NOTICE

The information contained in this report is regarded as confidential and proprietary. It is provided subject to the provisions regarding confidential, proprietary information contained in the Research Agreement among the Participating Parties.

15\05\005\006

MOBIL RESEARCH AND DEVELOPMENT CORPORATION

RESEARCH DEPARTMENT

TECHNICAL MEMORANDUM NO. 67-17

HIGH FACE ROTARY DRILL JUMBO

ANVIL POINTS OIL SHALE RESEARCH CENTER

Rifle, Colorado

September 27, 1967

Author:

F. W. Brackebusch

Approval:

RH Cramer

R. H. Cramer
Program Manager

C. to JCK - WRB

The primary object of the Anvil Points Oil Shale Research Center TECHNICAL MEMORANDUM is to advise authorized personnel employed by the Participating Parties[1] that various activities are in progress or that certain significant data have been obtained within the Research Center.

These TECHNICAL MEMORANDA have been prepared to provide rapid, on-the-spot reporting of research currently in progress at Anvil Points. The conclusions drawn by project personnel are tentative and may be subject to change as work progresses. The TECHNICAL MEMORANDA have not been edited in detail.

[1] Mobil Research and Development Corporation, Project Manager

Continental Oil Company
Humble Oil and Refining Company
Pan American Petroleum Corporation
Phillips Petroleum Company
Sinclair Research, Inc.

HIGH FACE ROTARY DRILL JUMBO

TABLE OF CONTENTS

FIGURES

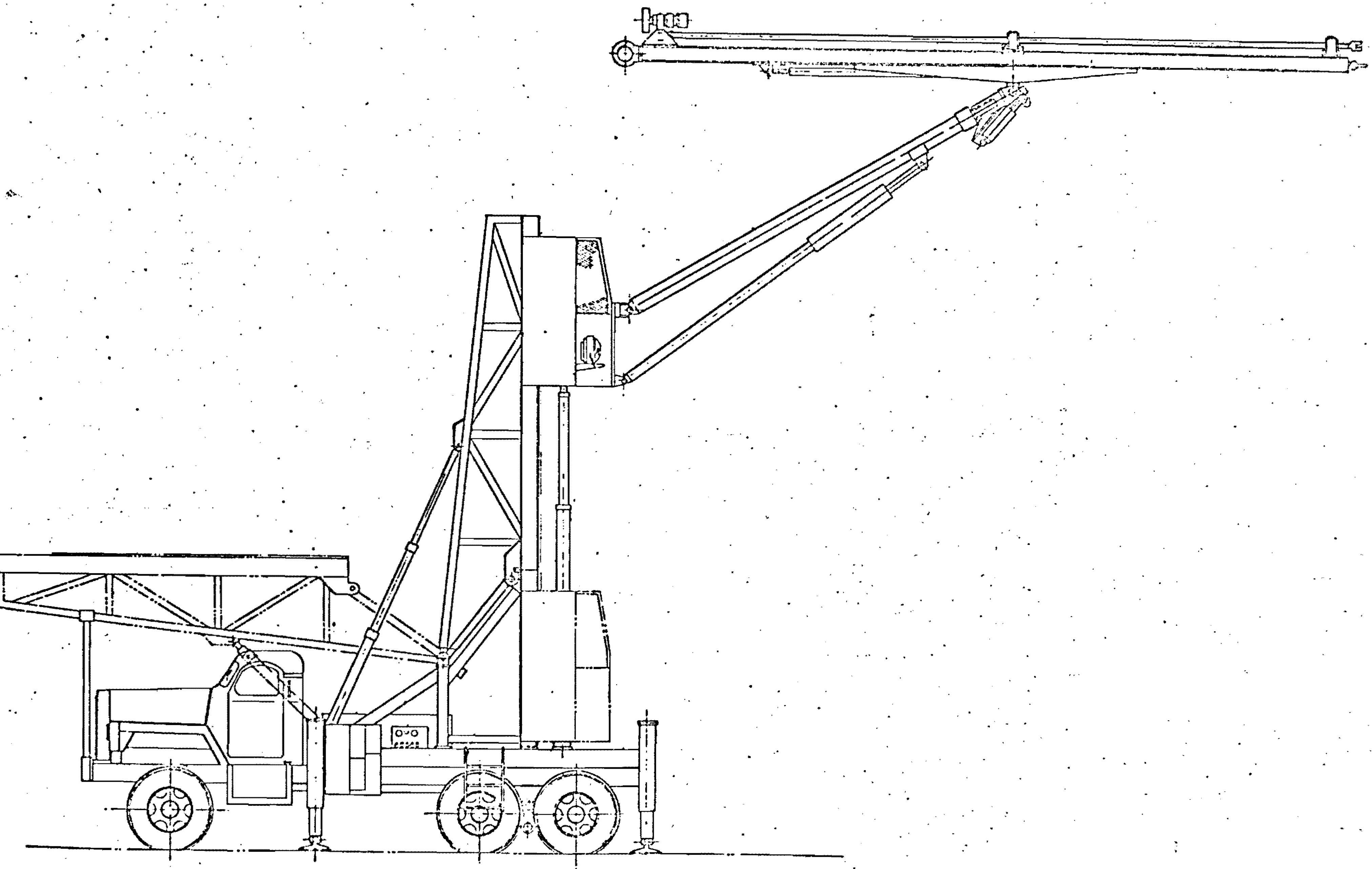
HIGH FACE ROTARY DRILL JUMBO

I. INTRODUCTION

The Green River Formation at the Anvil Points mine is a flat-lying, sedimentary, marlstone containing beds rich in kerogen. The 73 feet thick Mahogany Ledge is the thickest mineable layer of kerogen-rich marlstone present in the Green River Formation at Anvil Points. The Mahogany Ledge has an average Fischer Assay of 30 gallons per ton but is composed of alternating rich and lean beds. The upper part of the 73 feet thick layer is mined by driving headings, and the lower part is mined by benching the floor of the headings.

The heading operation at the Anvil Points oil shale mine employs headings 40 feet high in order to provide ore with Fischer Assay near 30 gallons per ton. Because of the stratigraphy, no other lesser height of heading which has its roof line at the top of the Mahogany Ledge will provide ore at a Fischer Assay of 30 gallons per ton. However, lesser heading heights could be used if the heading ore were to be blended with benching operation ore. Heading rounds normally require drilling horizontal holes near or at the roofline. Gardner-Denver designed and built a rotary drill jumbo (JED-1) for a 40 foot high heading. Because, at the time of design, it was not known exactly what drilling pattern would be required, the drill had to be versatile in order to drill different experimental rounds in a 40 foot by 60 foot heading. JED-1 is so versatile, in fact, that a 30 foot vertical hole can be drilled in the roof. Figure 1 shows a sketch of JED-1.

FIGURE 1



HIGH FACE ROTARY DRILL JUMBO
(SERIAL NO. JED-1)

II. SUMMARY AND CONCLUSIONS

Gardner-Denver Company built a prototype rotary drill for drilling heading rounds. The drill (JED-1) was designed to be versatile in order to experiment with different drilling configurations. The operation of JED-1 has shown that efficient, low cost drilling of oil shale can be accomplished.

JED-1 has an electric-hydraulic power system. Variable displacement pumps are used to drive the hydraulic motors because of their positive control and efficiency advantages. The feed and drill motors are fixed displacement type hydraulic motors. The feed and drill controls on JED-1 would not be desirable for a production drill because of energy waste of the feed control and because only two rotation speeds are provided by the drill control. JED-1 requires 350 cfm of air to clean cuttings from a four inch hole and 0.75 gallons of water per foot of four inch hole. Setting up JED-1 requires an excessive amount of time because: (1) an external source of compressed air must be provided, (2) the drill platform is not maneuverable. Rows A, B, D, and E of the standard heading round (Figure 2) can be drilled at 170 RPM, but Row C must be drilled at 110 RPM because of its low drillability.

The performance of a high face rotary drill can be improved by:

1. Solving hose breakage problem.

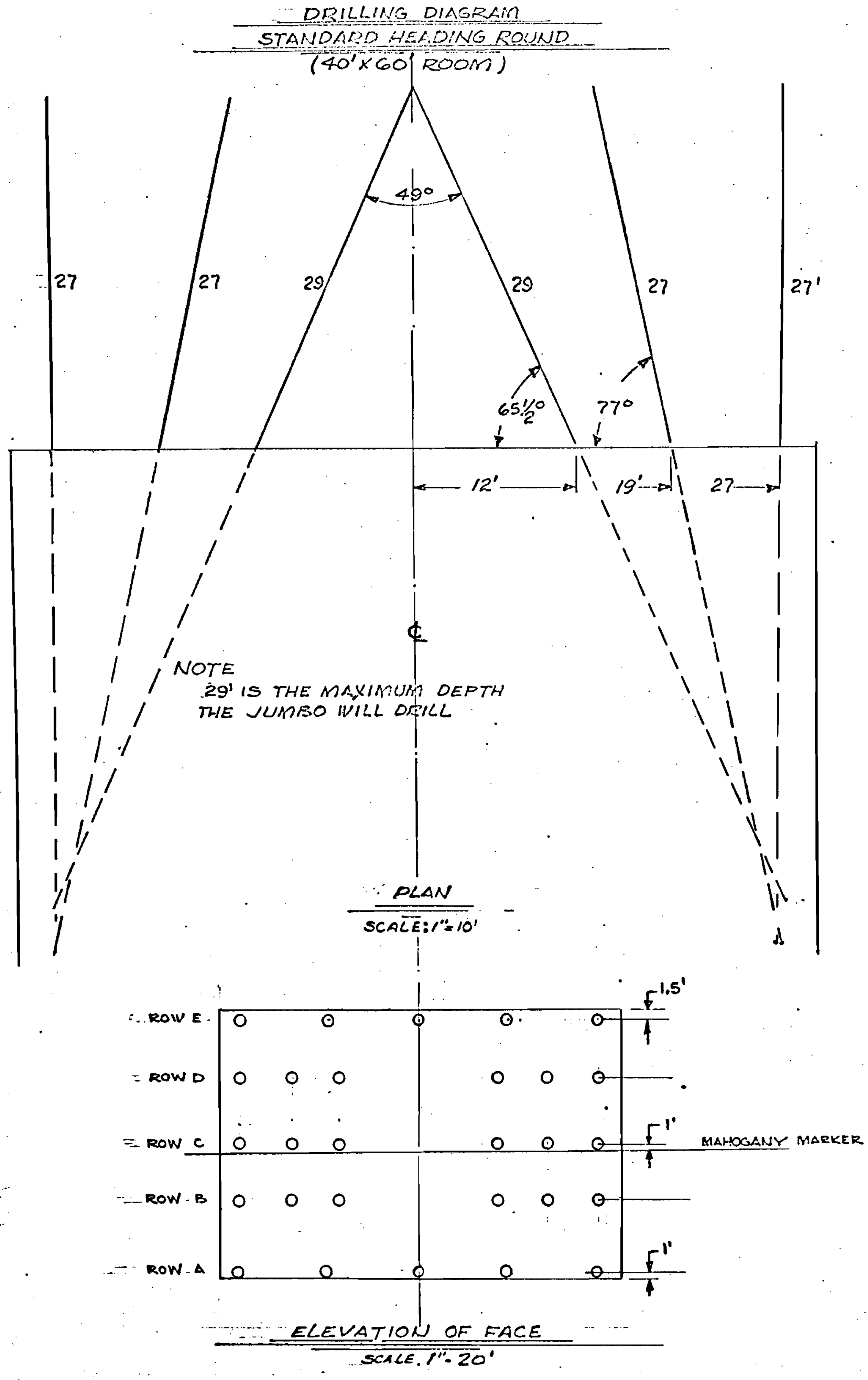
2. Designing drill to maintain up to 30,000 pounds thrust and 80 to 200 RPM.

3. Providing a compressor on the drill. A compressor was not provided on JED-1 in order to keep down the capital cost of the drill.

4. Improving the control of the variable displacement pumps so that a constant displacement can be maintained at any level between zero and full displacement.

5. Redesigning the structure of the drill taking into account the dynamic loads.

FIGURE 2



DRILLING DIAGRAM
STANDARD HEADING ROUND
(40'x60' ROOM)
49°
27
27
29
29
27
27'
65½°
77°
12'
19'
27
℄
NOTE
29' IS THE MAXIMUM DEPTH
THE JUMBO WILL DRILL
PLAN
SCALE: 1"=10'
ROW E
ROW D
ROW C
ROW B
ROW A
1.5'
1'
1'
MAHOGANY MARKER
ELEVATION OF FACE
SCALE. 1"=20'

III. DISCUSSION

A. General Description of JED-1

The high face rotary drill is mounted on the frame of a Mack thermodyne four-wheel drive truck. An electric-hydraulic power system supplies power to the various hydraulic motors and pistons. For efficiency and control, variable displacement hydraulic pumps are used to transmit power to the feed and drill motors. Being a prototype drill, JED-1 cost about $75,000.

Following are the various movements JED-1 is capable of executing as shown on Figure 3.

1. Mast can be raised and lowered.

2. Cab can be raised and lowered. The cab rides on rollers on an I beam, and two telescoping hydraulic pistons form the elevator.

3. Boom can be raised and lowered.

4. Boom can swing left or right.

5. Feed can swing left or right about an axis on the end of the boom.

6. Feed can dump up or down relative to an axis on the end of the boom which is perpendicular to the swing axis.

7. Feed can rotate 360 degrees about an axis parallel with the boom.

8. Feed can be extended toward the face a distance of eight feet.

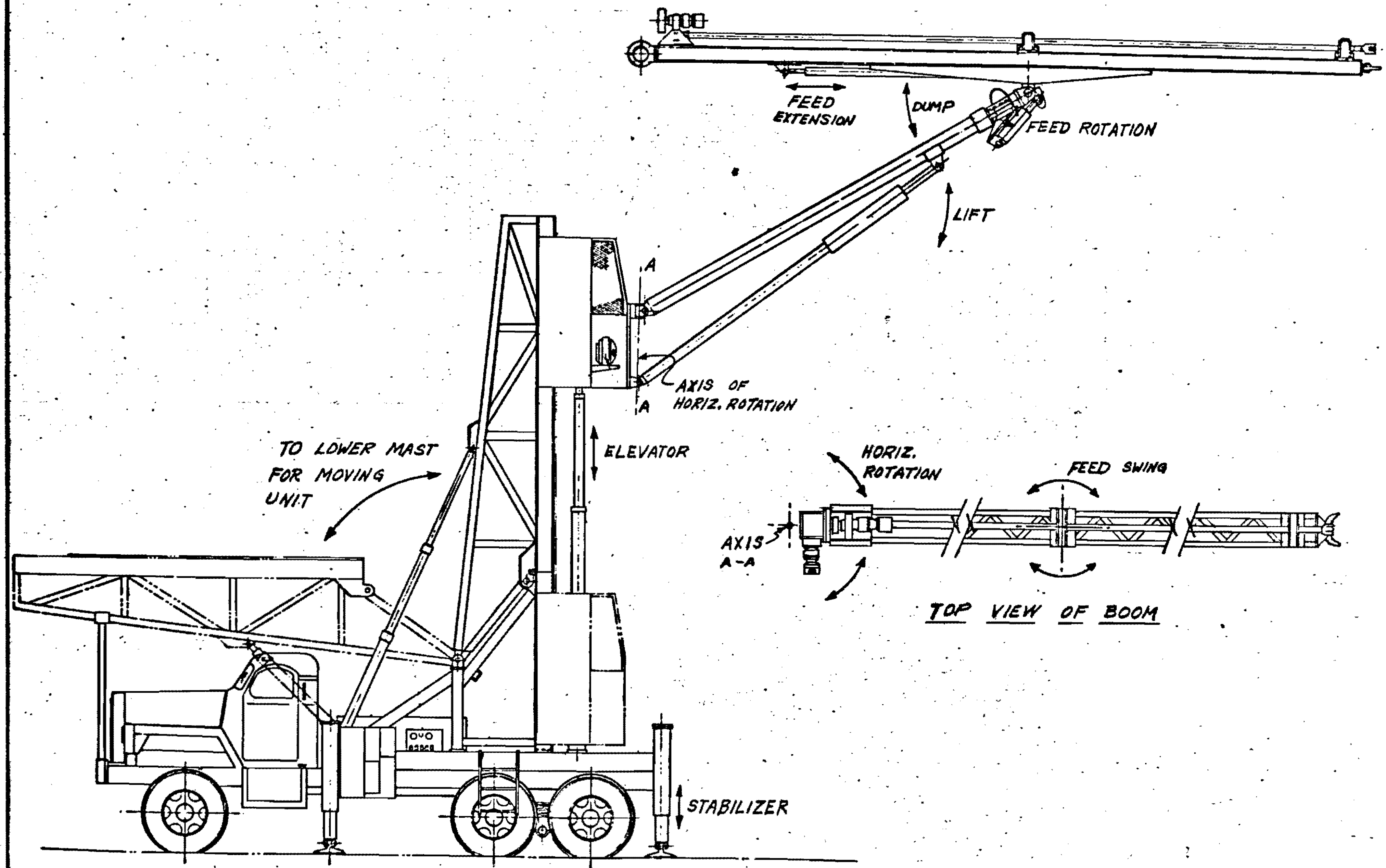
9. Stabilizing jacks when extended give the drill stability.

All these movements are performed by hydraulic pistons.

B. Electric and Hydraulic Drive System

JED-1 is powered by a 100 hp, 3 phase, 440 volt electric motor. The electric motor drives three hydraulic pumps through a Funk gearbox. Two of the hydraulic pumps are Dynapower variable displacement axial piston type pumps. One of the variable displacement hydraulic pumps drives the feed motor which provides thrust to the bit. The other variable displacement pump drives the drill motor which provides torque to the bit. The third pump driven through the Funk gearbox actually consists of two gear pumps (Commercial Shearing P-25) on the same shaft. It is the duty of one gear pump to charge the two Dynapower pumps

FIGURE 3



HIGH FACE ROTARY DRILL JUMBO
(SERIAL NO. JED-1)

with hydraulic fluid at ≈ 200 psi. The other gear pump provides ≈ 2,000 psi to operate all the hydraulic pistons on the drill.

Hydraulic hoses transmit fluid from the pumps to the motors and various pistons. The hoses from the variable displacement pumps to their motors must transmit fluids at 3,000 psi. The hoses from the gear pump to the various pistons must transmit fluid at ≈ 2,000 psi. Numerous hose failures were encountered while drilling with the high rotary drill jumbo - causes and design modifications are discussed later in this report.

The feed motor is a fixed displacement (gear type) Dynex hydraulic motor. The feed motor is attached to the feed chain sprocket with a reduction mechanism that has a reduction ratio of 80:1. The drill motor, a fixed displacement type hydraulic motor, rotates the drill steel through a reduction gearbox with a reduction ratio of 6.8:1.

C. Control System

The advantage of using a variable displacement pump for driving a hydraulic motor is that the speed of rotation and direction of the motor can be controlled by adjusting the displacement of the pump. The rotation rate of a hydraulic motor can be controlled with a bypass flow control valve (similar to the feed system control now used on JED-1 - see Figure 4) and using a fixed volume pump; however, this type of control and pump causes a significant waste of energy due to friction of fluid flowing through the bypass flow control. This waste of energy from friction increases the temperature of the hydraulic fluid, necessitating large heat exchangers.

The displacement of Dynapower axial piston pumps is controlled by moving a lever on the side of the pump that alters the stroke of the axial pistons. Of course, at any adjusted displacement, as the motor load increases, the pressure output of the pump increases until the bypass pressure is reached. On JED-1, the feed pump bypass pressure is adjusted to 2,000 psi, and the drill pump bypass pressure is adjusted to 3,000 psi.

The displacements of the feed and drill pumps are controlled with air pistons and valves. When JED-1 began service in November 1966, the controls were very "touchy" and caused broken drill steels and broken feed chains. After several attempts to modify the existing controls, Gardner-Denver installed the control systems shown in Figures 4 and 5. The feed control method consists of using the feed pump at a constant displacement and changing the flow of oil through the motor by opening and closing the flow control valve which short circuits some of the hydraulic fluid. As previously mentioned, this control method causes waste of energy due to friction and, actually, cancels out the advantages of using a variable volume pump. The drill or rotation control was modified to provide a mechanical stop for the lever

FIGURE 4

FEED SYSTEM

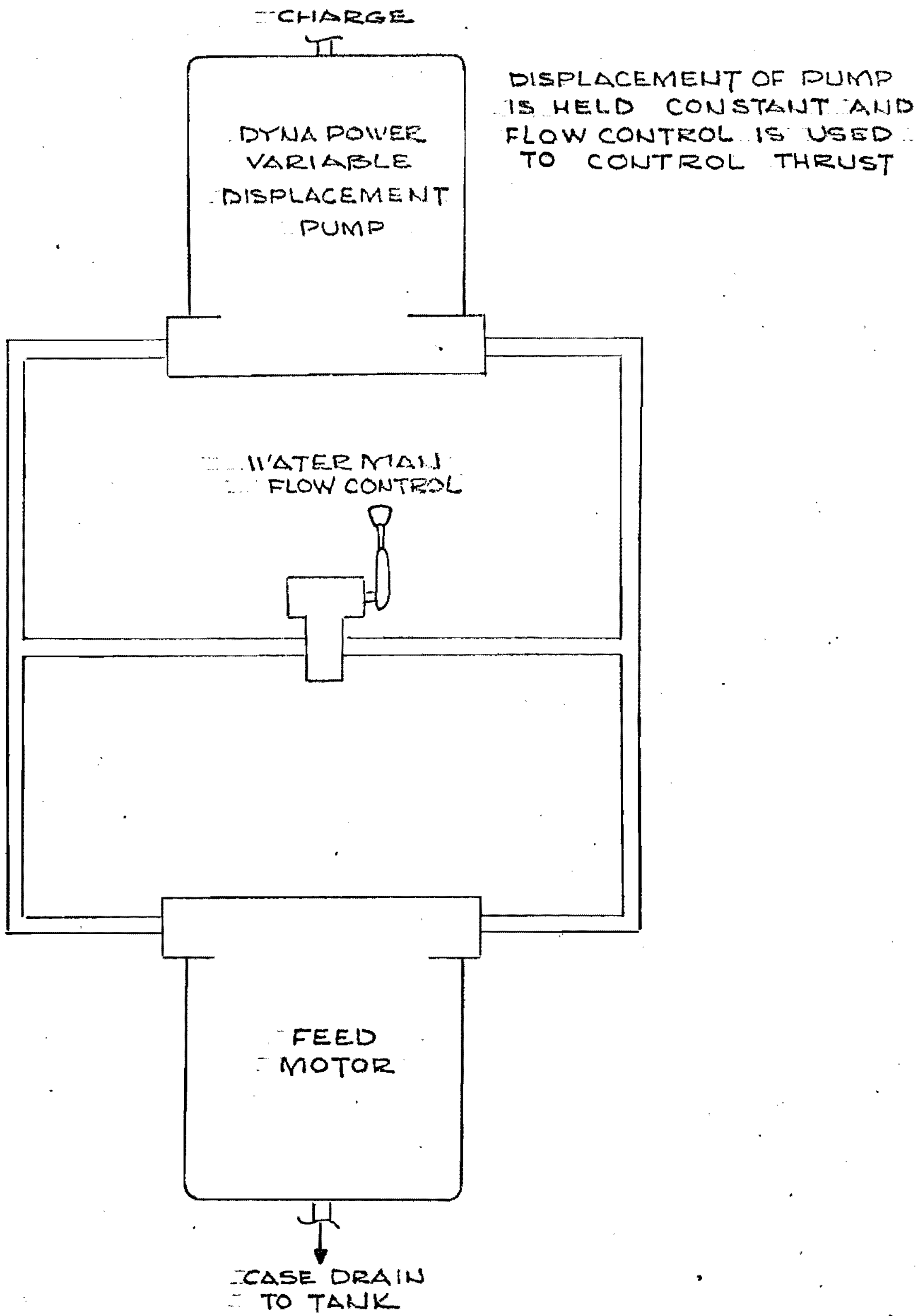
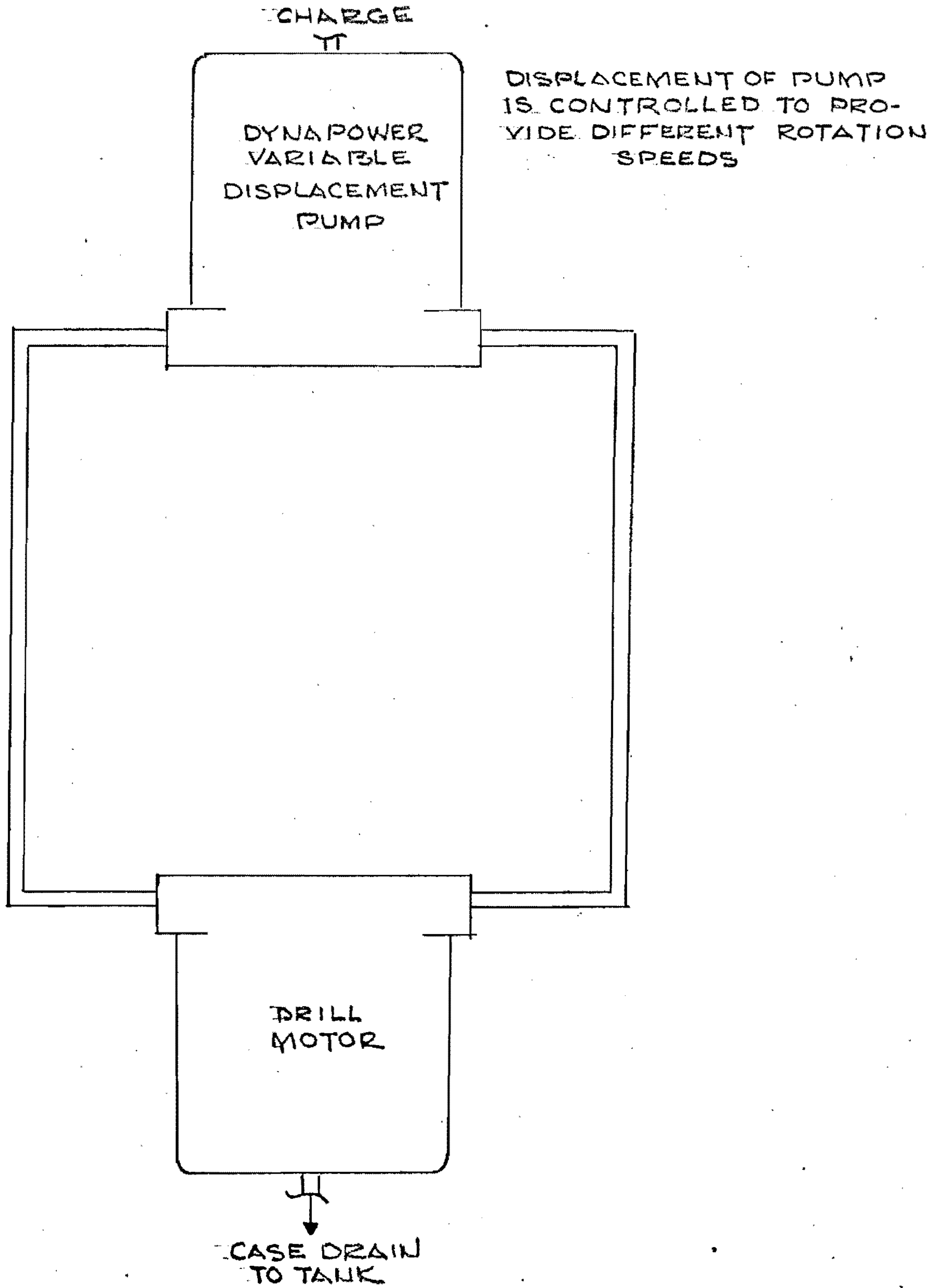


FIGURE 5

DRILL SYSTEM



which adjusts the pump displacement. Thus only two drill steel rotation rates are available - 110 RPM and 170 RPM.

In order to prevent damage to the feed chain, while retracting the feed, a decelerator is located near the feed motor which prevents the top drive mechanism from slamming against the back stop. This decelorator automatically stops the feed motor as the steel becomes fully retracted.

The control of the various pistons on JED-1 is accomplished by the use of Commercial Shearing valves located both in the cab and on the lower control panel.

D. Water and Air Systems and Requirements

Cuttings created by the bit are removed from the hole by the flow of air through the hollow drill steel and bit and out the hole. Water mist is injected into the air stream to control the formation of dust. For drilling four-inch holes, the approximate water and air requirements are:

1. Air at 100 psi $\rightarrow$ 43 cubic feet per minute (equivalent to 350 cubic feet per minute at atmospheric pressure)

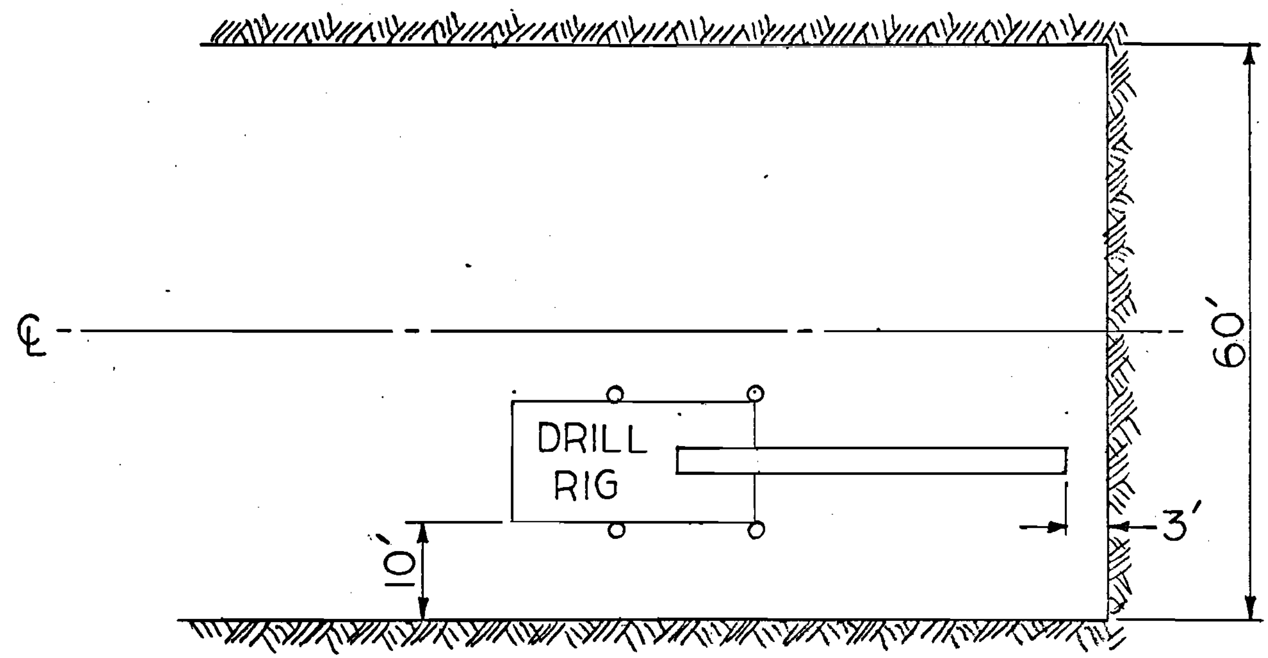
2. Water $\rightarrow$ $\approx$ 0.75 gallons per foot of hole.

Air is supplied to JED-1 from an external compressor. The drill has a 200 gallon capacity water tank which is pressurized by the air source. In order to maintain injection of water into the air stream, the pressure in the water tank must be kept greater than the air pressure at the injection point.

E. Operation (Drilling Standard Heading Round)

The setup of JED-1 requires a significant amount of time. Setup involves extending water hose and filling the 200 gallon water tank; extending 440 V powerline and hooking up; extending bull hose to provide compressed air to the drill. The work of extending the water, air, and power lines is tedious and time consuming when manually executed. Figure 6 shows the proper position to park the drill for drilling one side of a standard heading round. Of course, drilling the other side of the face requires parking the drill in the corresponding position. Before starting to drill the mast must be raised, and the two holding pins must be driven into place.

The most difficult job for the operator in drilling a heading round is to position the drill according to the drilling diagram in order to assure proper positioning of the drill holes. The drill has no direction finding mechanism; therefore positioning must be accomplished by using judgment and the references provided - paint marks and the ribs. Irregularities in the ribs



DRILL RIG LOCATION
FOR DRILLING 60 FT. WIDE FACE

FIGURE 6

and face complicate the positioning act. For drilling rows B, C, D, and E the feed rotation is kept in the upright position. The swing is used to give the feed the correct horizontal angle for the specific hole. The dump control is used to align the feed parallel with the strata. On JED-1, the operator must be careful not to jerk the piston controls which causes excessive bouncing of the heavy boom.

Stinging the face is accomplished by operating the extension cylinder on the feed. After stinging, the hole is collared with minimum thrust and slow speed rotation. As the hole is collared, the thrust is gradually increased and the RPM is increased when drilling rich shale. For drilling four-inch holes, 20,000 pounds of thrust is adequate for all rows of holes except the C row. JED-1 is not capable of maintaining thrusts above 20,000 pounds, but is is obvious that the thrust required for drilling the C row efficiently is greater. To prevent the bit from skidding in the hole, the C row is drilled at low speed rotation - 110 RPM. All other rows can be drilled at the high speed rotation - 170 RPM.

Changing bits on JED-1 involves lowering the boom to the floor and loosening the bit with a large pipe wrench and cheater. It takes about 800 ft. lbs. of torque to loosen a four-inch bit with 2 3/8 inch API regular threads. More torque is required if the threads are not greased for installation or if twine is not wound around the shoulder of the bit. Bits can be loosened using the rotation power of the drill and holding the bit with a special wrench, but all other joints in the steel must be spot welded or glued together. Perhaps time could be saved changing bits by using a bit with a square pin and a sub with a square box. A small pin or set screw would be used to prevent the bit from falling off the drill steel.

F. <u>Discussion of Design and Recommended Changes</u>

The electric-hydraulic power system on JED-1 is an efficient and safe method of transmitting power to the various driving mechanisms. Breakage of hydraulic hoses has been a problem operating JED-1. Causes of hose breakage are various: vibration, abrasion, faulty hoses, etc. (See Appendix A). The hose breakage problem can be solved by

1. Proper placement of hoses

2. Proper protection of hoses from moving parts

3. Using hoses and fittings with correct pressure rating

A major improvement on JED-1 would be to provide automatic reels which would eliminate hoses being dragged over rough edges.

A rotary drill, using 4 inch or 4 1/4 inch bits in a heading operation with the same strata as the Anvil Points mine, should be capable of maintaining thrusts as high as 30,000 pounds. The drill should be able to maintain rotation rates from 80 to 200 RPM. No measurements were taken on the power consumption of JED-1, but the power consumed by the feed motor can easily be calculated by multiplying the thrust by the penetration rate:

Assume at 30,000 pounds thrust 10 fpm is the maximum penetration rate, feed motor is 90% efficient and feed pump is 90% efficient. Then power input to pump is:

$$P(in) = \frac{\left[\frac{10\ \text{feet}}{\text{min}}\right] \left[30{,}000\ \text{lbs}\right] \text{hp}}{(0.90)^2 \quad (33{,}000)\ \frac{\text{ft lb}}{\text{min}}} = 11.2\ \text{hp}$$

On JED-1 maximum pressure required to turn the drill motor was 1,800 psi. This maximum of 1,800 psi was required to drill at high penetration rates in very rich shale with a four inch bit. The torque required to turn the bit under these conditions can be calculated:

$$\text{Torque output of drill motor} = \frac{1.16\ \text{in lb}}{(1)\ \text{psi}}$$

Reduction ratio is 6.8:1

$$\text{Torque to turn bit} = \frac{1.16\ \text{in lb}}{(1)\ \text{psi}} \quad \underline{1{,}800\ \text{psi}}\ (6.8) = 14{,}200\ \text{in lb}$$

Then, assuming rotation rate of 170 RPM, the approximate power needed to turn the drill steel is

$$\frac{14{,}200\ (\text{in lb}) \quad \text{ft} \quad (170)(2\pi)\ \text{radians} \quad \text{hp}}{12\ \text{in} \quad \text{min} \quad (33{,}000)\ \frac{\text{lb ft}}{\text{min}}} = 38\ \text{hp}$$

During the first months of operation, several Dynapower pumps were damaged because of minute amounts of solid contamination (dust and metal particles). The source of the contamination was the charge pump and repaired hydraulic hoses in the pump-motor system. In June 1967, Gardner-Denver announced that a change was made in the construction of the Dynapower pumps which makes the pumps much less susceptable to damage from contaminated hydraulic fluid. Gardner-Denver conducted tests with Dynapower pumps running them at very high pressures for long periods of time with contaminated fluid. Good results were reported.

In order to eliminate time and effort involved with hooking up the drill to an external source of compressed air, it is recommended that the rotary drill be fitted with a suitable air compressor.

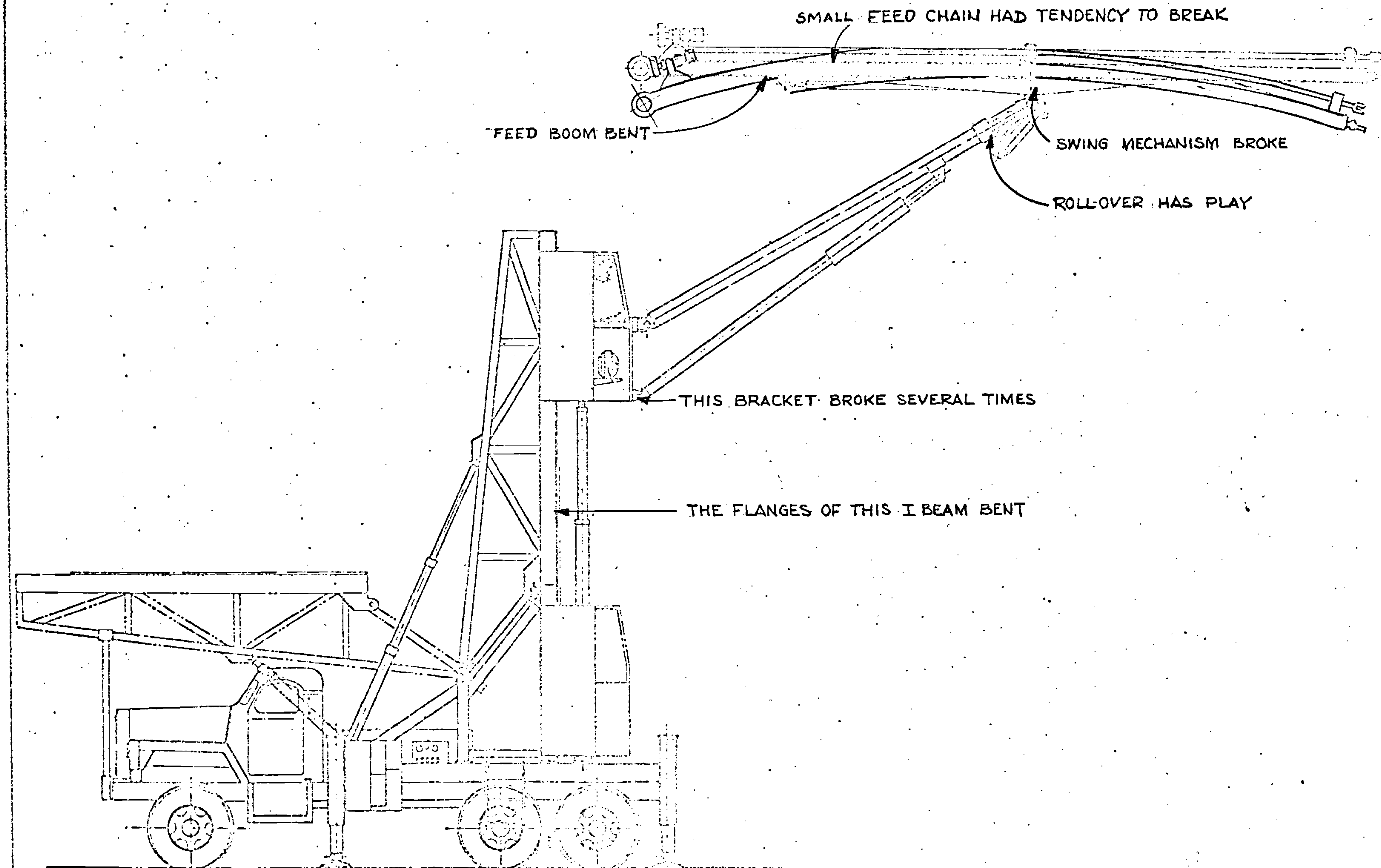
The control system of JED-1 can definitely be improved. The controls which alter the displacement of the variable displacement pumps are inadequate on JED-1. As mentioned before, the bypass flow control on the feed system of JED-1 causes a significant waste of energy (see Figure 4). The control of the displacement of the drill pump on JED-1, which allows only two rotation speeds, is not sufficiently flexible for drilling in beds of varying hardness. In order to utilize the pumps efficiently, the controls must allow an infinite number of settings between zero displacement and full displacement. In addition, the controls must be positive and easily operated. This could easily be accomplished by locating the Dynapower pumps and electric drive in the operators cab and using mechanical controls. Location of the pumps in the cab would also eliminate the need for many air and hydraulic hoses from the truck up to the cab. However, the additional weight of the pumps and motor in the cab would necessitate strengthening the structure of the elevator.

Figure 7 shows the major weak points of the structure of JED-1. Failure of the structure at these weak points is described in Appendix A, but, generally, the failures can be attributed to underdesign or not taking into account various dynamic loads.

G. Additional Remarks

While the operation of the high face rotary drill (JED-1) exposed many problems of design and maintenance, most of these problems were solved or the solutions were attainable. The basic design of the drill, including the power system and various movements, is sound. The 360° boom rotation is not necessary for drilling the round on which we finally standardized; 180° rotation is adequate. The magnitude of the other movements of the booms probably can be reduced now that a standard heading round has been developed. Perhaps the length of the drill can be reduced by locating the elevator nearer the center of the truck. The truck should have lower gears and more undercarriage clearance than now exists on JED-1. A 600 gallon water tank would decrease the time necessary to drill a heading round.

FIGURE 7



HIGH FACE ROTARY DRILL JUMBO
(SERIAL NO. JED-1)

REFERENCES

1. Parts List and Service Manual, Serial Number JED-1, Gardner-Denver Company, 4400 Hatcher Street, Dallas, Texas

2. Dynapower Hydrostatic Transmission System, Installation and Field Maintenance Manual; Hydreco Division, The New York Air Brake Company, Kalamazoo, Michigan, Bull. DT-6.1.

3. Letter of Specifications of JED-1, Technical File 310.00 - 319.99. Refer to Technical Memorandum by C. J. Verdeur on the file system for access.

APPENDIX A

MAINTENANCE DATA

Trouble: Broken hydraulic hoses and air hoses

Causes:

1. Hoses getting caught between booms and smashed
2. Hoses getting caught on rough edges and pulled to failure
3. Too many hoses inside pipes - the vibration and expansion of the hoses caused wear to outer surface of smaller hoses in pipe
4. Hoses being eroded by sliding over rough surfaces
5. Hoses bursting - faulty hoses
6. Faulty connections between steel and rubber
7. Hoses getting caught in driveline of truck

Corrections: Splicing hose, replacing fittings, re-direction of lines and installation of protective shields

----

Trouble: Insensitive feed control

Causes:

1. Inadequate control mechanism
2. Feed motor had too high advance speed

Corrections:

1. Installed adequate feed control
2. Installed lower geared planetary mechanism and lower speed feed motor

----

Trouble: Could not regulate drill steel RPM

Correction: Installed adequate control to regulate drill steel RPM to a high speed (170 RPM) and a low speed (110 RPM)

Trouble:	Drill motor would stall at 110 RPM when enough thrust to drill properly was provided
Correction:	A "higher torque at low RPM'S" drill motor was installed.

Trouble:	Feed chain breaking
Causes:	1. Weak centralizer link
	2. Feed being brought back too fast and hitting the stop with enough force to break the chain
	3. The 1 1/2 inch chain with standard pins was too weak
	4. A 1 1/2 inch chain with high tensile pins was too weak
	5. Poor control of feed when first put into service
Corrections:	1. Installed 1 3/4 inch chain and larger sprockets to handle the greater thrust
	2. Installed decelerator to prevent feed from hitting the back stop
	3. Modified feed control system

Trouble:	Cavitated feed and drill pumps
Cause:	Charge pump was faulty and did not supply enough charge pressure
Correction:	New charge pump installed

Trouble:	Cavitated feed pump
Cause:	Filter between charge pump and feed pump was not large enough to take the impact and surging of oil during startup of the electric motor and it allowed metal particles to pass from the charge pump to the feed pump
Correction:	More filter area and volume provided by installing separate hydraulic lines and filters from charge pump to feed and drill pumps

---

Trouble:	Stinger allowed bit to touch face before it (the stinger) touched face, also stinger did not rotate freely.
Cause:	Stinger too short and fitted too tightly
Correction:	Built new, longer, better fitting stinger from one inch steel plate

----

Trouble:	Boom rotation did not have sufficient power to rotate boom
Causes:	1. Pitch of rifling mechanism too shallow
	2. Hydraulic cylinder too weak
	3. Hydraulic pressure too low
Corrections:	1. Bigger hydraulic cylinder installed
	2. Operating pressure on this system was increased

Trouble:	Last stage of hydraulic cylinder that raised right side of mast was bent
Cause:	Lower hinge on cylinder limited the swing of the cylinder causing there to be a bending moment in the cylinder
Corrections:	1. Last stage replaced
	2. Hinge cut out with torch to allow the cylinder to move freely

----

Trouble:	The lower strut of the boom failed near the lower hinge
Possible Causes:	1. The strut touched the hinge lugs when the boom was swung to its maximum left position
	2. The dynamic loading (bouncing) caused failure
Correction:	The lower strut was welded and the hinge lugs were chambered

----

Trouble: Flanges of I-beam that cab rollers ride in were bent

Causes:

1. Dynamic load (bouncing of the boom) caused by lock-check in boom lowering control
2. Beam not strong enough for the stresses applied
3. Rollers too far from the web - giving a greater bending moment to the flanges

Corrections:

1. Flanges straightened by heating and hammering then reinforced
2. Balancing valve to stop bouncing action installed

Trouble: Seals leaking on the two big hydraulic cylinders that swing and raise-lower the inner boom

Possible Causes:

1. Dirt eroding seals or piston rod
2. Faulty seals

No correction because leaks are not large enough to justify the time and effort of repairing seals

---