Y/OWI/SUB-77/22324/1

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EMPLACEMENT HOLE DRILL EVALUATION AND SPECIFICATION STUDY

VOLUME I

Report No. Y/OWI/SUB-77/22324/1

Submitted to

Office of Waste Isolation
Union Carbide Corporation
Nuclear Division

Order No. 89Y22324

by

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GLOSSARY

bailing - lifting drilled cuttings from a hole

inby - mining term describing a position as being towards the inside of the mine

mucking out - bailing

outby - opposite of inby

spudding in - the process of starting to drill a hole beginning when the drill bit first engages the strata and lasting until the drilling process is continuing without special equipment or procedures.

1. INTRODUCTION

The Nuclear Waste Terminal Storage Facilities will be a final repository for spent nuclear fuel removed from commercial nuclear power stations. If this facility is established in an underground mine, then the nuclear material will probably be placed in long cylindrical holes in the floor of the mine. These holes can be drilled in many ways. This report describes the results of a conceptual design program conducted by Foster-Miller Associates under contract to Office of Waste Isolation, Union Carbide Corporation, Nuclear Division, Order No. 89Y22324, during which various types of drilling systems were analyzed for this application. The program is based on the concept that existing commercial drilling equipment or components can be used directly or with little modification. Five systems are considered. They are:

- *Raise borer with circulation bailing
- *Raise borer with auger flights
- Auger drill rig with auger flights
- Auger drill rig with circulation bailing
- Bucket drill rig.

All five systems are technically adequate and are available commercially in sufficiently rugged and reliable equipment. All can be operated safely. Initial cost, operating cost and service life can be traded off. Although one system, the auger drill rig with circulation bailing, has a lower cost, the final choice may be based upon other factors that are at present indeterminate such as noise, or dust, or the choice of haulage vehicles, or decisions on power distribution or, finally, on cash flow requirements. It will be shown in Section 5 that the auger drill rig with continuous auger flights are noncompetitive.

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*Used in the blind drilling mode.

2. FACILITY DESIGN CRITERIA

The operation, drilling site and environment of the facility have been determined by others to a large extent and are reported in greater depth elsewhere. They are presented and expanded within this report because of their obvious influence on the drilling system design. To present, first, an overview of the drilling tasks, these criteria are summarized in Table 1.

The cannisters of waste will be stored in vertical holes in the floor of the mine. This study considered finished holes from twenty to forty feet deep and from twelve to thirty-six inches in diameter. They will be plumb within one degree to facilitate handling of the long storage cylinder and plug. This is especially critical considering the transfer operation from the shield cask in the transport vehicles.

For the pilot facility, the holes will be lined with a steel sleeve to facilitate retrieval of the cannister (see Figure 1). The hole will be covered with a concrete plug which will be supported by a step in the sleeve. The sequence of operations is: The hole will be drilled oversize, the sleeve will be inserted, the annulus will be backfilled with loose salt and compacted. Afterwards the cannister will be emplaced and the hole will be plugged. For later facilities, the cannisters may not be retrievable in which case they would be buried directly without a sleeve and backfilled completely with salt. The drilling of the hole will be a part of the mining process. The sleeving of the hole will be done prior to the emplacement of the waste.

As described in the preliminary design, the storage rooms or entries will be about 600 feet long, at least 18 feet wide and 18 feet high with an entrance from an interconnecting corridor at one end only. The floor will be level with local deviation

Table 1. Summary Criteria

<u>What is to be drilled?</u>

Over 400,000 straight holes
12 to 36 inch diameter (maximum 48 inch)
20 to 40 feet deep (maximum 70 feet)
Plumb to 1 degree

<u>Where?</u>

Underground mine
Bedded or domed salt (slate, limestone, granite?)
Room 18 feet high
  18-36 feet wide
  600 feet long
Minimum 5 feet from side wall
Minimum 20 feet from end wall
In straight line patterns
4 to 17 feet between centers

<u>Environment</u>

$20^{o}F$ to $115^{o}F$
5% to 95% RH
Maximum 10 mg/cubic meter dust
Nongassy, nonexplosion proof
Noise probably over 90 dba

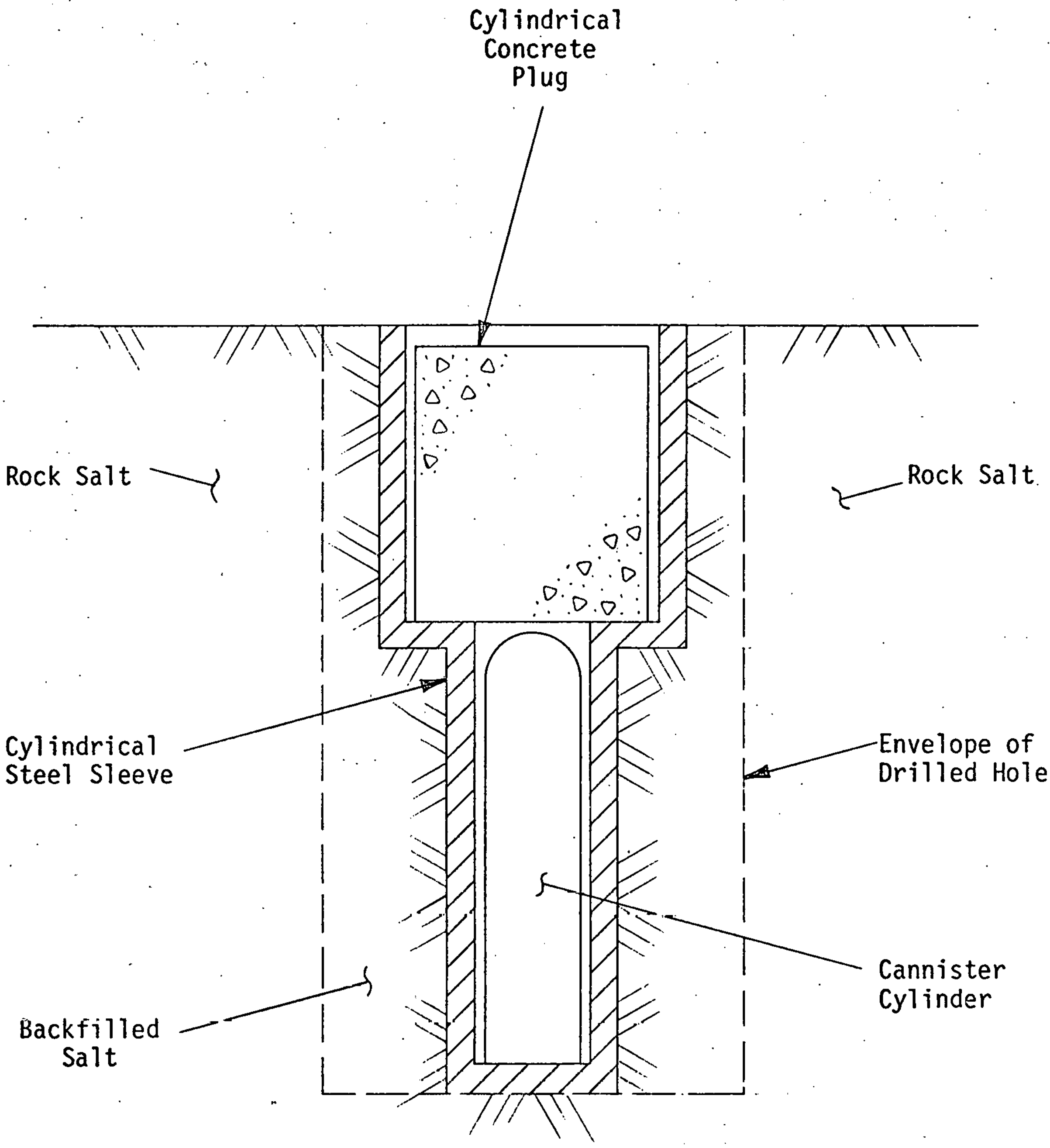

Figure 1. Waste Cannister
Stored in Sleeve

ramping no more than four inches in 10 feet. The holes will be located in straight line patterns and will be nominally spaced 4 feet to 17 feet apart. The holes at the side of a room will be centered no closer than 5 feet from the side wall. The holes at the end of a room will be centered no closer than 20 feet from the end wall.

The bottom of the hole may be contoured by the shape of the drill bit or tool. Some loose salt may be left in the hole since it will be cleaned by the crew that installs the sleeve. The entire operation will be performed without water for dust suppression or for chip bailing.

One of the main problems to be considered in the development plan is the order in which holes will be drilled. The holes are presently spaced on the floor of the mine in a way that hampers haulage of the cut salt. To minimize the danger to men and equipment that the holes present, it would be preferable to drill them in a retreating fashion. That is, the drilling would start at the inby end and proceed outward. All equipment would be outby of the hole. This presents a problem of loading the salt onto haulage vehicles since there is not enough room in an eighteen foot wide entry to accommodate both the drill and the haulage vehicle side by side if the drill is centered. (All standard rigs are built this way.) Hence the cuttings have to be carried the length of the drill rig before loading. Alternatively, the drill can be positioned inby of the hole to ease the loading problem, but then the drill would have to drive over the holes after drilling.

If there is to be more than one row of holes in a room, then each row should be started at the inby end because there is simply more travel involved in haulage than in moving the drill, and the danger from the open holes would be greater.

The loss in travel time from one end of the room to the other is preferred over the loss of a hole, damaged equipment, stuck equipment, or any personnel injuries. Of course, if the hole pattern could be arranged so that avenues for travel are left, then the danger is minimized. Storage rooms open to corridors at both ends are preferable for many reasons.

It has been presumed that no permanent services will be installed in the entries such as prime electrical power for heavy duty machinery or for lighting, and no ventilation. Consequently, these items will have to be provided by the drilling system.

The main and sub-main corridors will have the same height as the entries, eighteen feet. However, it is expected that there may be services strung from the roof which will limit the overhead space. These corridors will have two way travel, but their width will permit faster moving vehicles to easily pass by slower vehicles.

To facilitate the task of moving the equipment underground through narrow shafts, the equipment shall be capable of being broken down into modules 8 x 8 x 10 feet and reassembled. The drilling mast, however, may be 10 x 3 x 5 feet.

The environment of the mine will be a combination of the basic mine environment and that of the surface area above it because of the circulating ventilation air. The mine ambient temperature may range from 20^{o}F to 115^{o}F with locations near the intake air getting cooler for Northern mines. The rated storage temperature for a drill would have to be from -40^{o}F to +130^{o}F to cover transportation from the factory for the general case. The humidity of the mine would be dependent on the outside air to a large extent and could range from 5% to 95% relative humidity. The levels of dust in the air could be quite high locally due to the mining and drilling operations, but will have to meet MESA standards of 10 milligrams per cubic meter.[1] To meet these limits, special care must be taken in the design of drilling, loading and haulage equipment. This is especially critical in view of the restrictions on the use of water.

Salt mining generally does not require explosion proof equipment or equipment approved by MESA for use in gassy mines. Salt does not oxidize, therefore its dust cannot burn or explode. Generally, domed salt contains methane only at the edges which are avoided for other mining reasons. Some exceptions have been noted in the Winnfield dome in the Northern Louisiana area.[2] Some salt deposits contain small pockets of methane which can be hazardous if they are ignited before they are dissipated by the ventilation system. These features are discernible by exploratory drilling before developing a mine. Considering the problems in procedures and practices, design of the mine equipment to be used, etc., presented by operating in gassy mines, it is well worth the effort to avoid the issues rather than accommodate them. Therefore, the program has been pursued on the basis that the mines will be nongassy.

The number of holes to be drilled for direct storage of spent fuel elements are:

January 1983 to June 1984	-- 50,650 holes
1988 to 2000	-- 32,000 holes/year

Prototype drills will be needed in 1979 at the earliest.

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[1] MESA advises that an analysis of trace elements may be needed and that this limit may be reduced.

[2] Kupfer, D.H., "Structure of Salt in Gulf Coast Domes," Proceedings - Second Symposium on Salt, 1962, Northern Ohio Geological Society, Inc., Cleveland, Ohio.

3. DRILLING SYSTEM DISCUSSION

3.1 The Drilling Operation

The drilling operation can be broken down into the following processes:

(a) Starting the hole (spudding in)
(b) Cutting the rock chips
(c) Cleaning the cutting face
(d) Lifting the chips (bailing, mucking out)
(e) Loading onto the haulage vehicle
(f) Break down, moving and setting up at the next hole.

As with any system, all the steps are interrelated to some extent and some steps are more important than others. Also, there are many types of equipment that can be used to implement these processes which provide a variety of combinations of practical candidate drilling rigs. In the final analysis, the common denominator is cost. In order to provide a better understanding of the available hardware and how it can be used for this application, some of these steps will be discussed.

3.1.1 Starting the Hole

Starting the hole is important from two aspects - exact location of the hole and the starting of the bailing of the chips. Presuming the drill has been spotted within three inches of the target location and has been leveled, the exact location of the hole may still change slightly. Because rock bits cut very coarsely and their teeth are widely separated, and because the floor of the mine is not necessarily level and smooth, one of the cutter teeth will engage first providing a horizontal force shifting the drill slightly. This shift can be lessened using bushings on the bit or on the drill stem.

Continuous bailing systems using compressed air or vacuum to convey the cuttings out of the hole depend upon fixed air paths with fixed cross section to develop sufficient air velocity to entrain the cuttings. Compressed air would blow the cuttings into the air while vacuum may not move the cuttings at all, and they will plug up the bit. (These problems do not occur when augers or buckets are used.) A frequent practice has been to excavate a starter hole by hand or to remove the cuttings by hand until the drill systems are operating. Because of the number of holes to be started, however, this method should be avoided.

Bit design can provide considerable help with all of these problems. If the bit is conically shaped, then the leading tooth would have a small moment arm to offset the drill string. The further the bit advances, the more it is stabilized by the wall of the hole. Also, if the bailing ports in the bit are located near the center, then the ports would be buried into the hole quicker for a conical bit, hence the bailing would be started earlier. The rotation speed and downward speed of the drill should be infinitely variable between 0 rpm and the maximum speed of each drill type.

3.1.2 Cutting The Salt

3.1.2.1 Specific Energy

Cutting of salt, or any rock, can be discussed in terms of the input power or energy needed to cut a given volume of rock using a given bit configuration. This relationship has been empirically determined using a factor called "specific energy" and is used in the expression

$$CR = \frac{2\pi NT}{J}$$

where CR is cutting rate (volume)
N is rotation rate (revolutions per minute)
T is applied torque (length x force)
J is specific energy (length x force/volume).

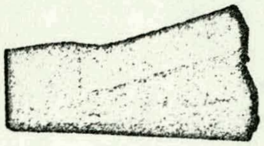
The specific energy has been shown to be from 0.5 to 1.0 times the compressive strength for picks and for disc or milled tooth roller cutters. The maximum compressive strength of salt has been assumed to be 6000 psi. Thus, calculation of the cutting rate can serve as a basis for comparing theperformance of various systems. (Other, more complicated means of calculating cutting rates are used; however, the one described here seems sufficient for the purposes of this study.) Thrust does not enter into these calculations.

3.1.2.2 Rock Cutters

For soft rocks, there are three types of cutters that are efficient. They are pick cutters, milled tooth roller cutters and disc roller cutters (Figure 2). Pick cutters are normally used for softer rock and soils, and seem ideally suited to salt. Roller cutters are used when rock becomes harder, the crossover point between pick and roller being nebulous but ranging from 6000 psi to 12,000 psi compressive strength. The cutting action of the two types are different. The pick scrapes, gouges and chisels the rock causing mostly tension failure in the strata. Roller cutters bear into the rock causing first compression failure immediately under the tooth pulverizing the rock and providing relief for tensile stresses in the strata which in turn breaks off chips (Figure 3). Pick cutters require high torque and low thrust while roller cutters require low torque and high thrust. Roller cutters can be skewed so the teeth also gouge the face somewhat.

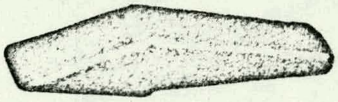
Disc cutters are another type of roller cutters which penetrate the same way. However, they are arranged on the bit to cut even, concentric grooves on the face which produces large

842-006



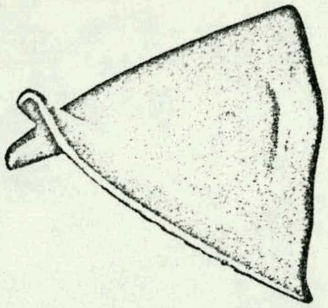
A crimp-on type tooth, relatively rugged but not reversible. Wt. 1½#

845-004



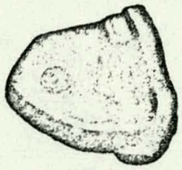
A loader type shank with indentation in body for tooth to be peened-on to hold it fast. Wt. 2½#

843-001



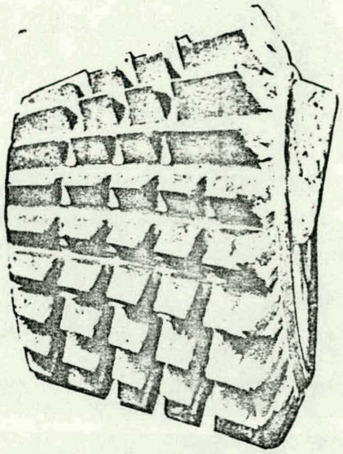
A small fishtail, used as pilot in standard digging conditions. Wt. 3#

845-013

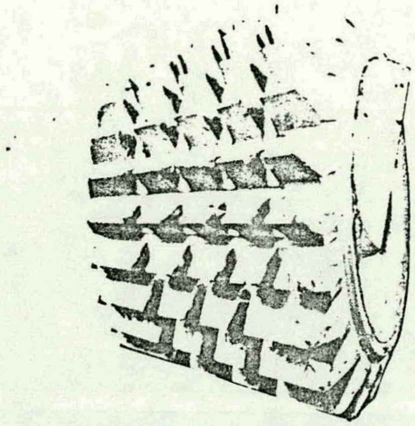


Weld on drive lug for small fishtail (843-001). Wt. 1½#

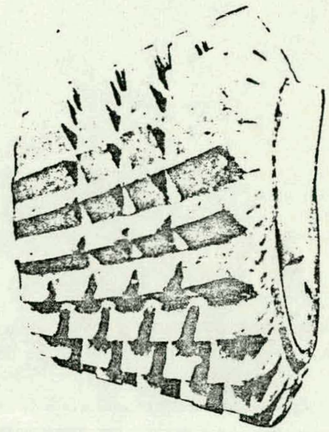
Pick Cutters



GTA TYPE 2 LEFT GAGE CUTTER

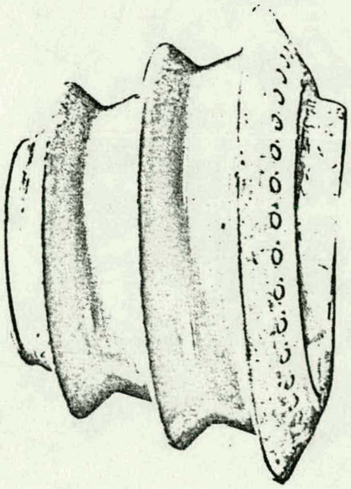


GTA TYPE 2 STRAIGHT GAGE CUTTER

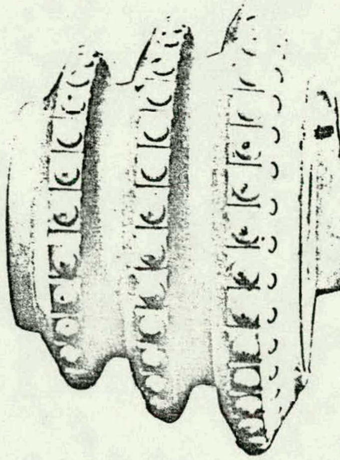


GTA TYPE 2 RIGHT GAGE CUTTER

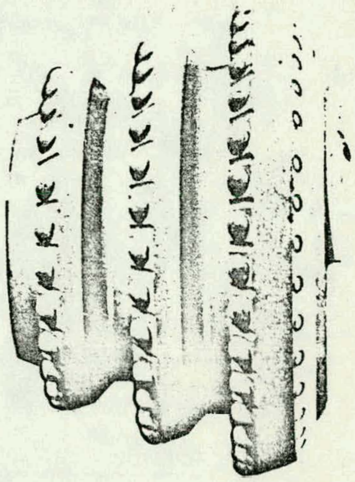
Milled Tooth Roller Cutters



GTA TYPE D3 DISC CUTTER



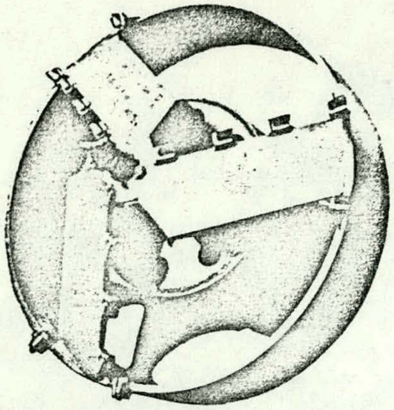
GTA TYPE D9 NO. 1
INSERT DISC CUTTER



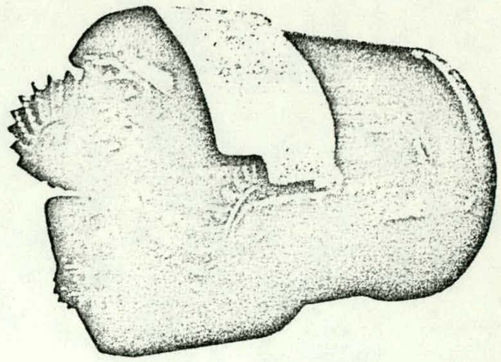
GTA TYPE D9 NO. 2
INSERT DISC CUTTER

Disc Roller Cutters

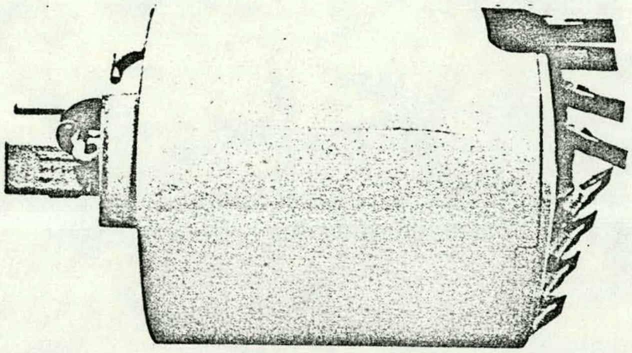
Figure 2A. Three Cutter Types



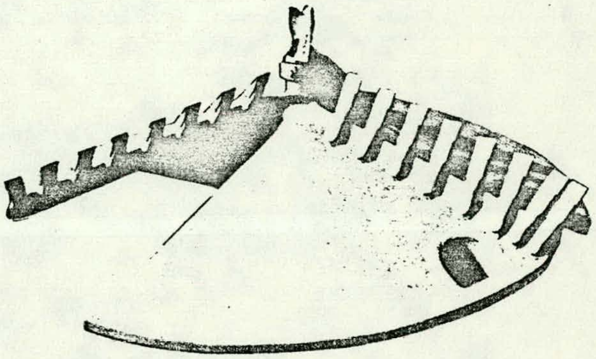
Drag bit for reverse-circulation operation.



A 31" flat bottom bit.



Calweld heavy-duty drilling bucket, equipped with Calweld all-purpose insert teeth.



Extra-heavy duty, large-diameter bucket-bottom with flaps, Calweld's shanks, teeth and fishtail.

Figure 2B. Bit Bodies

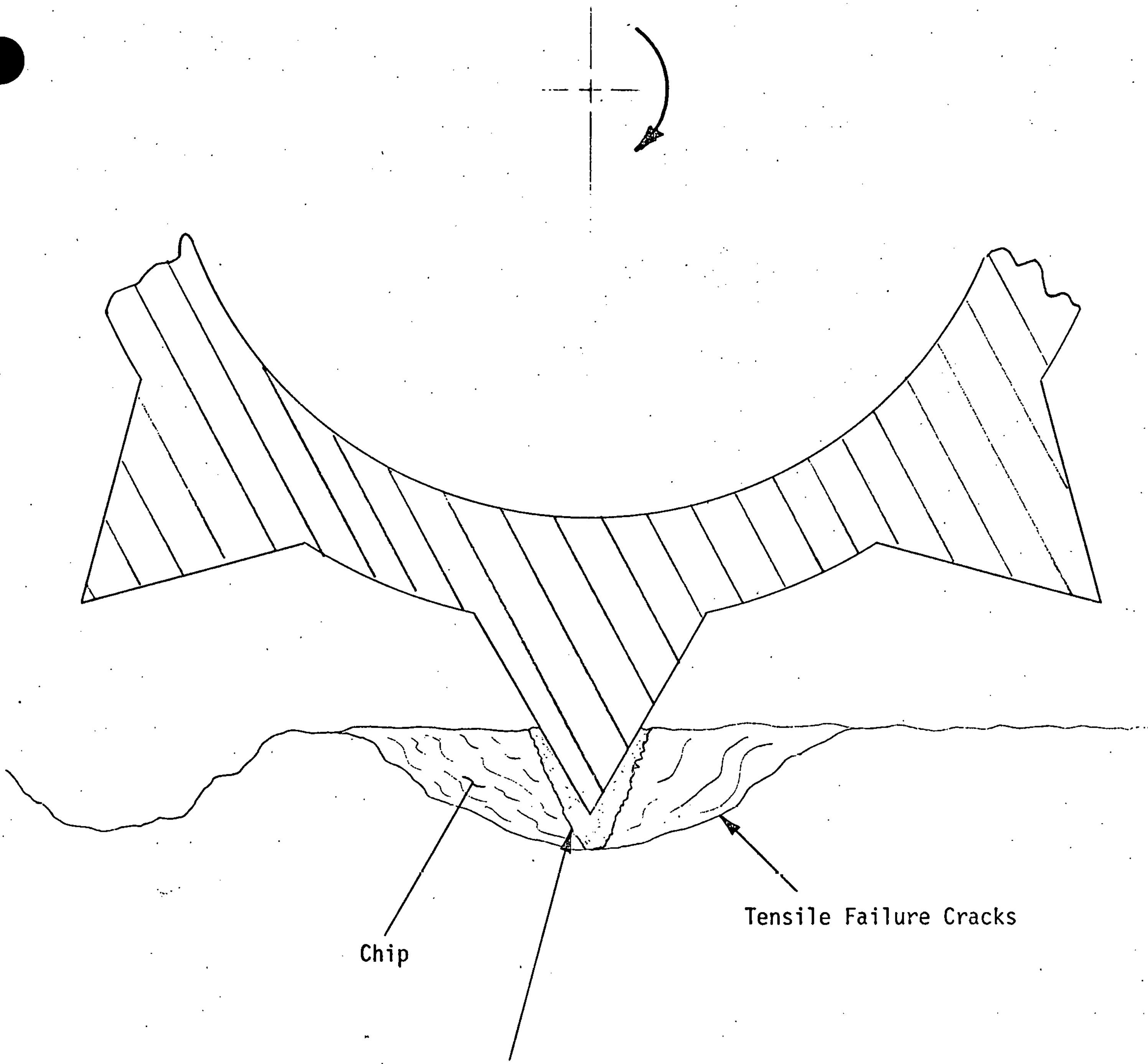


Figure 3. Roller Cutter Cutting Mechanism

chips. These chips are hard to remove and are frequently reground. Because of the chip size, disc cutters are usually used only with drilling mud which bails heavy chips much easier than air streams.

3.1.3 Cleaning The Cutting Face

The chips cut from the rock face must be moved into the bailing system in some manner. For bucket drills, the cuttings are forced into the bucket through a slot in the bottom, the teeth providing wedges and later cuttings forcing the earlier cuttings through the slot, to fill the bucket and be carried away during the disposal cycle. The throat of an auger is filled in the same way; however, friction of the cuttings on the walls moves the cuttings up the flights.

Circulation bailing systems are more complex. The cutters work the chips the same as for the bucket and augers above. However, the chips in this case must be entrained in the air stream, which requires a certain threshold air velocity dependent upon chip size, shape and density. For practical reverse circulation systems, this threshold velocity is reached only near the air ports in the bit body. The chips must then be conveyed by other means to the ports. The air flow does help to move the chips. Frequently, sweep arms are welded to the bit body which gather the chips into the port. Air jets can be positioned on the bit body to direct the chips. Also, the shape of the port is long and narrow and sweeps the face each revolution. Gravity can be used effectively by making the bit face conical.

The ideal situation, of course, is to clear all the chips from the face before they are reground. If the chips are too big, they must obviously be reground before they can be entrained in the air stream. If too much regrinding occurs, then the system loses too much energy, and sometimes the chips pack between the teeth reducing their effectiveness (called balling). The net effect is a reduction in the penetration rate.

3.1.4 Lifting The Chips (Bailing)

Chips or cuttings can be bailed from the hole by lifting them out in a bucket or caught in the auger flights, by raising them on the auger flights or by entraining them in circulating air. Bailing by bucket or by short auger requires the drill tool be raised to unload cuttings, thus detracting from the drilling time. The continuous auger solves this problem as long as there are new cuttings to feed the throat. However, once the full depth of the hole is reached, the auger must be removed[3] and many of the cuttings fall back into the hole. These cuttings must be removed some other way or the hole must be overdrilled in length to allow for the dropped cuttings. Also, the power used to raise the cuttings must be delivered through the rotary drive, adding to its already heavy load.

Circulating air systems clean the hole continuously, reducing the time per hole, and can be implemented either with compressed air or with vacuum. Further, the air can be circulated either directly (air flowing into the drill stem and out the annulus), or in reverse circulation. Also, compressed air can be used to create the vacuum by venturi action or jets. Finally, dual concentric pipes or pipes with added feed lines can be used to establish the air circulation. See Figure 4.

As a rule of thumb, an air velocity of 4000 feet per minute is needed to lift cuttings. Since the area of the drill pipe is smaller than the area of the annulus, less volume of air would be needed to reach this level for reverse circulation. As the hole diameter increases, this factor becomes more important. Reverse circulation by compressed air would require

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[3] Contrary to theory which states that a properly designed auger can clear itself of chips by continuing to rotate, practical drillers indicate these cuttings will not be raised with no material behind it in the auger throat.

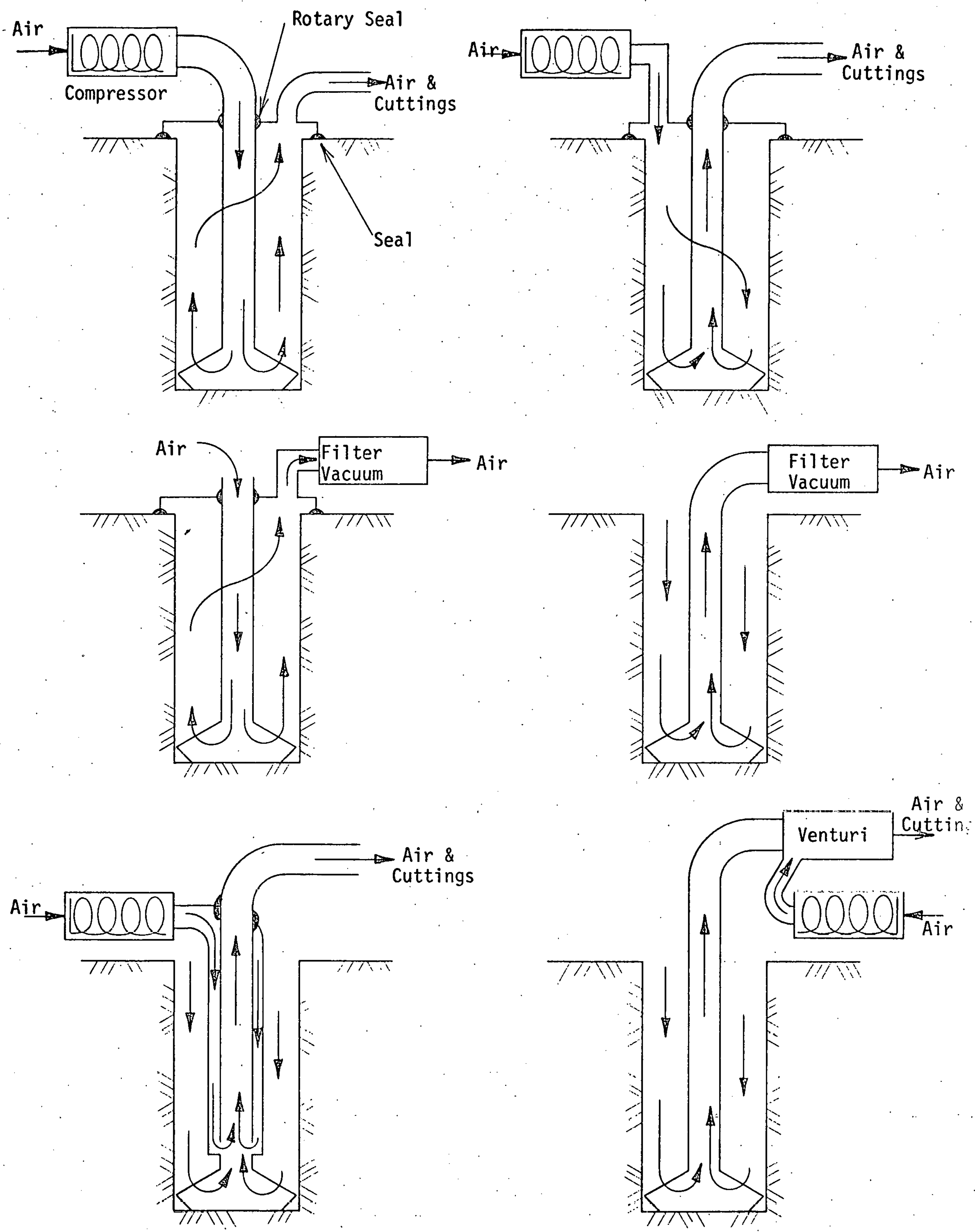


Figure 4. Circulating Air Schemes

a seal at the top of the hole while the vacuum could be used without a seal. Both the duo tube or auxiliary pipe and the venturi system are driven by compressed air creating a vacuum for chip transport and can also be used without sealing the hole. However, they both need extra space at the top of the hole where space is quite precious.

3.1.5 Loading onto the Haulage Vehicle

Once the cuttings are bailed from the hole, they must be loaded onto the haulage vehicle. For a bucket drill, a conveyor with a surge hopper input to accept the cuttings and a chute output to direct the cuttings into the haulage vehicle is the simplest approach.

An auger is more complicated since, for a short auger using a disposal cycle, the cuttings are lifted from the hole on the auger and spun outward to clean it. This process makes cuttings pick-up rather difficult. Compressed air could be used to clear the auger rather than spinning it, and could also be used to convey the cuttings into the haulage vehicle. The same techniques could be used on the continuous auger, also.

Compressed air circulating systems blow the chips out of the hole. If the air is channeled through a hose at the top of the hole, it can be directed to the haulage vehicle. The hose would be connected to a diverging nozzle where the velocity of the air drops due to the enlarged cross section and the chips will fall into a bin. This is a fairly dusty method and frequently water sprays on cloth filters are used to suppress the dust.

A vacuum system would present other difficulties. The vacuum system must be filtered and sealed, and it must be located at the end of the cuttings' path, namely at the haulage vehicle. Thus special vehicles which provide a sealed container to empty the vacuum filter would be needed.

3.1.6 Moving to the Hole, Setup and Breakdown

These steps appear to be the simplest of the six. All drilling rigs are portable but in varying degrees. Bucket drills and auger drills are usually truck mounted for land use because the holes they drill are shallow, rarely penetrating rock very far, and hence many holes (in many sites) are needed to justify the equipment. Raise borers are usually skid mounted because they are set up at one site for a long time, drilling deeper and larger holes, and the transport vehicle can be used for other work while drilling is being done. For underground use, the space limits of a mine require that riase borers be modular for transport into a mine and in this regard, a drill transport vehicle would be extra equipment serving no function. Also, the size of the larger borers would tax a single truck. On the other hand, some smaller, lighter duty models have been produced for special purpose applications which are crawler mounted or which are provided with a separate crawler transporter which is detached while drilling.

The transport base can be wheeled or crawler mounted, both providing adequate flotation to prevent scarring of the mine floor. Rubber-tired vehicles can be steered either by turning the wheels as in conventional trucks or by squirming (locking one set and driving the other set - loose salt on the floor provides a natural lubricant in this case). Steered, wheeled vehicles move faster because they are designed for highway use and yet can be maneuvered along a straight line or around turns easily enough. Squirmed vehicles, whether wheeled or crawler, are slower in tramming. This is important only between rows of holes or between rooms. However, they can be positioned more precisely. Positioning would be important if an error were made in moving between holes and the drill were misaligned on the first try, or if the hole pattern requires holes closer to the rib than five feet or closer to the end wall than twenty feet.

If the mine development plan were such that the drills had to pass over holes after drilling them, then there would be no standard truck bodies of sufficient size that would not cause the wheels of the truck to pass over the edge of the hole, causing not only a hazardous situation to men and equipment, but also incurring rework to or loss of the hole. Crawlers, on the other hand, are available on frames such that the track can pass between holes on four foot centers. The distance between tracks can be changed easily if specials are needed. Tracks also can easily span the edge of a hole with little danger or damage in case of a steering error. Narrower vehicles can be built with tracks which permit them to get closer to the rib. Since crawlers are more compact than wheels, the space available above the crawlers is greater for packaging equipment. Also, crawlers can easily be built with a slewing joint between the transport frame and the drill rig so the rig can be rotated to the side to accommodate drilling closer to the rib in some cases. Finally, wheeled vehicles have two engines while crawlers would use only one engine for both drilling and moving. All of the manufacturers solicited recommended crawlers for the reasons above. In spite of the overwhelming flexibility provided by crawlers, it should be emphasized that rubber wheeled vehicles are entirely adequate for the base line case except for the modular size requirement. It is only when changes to the comparison criteria are considered that the crawler mount becomes technically preferable.

Set up and break down are basically the reverse processes. After the rig drilling center line is positioned over the hole site, the drill is plumbed using hydraulically operated stabilization jacks. Level indicators at the operator's station will facilitate this operation. All drills can be trammed at low speeds without folding down the drilling mast. (It seems the only time this folding feature will be used is during initial installation, trips to the maintenance shop which should be infrequent since most maintenance will be done on section, mothballing storage or extended place changing. For some units it is conceivable that the mast will be folded only four times in its entire lifetime. If it were not already a part of standard design, it might not be worth the added cost.)

3.1.7 Other Equipment Considerations

In addition to the drilling steps and the key equipment features that affect them, there are other equipment features that must be considered. These features are:

The rotary drive and drill stem and thrust
Stem handling equipment
Attitude adjustments.

3.1.7.1 Rotary Drive and Drill Stem and Thrust

The rotary drive, the drill stem and the thrust equipment are so closely related they should be discussed together. There are two basic drives for rotary drills. The first is a power swivel which is connected to the top of the drill stem. The torque motor is mounted on the swivel and either drives the drill string directly or through a gear train. The motor is reacted through a crosshead to the drilling mast. Thrust is provided either by cylinders, sometimes with reaved cables, or by drum driven cables moving the crosshead. These arrangements can be used with all of the drill types discussed.

The other rotary drive is a rotary table which has a square hole through which a square piece of drill steel called a Kelly is passed. The Kelly is connected to other drill steel or to the drill bit and it is free to descend as the hole is drilled. The Kelly is hoisted or lowered by cables suspended from a derrick. Thrust is provided by dead weight, or by hydraulic cylinders acting against clamps on the Kelly, or by a powered crosshead as above.

An interesting innovation on the single Kelly is a telescoping Kelly. The added sections provide for drilling a greater depth hole without extending the height of the mast. Some telescoped sections are latched together when extended while others rely on friction under torque to keep the sections locked. The smaller sized tubing used for the inner sections may reduce the maximum allowable torque, however. It is also possible to seal the joints between sections to provide circulation bailing.

3.1.7.2 Stem Handling Equipment

Stem handling equipment is for the most part mechanized. Drill pipe is grasped between pressure pads while auger flights for continuous augers are grasped with larger pads or hooks on cable. Considering the number of times an auger would be handled in a day, the hook handling of the flights is rather slow. For torquing purposes, the pressure pads should be replaced by wrenches on flats on the steel because the pads slip and wear the pipe. The storage of pipe or augers can be in linear racks or on a carousel.

3.1.7.3 Attitude Adjustments

Attitude adjustments of the drill rig include base positioning and mast tilting. Stabilization jacks are used to level the base of the rig. Some rigs provide rotary slewing and front-to-back slewing. All mast rigs tilt front-to-back while some also tilt sideways. The bucket drill is the only one that cannot drill on an angle.

3.2 Safety

From a safety standpoint, two men will have to be present during all operations of equipment, thus defining the minimum crew size. Communications and fire fighting equipment will also be needed but is not considered a part of this study. Scrubbers will be needed on any diesel engine exhaust, and these engines must be MESA approved. Gasoline engines will not be allowed. Holes around the working area will be covered to prevent men and equipment from falling into them. A canopy should be positioned directly over the operator's station at the control panel to protect him from roof falls. This is especially important considering that the drill will have to jack against the roof to provide sufficient reaction against the thrust of the drill.

Because miners prefer to have more than one escape route and prefer not to work continuously between equipment and blind entries, it is preferred that the drill will be inby of the operators.

3.3 Noise

Noise in the drilling area will be a particular problem. Operators will probably be subjected to it for six hours out of the eight hours they work. The OSHA limit for this period is 92 dba. Considering all of the drilling equipment, ventilation equipment, haulage equipment and the close confines of the storage room, some measures will have to be taken to protect personnel.

3.4 Other Considerations

It is not clear that the split between the mining process and the emplacement process should occur after drilling. On the one hand, the walls of the hole are bound to slough, filling the bottom of the hole unevenly and leaving an uneven surface. The sloughed salt will absorb moisture from the atmosphere and solidify if left long enough which may require dressing the bottom of the hole before installing the sleeve. Before insertion of the sleeve, any loose salt will have to be removed to prevent it from falling under the sleeve and upsetting the vertical registration. Also, this sloughed salt will leave recessed voids which will be harder to backfill. Finally, the drilled salt will have a random distribution of particle sizes which will not need crushing before being used for backfilling, while mined salt and salt left to stand and absorb moisture will require additional processing before it can be used for backfilling. If the sleeve is installed right after drilling, the operation will be much cheaper.

Another point to consider is that the blind end storage room may not necessarily be the best layout from an operational or safety standpoint. Ventilation is much more complicated. During mining, ventilation and dust suppression at the face are inescapable problems. However, during the drilling, emplacement and inspection procedures, the portable blower and duct work would not be needed if both ends of the room were open. Haulage loading is also more complicated. With one entrance, either the drill has to be inby of the hole for direct loading of the haulage vehicle, thus causing the drill to drive over the holes, or both the drill and the haulage are outby of the hole causing extra equipment being needed to carry cuttings around the drill. From a safety standpoint, it is always desirable to have two escape routes away from a work area in the event of fire or a roof fall. Most miners do not like to work inby of an operating machine continuously and if a system were set up this way, eventually they would find a way to change it. Access to the holes for emplacement and inspection would obviously be enhanced especially in the event of an accident.

4. AVAILABLE EQUIPMENT

Of all the types of drilling rigs available, there are two groups that stand out for this application. One group is raise borers and the other group includes bucket drills and auger drills. Raise borers are compact, heavy duty drill rigs used to drill small diameter, blind pilot holes and then back ream them to very large diameters. They are applied to drill large ventilation or man and materials shafts, both underground and on the surface. Hence they are set up for extended periods in one place that may be cramped for space. They are generally portable, but not mobile in the sense of providing their own carriage (although a few do just that). They are customarily powered electrically from an outside source. The power pack, operating controls and drill rig are usually separate units. Since these rigs are usually used to cut hard rock, they are equipped with roller cutters, which require very high thrust. The pilot hole diameter is small so the torque is low while the speed is high, and the rig is fitted for direct air or water bailing. For raise reaming or boring, the torque is very high while the speed is very low, and the bailing is done by gravity. For the emplacement hole application, only the blind drilling mode would be used.

The other group of drills, bucket and auger drills, are intermediate to light duty rigs used to drill smaller holes in soil and soft rock for pilings, post holes, cisterns, etc. The holes are short and most commonly under 3 feet in diameter.

They use drag bits which demand higher torques and lower thrust than roller cutters. They usually operate on a disposal cycle which means the operators cut the strata enough to fill the bucket or a few turns of the auger flight and then hoist the tool out of the hole to empty it. The bucket swings out to the side and the bottom opens, while the auger is spun quickly and the cuttings fly off it and land in a ring around the top of the hole. A continuous flight auger is also available but is rarely used for many operational reasons and is not competitive in this application. These rigs are generally mobile, having their own motive power and drive power so they can operate for a short time drilling a few short holes, and then move quickly to a new location. Figures 5, 6 and 7 show these various drilling rigs.

4.1 Standard/Nonstandard Rigs

The market was surveyed to determine what features of these rigs are available, to match them to the application, to determine their cost and to asses their reliability. As might be expected, none of the standard catalog items exactly suited the application. It is quite clear, however, that components of various rigs have frequently been assembled for custom purposes by nearly all manufacturers. Most manufacturers are willing to make changes in varying degrees to optimize their equipment, although all are emphatically reluctant to use components with which they are not familiar.

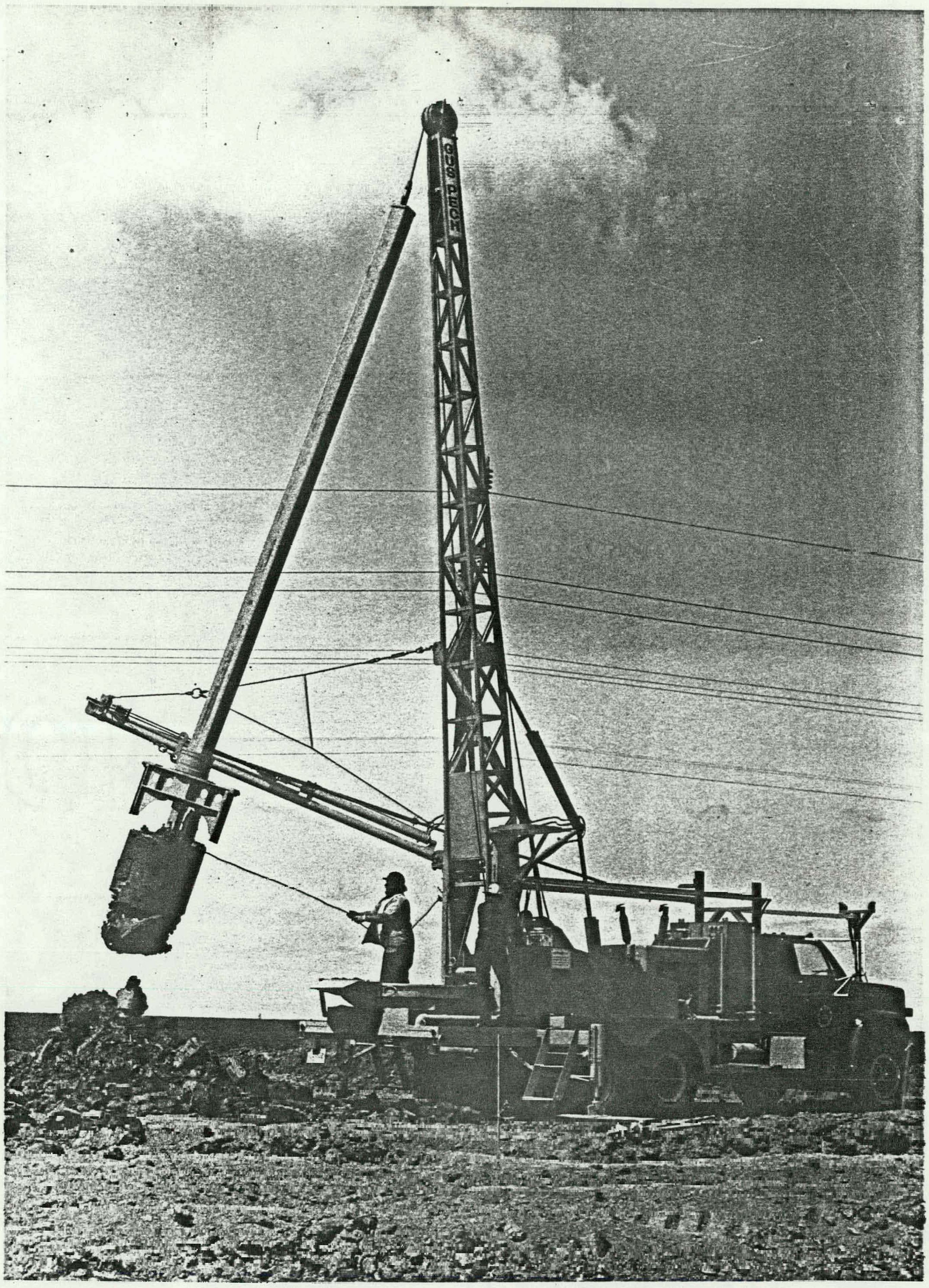


Figure 5. GUS PECH Bucket Drill Rig

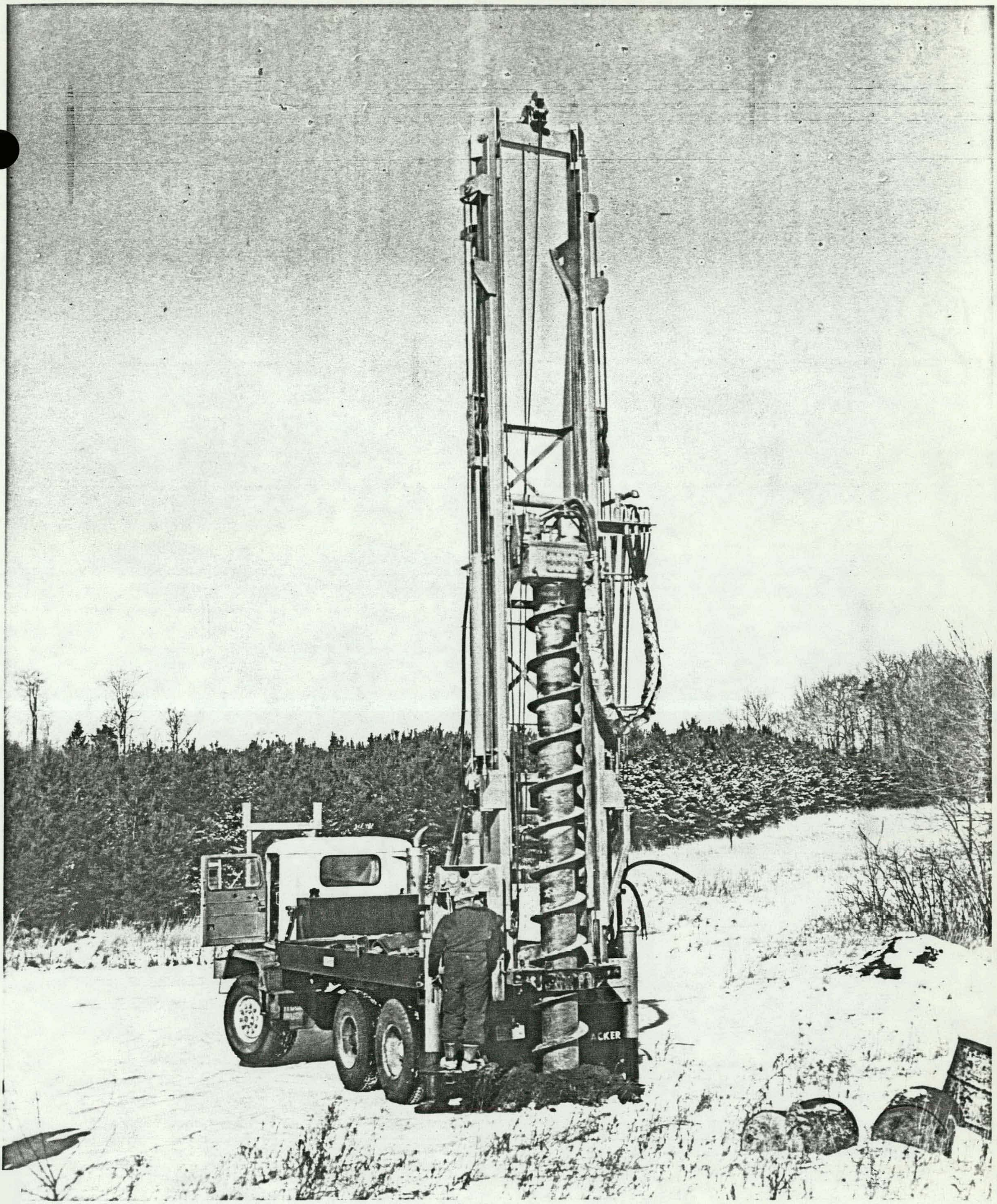


Figure 6. Acker Continuous Auger Drill Rig

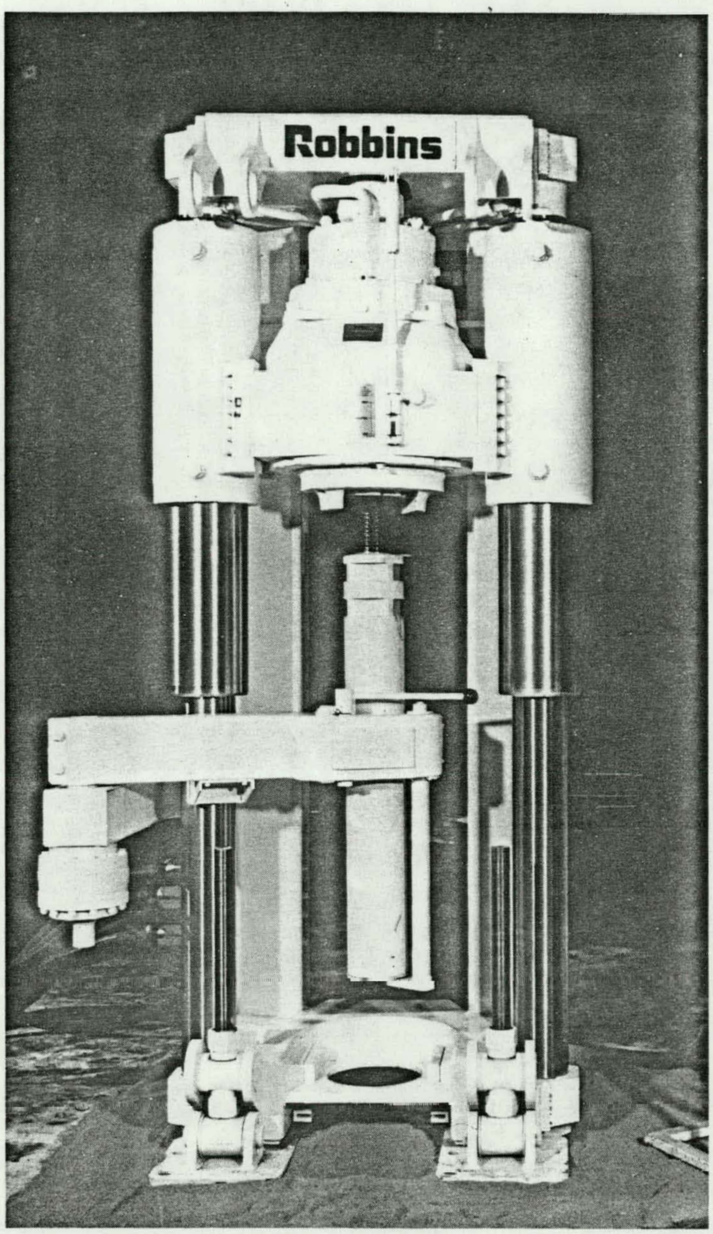


Figure 7. Robbins Raise Borer

Many of the suggested rigs can do the job and all are sufficiently rugged and reliable for this service. The issues are efficiency, cost and safety. In the sections below, the equipment available from the eight manufacturers solicited and the modifications they offered to optimize the systems will be discussed. Data sheets and drawings submitted by these manufacturers during the program appear in Appendix A.

4.2 Raise Borer Discussion

Ingersol-Rand

Ingersol-Rand manufactures two raise borers. The smallest unit, an RBM6, is over 17 feet high without a carrier and is too tall for this application. This unit is one of the largest considered as it can apply 160 horsepower to the drill steel, which is twice the power from many other units. Ingersol-Rand is not interested in modifying their equipment and has no other custom rigs available for this purpose.

Robbins

Robbins manufactures the largest line of raise boring machines of all the manufacturers. They have recommended their Model 23R mounted on crawlers and using a vacuum, reverse circulation for bailing. Their concept is shown in Figure 8. The modifications to the standard 23R rig are:

- Add crawler mount with leveling jacks and roof jacks.
- Add pipe handler.
- Add vacuum bailing.

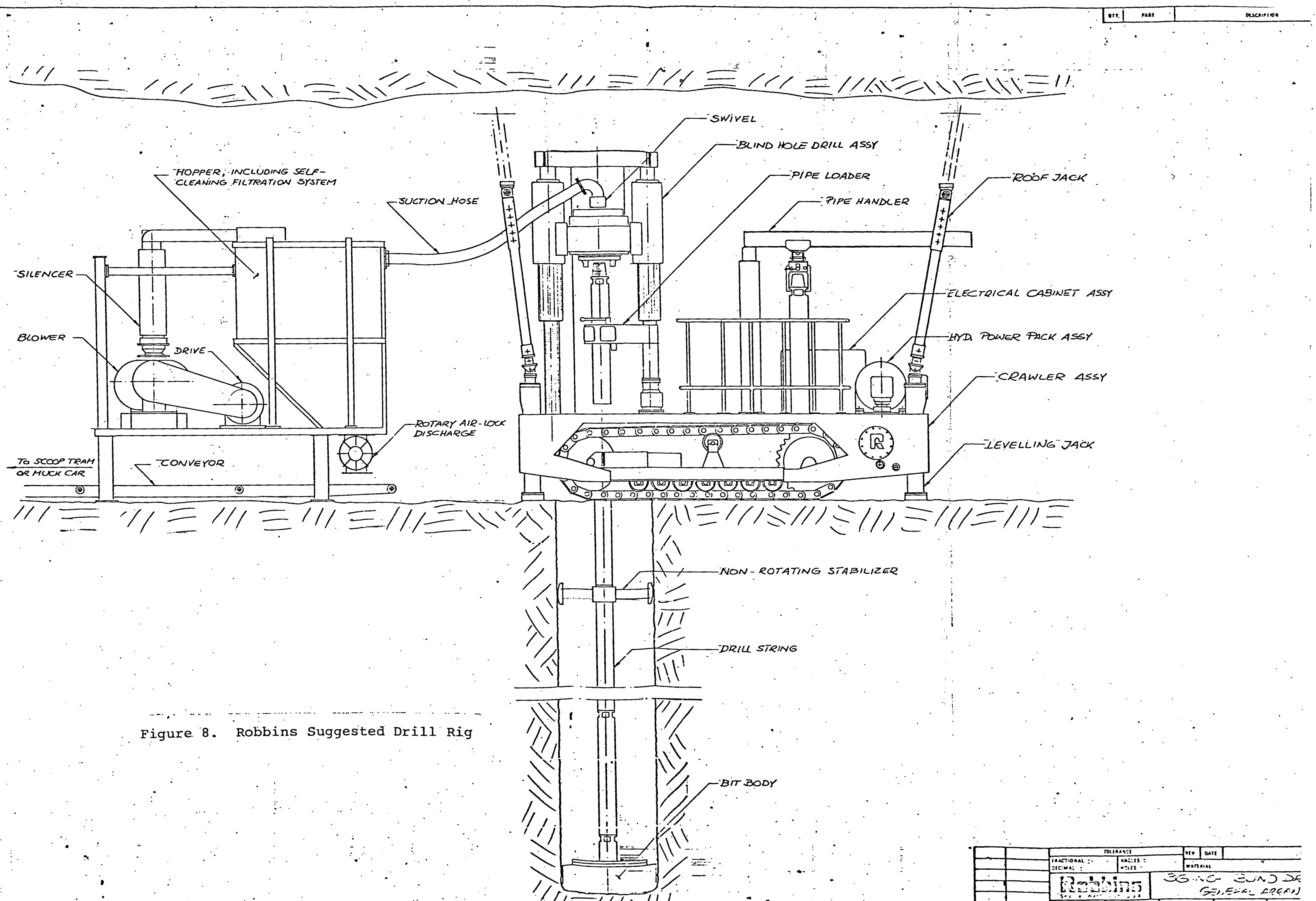


Figure 8. Robbins Suggested Drill Rig

- Attach controls.
- Change feed rate.

Other changes recommended that Robbins is willing to do at this time are:

- Add crawlers to the vacuum system.
- Add lights.
- Convert from air motors to hydraulic motors for the crawlers.

However, there are three major changes recommended that Robbins is reluctant to offer. First, it is recommended that the drill pipe length be increased from 4 to 10 feet to reduce the handling time per hole. Robbins objection is based upon the engineering time to increase the cylinder and leg lengths of the mast, and strengthen the cross head, crown plate and base supports required due to the increased lever arm. FMA considers this a reasonable viewpoint.

Second, it is recommended that a diesel generator set be added for prime power. Robbins' objections are based on the fact that this equipment is available in existing mobile units that can easily be moved on site and that there is not enough room on their carrier frames. Considering that the power and services plan for the mine has not been completed at this point, it is possible that electric power will be available for drilling. The cables required present a handling, maintenance and production problem and are considered undesirable, nevertheless.

Third, it was recommended that all equipment be mounted on one carrier frame. Robbins' objections here are based upon the fact they have experience only with this size frame and are reluctant to try a new one. This objection is understandable and appreciated. On the other hand, vacuum systems are commercially available that are one-half the size shown and still adequate for the task. Also, larger crawler frames are readily available in proven designs which would be a small risk and well worth the benefits to be gained. Also, the pipe handler rack shown holds 48 pipe joints while only 5 are needed. The use of two carriers is viewed as a serious drawback due to capital cost and operation complexity involving moving and cable and hose handling.

Dresser

Dresser manufactures two raise boring machines. The smaller unit, the Model 300, has the transmission mounted on the cross head. The transmission has a hollow spindle for circulation of air, but it is only 2.5 inches ID which is inadequate for this application, and the downward speed is too slow for this application. The Model 500 is 17 feet 9 inches tall without a carrier and would not fit into the mine.

However, Dresser makes a custom drill rig which they call a PRS Drill. (See Figure 9.) This rig is a combination of Model 300 components and other components from previous designs.

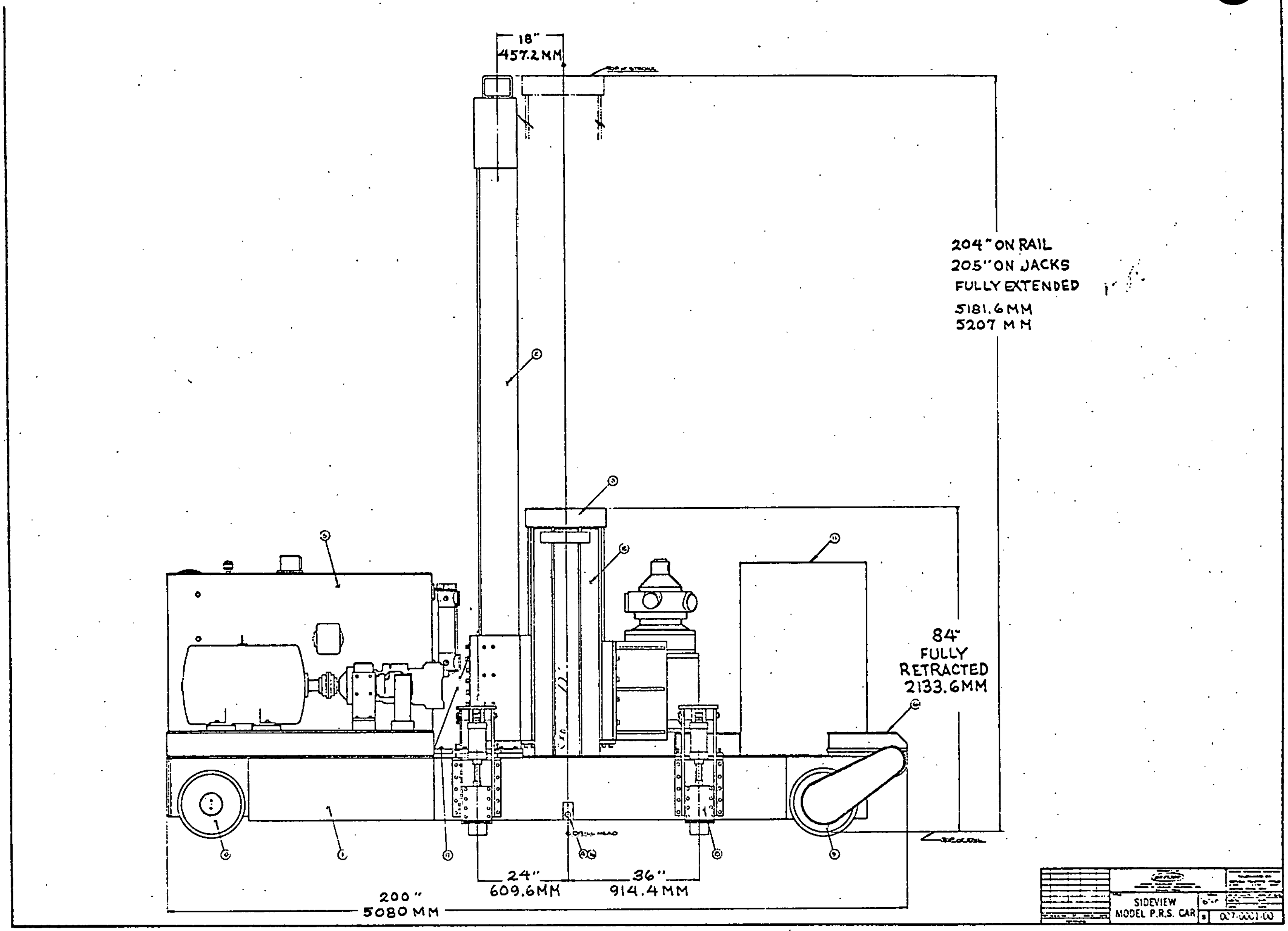


Figure 9A. Dresser PRS Drill Rig

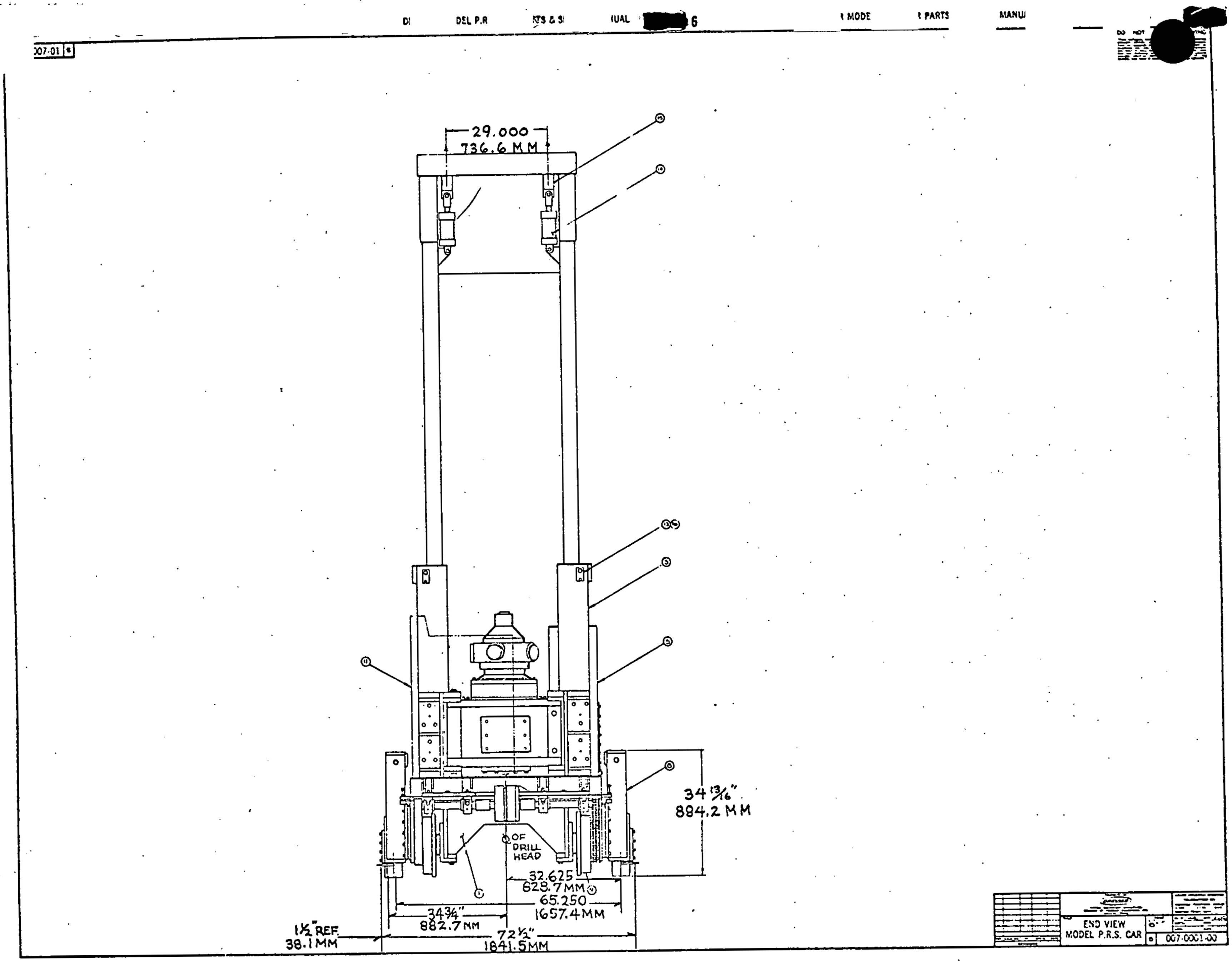


Figure 9B. Dresser PRS Drill Rig

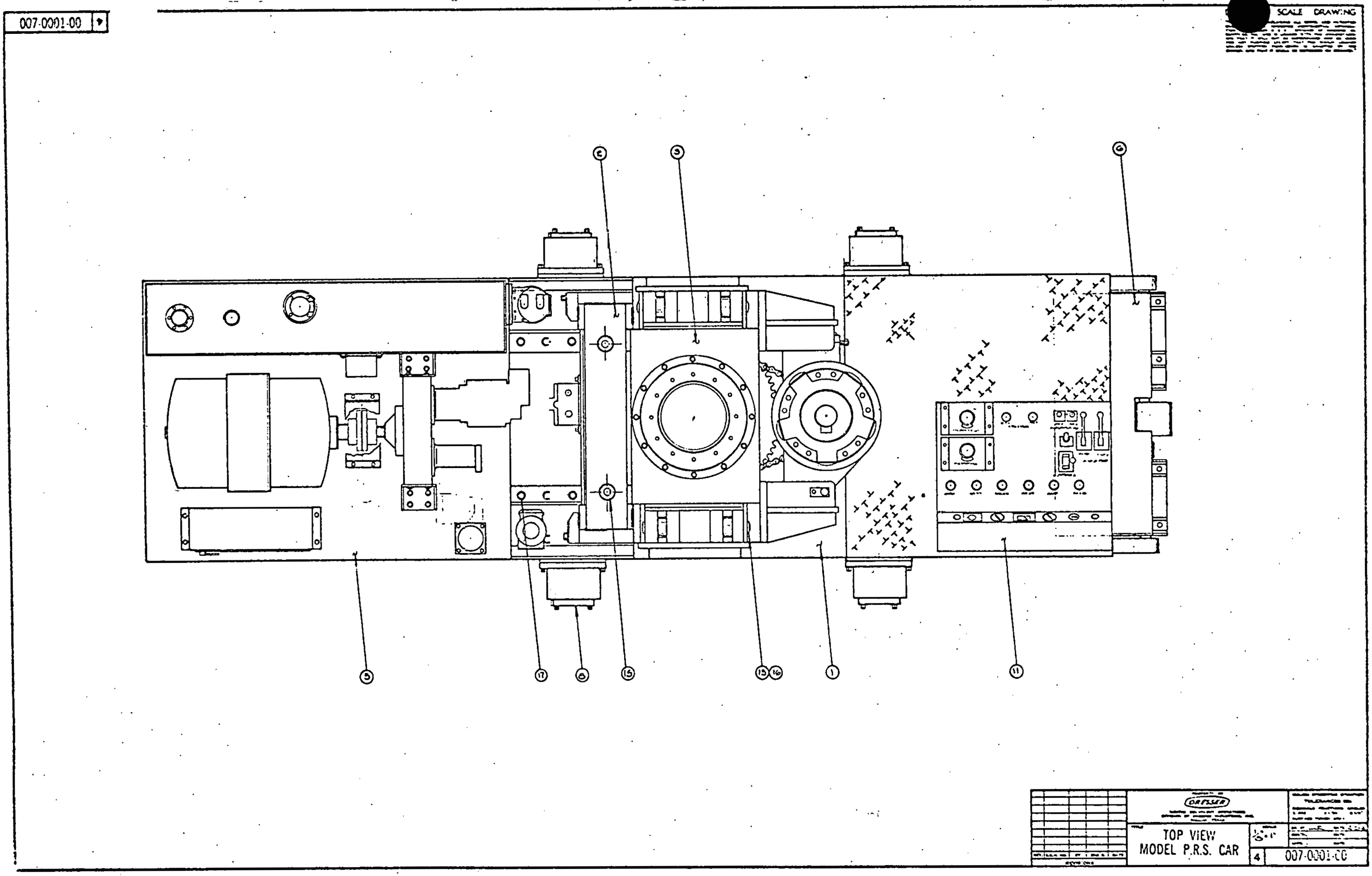


Figure 9C. Dresser PRS Drill Rig

This rig could easily be adapted by:

- Adding crawlers and stabilizer jacks.
- Adding diesel motor.
- Adding pipe storage and handling.
- Adding vacuum bailing.
- Adding roof jacks.
- Moving the mast to one end and making it fold.

Dresser states that the package will easily fit onto a 30 foot long frame.

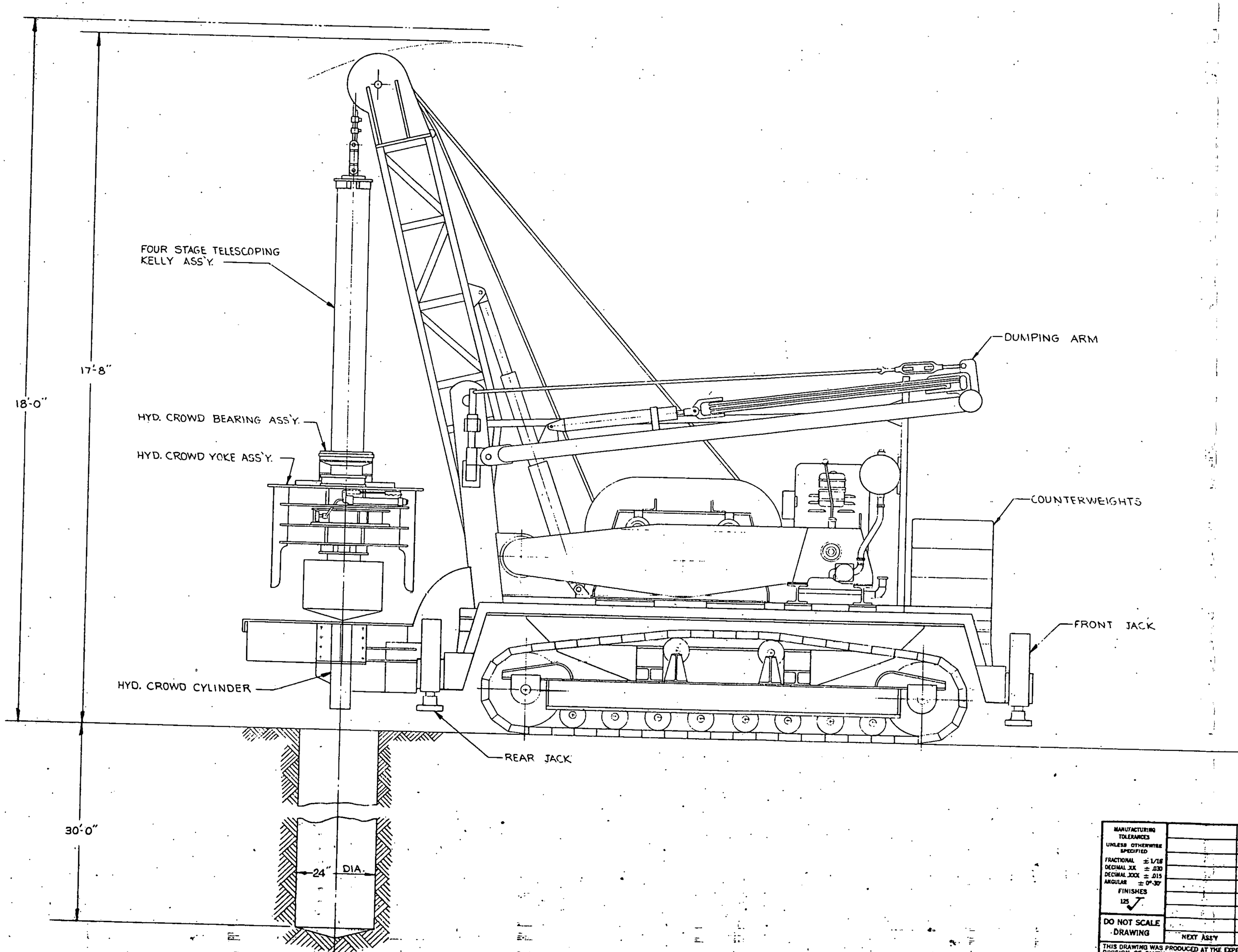
Subterranean

Subterranean, Division of Kennemetal, manufactures three raise borer machines. The Model 004 is slightly small for this application, although it was recommended by the manufacturer. The Model 005L seems to fit quite well however. The transmission is offset from the drill stem center line, permitting the longest section of pipe in the lowest height.

4.3 Bucket and Auger Drills

Calweld

Calweld has recommended their Model 150C Bucket Drill mounted on crawlers (see Figure 10). The shorter telescoping boom has three sections that will reach 35 foot depths. These are the only modifications which are required; all other features are met by standard options. Roof jacks will be required to react the thrust, and lights will be added. The only drawback seen with bucket drills is the fact that the operator must make and break the crowd cylinder mechanism, attach and detach



MANUFACTURING TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONAL ± 1/16
DECIMAL .XX ± .030
DECIMAL .XXX ± .015
ANGULAR ± 0°-30'
FINISHES 125

DO NOT SCALE DRAWING

NEXT ASS'Y | QTY.

ITEM NO. | NO. REQ'D | PART NUMBER | DESCRIPTION | WEIGHT

CALWELD
Division of Smith International, Inc.
9200 SORENSEN AVE. SANTA FE SPRINGS, CALIFORNIA

TITLE
MODIFIED 150C-CRAWLER MTD- W/HYD CROWD

DWN W.E.B. DATE 8/22/77
STRUC. ENG. FIELD ENG.
CKD DATE PROJ. ENG. SCALE
PRIORITY

HEAT TREAT
TOTAL WEIGHT
REV.
PART NUMBER
D-50015-009

the bucket bottom trip rope, trip the bucket and guide the Kelly yoke back into the rotary drive for every disposal cycle. This manual involvement appears dangerous. Another small point is that the bucket bottom is closed by dragging it across the edge of the rotary table. This would appear to be dangerous to the teeth on the bottom of the bucket.

Gus Peck

Peck manufactures three bucket drills that are generally similar to those of Calweld and appear to be just as adequate, and the changes would be the same.

Acker

Acker Drill Co. manufactures a large number of drilling rigs and equipment. They have recommended their Model WAII mounted on crawler tracks and fitted with circulation bailing. Figure 11 shows this rig mounted on a truck body. The modifications for this unit would be:

- Change to crawler mount.
- Add vacuum bailing.
- Add lights.
- Add pipe storage and handling.
- Shorten the mast.

Hughes

Hughes Tool Co. manufactures a standard line of Auger type rigs and has recommended their Model HD200. This rig has a

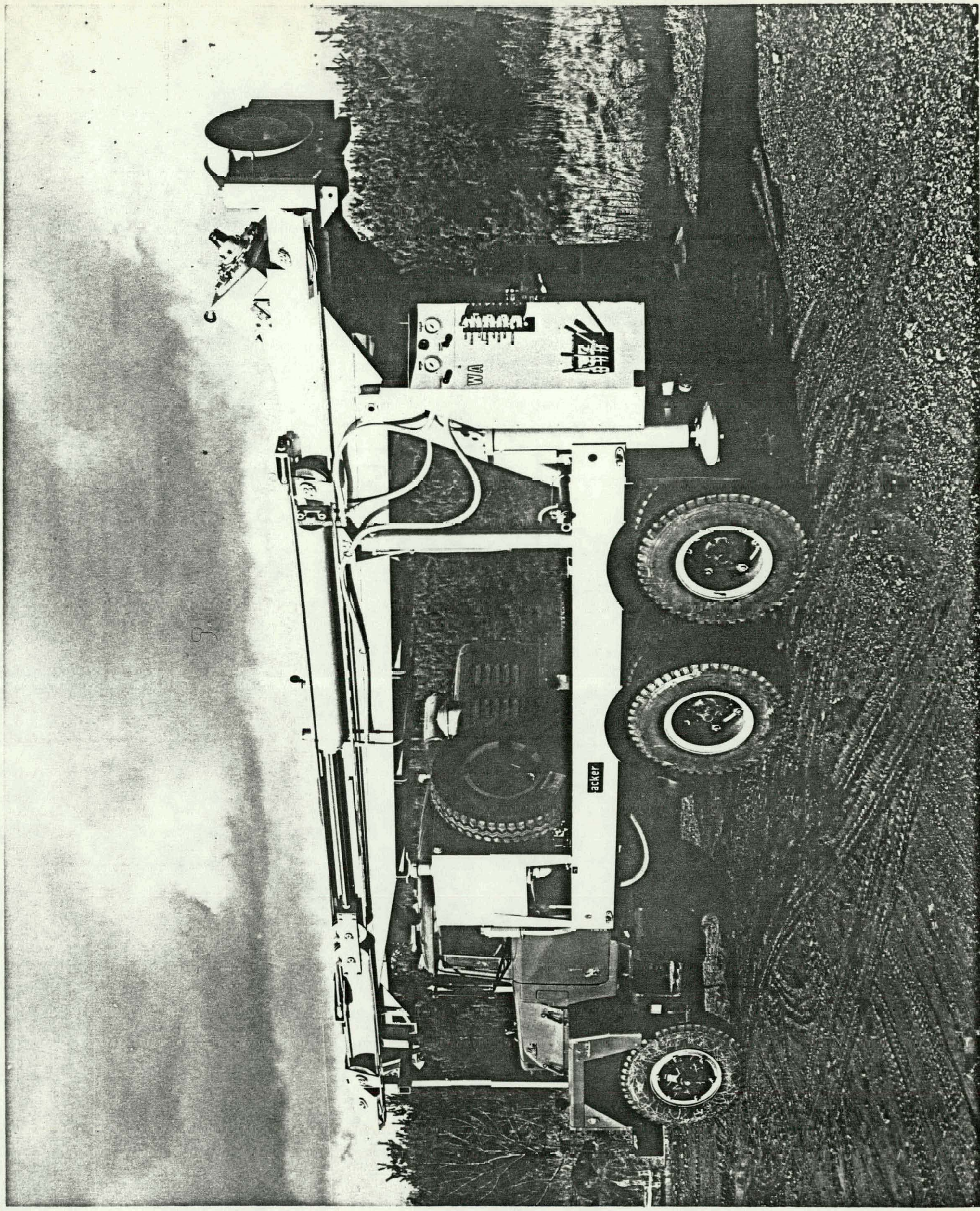


Figure 11. Acker WAII Drill Rig

telescoping Kelly. The modifications recommended are:

- Change to drill steel.
- Add pipe handling and storage.
- Add vacuum bailing.
- Change to crawler mount with roof jacks.
- Add lights.
- Shorten the mast.

Hughes also has walking beam designs which could be used to reduce the transport time between holes if the spacing is 4 feet. The beams can be moved while the main carrier is stabilized for drilling. However, if the spacing is greater, then time is lost. For instance, to move 17 feet would take about 12 minutes compared to 2 minutes for crawlers.

Hughes also makes a larger rig, Model LHD, which is slightly oversize but which might be adapted. It is similar in size to the Peck SGH 48 and the Calweld ADL.

4.4 Reliability

The raise borer machines are designed primarily for heavy duty, up-reaming operation with adequate design for drilling about 12 inch diameter pilot holes in hard rock with roller cutters. Consequently, the main frame consisting of the bases, guide pillars, crown plate and low speed torque and thrust equipment is very rugged and would be rated far in excess of the need for this application. However, the running gear for pilot drilling would be operated from one-half to full rated capacity and in some cases may need improvement or lower performance rates would be imposed. Also, the carrier, prime power and bailing equipment would be driven near rated capacity. As a result, the only benefits derived from the raise borer's ruggedness would be in the long life frame.

Electrically powered raise borers have little problems as long as the motors are a.c.; on the other hand, the major failure mode of d.c. systems has been the rectifier/control unit due to input spikes and overvoltage problems. The next major failure mode of all rigs is the hydraulic systems; the primary failures being components wearing out or dirty fluid or dirty filters. Manufacturers declined to point out any particular component, but motors and pumps were mentioned most frequently. Following this would probably be failure of drill steel or thrust bearings due to normal wear.

Auger and bucket drills are intermediate duty rigs well suited for this type of drilling service and would have the usual life of heavy duty construction equipment. In addition to the problems of hydraulics and thrust bearings noted above, cables would appear to be an early failure component. The telescoping Kelly bars and the derricks on a bucket drill would be driven the hardest. The reaving cables used with crowd or thrust cylinders would be more protected and have a much greater life.

All drills would be faced with the problem of lost teeth and shanks from the bits. In mines using continuous miners or chain saws, this would be well understood. The problem will be more prevalent in bedded salt where there are hard stringers and where there are very large crystals which do not fracture easily.

4.5 Summary Performance

The available performance ratings of the eight machines discussed have been tabulated below. The cutting rates were calculated using the method described earlier in this report. All of these drills can complete a hole within the one hour limit; a detail analysis of the operation times is shown in Section 5, below.

The two raise borers with the best performance are too large to fit into an 18 foot high storage room. They are the Ingersoll-Rand RBM-6 and the Dresser 500, and they are included because the 18 foot height may be changed later. Robbins also has units that fit into this category. Of the remaining drill units, the most significant fact is that generally the auger drill rigs and the bucket drill rigs have higher horsepower and torque ratings than raise borers have in the pilot drilling mode and are better suited to drag bits or pick cutters.

TABLE 2

DRILL RATINGS

	RAISE BORERS							BUCKETS		AUGER RIGS			
MANUFACTURER	*I-R	Robbins	Dresser	Dresser	*Dresser	Subterranean		Calweld	Pech	Acker	Calweld	Hughes	Hughes
MODEL NO.	RBM6	23R	300	PRS	500	004	005	150C	SGH48	WAII	ADL	LDH	HD200
HP at Drill Stem	160	85	50	75	134	57	150	70	100	66	87	100	40
Torque (ft-lbs x 1000)	24.7	13.1	22.0	22.0	13.0	3.0	23	14.9	18.0	10.0	13.0	50	-
Speed Range (RPM)	0-77	0-117	0-60	0-60	0-54	0-100	0-90	0-37	0-29	0-34	0-59	-	-
Thrust (lbs x 1000)	103	77	90	60	225	80	100	23	-	28	-	37	-
Cutting Rate (FPM) (24" diam. hole in salt)	3.9	2.1	1.2	1.8	3.3	1.4	3.6	1.7	2.4	1.6	2.1	2.4	1.0

*Will not fit in 18 foot height.

5. LIFE CYCLE COST ESTIMATE

5.1 General

The life cycle cost of three of the drilling systems studied have been developed. Each system is a combination of available equipment which would require modification. The rigs are all diesel powered and require no outside power source. A two man crew consisting of an operator and a helper would be capable of operating any of the three systems.

A drilling cycle time study for each of the systems is shown in Table 3. Cycle times are based on the mine model furnished by the Office of Waste Isolation (OWI). The drilling cycle includes a move of 17 feet along the length of the mine room. Time for moves from one row of holes to another either within a room or between rooms has been excluded from this study. In addition bad holes due to cave-ins, misplacement or out of tolerance holes have not been taken into account. Drilling rates are based on the operation of standard equipment of each kind but are limited by the penetration rates discussed in Section 4.

The summary times in the drilling cycle appear to be competitive for three rigs but the auger rig with continuous auger flights is noncompetitive. Although the drilling time is comparable, the handling time is excessive due to the lack of threads on the end of the flight requiring a man to be at the top of the rig to release the flights from the power swivel, and also due to the need to overdrill because the hole cannot be completely cleaned.

Table 3. Cycle Times

	Time - Minutes			
	Auger w/Auger	Bucket Drill	Auger w/Vacuum	Raise Borer
Transit Time-Drill	2.0	2.0	2.0	2.0
Transit Time-Conveyors	-	4.0	-	-
Setup, Align, Spot Haulage	5.0	5.0	5.0	5.0
Start Hole (Bury Bit/Set Collar)	0.3	1.0	1.0	1.0
Drill	5.8	30.0	4.38	3.89
Change Steel or Flight	3.0	-	1.0	1.0
Drill	6.67	-	5.0	4.44
Change Steel or Flight	3.0	-	1.0	1.0
Drill	6.67	-	5.0	4.44
Change Steel or Flight	3.0	-	1.0	1.0
Drill	6.67	-	5.0	4.44
Withdraw Steel or Flight	1.66	-	1.33	1.33
Remove Steel or Flight	12.00	-	3.0	3.0
Break Down	2.0	2.0	2.0	2.0
Overdrill Time	4.83	-	-	-
Cycle Time - Minutes	64.93	44.0	36.71	34.54
Drilling Time - Minutes	29.67	30.0	19.38	17.21

The number of machines required is based on the currently projected drilling schedule furnished by OWI. A sufficient number of each type machine is included to meet the projected drilling schedule with allowance for maintenance down-time. The purchasing schedule was selected to use as much of the useful life of all machines as possible.

Raise borer machines as normally used can last from 5 to 10 years. Their duty cycle under normal operation is 24 hours per day while operating. However, it is believed that they are operated under normal conditions approximately 3 months of the year. Their operating life over 7 years then is 16,000 hours with major overhauls every 2 years. Bucket drills and auger drills normally used in heavy construction are reported to last about 15 years under normal usage. Normal usage in heavy construction is from 4 to 5 months per year at 10 hours a day. Thus the life of this equipment is 16,000 hours with normal maintenance. Heavy equipment manufacturers such as Caterpillar Tractor also list life for this type equipment as 16,000 hours. Therefore an average life of 16,000 hours was selected for the life cylce of all equipment considered.

5.2 Projected Drilling Schedule

For storage of spent fuel elements, the OWI projected schedule calls for drilling opearations to begin in 1983. In the following 18 months 50,650 holes are to be drilled to provide 5 years storage capacity. Drilling equipment will then be stored until 1989. Drilling will then be resumed with 32,000 holes per year being required to keep 1 year ahead of emplacement operations until year 2000. Work is to be carried on three shifts a day. To meet this schedule prototype drilling machines will be required some time during a peirod 1979 through 1981. For cost estimating purposes, a 400 hour test of the prototype covering a 3 month period was assumed during 1980.

5.3 Assumptions

a. Costs of material and labor are based on 1977 prices.

b. Annual inflation rate is assumed to be 8 percent per year on material and labor.

c. The two man crew on each system consists of one operator at $11.70 per hour and one helper at $9.10 per hour. (R.S. Means, Construction Consultant, incl. gov't employee benefits.)

d. Operating efficiency of each system is assumed to be 80 percent during production drilling and 40 percent during the 3 month prototype test in 1980.

e. Ten percent of equipment capital cost is allowed for maintenance and is assumed to be half labor and half material.

f. Tooling costs are considered an expense item and not included in capital costs.

g. Cycle time for each system is based on continuous haulage being available with no stoppage.

h. All systems are assumed to be moved from hole to hole with its mast erected ready for drilling.

i. Reconditioning costs at the start of the second phase of mining and drilling are omitted.

5.4 Bucket Drill

The bucket drill system consists of a crawler mounted drill and two portable rubber tired conveyors. Telescoping Kelly length and mast height of the drill are reduced to suit an 18 foot high mine room. In operation the unit will be backed to the first hole location at the in-by end of a room. Work progresses toward the main tunnel. Over long distances the conveyors can be towed by the drill rig. By backing into the room, the drill located at the center rear of the unit can be located well within 20 feet of the end wall and within 5 feet of a pillar if required. The conveyors are arranged along side the drill rig to receive cuttings from the bucket and transport them to a haulage unit located in front of the drill, towards the room entrance. The conveyors use power from the drill engine.

Hole to hole cycle time with the above arrangement is estimated to be 44 minutes. With proper maintenance a useful life of 16,000 hours is expected from this equipment. Allowing for down time and efficiency nine machines are required to meet the production schedules during the first year and eight units from 1992 on. Therefore the life cycle cost assumes the purchase of the first system in 1980 with eight more added in 1983 when production drilling begins. All nine would be replaced by eight in 1992. These in turn would be replaced by eight sets in 1996. This replacement schedule would allow the use of 100 percent of the first two sets and essentially 100 percent of the final set of eight with the total number of systems being 25.

Buckets are considered to be replaced once a year. However cutting teeth are estimated to last on the average through 2000 feet of hole and cutting tool holders replaced twice each year.

5.5 Auger Type Drill with Blind Hole Bit and Vacuum

A standard auger type drill is altered by shortening its mast and mounting the unit on a Crawler base. A conventional blind hole bit will be used with drill pipe and a vacuum unit for reverse air circulation. Drill pipe will be mechanically handled to and from a storage carrousel.

The drill mast and drill pipe handling and racking equipment will be located at the rear of the unit with the vacuum and cuttings discharge at the front.

A conventional blind hole bit would be used. The vacuum unit connected to the top end of the drill pipe through a swivel draws air down the hole flushing chips off the hole bottom and up the drill string to the vacuum unit. Cuttings are dumped to the hauler and the air is filtered before leaving the vacuum unit.

Hole to hole cycle time for this unit is expected to be 36.71 minutes. It is planned to buy the first unit in 1980 and six additional units in 1983 for full production drilling. All seven units will be replaced in 1991 and again in 1996. Using this schedule the entire life of the first 14 units would be consumed and the last 6 would be used to essentially 100 percent of their useful life at the end of the year 2000.

5.6 Raise Bore Drill with Vacuum

Underground a raise bore machine is normally used to drill a small pilot hole downward between levels of a mine then pull a large bit towards itself to enlarge the hole. These machines have more than adequate thrust for blind drilling 3 foot holes in salt. The system considered is track mounted. Configuration would be similar to the auger rig previously discussed. The system is set up to drill at the in-by end of a room with the vacuum end facing the room entry allowing a hauler easy access to the cuttings discharge chute. Work progresses toward the room entry.

Cycle time for the system is estimated to be 34.54 minutes. The prototype system would be purchased in 1980 with five additional units added in 1983. For a 16,000 hour life all five sets would be replaced in 1992 and again in 1997.

Drill bits and drill pipe are replaced annually while average cutter life would be 2000 feet of hole. Holders would be replaced twice a year.

5.7 Conclusions

The total costs for the three rigs is presented in Table 4. Backup detail sheets are in Appendix B. The spread of costs is felt to be significant but at this time the estimated drilling rate is inexact and firm figures should be developed depending upon the unit chosen.

Table 4. Life Cycle Costs

Bucket Drill		
Unit Cost - 1977	$ 151,000	
No. Units	25	
Capital Cost		11,116,000
Operating Cost		
Labor - Operating	$ 49,431,000	
Labor - Maintenance	3,105,000	
Materal - Operating	1,878,000	
Material - Maintenance	3,105,000	
Fuel	3,458,000	
Operating Subtotal		60,977,000
Total Cost		72,093,000
Raise Bore with Blind Hole Bit and Vaccum		
Unit Cost - 1977	$ 278,000	
No. Units	18	
Capital Cost		15,621,000
Operating Cost		
Labor - Operating	$ 36,123,000	
Labor - Maintenance	4,191,000	
Material - Operating	2,408,000	
Material - Maintenance	4,191,000	
Fuel	4,014,000	
Operating Subtotal		50,927,000
Total Cost		66,548,000
Auger Drill Rig with Blind Hole Bit and Vaccum		
Unit Cost - 1977	$ 143,000	
No. Units	21	
Capital Cost		8,777,000
Operating Cost		
Labor - Operating	$ 42,141,000	
Labor - Maintenance	2,508,000	
Material - Operating	2,621,000	
Material - Maintenance	2,508,000	
Fuel	4,266,000	
Operating Subtotal		54,044,000
Total Cost		$ 62,821,000

6. OTHER CONSIDERATIONS

The effects of changing the presumptions upon which the design is based may affect the final choice of the drill. In this section the possible changes known are discussed.

6.1 Strata

The storage facility may be established in strata other than salt. If the strata is limited to softer rock such as shale and soft limestone - up to about 12,000 psi compressive strength - then the auger and bucket rigs can still be used with reduced performance rates. However, if the rock is harder, then the pick style cutter will no longer be economical and roller cutters should be used. In this case, less torque and more thrust are needed. The thrust per inch of hole diameter for roller cutters can be ten times the thrust used for a drag bit of the same size. Even the largest raise borer listed above would be marginal. The drill steel used would be increased to at least 8.625 inch diameter nominal, stabilizers on the steel would be used to keep the drill straight, the roof jacks would be increased, make up and break out tools would be changed, and the vacuum system would remain the same or the circulating fluid could be changed to mud instead of air. The penetration rate would drop by a factor of about 10. The roller cutter would change from milled tooth to button type and all bit and cutter life would decrease drastically.

6.2 Hole Length

The present specification considers hole depth from 20 to 40 feet. Increasing the depth to 70 feet would eliminate bucket drills completely. One bucket drill manufacturer cannot reach over 25 feet because his telescoping Kelly is limited to two sections, while a second manufacturer is limited to 35 foot depths with three sections. Only one manufacturer can reach about 46 feet with a 4 section Kelly. Any added height in the rooms will improve this limitation obviously.

For rigs using drill steel, the only hardware impact is storage and stabilizers. The stabilizers will obviously pose a handling problem and a special rack and hoist would be needed. The vacuum system would remain the same.

6.3 Hole Diameter

The present specification for hole diameters is 12 to 36 inches. Naturally each diameter would require a different bit. Increasing the diameter to 48 inches would also require another bit. More important, the thrust required would increase well beyond the limits of the present auger and bucket rigs, and the arguments about thrust in Section 6.1 for soft rock would apply here also. Also, the roof jack pads would increase in size.

6.4 Hole Position

During the course of the program there has been considerable discussion of the location of the holes in the storage rooms. If the center line of the holes is located closer to the rib than five feet, then it is quite possible a special drill rig will be needed with either an offset drill center line or with a rotation skew to the drill frame. The former may also be compounded by the need for right and left hand configurations which would add to logistics in operation.

6.5 Hole Angle

The hole is presently specified as vertical. However, both the raise borers and the auger rigs can drill at least up to forty-five degrees from the vertical with no adverse effects other than a slight curvature downward as the hole lengthens. This can be reduced by stabilizers. The roof jacks would obviously have to be repositioned and possibly two more added. Bucket drills could not drill on an angle.

6.6 Primary Power

The primary power chosen for these rigs is supplied by a local diesel engine. This was based upon an expected lack of high electric power in the area. If this power is available, then the raise borers can use their standard power systems while the bucket and auger rigs will have to be modified.

7. CONCLUSIONS AND RECOMMENDATIONS

Two classes of drills can be used to drill emplacement holes in salt. Both are sufficiently rugged and reliable. Raise borers have a higher capital cost and require more modifications, but will be more flexible in other applications and require less labor. The life cycle cost for the raise borers and for the auger rigs are about the same, while the life cycle costs of bucket drills are much higher. As long as the hole is 36 inches in diameter or less and 40 feet deep or less in salt, then the auger rig is recommended because of the lower capital cost and lower operating cost.

Of the two bailing systems, circulation systems are preferred over disposal cycle systems because (1) the tool bit is cutting continuously rather than intermittently, and (2) the loading of haulage is simplified.

The circulation can be established by pressure or by vacuum. The latter is preferred for cost and noise reasons. Also, the circulation can be established in direct or reverse modes. Reverse circulation is preferred because the volume flow is lower for the pipe than for the annulus, and because no seal is needed on the top of the hole. The one drawback of vacuum is the need for special haulage bin that seals to the vacuum circulation is the need for special haulage bin that seals to the vacuum system. If this cannot be accommodated, then the next best system is reverse circulation using compressed air injected through a cover on the hole that is held in place by the drill rig.

The bit should have a conical face to help bailing and it should be laced with drag bits. Roller cutters cannot be used with the hole diameters and thrust loads available with this equipment. The carrier should be a crawler frame because they are lower and more maneuverable than truck bodies. If small squirmed rubber tired frames were available, they would be preferred over all. The primary power should be a diesel engine rather than mine service electric power because the cable handling is a major failure mode, and because the flexibility provided by the diesel is useful. The one drawback of the diesel is the noise it produces compared to an electric motor.

These recommendations have been embodied in Drawing No. A-12510 entitled, Procurement Specification - Emplacement Hole Drill and Drawing No. J-12511 entitled, Emplacement Hole Drill - Envelope Drawing, which are to be found in Appendix C.

This recommended system represents what is throught to be the best combination of available drill components assembled into a drill rig which will provide at least adequate performance. Furthermore, this drill system can be procured from at least three manufacturers. If the facility criteria change significantly, however, then the drill rig recommendations will have to be reassessed on the merits of the changes. The drill rig manufacturers can be quite flexible in combining components provided the buyer is willing to accept components with which the manufacturer has had experience. If this condition can be met, then most drill rig manufacturers will include the associated design cost as part of the drill cost. If special components are required, however, then the number of manufacturers willing to participate in a procurement may be severely reduced.

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