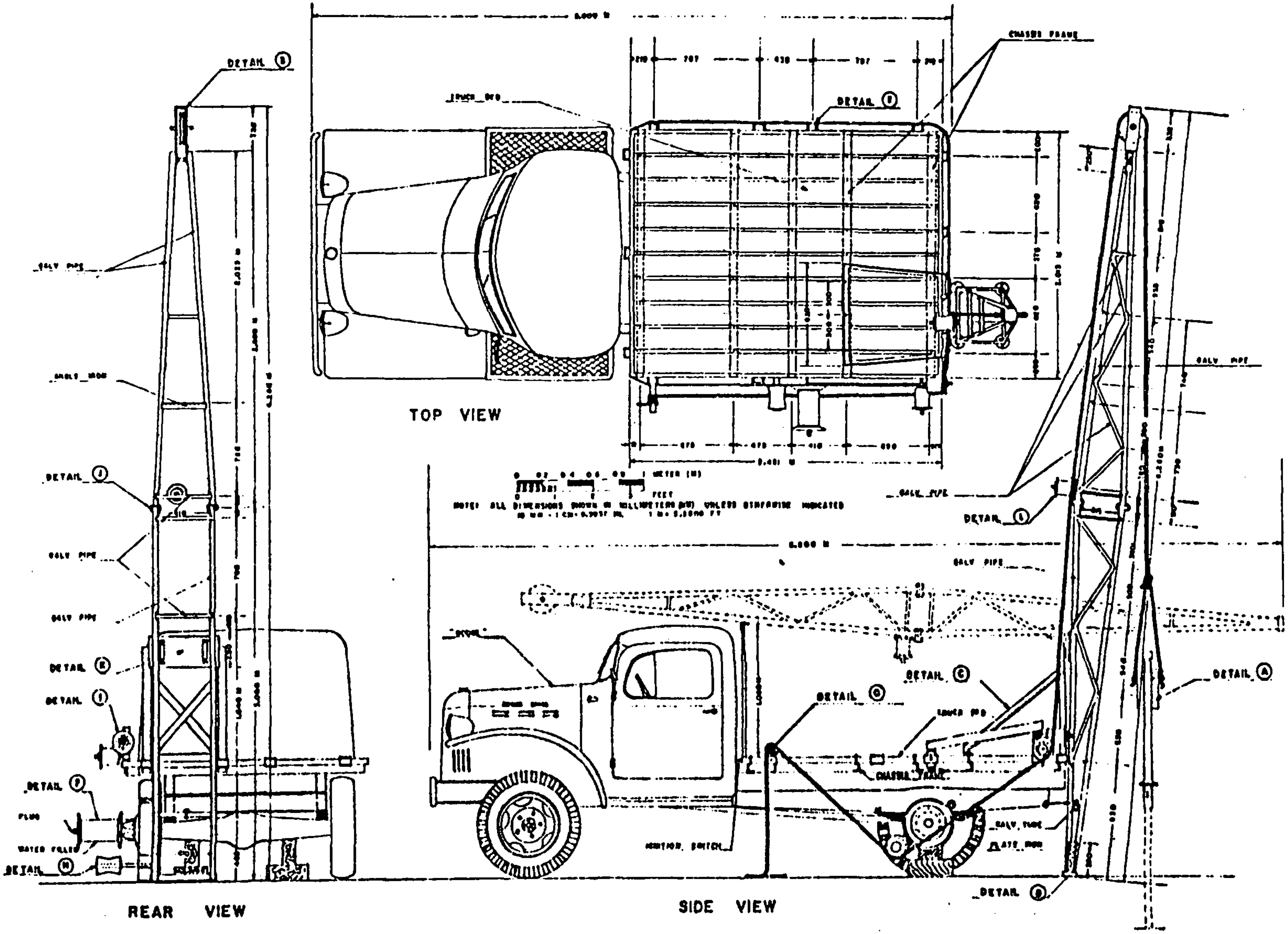


Figure 38 TRUCK-MOUNTED, JETTING-DRIVING WELL DRILLING RIG.
F. McJunkin (21)

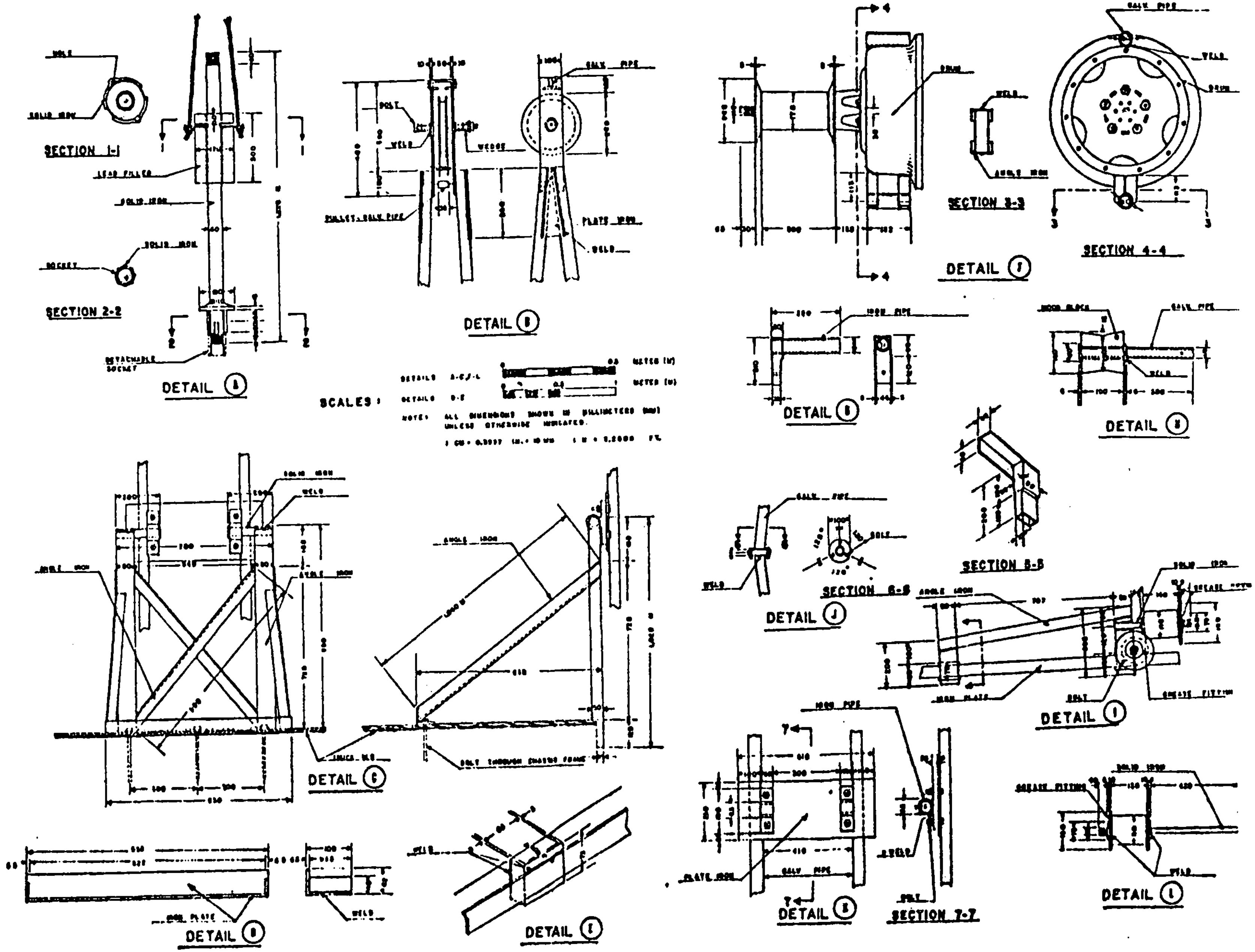


Figure 39 DETAILS OF WELL DRILLING RIG SUBASSEMBLIES

F. McJunkin (21)

techniques and mechanical operation of the rig should be on-site at all times to evaluate geologic conditions, record a written log of the well, and supervise the drilling.

Fabrication Skills

Except for the truck and water pump, the entire rig was fabricated locally from steel tubing, scrap metal plate and short sections of well casing. Construction and assembly of the rig required an experienced metal worker and a fully equipped machine shop plus the use of an oxygen-acetylene torch and an electric arc welder.

Cost of Equipment

The 1961 cost for materials and fabrication in Cambodia was approximately $100. Comparable costs at 1978 rates could easily be as much as ten to fifteen times the 1961 value.

2.5.2 Walking Beam Percussion - Jetting Rig

Equipment and Method

The walking beam percussion-jetting rig described in this account was built in 1950 by the United States Geological Survey (8). The rig was used to conduct a low-cost well drilling program in an agricultural area surrounding Fairbanks, Alaska. Basic components of the rig pictured in Figures 40 and 41 are a 25 foot (7.6 meter) wood derrick, a 100 psi (7 kg/cm^2) positive displacement water pump powered by a three horsepower gasoline engine, a water swivel, and a string of drill rod constructed from one inch (2.54 centimeter) heavy wall pipe.

This rig uses the usual arrangement of settling pits; it circulates a solution of water and drilling mud (bentonite clay) through the drill rods. The drilling fluid issues from side ports on the drill bit, then suspends the bit cuttings and carries them upwards to a settling pit. The bentonite is used to thicken the drilling fluid, thereby increasing its ability to suspend and remove heavy cuttings from the borehole. While, jet drilling in clay and silty soils requires little or no bentonite, six to ten handfuls of bentonite may be added to the fluid when sand or hard rock are encountered.

In conjunction with the jetting action, the walking beam raises and drops the drill rods at a rate of 30 times per minute. As the bit strikes the bottom of the hole, a helper rotates the drill rod by 1/4 turn. This helps to dislodge drill cuttings and greatly increases the drilling rate. A cathead attached to one of the pulley shafts is used for both hoisting drill rods and for operating a drive hammer to advance casing through unstable formations.

Geological Applications

The rig is well adapted to alluvial formations consisting of silt, clay, and sand. Drilling in areas with numerous boulders is discouraged. Boulders tend to deflect the drill bit, creating a crooked hole which makes continued drilling impossible. In addition to alluvial deposits, the rig can be fitted with a hardened steel or carbide rock bit for drilling through weathered and moderately hard bedrock such as sandstone and shale. The average drilling rate for alluvial formations was approximately 1 1/2 minutes per foot (30.5 centimeters). Depending upon soil conditions, a three inch (7.6 centimeter) diameter well could be drilled to an average depth of 145 feet (43 meters) in a single day's time. When drilling in hard metamorphic rock, which consisted of weathered schist containing veins of quartz, the drilling rate slowed to 15 to 20 minutes per foot (50 to 70 minutes per meter).

Labor Requirements

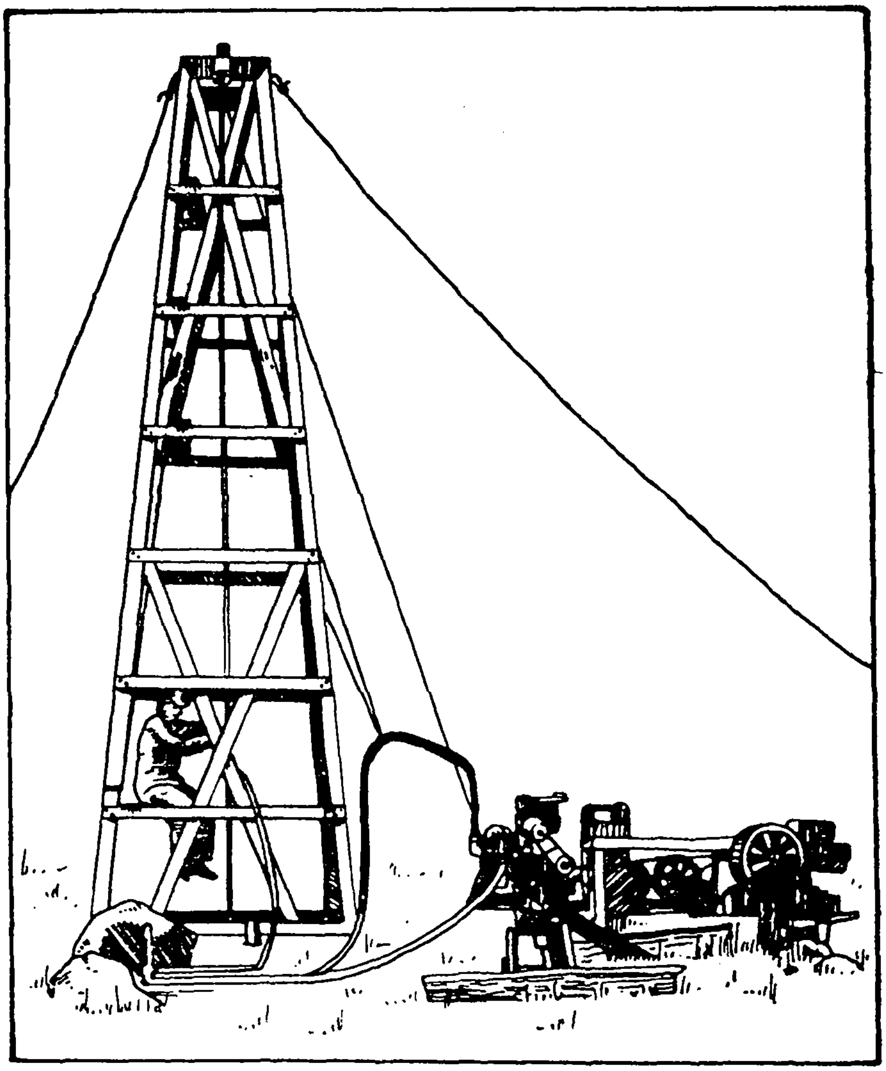
The rig used in Alaska required a three man drilling crew. Each crew member had specific duties calling for varying amounts of technical skill. The least skilled member was the driller's helper who stationed himself on the derrick, rotated the drill rod and maintained a straight drill hole. A second individual, who was familiar with gasoline engines and drilling techniques was required to operate and maintain the rig. The third crew member attended to the water supply, sampled the drill cuttings, kept a drilling log and maintained a proper bentonite-water slurry whenever coarse material was encountered.

Fabrication Skills

Aside from two gasoline engines and a high pressure water pump (capable of handling abrasive solutions) the basic walking beam percussion-jetting rig is assembled from hardwood timber, and commercially available pulleys, chain sprockets, steel bar stock, and pillow-block bearings. These items may be assembled by a local machine shop or may

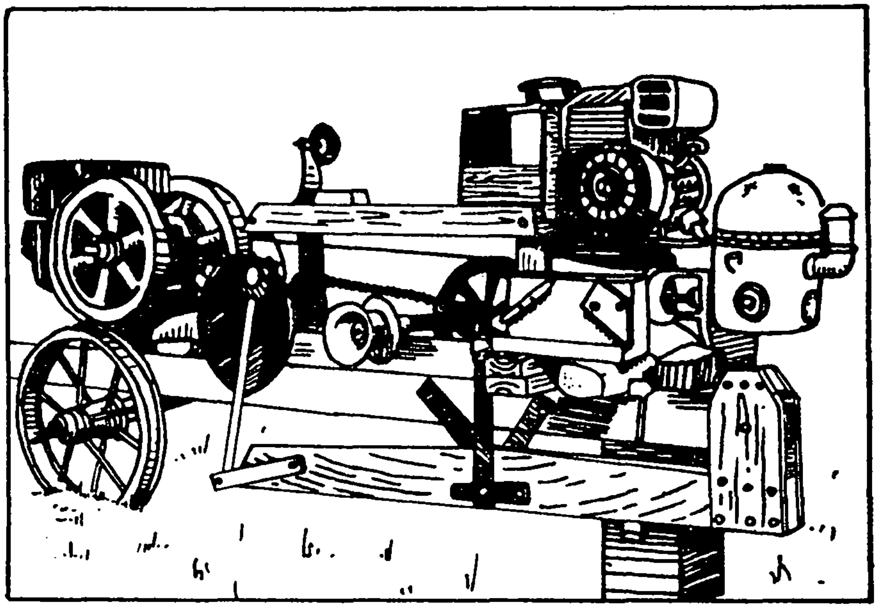
Figure 40

Walking Beam Percussion-Jetting Rig used in the Fairbanks Alaska Area



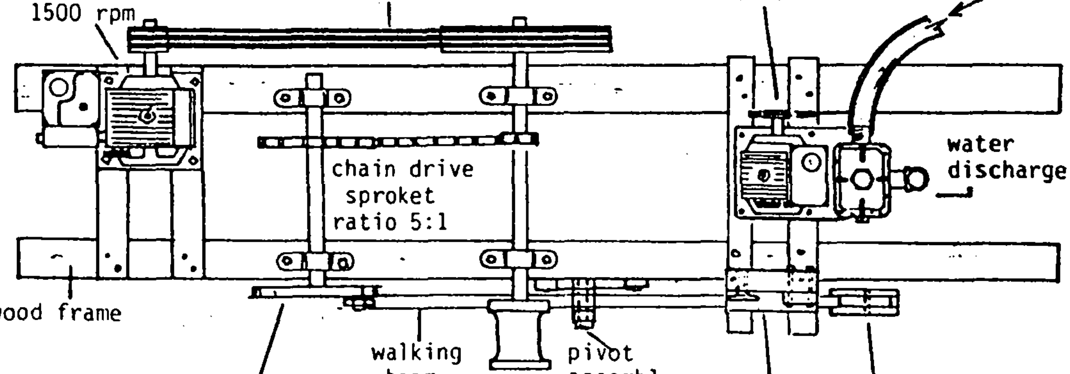
Separate gasoline engines are used for the walking beam and for the water pump. A drilling helper stationed on the derrick scaffold rotates the drill rods to maintain a vertical well.

Figure 41
Details of Walking Beam Drilling Rig and Subassemblies



Perspective view showing location of rig components and a top-mounted workbench which also serves as a belt guard.

Components of a Simple Walking-Beam Drilling Rig



incorporate foundry and machine operations to provide additional worker employment and produce low cost locally manufactured components.

Cost of Equipment

The United States Geological Survey did not include materials and construction costs. However, based upon 1978 equipment costs, a suitable three horsepower gasoline engine water pump would cost $250 and a seven to eight horsepower gasoline engine would cost from $200 to $400. The total cost for required chain sprockets, pulleys, shafts, and bearings should not exceed $300. Fabrication of a wood chassis and assembly of the rig components could add another $100 to $300, bringing the total rig cost to $1,250. This cost does not include tripod, drill rods, bit, water suction and discharge hoses, water swivel, or assorted hand tools. The additional cost for this equipment may range from $500 to 1,500 dollars; increasing the cost of a complete, fully equipped rig to $2,750.

2.5.3 Rotary Percussion Exploration Drill

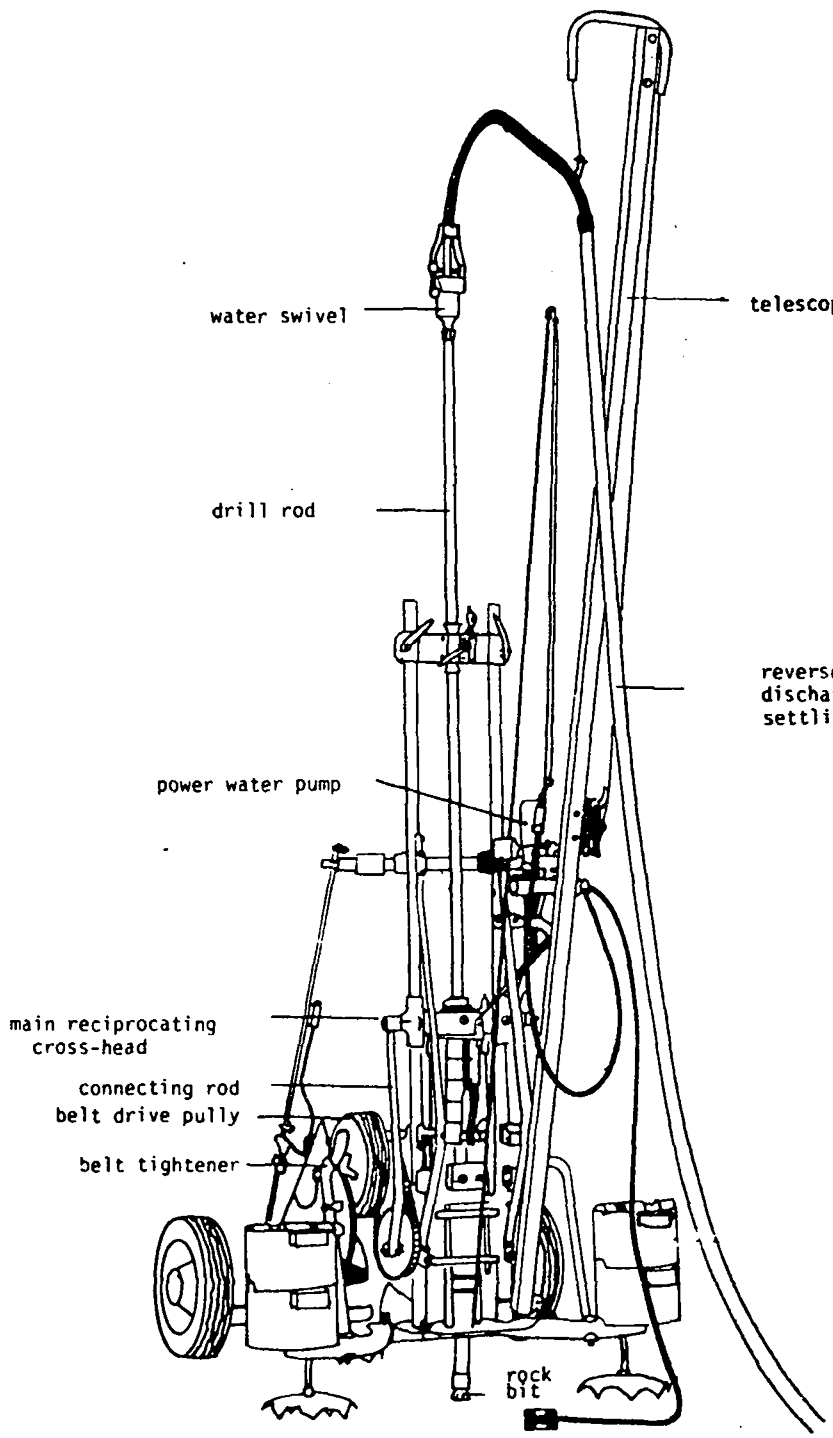
Equipment and Method

This drilling machine called the Hossfeld Exploratory Drill (M-23), is designed as a field portable rig for drilling blast holes in quarries (Figure 42). Its operation is very similar to reverse circulation drilling by the sludger method; it can easily be utilized as a low cost well drilling rig for small diameter wells. A nine horsepower, four cycle engine supplies the necessary power. Through a system of pulleys, a clutch, and an excentric crank arm, the engine repeatedly raises and drops the drill rods. The cutting action is provided by a carbide-tipped rock bit. In addition to their reciprocating motion, the drill rods rotate, thus, the bit never strikes twice in the same position. As with the manual sludger method, the reciprocating motion circulates drilling fluid through a one-way valve in the drill stem. As the rods successively rise and fall, the pumping action lifts the water-suspended drill cuttings up through the hollow drill rods and hose to a settling pit. The cuttings settle out and drilling water recirculates back to the hole.

Geological Applications

The exploration drill rig is designed principally for use in hard rock formations such as sandstone, limestone, shale, granite, and basalt. Manufacturer

Figure 42
Exploritory Drill Hossfeld Manufacturing Co. (M-23)



specifications indicate the drill can be equipped with rock bits for two to three inch (5 to 7.6 centimeter) diameter wells and can effectively drill to depths of 150 feet (45 meters).

Labor Requirements

The Hossfeld Exploration Drill, like any other motorized rig, will require a trained or experienced operator. A great portion of the rig's effective operation will depend upon a driller's ability to sense subsurface conditions by the sound and manner in which the machine operates. Therefore, at least one skilled operator, who is experienced with both mechanical drilling equipment and small engine operation is required. In addition to the chief operator a drilling assistant or apprentice is required to handle drilling tools, water supply, and learn the "feel" or technique of rig operation.

Fabrication Skills

The entire exploratory drill comes direct from the manufacturer with six rock bits, 70 feet (21 meters) of drill rod, tool box, rig tools, and spare parts. Options such as a self operated auxiliary water pump, casing driver attachment, and trailer hitch are also available. Construction of the drill is both simple and durable. If replacement parts other than those included with the rig, are required a local machine shop should be able to fabricate them at a fraction of the cost involved with international shipping and customs regulations.

Cost of Equipment

The 1978 cost of the entire basic drill unit including all accessories and an additional supply of carbide insert rock bits and coupling adapters for drill bits should not exceed $2,500. The base price without these additional options is approximately $2,025.

2.5.4 Hydraulic Rotary Rig

Equipment and Method

Numerous sophisticated hydraulic rotary drilling rigs are manufactured by the companies listed in the Manufacturers Bibliography. Of these various drilling rigs, the Simco model 2400 was chosen as a low cost rig representative of hydraulic rotary drilling equipment. The Simco 2400, shown in Figures 43 and 44 utilizes a stationary twenty-four horsepower gasoline engine to provide power for a hydraulic pump. The high pressure side of this pump connects to a series of control valves which in turn direct the fluid to various hydraulic motors, cylinders and jacks. The Simco 2400 incorporates three high torque hydraulic motors, one for the drill spindle, one for the cathead, and one for a chain drive system which raises and lowers the rotary drill head. The first of two additional hydraulic valves controls a hydraulic cylinder which raises the mast. The second valve operates a leveling jack.

The hydraulic rotary rig is well suited to effectively perform a number of rotary drilling methods such as auger boring, jet drilling, rotary drilling and diamond core drilling.

Auger Boring

Auger boring is accomplished by attaching a series of continuous flight augers to the rotary spindle. In a process very similar to that used in hand augering, additional augers are added to the drill string. Their continuous rotation transports drill cuttings up the helical auger flights where they accumulate at the surface. Frequently, small amounts of water are added to the bore hole. This water helps to lubricate the auger flights reducing frictional drag and also helping to remove dry cuttings. High torques produced by the hydraulic motor enable the augers to easily drill to depths of 30 to 60 feet (9 to 18 meters). Once a sufficient thickness of an aquifer is logged, the augers are quickly withdrawn and a well screen and casing are set inside the open hole.

When a bore encounters caving sand, one of three methods is generally used. First, the well point may be driven by means of the cathead and a drive hammer. A second method is to advance the well screen by washing down (or jetting) the screen through the caving material (Figure 45). This action is accomplished by forcing high pressure water through a port at the bottom of a well screen. The jetting water circulates from the pump through an internal pipe which extends inside the casing to the base of the well screen. After reaching the base of the well screen the water passes through a one way valve and washes any loose material away from the well point.

A third means for eliminating caving problems is through use of hollow-stem augers. The hollow stem auger (Figure 46) is similar to the standard helical auger, but uses a 2 to 4 inch (5 to 10 centimeters) tubular auger shaft. Before drilling, a cork or wood plug is placed in-

Figure 43
Hydraulic Rotary Rig Mounted on a 1-Ton Pickup Truck

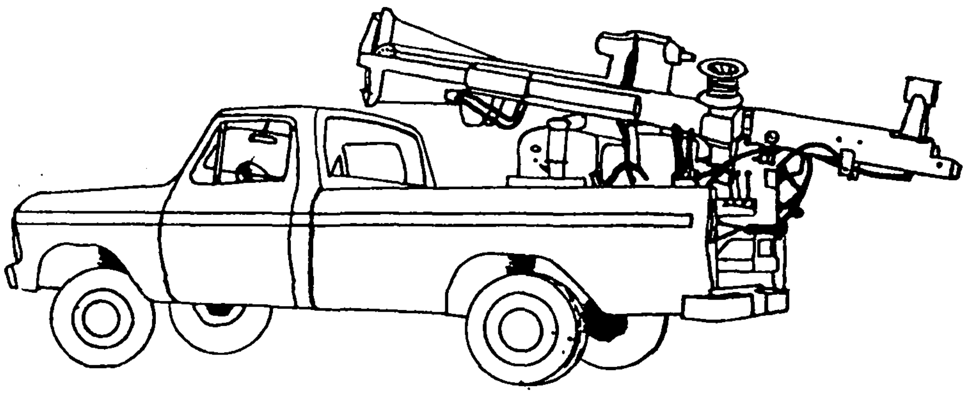


Figure 44

General Diagram of a SIMCO-2400 Trailer Mounted Drilling Rig

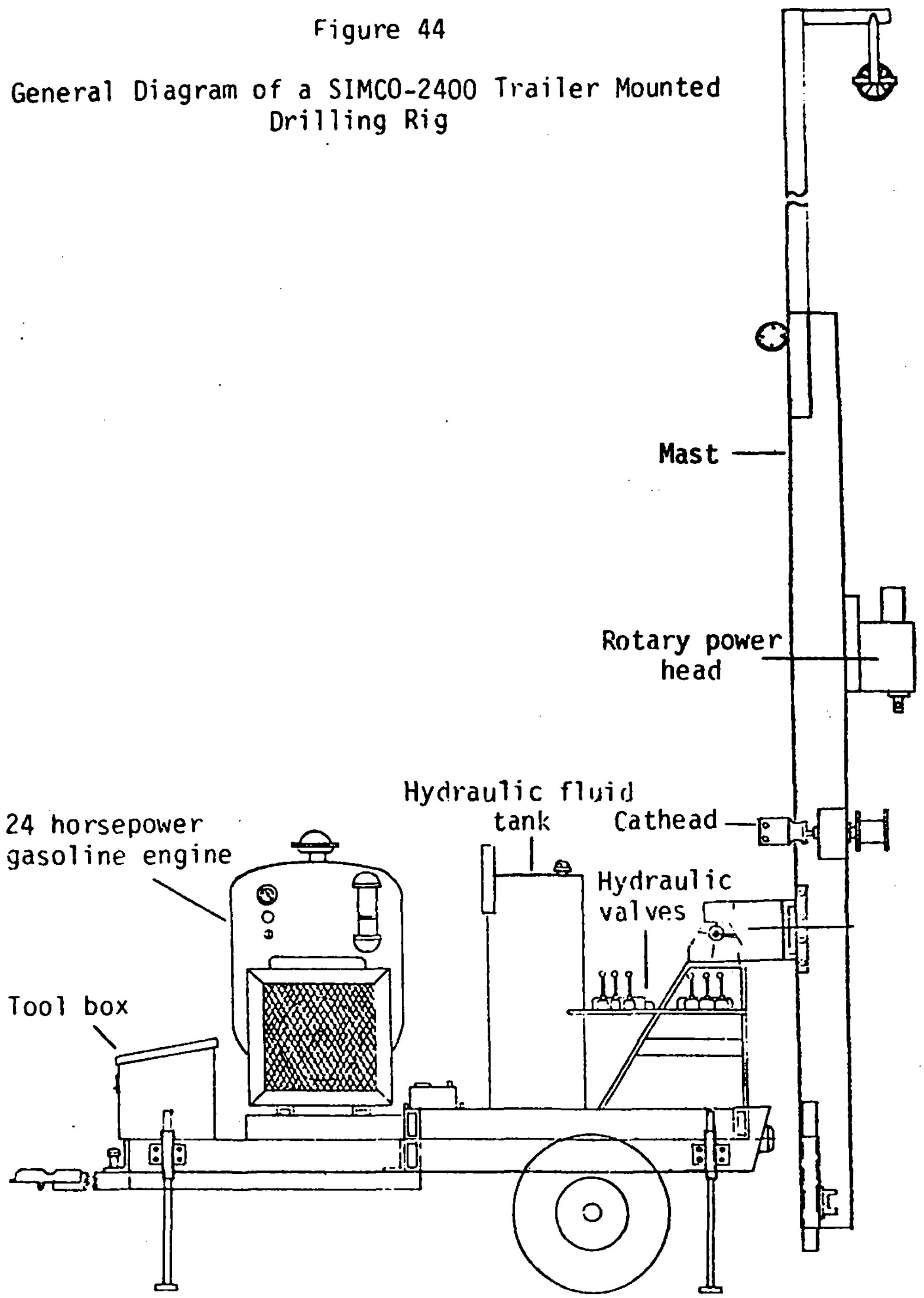
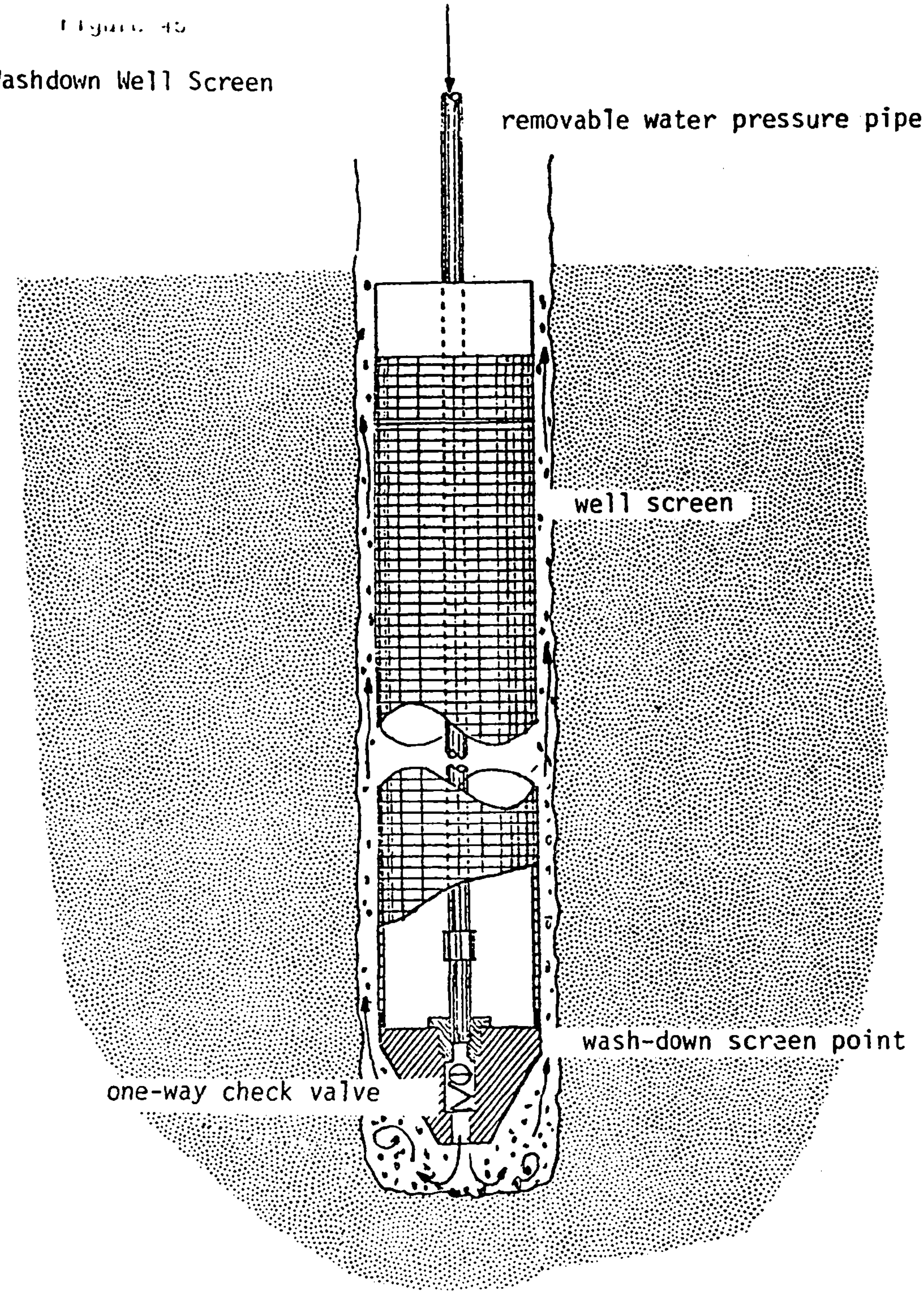


Figure 45

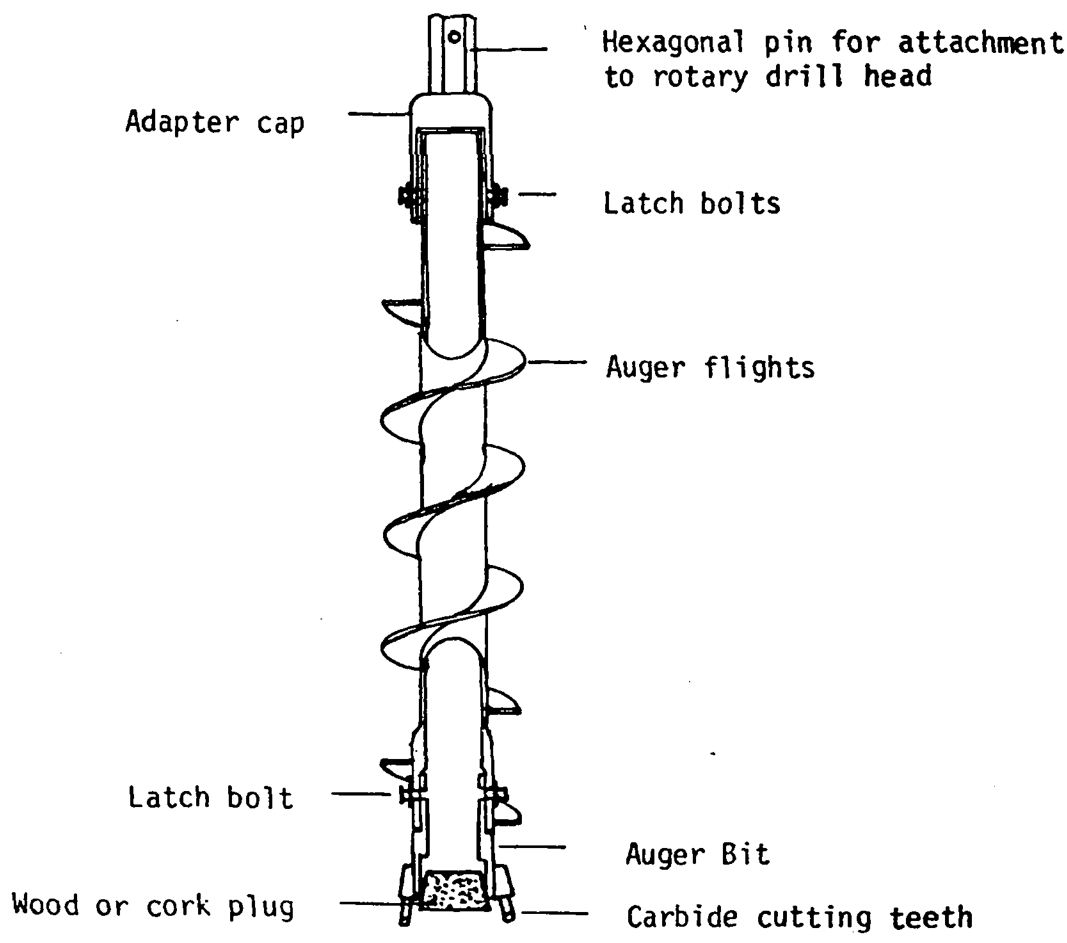
Washdown Well Screen



When washing down a well screen, a high pressure water jet flushes loose cuttings from the boring. This flushing action allows a well screen to penetrate areas of caving soil or flowing sand which would prohibit well screen installation by conventional methods.

Figure 46

Hollow Stem Auger



side the bit. This plug prohibits rock and soil materials from entering the interior of the augers. When a sufficient thickness of material is penetrated, an assembled well screen and riser pipe are dropped inside the tubular auger to drive the temporary plug out of the bit. The augers are then raised, leaving the screen and riser pipe in place within the well. Whenever practical, this method also enables the drilling crew to create high efficiency gravel packed wells by slowly adding a mixture of coarse sand or fine gravel to the annular space between augers and the well screen. Although hollow stem augers are extremely expensive, they represent an expedient and economical method for placing gravel packed well screens. Since no casing is required to maintain an open hole, an efficient crew working with hollow stem augers can drill and install a 60 foot (18 meter) deep gravel packed well in less than three hours. The 2400 series hydraulic rig can easily accomodate hollow stem augers up to five inches (12.7 centimeters) diameter having a hollow stem of two inches (5 centimeters). Well screens of greater diameters will require respectively larger hollow stem augers and more powerful hydraulic motors.

Wash Boring

For wash boring, the hydraulic rig incorporates the usual arrangement of drilling tools consisting of a portable high pressure water pump, water swivel, drill rods and a drill bit. When attached to the drill spindle, the bit rotates and is slowly advanced as cuttings are carried out of the hole. In this procedure, no percussion or hammering action is attempted.

Rotary Drilling

If hard rock is encountered the traditional wash boring bit is replaced by a roller bit commonly called a tri-cone (Figure 47). By applying pull-down pressure to a tri-cone bit, most sedimentary formations such as limestone, sandstone, and shale can be drilled. Again, as with jet drilling, a mixture of water and drilling mud issues from ports in the bit to suspend and remove drill cuttings from the hole. A variation to this method uses air pressure rather than water to remove the cuttings.

Larger, heavy duty hydraulic rigs may employ an air powered down-hole hammer; the down-hole hammer is a device similar to an air hammer. It attaches to the lower end of the drill rods and provides one of the principal means for drilling extremely hard rock formations.

Core Drilling

This form of drilling is extremely expensive and requires considerable technical experience. It employs an expensive diamond impregnated bit which attaches to a tubular core barrel (Figure 48). Water circulates through the core barrel and washes the drill cuttings away from the diamond bit. As coring progresses a solid column or rock core accumulates inside the barrel. When full, the barrel is hoisted to the surface and emptied. Visual inspection of the solid rock core provides valuable information on subsurface geological conditions. Core drilling is used almost exclusively for engineering and mineral exploration purposes and should be considered as a well drilling method only when hard rock or other unfavorable conditions preclude the use of alternative methods.

Geological Applications

The small hydraulic rotary 2400 series rig is well suited for shallow depth drilling under all geologic conditions. The rig is particularly adept at auger boring in alluvial materials, but can be easily equipped to perform jet, wet rotary, air rotary, downhole hammer and diamond core drilling functions. The average maximum depth for a five inch (12.7 centimeter) auger hole with this rig is 30 to 60 feet (9 to 18 meters). This depth may vary, depending upon soil types and subsurface conditions. Greater depths may be attained by switching to a smaller auger diameter or by circulating water through the hollow stem augers as in jet drilling. Jet drilling and the remaining rotary methods which utilize drill rods rather than augers are capable of drilling to depths of 200 to 250 feet (60 to 75 meters).

Labor Requirements

The hydraulic rig requires a minimum drilling crew of two men. The chief driller must be trained and experienced in operation and maintenance of the equipment, and with the various drilling techniques for which the rig is equipped. The second crew member, a helper, is usually an unskilled laborer or apprentice who is learning how to operate the equipment. Additional laborers may be added to the crew for preparing a work site, digging settling pits, handling casing, and carrying or pumping water.

Fabrication Skills

Drilling rigs, similar to the one discussed, may be fabricated from standard structural steel forms. Mechanical equipment such as the stationary power engine,

Figure 47

Tri-Cone Rotary Drill Bit

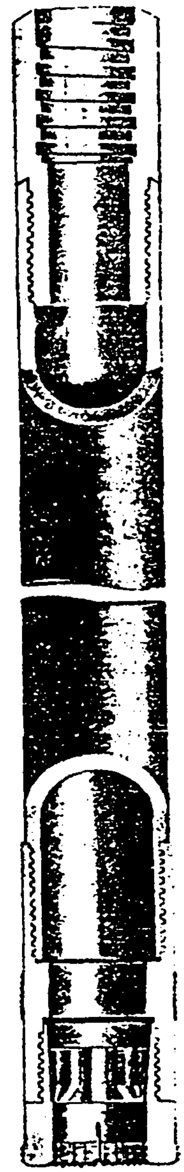


Figure 48

Core Barrel and Diamond Bit

hydraulic pump, hydraulic hoses, valves, cylinders, motors and bearings must be purchased or imported. Aside from these imported items, an entire rig structure could be produced in a small scale machine shop using standard metalworking tools and an electric arc welder. Fabrication of drilling tools such as high quality drill rods and flight augers will require precision machining and welding operations. Auger bits are usually cast items and must be produced by a foundary operation.

Cost of Equipment

Purchase costs in the U.S.A. for a small hydraulic rig (M-36) are approximately $6,600. This rig may be mounted upon a one ton (metric) pick up truck or upon specially designed trailer. If the rig is fully equipped to perform several drilling functions, the cost of drilling tools may very well exceed the initial rig cost. Current U.S.A. prices for a full inventory of drilling equipment are listed in Table 4.

As illustrated in Table 4, the purchase cost for a full set of drilling tools can easily exceed a low-cost drilling equipment budget. This cost may be reduced in two ways. The first is through the wise selection of drilling tools to fit only the conditions in which a rig will operate. Therefore, solid flight augers are recommended for shallow wells drilled in cohesive soil. Hollow stem augers are best utilized in noncohesive or caving soils. If the average well exceeds a depth of 30 feet (18 meters), a small rig should be equipped for jet drilling which is effective to depths of 250 feet (75 meters). Thus, by equipping a rig for specific conditions, the cost of unnecessary equipment can be avoided. The second method for reducing costs results from increased production and the lower labor requirements which are possible with a small rotary rig. The trailer or truck mounted hydraulic rotary drilling rig operated by a crew of two to four men can easily complete a well in one-quarter of the time and at a lower cost than is possible with the most expedient manual drilling methods. This capability can be extremely useful whenever numerous low cost wells must be drilled within a limited time span.

Preventive maintenance is very important for trouble free operation of a hydraulic powered drilling rig. Annual costs for rig maintenance should equal approximately 20% of the rig's initial cost. This maintenance includes weekly service inspections such as changing both oil and air filters, lubrication of bearings, chain couplings, and sliding track, an inspection of all hydraulic lines, checking the hydraulic oil and rebuilding worn bits and augers with welding rod. A properly maintained rig should last at least ten years. Major repairs, which might be anticipated, are: (1) rebuilding or replacement of the gasoline rig engine after every 1,500 hours of operation time; (2) replacement of hydraulic hoses every two to three years.

Costs in 1978 for replacing a twenty-four horsepower engine run as high as $1,500 to $1,800. A complete set of hydraulic hoses (with connectors) may run as much as $300. Proper operation and preventive maintenance procedures will extend the life of these components, saving as much as $1,500 to $1,800 annually for replacement of an engine and as much as $300 annually for hydraulic lines.

TABLE 3

Relative 1978 Purchased Drilling Equipment Costs

Solid flight augers	Unit	Quantity	Cost
5' solid flight augers, 4 1/2" diameter	$ 97.00	12	$1,164
auger bit with carbide teeth	$ 63.00	2	$ 126
spare carbide teeth	$ 2.10	24	$ 50
spare wedge keepers	$ 1.35	12	$ 15
spare drive pins	$ 2.10	24	$ 50
auger holding fork	$ 58.00	1	$ 58
TOTAL			$1,464

Hollow stem augers			
5 ' hollow stem auger 5" OD 2 1/4" ID	$227.00	12	$2,724
hollow stem auger bit	$195.00	2	$ 390
spare carbide teeth	$ 2.10	24	$ 50
spare auger bolts	$ 2.50	24	$ 60
auger holding fork	$ 58.00	1	$ 58
TOTAL			$3,282

Drill rods			
5' size AW drill-rod (1 3/4" O.D.)	$ 32.00	40	$1,280
sidefeed water swivel	$165.00	1	$ 165
water pump & suction & discharge hose	$300.00	1	$ 300
rod pulling ring	$ 24.00	1	$ 24
carbide drag bit (2 7/8" O.D.)	$ 43.00	3	$ 129
roller bit	$ 79.00	3	$ 237
TOTAL			$2,135

Drive equipment - useful addition to all drilling methods			
drive hammer	$120.00	1	$ 120
drive head coupling	$100.00	1	$ 100
drive stem	$ 45.00	3	$ 135
drive ring	$ 19.00	1	$ 19
7/8" Manila rope	$.75/ft	80 ft.	$ 60
TOTAL			$ 434

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