DRAINAGE AND IRRIGATION DEPARTMENT
MINISTRY OF AGRICULTURE
GOVERNMENT OF MALAYSIA

JABATAN PARIT DAN TALIAIR
KEMENTERIAN PERTANIAN
KERAJAAN MALAYSIA

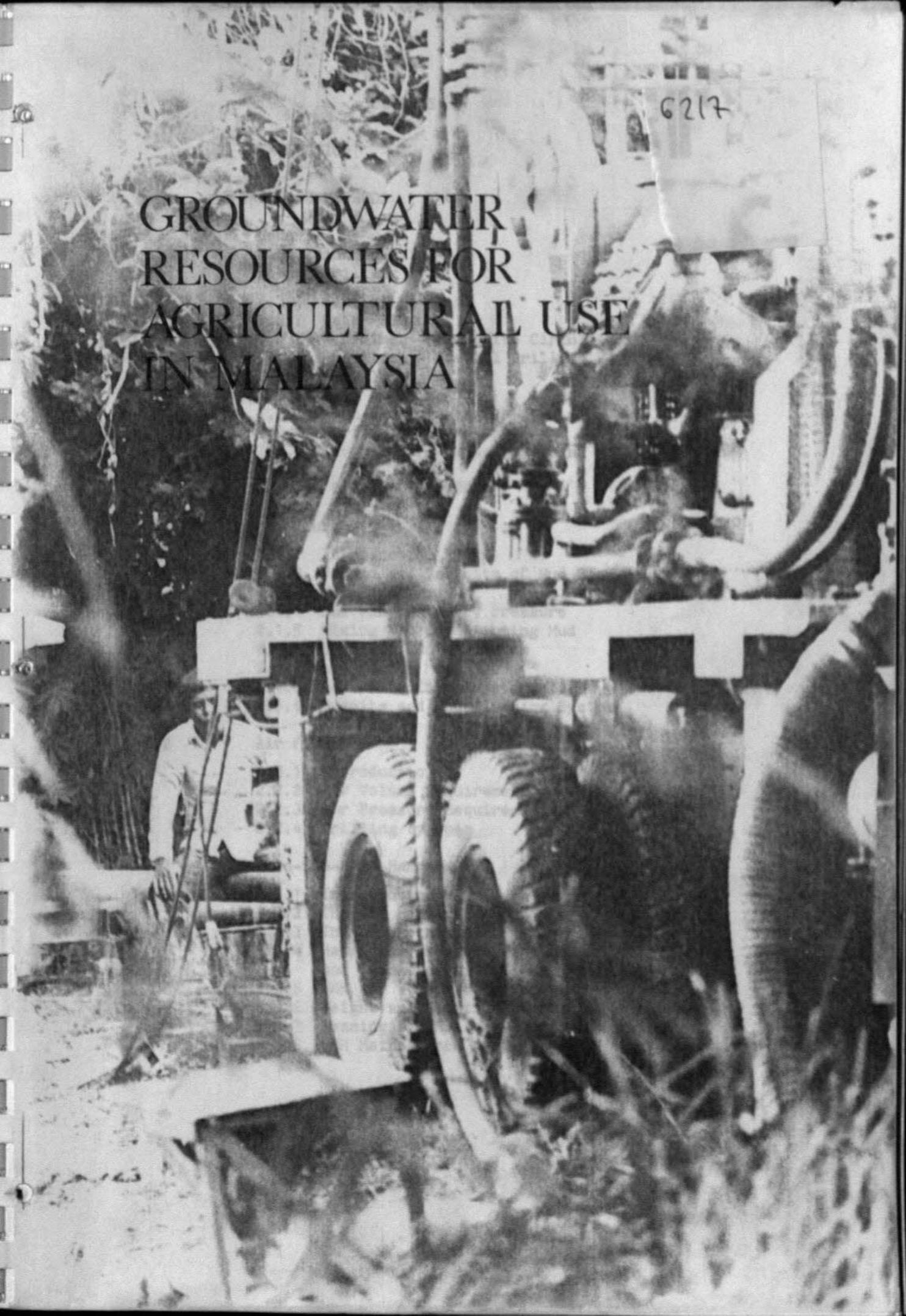# GROUNDWATER RESOURCES FOR AGRICULTURAL USE IN MALAYSIA

DRILLING MANUAL

GROUNDWATER RESOURCES FOR AGRICULTURAL USE IN MALAYSIA

APPENDICES

FIGURE 7-1 LOCATION OF DRILLING INVESTIGATIONS

FIGURE I-1 LOCATION OF DRILLING INVESTIGATIONS

AREA INVESTIGATED

PERLIS
1. Titti Tinggi
2. Padang Melangit
3. Wang Bintong
4. Mata Ayer

KEDAH
5. Padang Terap

PENANG
6. Mardi Bertam
7. Alma
8. Balik Pulau

PERAK
9. Bukit Gantang
10. Enggor
11. Cangkat Jong

PAHANG
12. Sungai Tekam

KELANTAN
13. Pasir Putih

0   25   50   75   100 KM
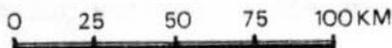
Introduction

In 1980, the Department of Drainage and Irrigation (JPT) purchased two Tone Top 750A top drive, chain pulldown type drilling rigs together with casing, ancillary drilling tools and geophysical equipment for groundwater exploration. The rigs were commissioned at the JPT Research Station, by drillers and mechanical engineers from the rig manufacturer; during this commissioning period, some instruction was given to JPT staff in rig function and use.

In 1981, JPT appointed the Consultants Sir M. MacDonald and Partners Ltd.whose task it was to assess the drilling rigs and equipment in relation to the needs of the planned drilling programme and to recommend improvements or modifications; these recommendation, which sought particularly to increase the rig capacity to drill in hard rocks, were given in the project Inception Report, August 1981. Since then, the Consultant's role has been to assist and train JPT personnel in a programme of groundwater investigation and development in Peninsular Malaysia. Much of the consultant effort has been directed at the establishment of trained and effective operators for the drilling rigs, who were conversant with all aspects of drilling theory and practice in diverse geological conditions.

JPT mobilised two drilling crews, each of about 6 men plus labourers, and field drilling operations began in November 1981. A continuous two rig operation was seldom maintained, largely because of rig falures. Drilling investigations have been completed both in hard rock and unconsolidated rock conditions (Figure I.1), using direct circulation rotary mud or air flush techniques and down-the-hole hammer equipment. Up to May 1983, over 53 boreholes were completed and over 75% of drill penetration has been in hard rock.

In the course of these works, training has been provided either on the job site or by means of informal lectures and short courses. Traditionally, a prospective driller, although he may have a mechanical background and some academic qualifications, spends up to 5 years as a trainee, often on menial, cleaning tasks about the rig; he is gradually allowed to operate a rig and equipment on his own. The job then becomes a matter of experience. Experience gained is proportional to the number of metres drilled or stated another way, experience is being exposed to the greatest number of difficulties.

JPT drilling staff training has been much accelerated from the traditional pattern but has nevertheless been successful. It has been fortunate that both personnel appointed as rig helpers and those originally designated as drillers or tool pushers, have shown a keenness to learn and have been willing to undertake and share the considerable responsibilities involved in operating expensive, heavy and sometimes dangerous drilling equipment.

What follows is a manual on drilling theory and practice, focussed particularly on methods, techniques and problems encountered or to be anticipated under Malaysian conditions. It seeks to set out guidelines for the proper use of the JPT drilling equipment. Where material in this manual needs further amplification, then the reader if referred to the numerous other publications by manufacturers and service companies in the drilling industry.
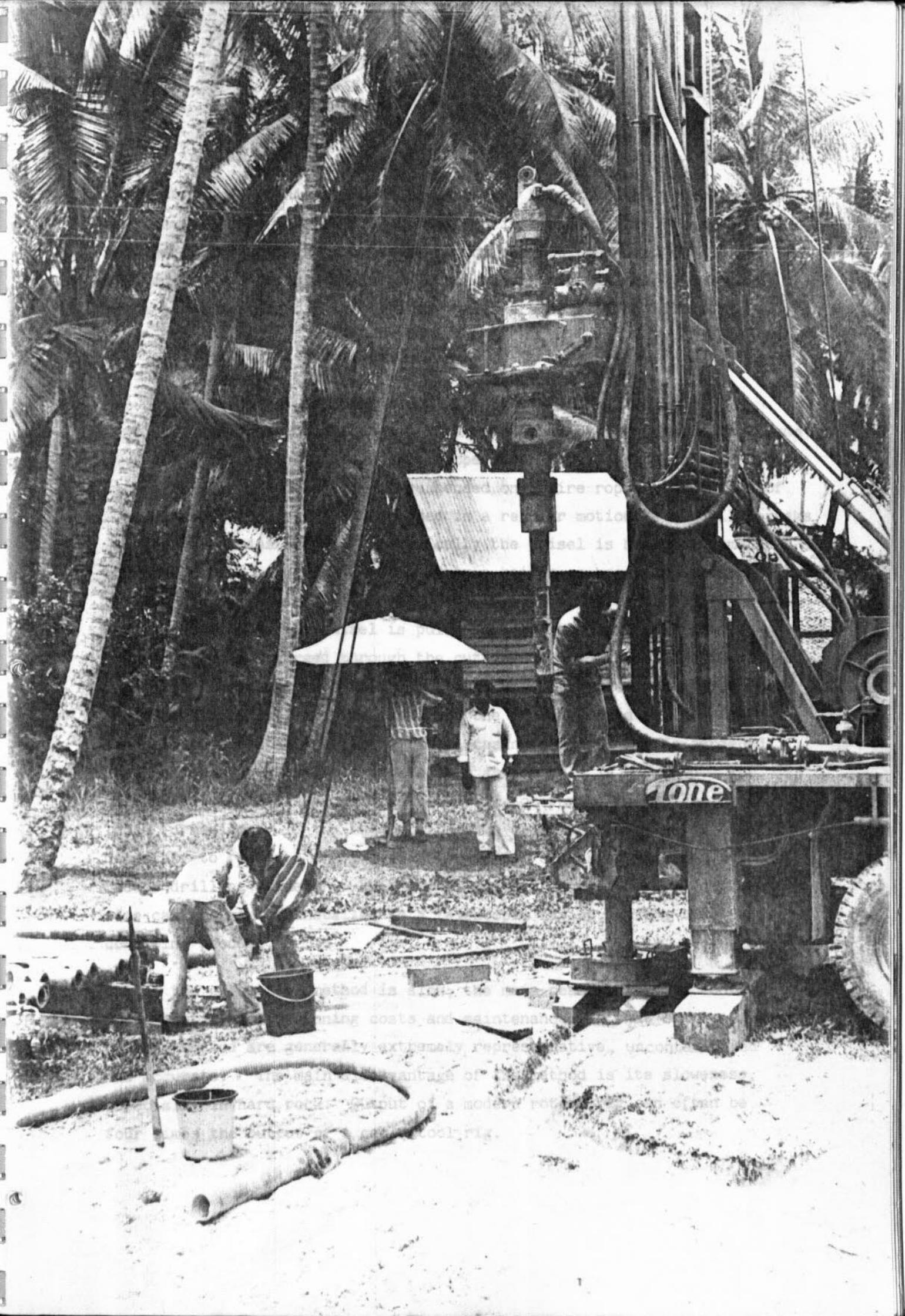
1. DRILLING METHODS

1.1 General

Basic drilling techniques are discussed here but it is the rotary method
and its derivations which are of specific interest to the JPT groundwater
section. The reverse circulation method has not been used but it is
mentioned below because it is in common use in several nearby countries
where large numbers of high capacity wells are drilled in alluvium.

1.2 Percussion Drilling

The oldest method of drilling a hole into the earth's surface is the
percussion or cable tool method. First practised by the Chinese thousands
of years ago, the system is still in operation today. With this method,
strata is cut by a heavy chisel suspended on a wire rope. The action of
the chisel, being raised and dropped in a regular motion, eventually breaks
up even the hardest rocks. Periodically the chisel is hoisted from the
bore and strata cuttings are removed by a bailer, a heavy, open topped
cylinder equipped with a flap valve at the bottom. After about each
metre of drilling, the chisel is pulled out and the bailer is lowered
down the bore and surged through the cuttings. When the bailer is raised,
the valve closes and retains the cuttings which are then brought to the
surface. The chisel is reinserted and the process repeated. In un-
consolidated strata, a lining of steel casing equipped with a hardened
steel shoe is progressively driven down as the hole is deepened. For
safety reasons, the driller does not drill too far below the casing in
loose formations. If the casing cannot be driven further, it is often
necessary to run in a smaller diameter string of casing and then to
reduce drilling diameter. When conditions are severe, several different
size casings may be installed in a telescopic fasion, a very time
consuming process.

Whilst the cable tool method is slow, the main reasons for its continued
use, apart from low running costs and maintenance, is that samples obtained
by this method are generally extremely representative, uncontaminated
and accurate. The main disadvantage of the method is its sloweness,
especially in hard rock. Output of a modern rotary rig can often be
four times the output of a cable tool rig.

The soils investigation department at JPT, Ampang use two small rigs
which operate on the cable tool principle; the rigs also have attachments
so that rotary coring can be carried out. Consideration should be given to
these rigs being used for special sampling, including coring and perhaps
small diameter bore drilling, on behalf of the groundwater department,
particularly where access to the 24 tonne Tone rigs is difficult.

1.3   Rotary Drilling

1.3.1   General

As the name implies, this method employs the rotation of a bit as a means
of cutting he formation. The bit is rotated via a hollow drillpipe or
drill string which extends to the surface. The drilling rig rotates
the drillpipe either by means of a rotary table or a geared motor powered
by hydraulics (power swivel). Variable weight is applied to the bit by
allowing part of the drill string assembly to rest on the bit or by forcing
the bit down under hydraulic pressure exerted from the drill rig. Drilling
debris is continually removed from the face of the bit to the surface by
either a liquid or air which is pumped down under pressure inside the
drill string. By using a specially prepared drilling fluid termed
drilling mud, bores can be put down rapidly in alluvium without the need
to 'case off' the formation.

The rotary drilling system and most of its tools have been developed
primarily by the oil industry and the average water bore (often termed
water well) is constructed using standard oil well drilling bits, drill
collars and drillpipe, and certainly uses the same theory. Usually,
water bores have greater diameters and far larger fluid yields than oil
wells.

Rotary drilling comprises the following drilling methods:

- water flush
- mud flush including water and special drilling
  fluids
- air flush
- foam flush
- down-the-hole hammer (a derivative of air drilling)
- coring (diamond drilling)
- reverse circulation

With modification in some cases, the JPT drilling rigs can perform most of the above duties but diameters and depths attainable may be limited. These constraints will be explained in a later section on drilling theory.

1.3.2   Water Flush

Direct circulation water flush can be used in certain circumstances in water bore drilling although the occasions are rare. The method is mainly used in conjunction with coring operations, for exploration purposes in hard rocks and where bores are of slim diameter. Where deep alluvium, and clays subject to hydrous disintegration (caving clays and shale) are present, it is not used.   Some sedimentary rocks including sandstones and limestones, and most igneous rocks, can be drilled by water without danger of bore caving. In karst limestone, where severe lost circulation is experienced, drilling 'blind' with water (that is without circulation) is a useful strategy.

A good supply of water should be on hand whilst water flush drilling is in progress; carting water by tanker to the site is not usually successful and a supply from a nearby stream is preferred.

Deep air drilled bores in metamorphosed shales and sandstones may be almost dry and become troublesome to drill because of stickiness in the bore wall; such bores may be continued by water flush if necessary. Shallow observation/piezometer bores can be drilled quickly using water flush in some circumstances, especially where the water table is not too close to the surface. So that any alluvium or surface sediments do not collapse, it is usual to keep the bore filled with water to the surface at all times.

1.3.3   Mud Flush - Bentonite Circulation

The drillers who used water flush for drilling in the early days of the oil industry noticed that their flushing water became 'muddy' when re-circulated down-the-hole, especially whilst drilling clay and shaly formations, and that this muddy water had advantages over plain water. The more viscous fluid produced was able to carry larger cuttings to the surface and further, when pumps were stopped in order to add another section of drillpipe, the bit did not block so easily nor did the bit get stuck so often. Before long, locally dug clay was being mixed with water to form a viscous fluid with which it was found possible to drill loose

3

unconsolidated strata without caving whereas earlier, such material had to be drilled using cable tool methods. It was soon realised that the heavier drilling fluid both helped to prevent holes collapsing and more importantly, it contained blow outs from high pressure oil and gas zones.

The preparation of drilling fluids is now a major industry and the complex subject of mud engineering as applied to the oil industry is of major importance.

The typical water bore drilling operation does not need the critical protection of specially treated drilling fluid because apart from occasional light artesian pressure, high pressure zones or high bottom hole temperatures are not encountered. Drilling mud is nevertheless necessary and without its viscosity, density and gelling properties, many drilling operations would fail. One of the disadvantages of mud in water bore drilling is that the fluid can penetrate the aquifer, especially in cracky or vuggy formations, and partially seal it off. In permeable formations there is the danger of build up of wall cake against the aquifer zone which can later be difficult to remove.

Mud drilling in limestones is difficult, because massive lost circulation zones may be present. Whilst lost circulation materials are available for dealing with the problem, and attemps at cementing off the loss zone (above the water table only) sometimes work, it is often easier to case off the offending zone, drill blindly for a while, or use an air/foam combination instead of mud. Since in limestones, the fractures and fissures may constitute both the circulation loss zone and the aquifer, the use of cement and loss circulation or plugging material should be avoided where possible. However where apparently solid limestone does contain fissures packed with loose deposits, there is no alternative but to use mud if hole caving is to be avoided. The group of bores drilled at Mata Ayer, Perlis (MA 1, 2, 3) by JPT fall into this category.

1.3.4   Mud Flush - Special Drilling Fluids

The use of organic polymers and 'Revert' type additives to form low solid muds for water bore drilling has gained popularity in the last twenty years. The material has certain advantages over bentonite including good sampling, separation of cuttings from the mud at the surface and an ability to stop clays and shale disintegrating through hydration. Advantages cited by

manufacturers include quicker, less costly development and more efficient bores. The ability of the mud, because of its low gel strengths, to allow cuttings to drop or separate from the mud stream at the surface, can be a decided disadvantage if the cuttings or cavings have not yet managed to reach the surface since pump stoppage allows suspended cuttings to fall in the bore annulus and cause blockage. Certainly more attention has to be paid to hole cleaning if larger cuttings are to be removed using these fluids.

Special muds, using oil as a base (as opposed to water) and salt water muds, are not of interest to the water bore driller. Their use is usually confined to oil well drilling operations although it is worth noting that these fluids are formulated because of certain advantages gained by their use under specific operating conditions.

Other examples of special drilling fluids can be cited; in the U.K., rock salt (halite) beds are drilled by using a full strength brine whilst deep potash exploration bores use diesel fuel as a drilling fluid.

1.3.5   Air Flush

In consolidated rocks the use of compressed air for drilling is preferred. The method offers superior penetration rates and a visual confirmation of any water zones cut. Where water for drilling mud is scarce and where lost circulation is a problem, air drilling can save much time and trouble.

Apart from the need for a suitable compressor, down-hole tools may remain the same as in mud flush drilling although special rock roller bits should be used.   Because air cannot support the formation, unconsolidated strata will cave soon after air drilling and such zones therefore need to be cased off. Friable strata is eroded by air drilling due to the necessary high up hole velocities (UHV) of the air in the bore/drillpipe annulus. Restrictions in drilling depths due to water inflow during drillpipe changes often terminate air drilling before target depth has been reached. Water shut-off techniques, including the casing or cementing-off of wet zones, are used to continue bores where compressor working pressure is limited.

As with the mud flush system, certain minimum volume/pressure requirements
need to be met for successful air drilling (Chapter 2).

In drilling terms, most of Peninsular Malaysia consists of 'hard rock'
and therefore, the majority of bore drilling is undertaken using compressed
air.

1.3.6   Foam Drilling

Foam drilling is classed with air drilling in that most of the same laws
apply; it too fails to support the formation and suffers depth limitations
although to a lesser extent.

The injection of a mixture of water and foaming chemicals into the air
supply allows much larger diameter drilling to take place for a given
compressor volume. As a result, 'thickened' air is able to carry cuttings
easily in a slow ascending foam mixture. The obvious advantages are that
great savings can be made on compressor requirements and fuel costs.
With a lower UHV, the possibility of bore erosion is eliminated whilst
in lost circulation zones, the foam mix often temporary fills the offending
fissures and allows cuttings to reach the surface.

1.3.7   Down-the-Hole Hammer (DHH)

DHH drilling is very efficient in hard to very hard rocks. The system is
basically percussive with a rotary action; energy from the flushing medium,
compressed air, operates the hammer before discharging through the bit.
In the harder rocks, penetration rates using the DHH may be four or five
times quicker than those obtained by a conventional rock roller bit.
Apart from the gains in penetration speed, the wear and tear on the drilling
rig is much less owing to the low bit operating weight which is a fraction
of that required by conventional drilling. Foam can be used with the hammer
when necessary. Depth limitations with the hammer in wet hole conditions
are even more pronounced than with straight air drilling. The reason for
this is that a pressure of 7 kg/cm^2 is required solely to operate the
hammer (available pressure on JPT compressors is 14 kg/cm^2) and any
restrictions on the free exhausting of the hammer cause severe reductions
in its efficiency.

Coring or diamond drilling is a method of obtaining cylindrical rock
samples or cores.   Basically a tube of steel, the core barrel, is fitted
with a cutting shoe (or bit) and is rotated via the drillpipes into the
strata to be sampled, while at the same time a fluid (or air) is circulated
through the core barrel and bit for cleaning purposes. Once inside the
core barrel, the core is retained by a tapered spring device, a core
catcher which closes around the core when the core barrel is lifted.
Superior core barrels have a double tube system where the inner tube is
suspended on a bearing and remains stationary. With this method, the core
is protected both from vibration and from the circulating medium and better
core recovery is possible.   The groundwater section do not have a core
barrel at present but often the geologist may need to examine rocks in
more detail than is possible from rock bit cuttings; cores may be needed
at specific intervals and rock changes especially in exploratory work.

A double tube core barrel, three metres long and designed to accept mud
flush, would be suitable for future JPT needs. The core barrel would be
used in conjunction with either 8.9 cm or 12.1 cm dia. drillpipe within
15 cm dia. casing. Therefore a core barrel of 14.6 cm dia. (S.F. size
according to B.S.) would be suitable. A smaller core barrel of 12.1 cm
dia. (P.F. size according to B.S.) could be used with the smaller drillpipes
only.   General purpose diamond bits of the face discharge type with 40-60
stones per carat (1 carat = 0.2 gramme) should suit most needs.

The JPT may in future wish to use the Tone rigs for civil engineering
purposes. Possible applications would be larger diameter bores, drilled
under bentonite using existing equipment, which may be used for piles
or else auger drilling (dry) for piling purposes or for soil sampling.
The soils department have an eight inch core barrel (soft soils) which is
too big for their rigs and this equipment, purchased by JPT for use by a
contractor engaged by them on a site investigation contract, could be used
in conjunction with the groundwater rigs.

1.3.9   Reverse Circulation Drilling

With the reverse circulation (RC) drilling method, circulation water is
drawn up the drillpipe into a settling pit whence clear water is allowed to
return down the bore via the annulus between drillpipe and bore wall.
Oversize drillpipes of 15 cm inside diameter are usually used with a minimum
bit diameter of 450 mm. Circulation of a high volume of plain water with
a suction gravel pump (15 cm bore) or by means of an airlift system enables
fast, clean drilling in alluvial strata. Large cobbles and gravel (up to
14 cm dia.) can be moved up the drillpipe without the necessity of first
grinding them small with the bit. A slow descending water velocity in the
annulus does not erode the walls of the bore. Because the system uses
plain water, sample quality is good and accurate and furthermore, a bore
drilled by the RC method needs much less development than one constructed
using mud flush.

The JPT rigs do not have the necessary drillpipe or gravel pump but the
rig is adaptable for this method. Such a considerable adaptation would
only seem justified if a large scale programme of large diameter production
bores in alluvium were contemplated.

The disadvantages of the RC method are as follows:

- it needs plentiful water supply, of about 7 l /sec.
  guaranteed at all times

- Static water level should not be less than 2.5 below
  ground level otherwise, in alluvium, there is danger
  of hole collapse

- static water levels greater than 20 m cause too great
  a water loss during drilling and water level in the bore
  cannot be maintained for the suction lift method.

2. THEORY OF DRILLING

2.1 Mud Flush

2.1.1 Introduction

All rotary drilling uses water or air under pressure. The functions are:

- to lubricate the

2. THEORY OF DRILLING METHODS

2.1 Mud Flush

2.1.1 Introduction

All rotary drilling systems depend on the circulation of a fluid
or air under pressure for hole cleaning. The tasks of the fluid
are:

- to lubricate bit bearings and cool the bit

- to remove material from the bottom of the hole as
  soon as it is cut, so that virgin strata is continually
  exposed

- to transport all the cuttings to the surface.

During pipe changes, any cuttings left in the hole need to be kept in
suspension. The amount of fluid required to carry out these tasks effectively
depends on the diameter of the hole and the drillpipe and the viscosity
and volume of the fluid.

The space between drillpipe and borehole wall is the annular area and the
rate at which the circulation fluid ascends in the annulus is termed
the uphole velocity (UHV).

2.1.2 Volume of Flow

Research has shown that between 50 and 75 cm/sec is the ideal UHV
for proper hole cleaning but this depends on viscosity of the fluid.
Lower velocities need a more viscous fluid but too high a viscosity
is not desirable for several reasons. These include difficulties
in cleaning the mud (which will not drop the drill cuttings), and the
high pump pressures required, but of more importance is the detrimental
effect of a thick wall cake, produced by excessively viscous muds.
A balance has to be reached between plain water flush (which would
require high volumes to function properly and which has the added danger
of erosion and caving of the borehole wall) and undesirably thick mud.
Experience shows that exploration type holes of 7 5/8" (19.3 cm) dia.
can be drilled using 4 3/4" (12.06 cm) o.d. drillpipe and the Tone 850
l/min mud pump and mud with a viscosity of between 36 and 40 secs
(Marsh funnel); this configuration gives excellent samples and allows
cuttings to drop after reaching the surface.

FIGURE 2.1 UP HOLE VELOCITY - MUDFLUSH.

The following formula shows the relation of UHV to the geometry of the system and the flow volume:

$$UHV = \frac{21,200 \, V}{D^2 - d^2}$$

where
UHV	=	Velocity in cm/s
V	=	Volume of Flow in m^3/min
D	=	Hole dia. (cm)
d	=	Drillpipe dia. (cm)
21,200	=	a Constant

Substitution of the figures quoted above gives:

$$UHV = 79.4 \, cm/s$$

This figure is slightly higher than necessary but once pump volumetric efficiency losses are deducted the actual velocity falls in the recommended range shown (Fig. 2.1).

The results of having a UHV which is too high can be seen in Fig. 2.2 which shows a composite borehole log of a test bore at Cankat Jong, Perak (CJ 3). The caliper log of the bore diameter indicates massive hole enlargement due to erosion and subsequent caving; over much of the section 3 m to 28 m, the bore diameter is oversize and may exceed 30 cm diameter. A 6¼" (15.8 cm) bit was used to drill this section with the full volumetric out-put of the mud pump; UHV in that case would have been 172.9 cm/sec.

The mud pump installed on the Tone rig is not equipped with a gear box or any form of speed control and has to be run at full speed via the transmission from the truck engine. The volume of mud being pumped down the bore is controlled by partially opening the valve (cock) leading to the mud mixer so that some of the mud bypasses the bore. Unfortunately, this involves the estimation of rates of flow; for accuracy, a small weir may be set in the mud channel leading from the bore to the mud pit.

Where a large number of small diameter bores are to be drilled, it would be simpler to fit smaller diameter pistons and liners to the mud pump (Table 2.1).

FIGURE 2.1   UP HOLE VELOCITY – MUDFLUSH.

FIGURE 2.2 COMPOSITE BORE LOG

FIGURE 2.2   COMPOSITE BORE LOG

COMPOSITE BORE LOG

LOCATION: CANGKAT JONG 3

STARTED 29.12.1982, COMPLETED 8.1.1982

DRILLING METHOD: Rotary mud flush

YIELD TEST: Air lift on 8.1.82

TOPO SHEET: 65 TAPAH

GRID REFERENCE: 496461

REFERENCE POINT (R.P) Top of casing

R.P. ELEVATION: m (above ground level)

LOCATION MAP

CJ 3

N

APPROX 1:97,000

CJ 3 GS 1144

TOTAL DEPTH	66 m	SWL 1.69 m
YIELD	2.5 l/s	EC 165 micro mhos at 25°C
REMARKS	See below

Construction / Drilling Data / Litho-logical Summary / Geophysical Borehole Logs

CONSTRUCTION — DRILLING DATA (ins, drill rate min/m, yield l/s) — DEPTH (m) — LITHO-LOGICAL SUMMARY

GEOPHYSICAL BOREHOLE LOGS: CALIPER — NATURAL GAMMA — RESISTIVITY AND SP

SCALES 6in — 8in — 10in — 10 20 30 CPS — 100 200 300 400 ohm

10" ∅ Casing

12¼" ∅ Open hole

0.045 Screen

0.035 Screen

0.045 Screen

6" ∅ Hole

tc = 2 sec

-50+ MV

SP

R

LEGEND

Symbol	Description
	Clay
	Gravel, Clay
	Course Sand and Medium Sand
	Course sand and Fine Gravel
	Course Sand
	Sand M-C and Peat
	Medium Sand
	Claystone and Peat
	Claystone and Medium Sand
	Claystone and Shale

Note:

Because of poor discharge the well assembly shown in the construction details was later raised by 15 m and the well re-developed.

This zone was a very poor producer too and all well-components were recovered for use elsewhere.

Table 2.1   JPT Mud Pump Output

Make (Model)	Size (in cm)		Alternative Liner diameter (cm)	Displacement Volume (lpm)	Maximum Pressure (Kg/sq.cm.)
	Liner dia. (cm)	Length of Stroke (cm)			
Tone	15.2	15.2		850	20.0
(NAS 6)			12.7	580	29.0
*			10.1	360	47.0
Gardner Denver	12.7	15.2		568	21.8
(FGFXG)			10.1	360	34.59
**			7.6	262	62.93

* Mounted on rig

** This pump is in Ipoh Workshops.

A gravel packed production bore equipped with 10" pump casing would need
to have a 15 inch (38.1 cm) hole drilled to accommodate it. It can be seen
(Figure 2.1) that UHV could only be 13.7 cm/s if the mud pump was used
at its maximum capacity.

The drilling of a shallow bore of this size would have to be in two stages,
a pilot hole of sufficient diameter to accommodate the lower bore casing
assembly and a second stage of reaming or hole opening at 15" dia.
for the upper bore casing. In deeper bores of large diameter, trouble
is experienced during drilling from partial hole cleaning if UHV is
insufficient. Large cuttings, gravel and clay lumps, do not reach the
surface and end up stuck to the borehole wall. Often, mud viscosity
increases because the bit regrinds cuttings which leads to an increase in
mud weight. A combination of these factors provides the conditions for
thick 'wall cake' and borehole 'necking' (Fig. 2.3).

Bores drilled under these conditions suffer later when gravel packing
is attempted. Often, the calculated volume of gravel will not pass into
the bore because of bridging at constricted areas and when the gravel does
eventually pass, it takes with it thick wall cake and other drilling
debris. The clay fraction in this material can then permanently block
large areas of screen.

FIGURE 2.3   RESULTS OF POOR HOLE CLEANING (MUD AND AIR)

NORMAL PRESSURE

BORE NECKING

BUILD UP OF CUTTiNGS

HIGH PRESSURE

MUD AND CUTTINGS

INVADING FORMATION
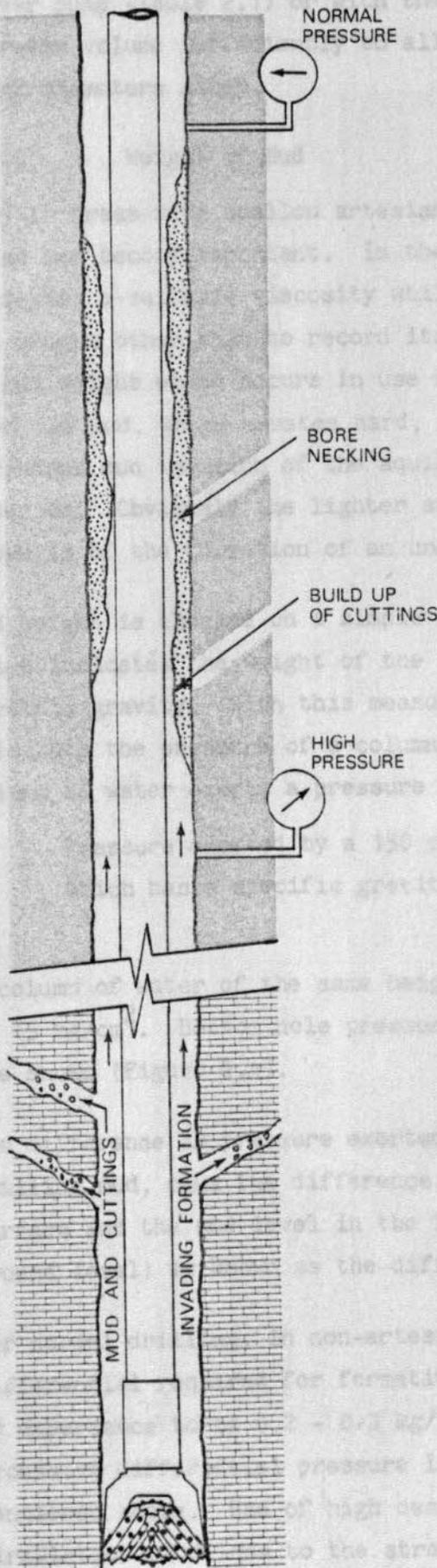
EXPLANATION

Poor hole cleaning due to insufficient Up Hole Velocity gives the following results:

1. Bad quality samples

2. Slow penetration due to bit not being cleared properly

3. Increase in mud viscosity due to regrinding cuttings

4. Necking of the bore due to build-up of drilling debris

   Necking of the bore then leads to the following problems:

5. High annular pressure below the necked zone - leading to.

6. Loss of circulation to fissures and highly permeable strata.

7. Invasion of the aquifer by mud and (perhaps) cuttings making development difficult later.

8. Difficulties in gravel packing which may lead to screen blockage or sand pumping.

9. Danger of getting drill string stuck during drilling.

If necessary, a near correct UHV may be obtained by compounding pumps.
The Tone mud pump, coupled with an auxiliary pump such as the Gardner
Denver pump (Table 2.1) or with the pump from the second rig, will just
increase volume sufficiently to allow deep, trouble-free drilling at the
large diameters cited.

2.1.3 Weight of Mud

Only in areas with shallow artesian pressure does the weight of newly
mixed mud become important. In the average bore, mud mixing aims at
achieving a suitable viscosity whilst little or no attention is paid to
mud weight other than to record its value. However, it is the increase
in mud weight which occurs in use by the mixing of cuttings and sediments
with the mud, which creates hard, thick wall cake. High mud weight also
increases mud invasion of the aquifer which causes development problems
later on. Obviously the lighter and cleaner the mud, the less chance
there is of the formation of an undesirable wall cake thicknesses.

Mud weight is checked on a simple piece of apparatus called a mud balance
which indicates the weight of the mud sample in pounds per US gallon or as
specific gravity. With this measurement, it is relatively simple to
calculate the pressure of a column of mud if it is known that a one metre
column of water exerts a pressure of 0.1 kg/cm^2. For example:

> Pressure exerted by a 150 m column of mud
> which has a specific gravity of 1.16   =   150 x 0.1 x 1.16
>   =   17.4 kg/cm^2

A column of water of the same height would of course exert a pressure
of 15 kg/cm^2. Bottom hole pressures for various typical fluid columns
are shown (Figure 2.4).

The difference in pressure exerted by a column of water and a column of
drilling mud, plus the difference between the natural formation piezometric
surface and the mud level in the bore (which should always be kept at
ground level) is known as the differential pressure.

For normal drilling, in non-artesian conditions, the minimum pressure
differential required for formation support (Figure 2.5) has been shown
by experience to be 0.2 - 0.3 kg/cm^2 (2-3 m head difference).
Excessive differential pressure leads to the extra tough wall cake
mentioned above. Use of high density mud can also cause loss of
circulation (mud loss to the strata) in fissured or gravelly formations.

FIGURE 2.4 BOTTOM HOLE PRESSURES–VARIOUS MUD WEIGHTS

(NOTE: 0 1 KG. / SQ. CM = 1.0 M HEAD OF WATER)

Ground Level

STATIC WATER LEVEL

6 m

CLAY

SAND

CLAY

SAND

100 m

BOTTOM HOLE PRESSURE = 9.4 Kg/sq. cm. BORE FILLED WITH WATER TO S.W.L.

BOTTOM HOLE PRESSURE = 10.4 Kg/sq. cm. BORE FILLED WITH NEW DRILLING MUD WITH S.G. 1.04

BOTTOM HOLE PRESSURE = 11.0 Kg/sq. cm. BORE FILLED WITH USED DRILLING MUD WITH S.G. 1.1

BOTTOM HOLE PRESSURE = 12.0 Kg/sq. cm. BORE FILLED WITH HEAVY DRILLING MUD WITH S.G. 1.2

NATURAL FORMATION PRESSURE

DIFFERENTAL EXERTED BY DRILLING MUD FILLING BORE HOLE FROM SURFACE

FIGURE 2.5 ROTARY DRILLING – FORMATION SUPPORT REQUIREMENTS

DIRECT CIRCULATION (DC)

WL2 ▽

GL ▽
WL1 ▽

AQUIFER 1

MUD

AQUIFER 2
(CONFINED
ARTESIAN)

PRESSURE HEAD ⟶

Pressure head profile
in formation

Pressure head profile
for low density mud.
Collapse danger in
zone*

Pressure head profile
in satisfactory high
density mud.

*

REVERSE CIRCULATION (RC)

GL ▽

WL ▽

WATER

ΔH

PRESSURE HEAD ⟶

Seepage losses from
borehole reduce
differential head ΔH

Pressure head profile
in formation.

Pressure head profile
in borehole.

FIGURE 2.6   MUD WEIGHT TO KILL ARTESIAN FLOW

Such formation invasion by mud at depth would be difficult to correct during later development of the aquifer zone.

No artesian flows have been encountered in bores so far drilled by JPT but technique for control of these flows is discussed here. When artesian layers are penetrated unexpectedly, there is the danger that the drilling mud weight may not be sufficient to prevent the flow and as a result, the bore will flow out of control; an added danger is that if the artesian layer is of unconsolidated material, this may collapse around the drill string. Artesian flows from shallow depths are harder to deal than those from deeper down.

The problem is dealt with by mixing a heavy drilling mud. The hole is then filled quickly via the drillpipes. If casing has been cemented in position, the casing can be capped and mud pumped down via a casing head. The mud weight required to 'balance' the flow has to be calculated (Figure 2.6). To do this, measurement or prediction of the piezometric head above ground level will be necessary and this height added to the depth of the zone below ground level (combined length) to give the total working length of hydrostatic column. A basic mix of new bentonite plus CMC (an additive) formed to normal drilling mud requirements, would not be sufficiently dense to handle the situation shown (Figure 2.6). Likewise, additional bentonite has the effect of increasing viscosity but with only a little increase in weight. Barite (barium sulfate, - $BaSO_4$), finely-ground for use in oil well drilling, has a specific gravity of between 4.2 and 4.3 and where artesian conditions are known to exist regionally, this material should be stocked on site so that required mud weight may be reached.

In an emergency, however, the driller will not have time to formulate specially weighted muds and instead will pump down the bore the heavy contaminated mud from the settling pit in an effort to kill the flow.

2.1.4   Mud Pump Delivery Pressure

Pressure is required to pump mud through the rig delivery hose and swivel, through the drillpipe and bit and then to raise cut strata to the surface. The force required depends very much on the viscosity and weight of the drilling fluid, the size of the bore annulus, the inside diameter of the various pipework involved (including the drill string) and the depth of the bore (Figure 2.7).

FIGURE 2.6   MUD WEIGHT TO KILL ARTESIAN FLOW.

BOTTOM HOLE MUD PRESSURE = 4.95 KG./SQ.CM.

CONFINING STRATA

ARTESIAN LAYER.

GROUND LEVEL
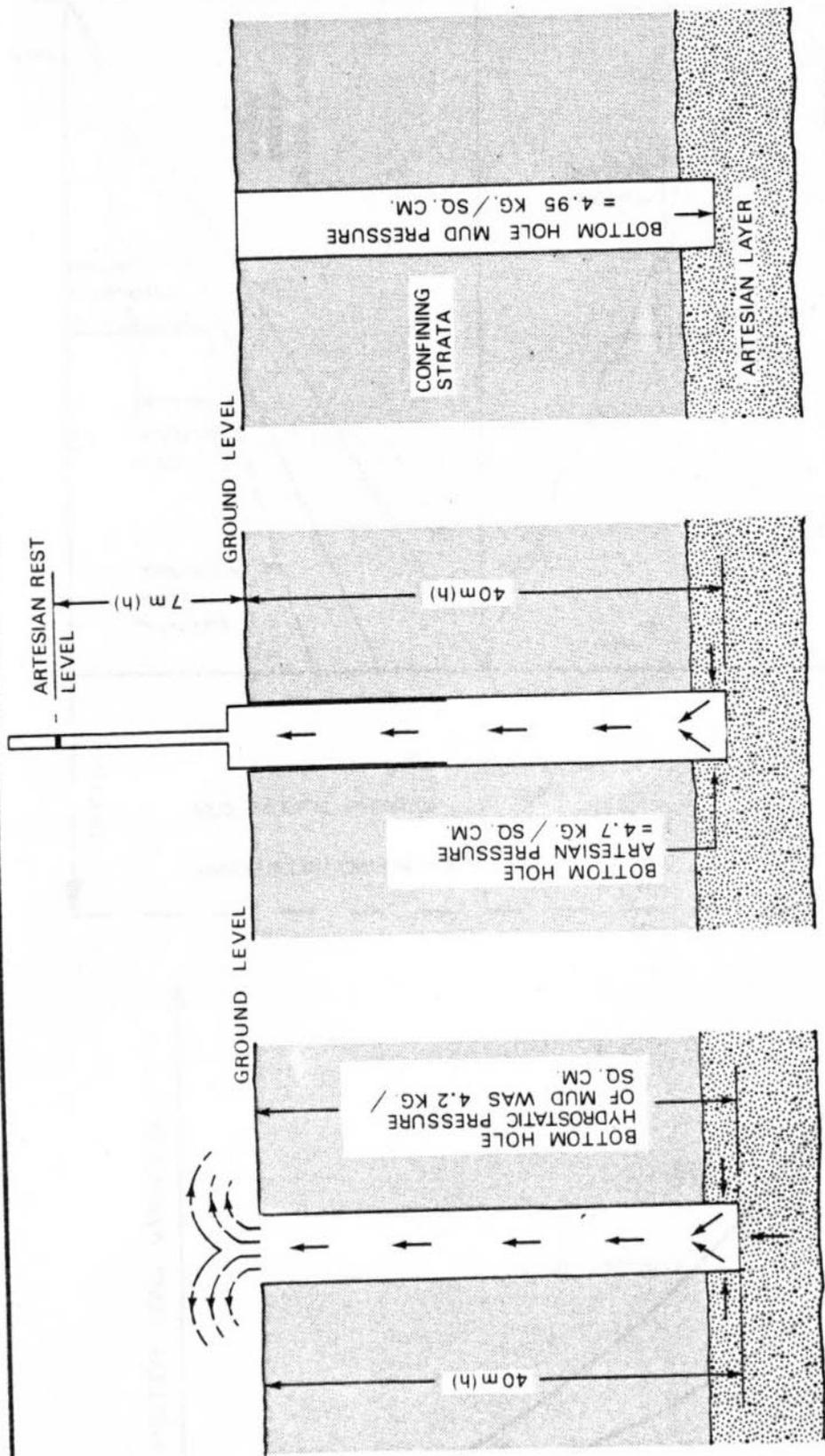
MUD WEIGHT REQUIRED TO BALANCE ARTESIAN FLOW = S.G.

$$= \frac{H+h \times 0.1}{H \times 0.1} = \frac{40 + 7 \times 0.1}{40 \times 0.1}$$

BALANCE WEIGHT = 1.175

SAFE WORKING MUD WEIGHT SHOULD BE GREATER I.E. S.G.=1.2

ARTESIAN REST LEVEL

7 m (h)

GROUND LEVEL

40m (h)

BOTTOM HOLE ARTESIAN PRESSURE = 4.7 KG./SQ.CM.

BEFORE FURTHER WELL CONSTRUCTION CAN CONTINUE, PIEZOMETRIC SURFACE OF ARTESIAN (REST LEVEL) SHOULD BE MEASURED OR ESTIMATED. TO DO THIS, CASING MUST BE SET INTO CONFINING LAYER ABOVE ARTESIAN ZONE

GROUND LEVEL

BOTTOM HOLE HYDROSTATIC PRESSURE OF MUD WAS 4.2 KG./SQ.CM.

40m (h)

DRILLING IS IN PROGRESS USING NORMAL WEIGHT MUD OF ABOUT 1.05 S.G. ARTESIAN ZONE IS ENCOUNTERED WHICH FORCES DRILLING MUD FROM BORE, IN UNCONSOLIDATED FORMATIONS HOLE MAY COLLAPSE.

NOTE: FOR THE PURPOSE OF THIS EXERCISE THE FOLLOWING MAY BE IGNORED:

1) PERCHED WATER LEVEL.
2) VOLUME OF ARTESIAN FLOW.
3) DIAMETER OF HOLE.

FIGURE 2.7   SCHEMATIC MUD PRESSURE LOSSES
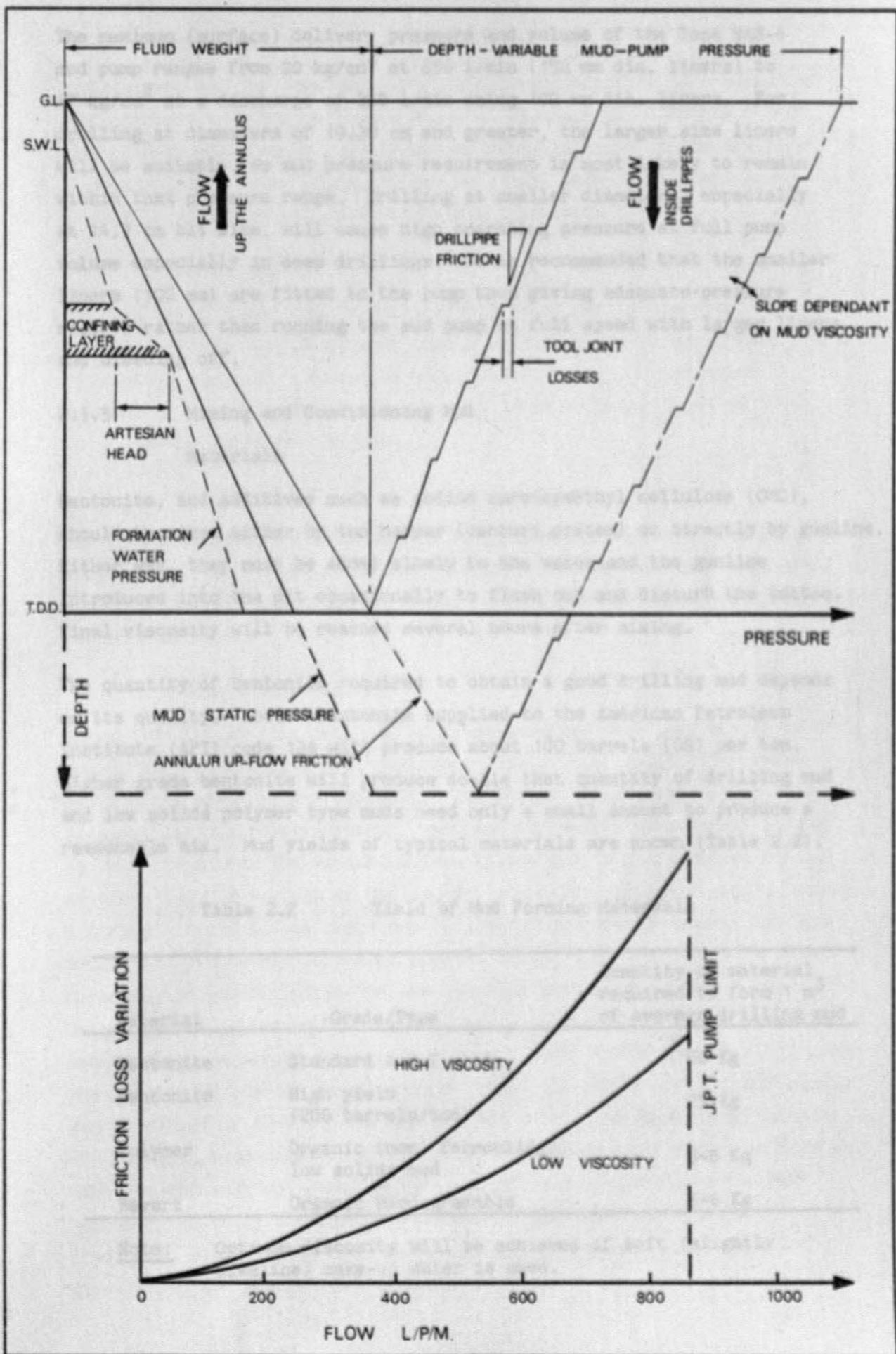
The maximum (surface) delivery pressure and volume of the Tone NAS-6 mud pump ranges from 20 kg/cm^2 at 850 l/min (152 mm dia. liners) to 47 kg/cm^2 at a discharge of 360 l/min using 102 mm dia. liners. For drilling at diameters of 19.30 cm and greater, the larger size liners will be suitable, as mud pressure requirement is most likely to remain within that pressure range. Drilling at smaller diameters, especially at 14.9 cm bit size, will cause high operating pressure at full pump volume especially in deep drillings. It is recommended that the smaller liners (102 mm) are fitted to the pump thus giving adequate pressure reserve rather than running the mud pump at full speed with larger liners and bleeding off.

2.1.5   Mixing and Conditioning Mud

          Materials

Bentonite, and additives such as sodium carboxymethyl cellulose (CMC), should be mixed either by the hopper (venturi system) or directly by gunline. Either way, they must be added slowly to the water and the gunline introduced into the pit occasionally to flush out and disturb the bottom. Final viscosity will be reached several hours after mixing.

The quantity of bentonite required to obtain a good drilling mud depends on its quality. Sodium bentonite supplied to the American Petroleum Institute (API) code 13A will produce about 100 barrels (US) per ton. Higher grade bentonite will produce double that quantity of drilling mud and low solids polymer type muds need only a small amount to produce a reasonable mix. Mud yields of typical materials are shown (Table 2.2).

Table 2.2   Yield of Mud Forming Materials

Material	Grade/Type	Quantity of material required to form 1 m³ of average drilling mud
Bentonite	Standard A.P.I. 13A	50 Kg
Bentonite	High yield (200 barrels/ton)	25 Kg
Polymer	Organic (non fermenting) low solids mud	5-6 Kg
Revert	Organic Biodegradable	5-6 Kg

Note: Optimum viscosity will be achieved if soft (slightly alkaline) make-up water is used.

Measurement of Drilling Mud Properties

Drilling mud and its treatment is a complex subject. It is a matter of great concern on a deep oil well where an engineer is in charge of mud and would be responsible for its proper conditioning. In the drilling of shallow depth water bores, mud control does perhaps not need such specialist attention but is nevertheless important.

Water Qualtity

The quality of water used for mixing with bentonite is important. A 'soft' water with a pH greater than 8 will give the maximum yield (viscosity) per sack. Where the water supply is acidic (pH below 7), soda ash or caustic soda is added to the water to bring it to pH 8 or above, before bentonite is added.

Mud Test Kit

Mud is tested on site during mixing and frequently during drilling. Three simple tests, for weight, viscosity and sand content, are perfomed using standard oilfield type apparatus. In addition, pH is monitored by using standard pH paper.

Weight Measurement

Weight (or density) is measured on a mud-balance. Readings are given in pounds per US gallon, pounds per cubic foot, p.s.i. per 1,000 foot of depth or as specific gravity (SG). The JPT drilling section uses the SG scale for their measurements. Samples for weight measurement should be taken from near the suction intake in the mudpit and recorded on the drilling log. A new mud of the correct viscosity will have weight between 1.03 and 1.05 SG but as the borehole gets progressively deeper, the mud will pick up cuttings particles and its weight will increase at a rate depending on how efficient the mud cleaning system is. Since light weight mud is preferred, for reasons explained in section 2.1.3, there comes a time on deeper boreholes where mud needs to be changed. To reduce mud weight, as opposed to completely change it, water can be added slowly over a period of time and surplus mud run off. The process of thinning the mud also encourages sand trapped in the circulation system to drop out into the channels and settling pit. Artificial weighting of the mud would not normally be necessary except to cope with the artesian conditions described in section 2.1.3, or for the rare occasion where extra formation support is required.

Viscosity and its Measurement

Viscosity of a drilling fluid is measured by using a Marsh Funnel; one US quart of clear water at 70°F will take 26 seconds to flow out of the funnel.

Mud mixed to give a final viscosity of between 35 and 40 seconds is found to be satisfactory for most drilling conditions (if UHV requirements are reasonable). Where UHV is low, or large gravel and other non crushed rock fragments are encountered, thickening of the mud may be desirable. Higher mud viscosity becomes useful during the hole-opening or reaming phase of bore construction, which usually comes last. Muds with a viscosity of 60-70 second are common in some situations. Low viscosity muds (less than 35 seconds) may lead to water loss to permeable strata and loss of circulation altogether. Volume of fluid circulated would need to be increased with low viscosity mud, but this carries an added danger of borehole erosion.

The gel strength of the drilling mud is closely related to its viscosity, because gelling ability depends on the quality and volume of the bentonite in the fluid. It is the gelling ability which suspends cuttings in the mud when the pump is stopped; without it, cuttings would descend around the drill collars and bit and the drill string would become stuck in the bore. Pumping of a high viscosity mud, especially after drilling has been suspended for a period and gelling has taken place, becomes more difficult and may be troublesome in that the pump safety valve may open frequently. This situation is compounded when the fluid has to pass through certain 'jet' type rockroller bits.

Sand Content Measurement

Measurement of the sand content in used drilling mud is necessary especially when mud pit systems are small. 'Sand' may consist of a natural siliceous sand or of drill cuttings produced by the action of the bit crushing harder strata of a non-siliceous nature. A poor mud cleaning (settling) system drilling muds of excessive viscosity or laziness on the part of the drilling crew soon allows the sand content of mud to increase to such an extent that in a very short time, mud pump and swivel parts become abraded and damaged. An excessive sand content, through being constantly recirculated, can also cause confusion during geological sampling of drill cuttings. It also leads to low and erroneous values from the Marsh funnel test.

FIGURE 2.8 EXAMPLE OF WALL CAKE BUILD UP

Mud should never be allowed to reach the maximum permitted sand content of 5% by volume. Either the mud in the borehole and pits should be changed completely or it should be thinned sufficiently so that sand may drop out in the settling pit or approach channels. A sand content test kit consists of a graduated glass tube and a 200 mesh sieve and funnel. A fixed quantity of mud, taken from the suction pit, is agitated with a fixed amount of water and poured onto the sieve; the caught sample is then washed into the tube and measured.

Wall Cake and Filtration Rate Measurement

The formation of wall cake opposite permeable strata during mud drilling, is due to migration of water from the drilling fluid into the formation (Fig. 2.8) which process allows the more solid constituents of the mud to deposit and form an impermeable seal or 'wall cake'. Some 'wall cake' is necessary otherwise there would be a continuous loss of fluid during drilling, with a danger that the hole could collapse if differential pressure was lost. Mud with a high solid content produces a thick wall cake which becomes harder and denser with depth. In consequence, the bore may be difficult to develop properly; the consequent formation damage will lead to an inefficient bore.

The apparatus for checking the filtration properties of drilling mud is available from mud supply companies; it is simple to use. On bores deeper than 300 m, routing checks of filtration properties should be made but it is unlikely these checks would be used frequently with the shallow JPT boreholes. The procedure for prevention of thick wall cake is however important.

To reiterate, the solids content or weight of mud should be kept low whilst the additive CMC helps in controlling water loss as well as in building up viscosity. CMC should be added slowly into the mud pits as it tends to ball up quickly. If mixed with fresh mud early on, CMC will substitute for a proportion of the bentonite normally used. Starch, which is much cheaper and available locally, does a similar job, but is subject to fermentation. One sack of CMC to every 10 sacks of bentonite is recommended as a suitable ratio when mixing mud.

FIGURE 2.8   EXAMPLE OF WALL CAKE BUILD UP.

BOREHOLE DIAMETER IN HARDER FORMATIONS FOLLOWS CLOSELY TO BIT SIZE.

IN SOFT AND UNCONSOLIDATED FORMATION HOLE IS OFTEN OVER GAUGE.

'WALL CAKE' FORMED IN PERMEABLE STRATA.

FORMATION AQUIFER PRESSURE AT 150 M LESS THAN 15 KG./ SQ. CM.

150 M HEAD OF MUD AT SPECIFIC GRAVITY OF 1.2 EXERTS A PRESSURE OF 18 KG. / SQ. CM.

WATER FROM DRILLING MUD ENTERS THE AQUIFER.

DIFFERENTIAL PRESSURE ALLOWS WATER TO BE SQUEEZED OUT OF MUD INTO THE AQUIFER. BENTONITE AND OTHER SOLIDS THEN FORMS A WALL CAKE WHICH BECOMES IMPERMEABLE

CLAY AND SILT

SAND AND GRAVEL

CLAY

NOTE

DIFFERENTIAL PRESSURE OF 3 KG. / SQ. CM. 42.6 (P.S.I.) -EQUAL TO 30M HEAD OF WATER- HELPS TO STOP UNCONSOLIDATED STRATA FROM CAVING BUT CAUSES PROBLEMS IN DEVELOPMENT LATER.

2.1.6 Drilling Mud Additives

Numerous chemicals are offered by drilling mud companies and these perform
a variety of functions. It is recommended that regular use should be made
of mud 'thinners' in areas of thick clay, where there is a tendency for
viscosity to increase to an unacceptable limit. The cost of 'thinners'
would to some extent be offset by the less frequent mud changes and by
later ease of well development. Thinners are mainly composed of glassy
polyphosphates (sodium acid pyrophosphate, sodium hexametaphosphate, tetra
sodium pyrophosphate and sodium tetraphosphate and various mixes of these).
Other thinners, such as the tannins which are derived from the bark of
various trees including mangrove, are in common use. It is also known
that lime used sparingly with mud helps to thicken it but thins it when
used in excess.

Thinning chemicals such as Calgon (used commercially for water softening)
are also used in well development operations. If used in larger quantities,
they act as dispersal agents for the breakdown of wall cake and clay which
has invaded the formation.

2.1.7 Low Solids Muds

The use of low solids mud by the water bore drilling industry has become
fairly common in recent years. Where used under the right conditions, these
muds show distinct advantages over conventional materials. Organic and
inorganic polymers, including self-destroying materials, all come under
the category of low solids muds. These materials are substitutes for
bentonite and have the advantage that a small quantity of material will
produce a viscous fluid having low solids content and hence less weight
(Table 2.2). All these fluids have the ability to control filtration
rate and are particularly useful when drilling through formations which
are subject to hydrous disintegration i.e. caving and swelling clays.
Because filtration rates are controlled, wall cake is minimised and less
development time is required. The extra cost of these materials is often
balanced out by the reduced costs of bore development and the likelihood
of a hydraulically more efficient bore.

Degradeable materials such as Revert (a product of the guar bean) are sensitive to increase in temperature and although breakdown can be retarded by treatment with chemicals, the operation of constructing a bore should continue on a 24 hour system if economical use of the materials is required.

2.1.8   Lost Circulation Materials

During drilling, drilling fluids tend to flow into any fissured, cracky and highly permeable formations and where large fissures are present, mud circulation may never be regained, even though many thousands of litres of viscous fluid has been pumped down the bore. A return of circulation may be achieved by drilling below these zones and casing the formation of but often, fluid is lost again only a few metres after drilling through the casing shoe, when another fissure is encountered.

Formerly, lost circulation was automatically tackled by mixing materials such as mica flakes or fibrous wood chips with the drilling mud and then pumping the mix down the bore. The action of the solid, flaky particles was to help bridge or fill such voids thus allowing the formation of a normal wall cake. This practice is still used, especially by the oil companies and in certain circumstances in water well drilling. However, it cannot be recommended for dealing with circulation problems in or near the aquifer zone. This is because the materials are difficult to remove afterwards and often lead to permanent blockages and aquifer damage. Under these circumstances, drilling blindly to greater depths is the preferred course of action. Alternatively, direct circulation air drilling will often give circulation where the water table has been penetrated. In deeper bores, reverse circulation airlift drilling may be found to restore circulation.

Foam drilling, where a 'stiffened' foam can very often temporarily pack fissures and allow cuttings to reach the surface, may be preferred to direct circulation air drilling.

Whilst lost circulation materials are not generally recommended for water bore drilling, there are occasions such as during the drilling of bore MA 2 in Perlis, where there was no alternative. In the case cited,

FIGURE 2.9   LAYOUT OF MUDPITS AND CHANNELS.

casing could not be driven further, lost circulation was a problem and air or foam could not be used because the formation was incompetent and contained fissures filled with sand and limestone rubble. Circulation was successfully restored by the mixing of padi husk to the drilling mud and drilling was resumed until a convenient depth was reached and casing was installed.

Newly mixed mud which is still in the process of hydrating should not be pumped down a bore, especially when the producing zone is being drilled. Such mud entering the formation will continue to swell and may permanently seal off any aquifer.

2.1.9   Mudpits and Mud Cleaning System

The system by which mud is cleaned before it is re-circulated back down the bore is important. The oil industry employs mechanical sieves and vibrating screens to clean their mud and such systems ususally have to deal with cuttings whose total weight may be hundreds of tonnes.

The water bore drilling industry generally relies on less sophisticated methods although on deep wells, a miniature mechanical system of cleaning may be used. The system found adequate for shallow and medium depth drilling programmes employs mudpits which are dug into the ground and rely on gravity to settle out cuttings; mud pits are inexpensive and efficient when arranged properly (Figure 2.9).

Basically the mud pit system depends on gravity to settle out cuttings into a channel and cuttings trap before the mud stream passes into a settling pit. Ideally the channel between bore and settling pit should be as long as possible and needs to be cleaned very often. During drilling, cuttings which do not manage to settle in the channel system end up in the settling pit. The settling pit should be longer than it is wide so that the mud has a better chance to separate itself from the cuttings. The volume of the settling pit in ideal circumstances should be equal to the drilled volume of the bore. Whatever, the intention should still be to remove the cuttings from the system in the approach channel before they get to the pits.   Channel cleaning should be carried out whilst each additional drillpipe is connected to the power swivel and cuttings should be carried in a wheel-barrow and dumped several metres away so that they do not slump back into the mud system; on deeper bores,

FIGURE 2.9   LAYOUT OF MUDPITS AND CHANNELS.
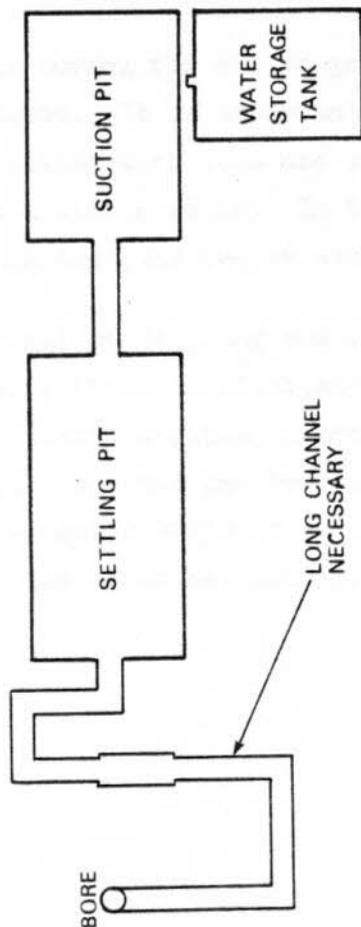
Notes:

1. Volume of the 'settling pit' ideally should equal the volume of the borehole.

2. Channel between bore and pits should be as long as possible and both channel and cuttings trap should be cleaned out when mud pump is stopped (during adding of each new drillpipe).

3. On deep bores both pits may need cleaning out before bore is completed.
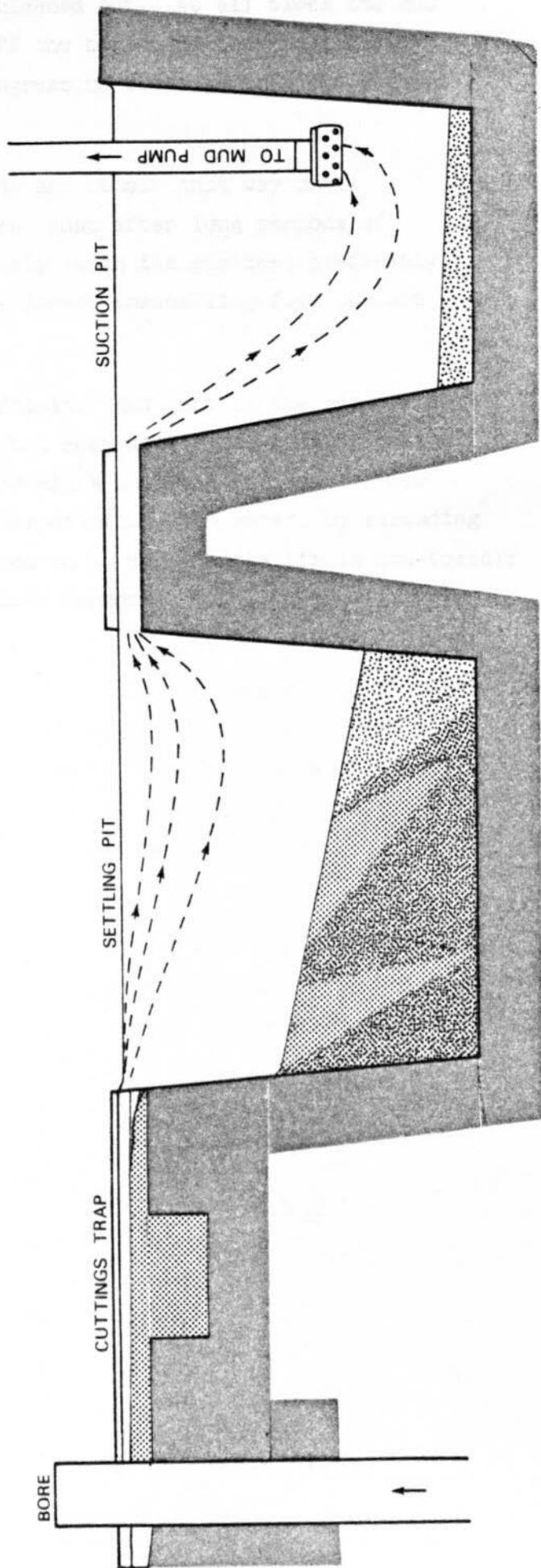
the pits themselves may need to be cleaned out. At all times the mud
pump suction inlet should be kept off the bottom so that periodic
checks can be made to monitor for ingress of cuttings from the suction
pit floor.

It is normal for mud to gel overnight and remain that way until
agitated. It is important, therefore, that after long periods of
inactivity both pits are jetted lightly (with the gunline) preferably
with a little water. In that way, a direct channelling flow pattern
across the pits can be avoided.

Disposal of drilling mud can be difficult. Mud left in the pits
remains there indefinitely and will not seep away. Backfilling of the
pits leaves a patch of ground which remains unsafe to drive over for
years. The mud can be disposed, after dilution with water, by spreading
on permeable soils or it can be pumped on to sandy soils (it is non-toxic);
this has often met with the approval of farmers.

2.2 Air Flush

2.2.1 Introduction

The use of air as a circulation medium has distinct advantages when
drilling consolidated rocks and certain semi-consolidated formations
but an incompetent formation requiring wall support is not suited to the
air flush technique. Air, used properly, allows fast drilling rates and
a cleaner bore which requires less development. The provision of water
supplies to site is unnecessary and the system generally results in a
cheaper operation. The air flush drilling principle relies on sufficient
volumes of air, at relatively high up hole velocities (UHV) to cool and
clean the bit, to blast cuttings from the bottom of the hole and to move
them rapidly to the surface. The system demands that all cuttings are
removed from the bore before drill-pipe changes otherwise these cuttings
will fall back down the hole and trap the drill bit.

A high percentage of JPT drilling to date has been carried out by the
air flush technique; conventional rockroller type bits have been used
as well as the Down-the-Hole Hammer (DHH) method. Because the compressors
fitted to the Tone rigs are of insufficient capacity, there have been
persistent problems with removal of cuttings, especially with DHH operation
underwater. Details of the DHH operation are given later, in section 2.3.

2.2.2 Air Volume Requirements

The minimum UHV requirement for air drilling is known to be 1.5 m/sec for
dry conditions, rising to 3 m/sec in sticky conditions. When a significant
aquifer is penetrated, an airlift system is formed within the bore and
UHV requirements are very much reduced.

The formula for calculating UHV for air drilling is:

$$UHV = \frac{192\ V}{(D^2 - d^2)}$$

where
UHV = Velocity in m/sec
V = Volume of air in m^3/min
D = Hole diameter (cm)
d = Drillpipe diameter (cm)
192 = a Constant

22

FIGURE 2.10   UP HOLE VELOCITIES - AIR FLUSH

It can be seen (Figure 2.10) that if a 12 cm diameter drillpipe and a 14.9 cm dia. bit are used for drilling through the 15.2 cm nominal bore casing which is commonly used as lining pipe for hard rock, then a suitable UHV is generated. However, the bit used to drill for a 15.2 cm bore casing, has to be a minimum of 19.3 cm diameter and UHV is then very much less than desired.

The detrimental results of insufficient volume of air (poor UHV) are similar to those mentioned in the section relating to mud drilling, but there are some differences.

Air drilling, unlike the mudflush system, cannot depend on fluid viscosity and gelling properties to help in carrying cuttings to the surface. Unless volume is adequate, the drilling will suffer in the following ways:

Dry Hole Conditions

- larger cuttings and rock fragments will not be expelled from the bore. When the compressor is stopped, they will drop around the drill collar and bit, resulting in the drill string becoming stuck

- without a non-return-valve in the bit sub, cuttings will enter the bit and block the air passage; the drill string will then need to be removed

- cuttings not immediately blasted from beneath the bit will be reground and penetration rates will fall with consequent extra fuel costs

- Bit wear will be accelerated if cuttings are reground, with early expensive replacement necessary

- reground cuttings (dust) are of little value for geological samples.

Sticky Hole Conditions

- Thin cracks and poor low permeability strata contribute small quantities of water to the bore and there is a tendency for dust and cuttings to stick to the wall of the bore. A build up of drilling debris then leads to borehole 'necking' (Figure 2.3) and even more cuttings are retained down the bore. Eventually air

FIGURE 2.10 UP HOLE VELOCITIES – AIR FLUSH.
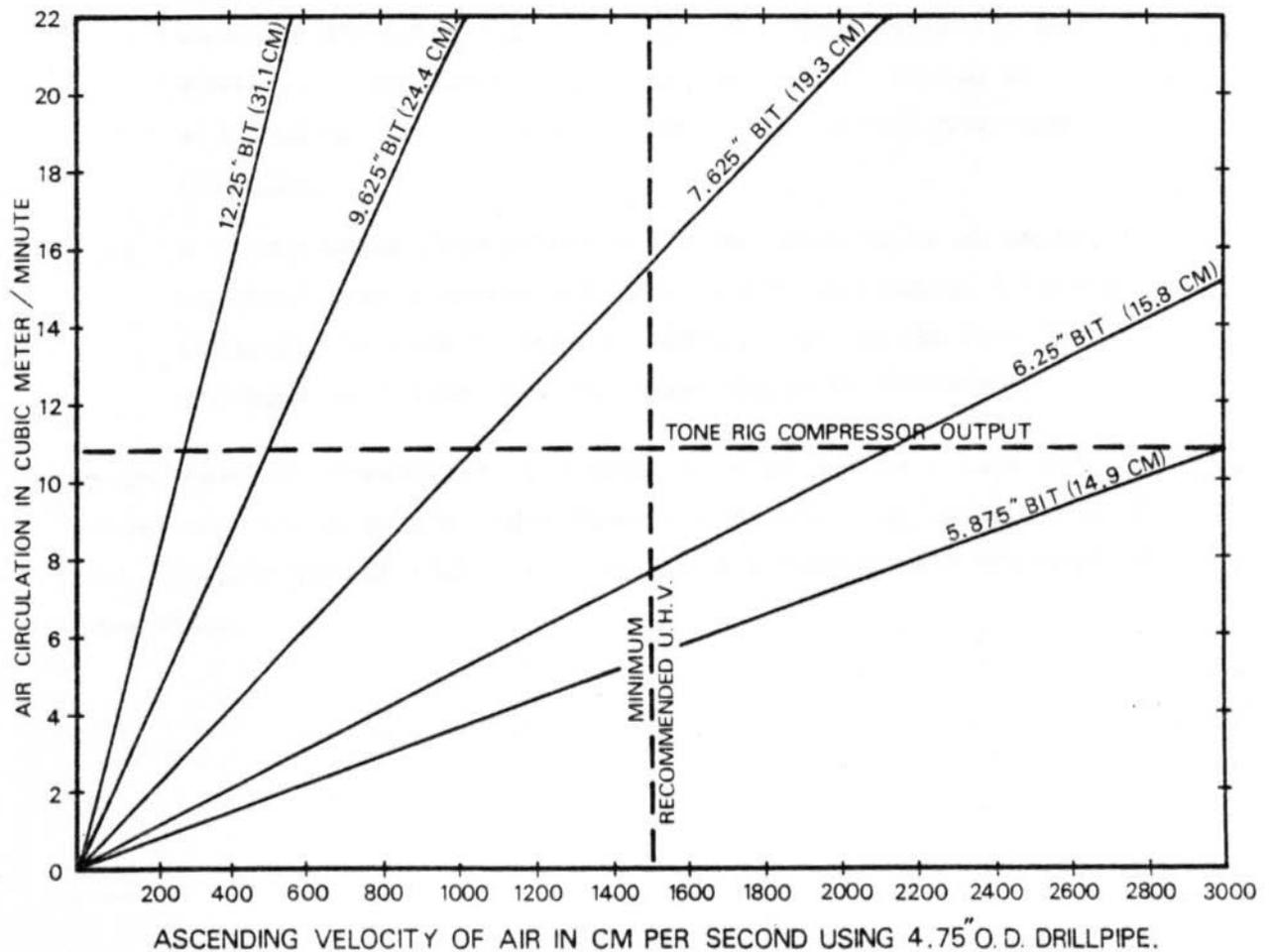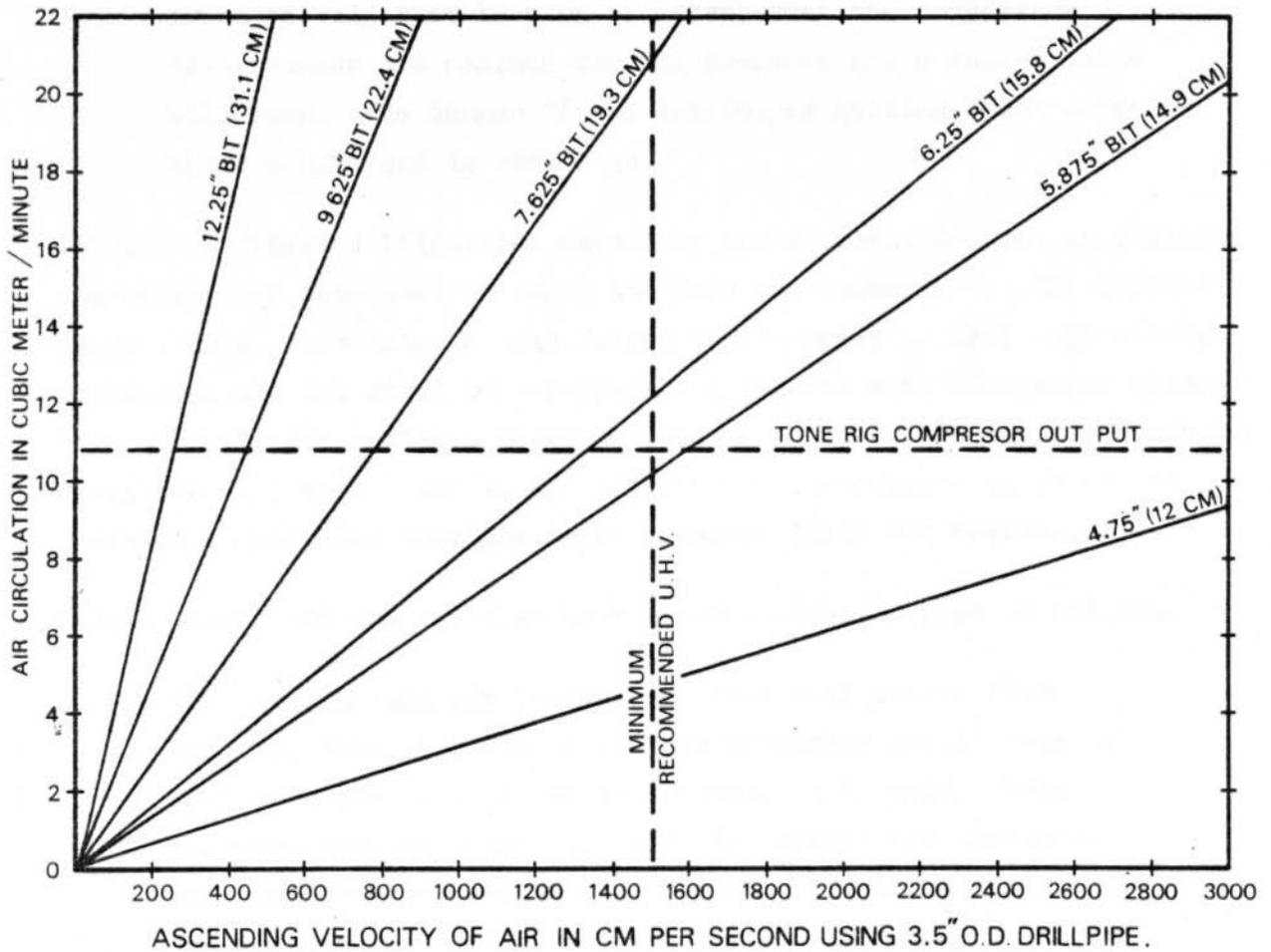
pressure will rise to such an extent that the compressor will
have reached its maximum working pressure and a relief valve
will open. The danger of the drillpipes getting stuck under
these conditions is very high.

To overcome these difficulties caused by insufficient volume, an auxiliary
compressor has been used to boost the Tone rig compressor. The combined
output, of 21.28 m^3/minute, has helped considerably to deal with sticky
conditions and has given better operating results with the larger diameter
bits at shallower depths. However, because of different maximum operating
pressures (7.5 kg/cm^2 and 14 kg/cm^2) the two compressors could not be
operated in parallel once the lower pressure limit was reached.

Excess volume and UHV can also have serious disadvantages as follows:

-   Hard rock strata may contain sections that suffer from
    wetting, that is shales and clays sometimes swell (hydrate)
    when borehole water comes into contact with them. Water
    invading bedding planes is known in certain circumstances
    to cause complete collapse of a bore. The softening action
    caused by water acting on these strata eventually leads to
    erosion of the bore, due to the combined action of an excessive
    velocity stream of air, fluid and cuttings ascending the
    annulus.   In these conditions, air volume should be
    adjusted so that it is sufficient only for bit and bore
    cleaning.

-   a strong water flow entering a bore (especially at depth),
    combined with a narrow annulus, causes compressor delivery
    pressures to rise to such an extent that the maximum working
    pressure is reached before target depth is achieved.

In the case of conventional air drilling with a rock roller bit, air
volume control is a help under these conditions, but in the case of
Down-the-Hole Hammer (DHH) drilling, an increase in air pressure is
imperative.

FIGURE 2.11 SCHEMATIC AIR DRILLING PRESSURE

2.2.3   Air Pressure Requirements

Whereas a sufficient volume of the circulating medium provides hole cleaning, pressure is required to compensate for friction losses and to lift drill cuttings (Figure 2.11).   If drilling by air flush was entirely in dry conditions, without sticky patches, then fairly low pressures (4.5 kg/cm^2) would be sufficient for the average bore.   The entrance of water into the bore increases the pressure requirement proportionately to the rate of water inflow and bore depth.   A condition then occurs where the weight of the hydrostatic column of water in the bore comes to exceed the working pressure of the compressor; drilling operations will then terminate at the interruption of drilling when drillpipes are added.   If, however, available pressure could then be increased sufficiently to lift the water, a pressure gauge would indicate a pressure rise until a point where the air pressure exceeds the equivalent pressure of the water column and initial lifting of water would begin.   After the first rush of water, an airlift system is developed and, depending on the diameter of the hole and the rate of water discharged, the working pressure may drop by about 40%. As already pointed out, if the air volume is lowered, especially when the up hole velocity is high, then the air pressure should also drop.

Prediction of the depth where an air drilling operation can no longer progress due to water filling the bore can be calculated if it is remembered that 0.1 kg/cm^2 air pressure will lift 1.0 m head of water.   An example is shown below, based on the use of the JPT. Tone rig compressor whose output is 10.95 m^3/minute at 14 kg/cm^2.   (The bore diameter and the volume of the compressor is of little consequence to this exercise).

Static water level (SWL) is 14.5 m

Length of water column that can be lifted from a static condition by this compressor   = 14 kg/cm^2 ÷ 0.1
                                                                                                = 140 m

Total drilling depth attainable in this case (below ground level)   = 140 m + 14.5 m
                                                                           = 154.5 m

FIGURE 2.11   SCHEMATIC AIR DRILLING PRESSURE LOSSES
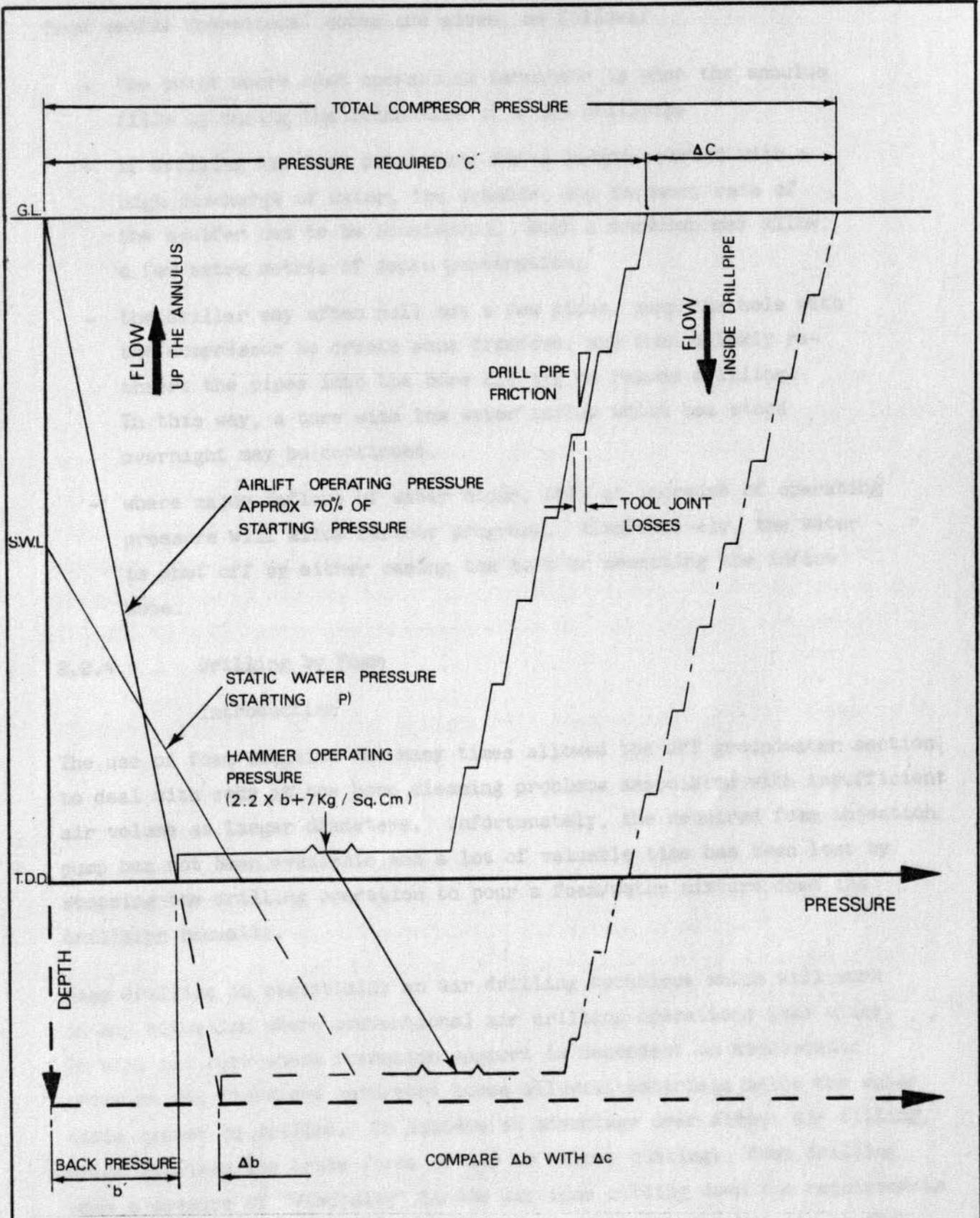
EXPLANATION: Drilling fails at depth if:

    (1) Compressor cannot produce air at sufficient pressure to overcome static water pressure plus 7 kg/cm^2 (to operate a D.H.H.)

                            OR

    (2) if extra air pressure cannot be produced to counteract back pressure (2.2 : 1 Ratio).

Some useful operational notes are given, as follows:

- the point where most operations terminate is when the annulus fills up during the connection of a new drillpipe

- if drilling has been proceeding for a lengthy period with a high discharge of water, the drawdown and recovery rate of the aquifer has to be considered. Such a drawdown may allow a few extra metres of depth penetration.

- the driller may often pull out a few pipes, pump the hole with the compressor to create some drawdown, and then quickly re-insert the pipes into the bore and try to resume drilling. In this way, a bore with low water inflow which has stood overnight may be continued.

- where major inflows of water occur, only an increase of operating pressure will allow further progress. Alternatively, the water is shut off by either casing the bore or cementing the inflow zone.

2.2.4   Drilling by Foam

Introduction

The use of foam additive has many times allowed the JPT groundwater section to deal with some of the bore cleaning problems associated with insufficient air volume at larger diameters. Unfortunately, the required foam injection pump has not been available and a lot of valuable time has been lost by stopping the drilling operation to pour a foam/water mixture down the drillpipe manually.

Foam drilling is essentially an air drilling technique which will work in any situation where conventional air drilling operations take place. It will not work where formation support is dependent on hydrostatic pressure and therefore saturated loose alluvial materials below the water table cannot be drilled. To achieve an advantage over direct air dilling, which requires the brute force of air to remove cuttings, foam drilling adds a measure of 'viscosity' to the air thus cutting down the requirements of excess air volume and up hole velocity. This 'thickened' air or foam can then carry out hole cleaning duties with an up hole velocity from 22-75 cm/sec and at much lower air inputs (Table 2.3).

Table 2.3 Air Flow Rate Required for Foam Drilling

Hole diameter		Volume of air required	
inches	cm	cfm	m^3/min
26	66	400 - 600	11.3 - 16.9
15	38	200 - 300	5.6 - 8.4
10	25.5	90 - 130	2.5 - 3.6
6	15	25 - 30	0.7 - 0.8

Foam is formed by injecting a solution of water and foaming agent into air. The resultant foam comprises a mixture of small bubbles closely packed together which, depending on the strength and type of the agent, will be stable for a period of time. By the addition of special high molecular weight polymers, the foam can be made into a tougher form with greater carrying capacity and longer life. One advantage of this is that foam entering fissures remains there for a sufficient time to lightly block off the aperture and allow the greater portion of the circulation medium to reach the surface.

Mixtures of 1 to 2 litres of a high grade foaming agent to 200 litres of water have been found to be satisfactory. By adding and mixing a drilling polyer powder to the water to increase its viscosity to 32-35 seconds (Marsh funnel), a satisfactory foam stabiliser can be formed. The resultant mix gives a foam which has a consistency of shaving cream. A kilogram of standard polymer (such as Quick Trol) added to one cubic metre of water usually gives the required viscosity. As a rule of thumb, a fluid injection rate of 1,000 litres per m^3 of borehole volume has found to be suitable. Actual injection rates therefore, will depend on the hole size and penetration rate but a pump with an output varying from zero to about 24 l/min covers most situations.

Compressor and Foam Pump

It is not necessary to have compressors of varying size to suit the requirements shown in Table 2.3. It is, however, a waste of fuel and maintenance to use large compressors that may be run at only one tenth of their designed volume output and therefore, as long as pressure requirements are met, the smallest suitable compressor should be used. Output of the compressor is by either of two methods depending on the compressor type.

FIGURE 2.12   SCHEMATIC FOAM PUMPING INSTALLATION

A piston compressor will have its output controlled by the speed of the engine whereas a rotary/screw compressor has a fixed speed and the output can only be controlled by running the machine with the air valve closed and then opening the valve sufficiently to allow only the required amount of air to pass through; a fine control valve is preferable in this respect.

'Foam Pumps' are generally pumps designed for other purposes, such as standard boiler feed pumps designed to be operated by stream pressure. Such pumps are successfully used with compressed air as the driving force. Another suitable type of pump is a 'diamond-drill' pump which would normally have its own independent engine. Pump output pressure should exceed maximum compressor pressure by at least 15%. Drilling rig manufacturers are now making pumps, driven from the hydraulic circuit of the rig, in the form of piston or rotary types. Any of these pumps are suitable as long as their output and pressure fits the requirements outlined above.

Any rig can be converted very easily for foam drilling. A schematic arrangement (Figure 2.12) shows an air-driven pump. The use of the non-return valve between the compressor and main line is particularly important as this stops foam being pumped or leaking back into the compressor when circulation has stopped. Another non-return valve positioned above the drilling bit is recommended as this will prevent foam, cuttings and water entering the bit when drillpipes are being added and circulation is interrupted.

Foam Drilling Practice

An operating sequence for typical foam drilling is given as follows:

- drill at as large a hole size as is consistent with maintaining up hole velocity. This is especially important where formations are plastic or sticky, when the drill penetration rate is high, or when cuttings are large, as in DHH drilling.

- set a short conductor pipe (especially in unconsolidated overburden). Use a tee or circulating head with a flow line (called a 'blooie' line) to direct foam returns away from the hole. The use of a dust deflector or rubber pipe wipers around the casing will help to keep the rig clean.

FIGURE 2.12   SCHEMATIC FOAM PUMPING INSTALLATION.
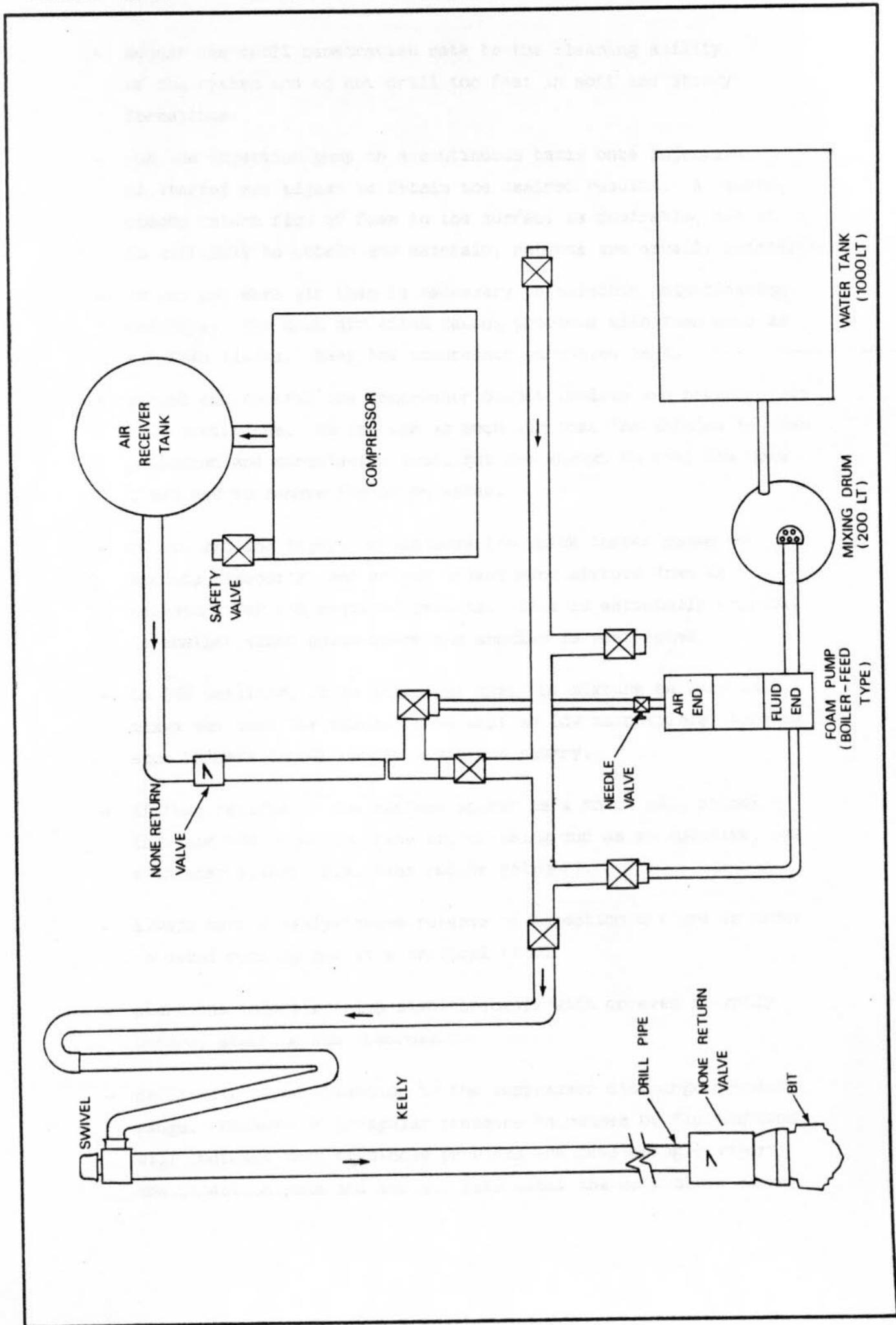
- adjust the drill penetration rate to the cleaning ability
  of the system and do not drill too fast in soft and sticky
  formations.

- run the injection pump on a continuous basis once injection
  is started and adjust to obtain the desired results. A smooth,
  steady return flow of foam to the surface is desirable, but it
  is difficult to obtain and maintain; returns are usually intermittent.

- do not use more air than is necessary to maintain hole cleaning
  velocity. Too much air often causes problems with foam such as
  air/foam blocks. Keep the compressor throttled back.

- adjust and control the compressor output (volume and pressure) to
  hole conditions. Do not use so much air that the annulus is over
  pressured and circulation lost, but use enough to keep the hole
  clean and to remove formation water.

- do not get the injection mixtures too thick (never above 40
  seconds viscosity) and do not inject more mixture than is
  necessary for the required results. This is especially critical
  in smaller sized holes where the annulus is restricted

- in DHH drilling, it is important that the mixture be very well
  mixed and that the viscosity be kept as low as possible, because
  some hammers cannot handle a viscous slurry.

- if foam returns at the surface appear as a thick mud, either
  increase the injection rate or, if using mud as an additive, use
  a thinner slurry (i.e. less mud or polymer).

- always have a ready-to-use reserve of injection mixture in order
  to avoid running out at a critical time.

- start the injection pump simultaneously with or even slightly
  before, starting the compressor.

- drill with close attention to the compressor discharge pressure
  gauge. Unusual or irregular pressure increases or fluctuations
  will indicate that down-hole problems are developing. Adjust
  the injection rate and the air rate until the hole blows clean.

- watch the 'blooie' line for foam colour, quantity, and
  consistency and adjust the injection and air rates as
  indicated. Returns will be intermittent. Do not drill too
  far without returns; increase the injection and/or the air
  rate until the hole is cleaned.

- every five or six minutes or so, stop drilling, pull the string
  off the bottom by about 0.30 m, and inject a concentrated slug
  of foam (or increase the rate of injection of mixture). This
  will help blow the hole clean and remove accumulation of extra
  large cuttings. This is especially helpful when drilling with the
  DHH or when over-drilling with a tricone bit in soft formations.

- before shutting down to make a connection, and with the bit on
  the bottom, speed up the injection rate for a minute (or add
  a concentrated slug of foam through the injection pump suction).
  This will help clean the hole when the compressor is started up
  and is helpful if the hole is producing water or if the connection
  takes a long time. If the hole gains a lot of water and you are
  approaching the limits of the compressor output, repeat the
  injections on starting.

- High torque as shown on the drilling control panel and an
  increase in torque may mean that cuttings are not being removed
  properly; the injection rate needs to be increased and penetration
  decreased.

- The foam at the surface should appear like shaving cream. It
  may not return in a continuous flow and slight surging is
  permissible.

2.3   Down-the-Hole Hammer

2.3.1   Introduction

The preceding sections have dealt with the theory and requirements
of using fluids and air in rotary drilling. Most of what has been said
already concerns drilling operations carried out with conventional drilling
bits which require a downward force to be exerted on them so that
penetration of the strata may be effected. The necessary force may be
given by the use of hydraulic pull-down at the surface or by the weight
of the drill string. Some rocks are so hard that bit weight may need to
exceed one tonne per centimetre of bit diameter and as a result, torque
requirements become high leading to excessive expensive wear and tear
on mechanical components. An alternative method of drilling hard rock
is with the Down-the-Hole Hammer (DHH), a system of air drilling which
concentrates the energy derived from compressed air to the bit with only
minimal weight and torque requirements. Penetration rates four and five
times faster than conventional methods can be achieved with this system.

2.3.2   The JPT Hammers

The drilling section is equipped with two DHH units. One, a Tone AD 150,
belongs to the original rig package and has been designed for operation
with 7 kg/cm^2 air pressure, a pressure considered low by modern standards.
The second hammer, a Dreser T6 can operate over a pressure range of
7-24 kg/cm^2. The AD 150 hammer drills at 15 cm dia. only, whilst the
T6 unit can drill at both 19 cm dia. which is large enough to accommodate
6" casing, and at 15 cm dia. which enables drilling to take place through
a 6" casing.

The usefulness of the DHH system has been demonstrated many times but
unfortunately the technique does tend to have unfavourable complications
in some circumstances. Because the system involves the operation of a
machine, the hammer, at the bottom of the bore, rules governing its
operation do not strictly adhere to those conditions required for
conventional air drilling. The special requirements for efficient hammer
operation are often misunderstood but it is hoped that the following
sections may clarify matters.

2.3.3 The DHH Mechanism

Mechanically, the DHH is a simple machine with three main components. A casing or cylinder contains a heavy reciprocating piston whilst a hammer bit (the third component) is attached to the bottom of the cylinder. Through a valving and porting system, compressed air causes the piston to strike the top of the bit at a variable rate of up to 1,500 blows per minute, depending on the air supply. Whilst operating, the hammer unit needs a constant supply of lubricating fluid.

The combined effect of high pressure air behind the piston and its kinetic energy, is transferred through the bit body to the bit inserts. The inserts are set evenly across the face of the bit and around the periphery. The shape of the insert protruding out of the bit body is hemispheroid 25. During the course of drilling, the surface area of insert material in contact with the formation is very small and the impact force, measured in hundreds of kilograms divided amongst them causes failure of the rock, the result of which is a chipping or cutting (Figure 2.13). It should be explained at this stage that rotation of the hammer is necessary to enable the impact forces to be distributed fully over the bottom of the bore hole; no crushing, gouging or grinding benefits result from rotation.

Penetration rates achieved with the DHH not only depend on air pressure but are closely tied to the cross-sectional area of the hammer piston; the larger the area the better. This is why hammers of different sizes are available, with each covering only a narrow range of diameters (Table 2.4). To give flexibility, some firms do manufacture large bits for some hammers and even though the penetration for them is rather slow, the results are still superior to conventional rockroller drilling. To suit the need of the civil engineering industry, the DHH has been scaled up to enable 90 cm diameter pileholes to be drilled into hard rock although the air requirements for this hole size are formidable.

2.3.4 Hammer Air Pressure Requirement and 'Back Pressure'

Most hammers require between 6-7 kg/cm^2 air pressures to enable them to function and less pressure leads to intermittent, ineffectual hammering or a halt to the operation. Pressure in excess of minimum requirements serves to increase efficiency and therefore increases in penetration rate are directly proportional to air pressure increase. The most perfect

FIGURE 2.13   BIT DRILLING ACTIONS.

HIGH PRESSURE AIR IN CYLINDER.

CYLINDER.

KINETIC ENERGY OF PISTON.

IMPACT FORCE TO THE BIT SHANK AT A RATE OF UP TO 1500 BLOWS/MIN.

15 CM DIA BUTTON BIT.

TUNGSTEN INSERTS.

CONSTANT WEIGHT OF 1000 KG. (AV) APPLIED TO D.H.H.

LOW TORQUE REQUIREMENTS.

LOAD

CRATERED AREA.

FRACTURED AREA.

SPHERICAL TUNGSTEN INSERTS CAUSES HIGH SINGLE POINT LOADING ON ROCK AND INDUCES FRACTURING.

VARIABLE WEIGHT REQUIRED ON BIT, RANGE 0 - 20,000 KG. FOR 15 CM DIA. DEPENDING STRATA.

MEDIUM TO HIGH TORQUE REQUIREMENTS.

15 CM TRI-CONE ROCK ROLLER TYPE (STEEL TOOTH).

LOAD

ROCK ROLLER BIT TOOTH ACTION IS CRUSHING, DIGGING AND GOUGING.

LIGHT WEIGHT REQUIRED ON BIT WITH MEDIUM TO HIGH TORQUE.

WILL NOT DRILL HARD ROCKS.

BLADE

TUNGSTEN OR HARD FACED.

DRAG BIT ACTION IS ONE OF PLAINING.

TABLE 2.4 DOWN-HOLE HAMMERS AND BIT AVAILABILITY

Manufacturer	Model	Optimum Working Pressure Kg/cm²	Bit Sizes Available cm
Atlas Copco	COP 4	17.5	10.5, 11.0, 11.5,
	COP 6	17.5	15.2, 15.6, 16.5, 21.6, 25.4
Dresser	T6 *	24.5	15.2, 19.0
	T5	17.5	12.7, 14.6
	T4	17.5	11.4, 14.6
	T3	17.5	9.2, 11.4
Halifax Tool Company (Halco)	MACH 6	17.5	15.0, 15.5, 16.5, 20.0, 22.5, 24.5, 30.0, 31.1
	MACH 5	17.5	12.7, 14.0, 15.0, 16.5
	MACH 4	17.5	10.5, 11.0, 11.5, 12.0, 13.0, 14.0, 15.0, 16.5
Ingersoll Rand	DHD 360	360, 24.5	15.2, 15.6, 15.9, 16.5, 21.6
	DHD 16A	100, 7.0	15.2, 15.5, 15.9, 16.5, 20.3, 21.6, 25.4
	DHD 15	250, 17.5	12.7, 14.0
	DHD 24	250, 17.5	10.5, 11.4
T.R.W. Mission	A100-15	250, 17.5	30.1, 33.0, 35.5, 38.1, 43.1
	A6315	250, 17.5	19.3, 20.3, 21.9, 25.4, 30.4
	A5315	250, 17.5	15.2, 15.8, 17.1
	A4315	250, 17.5	12.7, 13.0, 13.3, 13.9, 14.4
	A3415	250, 17.5	10.4, 11.4, 12.0
Tone Boring	AD150 *	7.0	15.0, 18.0, 20.0

Note: DHH manufacturers design bit shank and spline fixing arrangements differently and rarely is there bit interchangeability. The Dresser hammer range is exceptional in that they can use some Mission bits. One manufacturer (Halco) will make bits to the design of most hammer systems.

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Figure 2.14 PENETRATION GRAPH OF BORE PM3 PERLIS

conditions for DHH operation are in dry shallow bores put down in hard rock. The hammer does not like soft clayey material, sticky weeping zones, caving material or water; friction losses in the bore annulus caused by these conditions creates a 'back pressure' on the hammer which leads to a marked decrease in efficiency. Different hammers have different design characteristics and back pressure effects are variable. Whilst back pressure cannot be exactly calculated, it can be counteracted by air pressure increases. One major manufacturer of a 'valveless' hammer reports that back pressures can be counteracted by increments in air pressure according to the ratio 2.2 to 1. Hammers of the valved design do not need quite so much and so a 2 to 1 ratio could perhaps be considered as an average figure.

Pressure losses in the air drilling system are shown (Figure 2.11). It should be remembered that losses are related to depth and to volume of water inflow into the bore. Further, where high groundwater flow is encountered, a reduction in air volume (and UHV) would help in reducing back pressure.

The reason why the efficiency of a hammer drops off so drastically under water (or through other back pressure causes) lies in the downward movement of the piston. If the air used to move the piston up to the top of its stroke cannot escape or exhaust properly then the downward or impact stroke is 'cushioned' and the piston only lightly taps the bit shank. Impact frequency also drops off under these conditions and this can actually be heard or felt through the drill pipe. The effects of back pressure can best be illustrated in the penetration graph of bore PM 3 (Figure 2.14). The point where the DHH system of drilling has to be abandoned because of very poor or zero penetration rate is of course related to volume of water, depth of bore and the size of the annulus; the relationship between these factors is shown by an example (Table 2.5).

A low penetration rate in hard rock during conventional rock roller drilling is common but involves no danger of bit damage; if necessary, it can be tolerated for days until projected total depth is reached. The DHH system has poor toleration of slow penetration and continued use under high back pressure conditions very often leads to excess bit wear and breakage of the tungsten inserts.

Figure 2.14 PENETRATION GRAPH OF BORE PM3 PERLIS

EXPLANATION

THIS SECTION WAS DRILLED BY A 7 3/8" ROCK ROLLER BIT. ROCK HEAD WAS STRUCK AT 4.5 METRES. A DRILL COLLAR WAS ADDED AT 6.0 DEPTH. PULL DOWN WEIGHT WAS 6 TONNES.

THIS SECTION WAS DRILLED BY A DRESSER T6 D.H.H. WITH 6" BUTTON BIT WITH APPROX 1.0 TONNE WEIGHT ON THE BIT.

WHEN WATER WAS ENCOUNTERED, THE PENETRATION RATE WAS DRASTICALLY REDUCED.

THIS WAS DRILLED BY A 5 7/8" HARD FORMATION ROCK ROLLER BIT WITH 6 TONNES PULL DOWN PLUS THE WEIGHT OF THE DRILL PIPES.(TOTAL WEIGHT 8 TONNES).
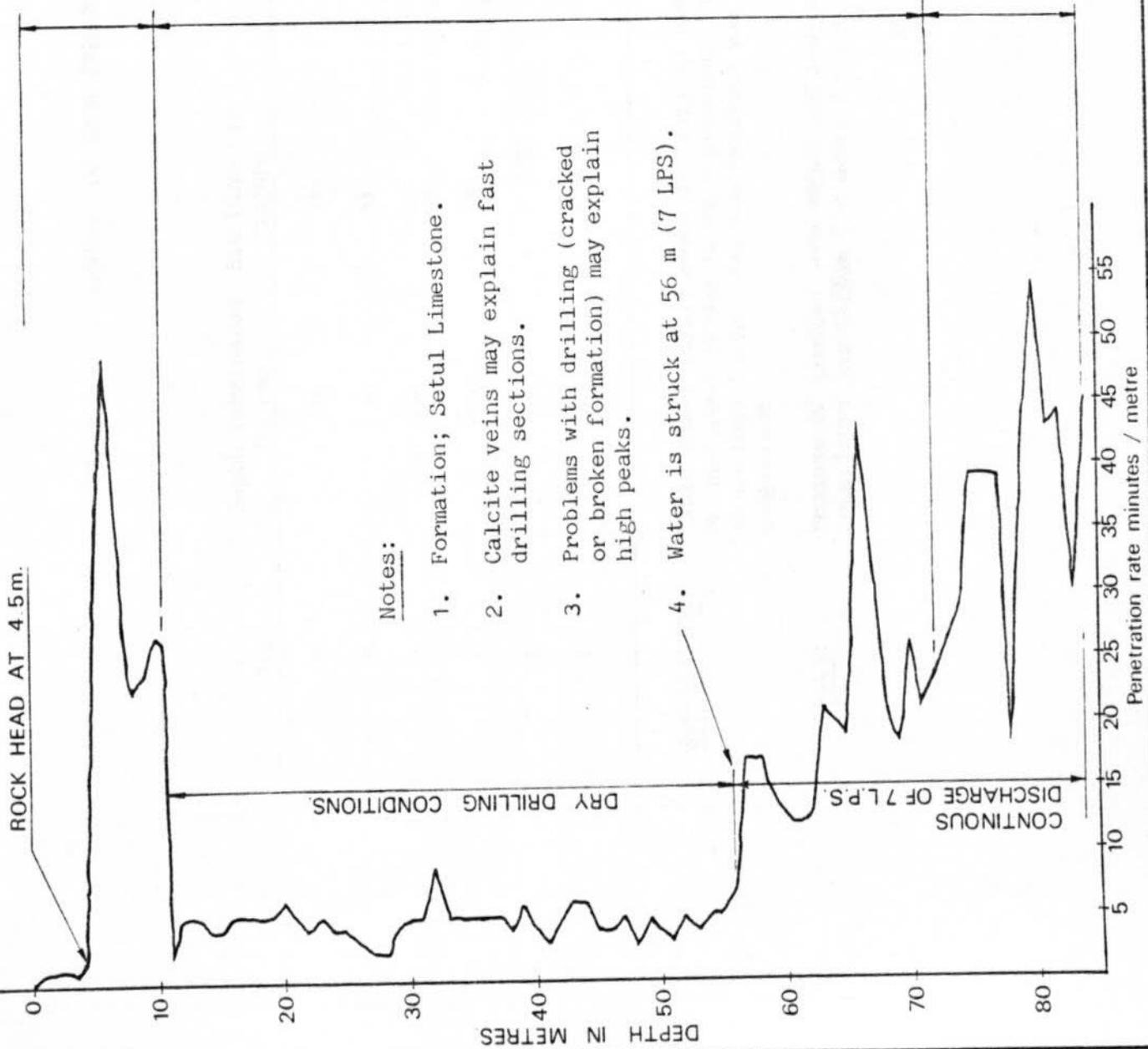
Notes:

1. Formation; Setul Limestone.

2. Calcite veins may explain fast drilling sections.

3. Problems with drilling (cracked or broken formation) may explain high peaks.

4. Water is struck at 56 m (7 LPS).

ROCK HEAD AT 4.5m.

DRY DRILLING CONDITIONS.

CONTINOUS DISCHARGE OF 7 L.P.S.

Penetration rate minutes / metre

DEPTH IN METRES

TABLE 2.5   EFFECTS OF BACK-PRESSURE ON DHH DRILLING

Bore	Depth Terminated Metres	Bit Diameter inches	Annular Dimensions Area (cm²)	Volume (m³)	Discharge During Drilling l/s	Compressor Pressure Kg/cm²
A	86	5¼	50	0.43	14.8	17.5
B	114	5¼	50	0.57	11.0	17.5
C	156	5¼	50	0.78	4.3	17.5
D	140	5¼	50	0.97	6.8	17.5
E	144	7 5/8	192	1.38	18.7	17.5
F	167	7 5/8	192	3.20	16.2	17.5

EXPLANATION: Table shows depths where drilling in hard basalt, with the DHH system become impossible or uneconomical due to back-pressure. The data is taken from the Betwa river basin project in central India. All the drilling was carried out using 4½ inch drillpipe and a 17 m³/minute compressor.

Note: Because of limited bore depth and low compressor discharge (free air) the JPT data is considered unsuitable for presentation here.

Compounding of different compressors to give supplementary air volume is possible up to a point but if one unit has a lower working pressure than the other, then it will unload or cut out as soon as its maximum pressure has been reached. For the purposes of DHH operations, compounding the Tone rig compressor (Gardner Denver 14 kg/cm^2) and a standard JPT compressor (Ingersoll Rand 7.5 kg/cm^2) is therefore of no use. It is possible however to run both rig compressors together in parallel; compounding the compressors from both rigs then increases volume to 21.9 m^3/min at 14 kg/cm^2, a figure more suitable to requirements. For future DHH operation, it would be desirable to purchase a trailer mounted compressor with a working pressure of 17.5 kg/cm^2 and a working volume of about 21.9 m^3/min.

2.3.5   DHH Air Volume Requirements

The UHV necessary for efficient hole cleaning for conventional air drilling applies equally to the DHH system. However since the pressure requirements for the DHH are so much higher, the air consumption or volume is increased accordingly. It can be seen (Table 2.6) that the Tone hammer will operate over a wide volumetric range since its pressure requirement is fixed; hence it is inefficient. Other hammers including the JPT Dresser T6 are more flexible and are able to take advantage of various pressure/air volume combinations.

The air consumption of hammers is controlled by altering the size of the air passages (and uniquely in the T6 hammer, the annuli) within the hammer itself. By fitting different size chokes to the control tube inlet at the top of a hammer cylinder, air can be metered. The T6 hammer has also a selection of sleeves which can be fitted to the cylinder ends and these also serve to vary air consumption. Table 2.7 shows the variation possible with both systems. It should be remembered for the lower consumption/air pressure shown, the resultant impact energy will also be low.

A blank choke with no aperture allows maximum performance from the hammer. However, where there is surplus air above and beyond the hammer's requirements, the compressor will unload itself and the air is wasted. By altering choke size, this surplus air is allowed to pass through the hammer and bit and can be usefully used for efficient hole cleaning.

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Table 2.6   Down Hole Hammers Air Consumption
(Similar Size Hammers)

Type and Model of of 6" Hammers	Operating Pressure Kg/cm^2	Average Air Consumption M^3/Min. *
Atlas Copco	7.00	8.7
COP 6	10.5	13.8
	14.0	17.4
Halifax Tool Co.	7.00	9.3
MACH 6	10.5	13.6
	14.0	20.0
Ingersoll Rand	7.00	—
DHD 360	10.5	9.3
	14.0	12.7
	21.5	16.1
Dresser T6 *	7.0	5.75
	10.5	9.99
	14.0	14.25
T.R.W. Mission	7.0	12.4
A5315	10.5	15.8
	14.0	21.3
Tone AD150 **	7.0	9.0 - 15.0

Notes: Compressor installed on Tone Rig is Gardner Denver 'WEG'

Discharge Volume   10.95   m^3/min.

"   Pressure 14.0   kg/cm^2

* i) JPT   Hammer (Separate Purchase)

** ii) JPT   Hammer (Part of Rig Package)
          Low Pressure Only

TABLE 2.7   DHH CHOKES AND AIR METERING

Air Consumption By Changing Choke Size, Tone AD150 Hammer

Choke Size (mm)	Air Pressure (kg/cm²)	Hammer Air Consumption (m³/min.)
0 (Blank)	7	9
6.5	7	11
9.5	7	13
12.5	7	15

Air Consumption By Changing 'Sleeve' Size on Dresser T6 Hammer.

Sleeve Size	Air Pressure (kg/cm²)	Hammer Air Consumption (m³/min.)
Thin Sleeve (upper)	7	6.79
	14	16.11
	21	25.20
Thick Sleeve (upper)	7	5.52
	14	13.11
	21	20.61
Thick Sleeve (both ends of the cylinder)	7	4.81
	14	12.40
	21	19.82
	24	23.42

Additional Air Metering By Bleeding Excess Air Through Choke of T6 Hammer. (To be used in conjunction with the above table).

Orifice Size inches	mm	Air Pressure (kg/cm²)	Choke Air Consumption (m³/min.)
0.125	3.17	14	1.69
0.1875	4.76	14	2.12
0.3125	7.93	14	5.52
0.4375	11.11	14	10.47
0.5	12.7	14	13.87

Where excess air is ported through the hammer, the result may be a very high UHV in the annulus and an increase in annular pressure. One manufacturer does not recommend velocities higher than 2.8 m/sec where water is present otherwise back pressure problems are exacerbated.

2.3.6   Weight and Rotation Speed of DHH Bits

The weight applied to a DHH bit should be more or less constant; a typical 15 cm dia. hammer bit requires between 750-1250 kg depending on strata. The purpose of loading the bit is to keep it in contact with the rock and to stop it bouncing. Too little weight allows bounce and also results in a decrease in the operating cycle, that is less blows/minute. The DHH will not drill faster even though more weight is applied to the bit. The result of excess weight is failure of the tungsten carbide inserts and bit body breakage. The operation of the DHH requires very careful control by the driller and as depth increases and more and more drill pipes are added, the driller needs to adjust the hydraulic feed accordingly to maintain the correct weight on the bit.

Rotation also has to be carefully controlled. The required speed of revolution is slow compared with other drilling bits. The harder and more abrasive the strata, the slower should be the speed; a range between 12-24 rpm is most commonly used. The torque gauge on the rig instrument console shows irregularities in rotation. Jerky and irregular movement, an indication of too low a rotation speed, may not be seen at the drillpipe but the gauge is sensitive to change. The effects of overloading the bit are shown clearly by the torque gauge. Faster than necessary rotation leads to rapid wear of the gauge inserts (peripheral) which results in a reduction in the bore diameter.

2.3.7   Reaming by DHH

Enlarging or reaming a bore by a standard hammer bit is only possible if there is a large difference in size between the bit and projected bore diameter. A 15 cm bore could be reamed out carefully to 25 cm dia. but otherwise, special hole-opener bits should be used.

Small increases of hole size by reaming are not possible as breakage
of the bit is certain. The DHH system relies on bottom hole resistance
for the drilling action and if the resistance offered is insufficient,
the bit will over-penetrate and get jammed in the hole.   In this context
it should be remembered that a bit having excessively worn gauge inserts
will be undersize and a new bit will be unlikely to follow it; attempts
to ream the bit down will only lead to breakage. The driller should
therefore have a selection of dressed bits in good condition and of
different sizes so that when a used bit is pulled for re-dressing, it is
calipered and a suitable replacement bit of the next size down is run into
the bore.

2.3.8   DHH Maintenance

Shock Absorber

Vibrations emitted from a hammer travel through the drillpipe and, if
they are not eliminated, can cause damage to power swivel components.
The Tone rig has a special damper unit fixed below the power swivel and
a splined shaft system absorbs some of the damaging vibrations. Other
hammers incorporate a shock absorber in the hammer itself.

Hammer Stripping

Because of vibration, it is often found that when a hammer is stripped
down for maintenance, the threads are abnormally tight. The Tone hammer
unit inlcudes a special hydraulic break-out system which makes the operation
easy. The Dresser hammer more typically depends on the normal rig break-
out system for the opening of threads and this process can lead to damage
since an accumulation of caught material on the filter will cause it to
burst.

Thread Protectors

Drillpipe used regularly for DHH drilling will have a coating of
lubricating oil on the inside. Extreme care must be taken to ensure that
durt and dust does not enter the drillpipe. During rig moves, such drill-
pipe should have its thread protectors firmly fixed and the pipe should not
be allowed to dig into the ground when loading onto the truck. Drillpipe
on the pipe rack waiting to be used should be protected from ingress of
drilling dust and cuttings.

DHH Lubrication

Special rock drill oils are available commercially. Such oil should exhibit good adhesion, a high flash point and stable viscosity properties; the use of engine or gear oils is not recommended. The Tone company allow the use of hydraulic oil in their hammers and it has been used successfully with the Dresser hammer. The use of hydraulic oil is attractive to this department because the rigs hydraulic system is changed often and the discarded hydraulic oil is clean and suitable for use with the hammers. The rate of oil injection is dependent on hammer type and compressor size but between 1.5 and 2 litres per hour of hammering time is average (Dresser) or about 0.12 litres per hour (Tone). The oil quantities mentioned above should be increased if the drillpipes being used are dry or alternatively, 0.25 litre of oil may be poured down each new 6 m drillpipe.

Bit Dressing

Bit maintenance is of extreme importance if good performance levels and long life are to be realized. During drilling, the tungsten inserts tend to develop 'flats' especially in the outer buttons and continued use in this dull condition leads both to a drop off in performance (up to 20%) and to torque increase and to possible failure. A bit grinding interval should be established to suit each rock type.

The hammer maintenance manuals show the bit dressing procedure in detail; it is sufficient here to say that the inserts (buttons) should be returned to their original shape as soon as flats of 3-4 mm width appear. Particular importance must be paid when grinding the outer buttons to ensure that no further reduction in bit diameter results from the bit dressing procedure (Appendix IV).

DHH Bit Breakage and Care

Failure at the shank of the bit through metal fatigue is not uncommon whilst recovery (fishing) of the broken piece remaining in the bore is difficult because of the hardness of the steel. A simply fabricated tool which has proved useful in the past, is shown later (Section 7.3).

Insert failure is very common; one piece of broken-off tungsten can damage the others and lead to the write-off of the bit. Pieces of broken insert may still remain in the hole and will have to be removed. If blasting with air and foam will not lift them out, a magnet will be

necessary. Inserts embedded in the rock will need to be broken up down-the-hole with an old rockroller bit before drilling can resume.

Tungsten, although extremely tolerant to wear, is easily cracked and broken and therefore bits should not be allowed to come into contact with steel. They should therefore be kept separate from each other in their individual boxes.

The hammer bit can be operated with a few inserts missing although it is important that any broken inserts are completely removed by grinding before further use. Any slight nicks in the bit shank should also be smoothed out as it is found that shank failure usually originates from such a defect. Pipe wrenches and chain tongs should be fixed to the hammer cylinder in such a way that they do not damage the threaded ends or the area where the hammer piston oscillates. Breakout is often facilitated if the hammer is connected to the drill head during the operation and the hammer is allowed to operate lightly against a hard wooden block.

Most hammers incorporate a wire mesh filter in the hammer connector. Its purpose is to catch drillpipe scale and dirt and other harmful objects before these can enter the hammer. Such material may not cause much damage to the hammer but could cause the hammer to stop operating. There is nothing worse than to pull 200 m or drillpipe from the bore solely to strip the hammer down. Every effort should therefore be made to bang out rust and scale from the drillpipe before use whilst drillpipe previously used for mud drilling should be washed out. It should also be borne in mind that the filter, which has limited area, can burst if it blocks completely.

DRILLING EQUIPMENT

Introduction

The original JFT drilling equipment package was basically suited to ...al conditions whereas the subsequent investigation programme ... largely been concerned with hard rock drilling conditions. This ... had necessitated procurement of some new ancilliary equipment in order to carry out the planned programme. ... the two major shortcomings in the rig ancilliary equipment could be overcome without further ... relatively high expenditure on major plant.

This chapter deals generally with the present equipment and also indicates ... improvements could be made.

The Rig

The rig type is classified by the industry as a Top Motor Machine, that is it has a power swivel and a pulldown facility. With this arrangement ... drillpipe, casings and other items of various diameters can be ...

Box to Box

Box to Pin

PXV-1
PXV-3
PXV-2
PXV-4
XV-5
XV-6
XV-9
XV-17
XV-7
XV-8
XV-9
XV-11
XV-10
PXV-12
PXV-13
XV-7
XV-14
XV-16

Pin to Pin

... by the head without any mechanical change. At the same time, fluid or air can be circulated. The pulldown system is particularly useful in ... situations where hard rock ... the face and the drill string weight alone is insufficient ... The system used in ... ... can be held back ... ... drillstrings especially when ... driving. ... to be applied to casing ... has become ... and to some degree allows ... drilling to take place ... casing ... than a drill and drive ... drilling method is ...

The building rig specification is given in Appendix II; some explanation of the more specific items is given below.

Drillpipe Size

... usually quoted by depth. It depends on the weight of the string ... and the pulling capacity of the rig which ... ... from above. For partial purposes, 75% of maximum is ... ... taken as a working figure as by doing so, some reserve power ... ... for emergencies. Table 1.1 shows the weight of various ...

3. DRILLING EQUIPMENT

3.1 Introduction

The original JPT drilling equipment package was basically suited to alluvial conditions whereas the subsequent investigation programme has largely been concerned with hard rock drilling conditions. This has necessitated procurement of some additional equipment in order to carry out the planned programme. Nevertheless, some major shortcomings in the rig ancillary equipment cannot be overcome without further prohibitively high expenditure on major plant.

This chapter deals generally with the present equipment and also indicates where improvements could be made.

3.2 The Rig

The rig type is classed by the industry as a 'Top Motor' machine, that is, it has a power swivel and a pulldown system. With this arrangement drillpipe, casings and other tools of various diameters can be rotated by the head without major mechanical changes; at the same time, fluid or air can be circulated. The pulldown system is particularly useful in situations where hard rock is close to the surface and the drill string weight alone is insufficient for bit loading. The system used in reverse can hold back the weight of heavy drillstrings especially when hammer drilling. The design also allows load to be applied to casing which has become stuck well above ground level and to some degree enables drilling to take place through such casing. Thus a drill and drive drilling method is possible.

Drilling rig specifications appear in Appendix II; some explanation of the rig specifications are listed below:

Drilling Capacity

This is usually quoted as a depth. It depends on the weight of the drill string in relation to the pulling capacity of the rigs winch or hydraulic pulldown system. For partical purposes, 75% of maximum loading should be used as a working figure as by doing so, some reserve power is available for emergencies. Table 3.1 shows the weight of various tubular goods.

TABLE 3.1   WEIGHT OF JPT TUBULAR GOODS

Type of Pipe (Nominal Size) inches	Size and Type of Thread	Outside Diameter of Pipe cm	Weight per metre kg.
3½ drillpipe flush O.D.	2 3/8" A.P.I. IF	8.9	19.5
4 3/4 drillpipe flush O.D.	3½" A.P.I. IF	12.1	27.5
6 Temporary casing	B.S. 879 Flush Joint	16.8	30
8 " "	B.S. 879 Flush Joint	21.9	36
10 " "	Screwed Socketed (Locally)	26.7	42
13 3/8 " "	B.S. 879 Flush Joint	34.0	85
6 Well casing	bevelled	16.5	19.5
10 " "	"	26.9	41.5
8 Drill collar	6 5/8" A.P.I. Regular	20.3	230
6 Well screen	bevelled	16.8	18

The 150 m depth figure quoted for the DHH system bears no relationship to either weight or drill pipe or even ideal drilling conditions.

Mast

It can be seen that the mast is strong enough to support the combined pull exerted by both winch and the hydraulics.

Pulldown System

As already explained, the 'pull down' system is also used in reverse (pull-back). The maximum load (14,000 kg) quoted in the specification can be applied during 'pull back' but not for pull down. The reason for this is that at about 7,000-8,000 kg pulldown, the rig starts to tilt off its jacks.

Draw-works or Winch

The rig was delivered with a winching arrangement which incorporates a single sheave travelling block whose maximum theoretical load is 10 tonne. It should be noted that this figure is derived from a 'bare drum' pull i.e. without any rope wound round it. A different configuration incorporating a 2-sheave travelling block is possible and this of course would double the winch power. A slightly smaller diameter wire rope would then be preferred.

Power Swivel

The 150 mm bore through the swivel head on this rig allows the use of the reverse circulation equipment. The rpm and torque shown in the specification are about average for this type of machine. The higher speeds suit dragbit and some rockroller work and the slower speeds are preferred for DHH and large diameter drilling. In both cases the speed is infinitely variable via the hydraulic swash. For small diameter coring operations, high speeds up to 500 rpm with very low torque are necessary otherwise meterage from the bit will be low. A suitable head motor could be fitted if necessary.

Mud Pump

Volume is controlled by bleeding off surplus fluid back to the pit system or by fitting smaller liners. The pump may be coupled with another to increase volume. Pressure increase is gained by fitting smaller liners (Table 2.1) although by doing so, volume is lost. In general,

the mud pump is adequate for the current work in hand although if extra
large diameter drilling was required, it be worthwhile compounding mud
pumps.

Compressor

The rig compressor is a poor choice. Although it has a reasonable pressure
output, it cannot be used properly with the DHH system because of lack of
volume.   Volume can however be augmented by compounding with an auxiliary
compressor until the pressure limitation of the smaller unit is reached.

The Rig Truck

The rig and ancillary equipment are permanently mounted on the truck, which
means that it is fully loaded at all times; the distance travelled yearly
by the rig truck is normally very low as it spends the majority of its time
on site. Unfortunately, the truck gearing ratio is more suited to the
highway and several clutches have worn out on each rig. this subject is
dealt with separately in the maintenance section (Chapter 8).

Drilling Accessories

A basic list of accessories appears in Appendix III where appropriate items
are discussed in detail.

3.3   Drill String Composition

3.3.1   Introduction

Rotary drill strings usually follow a standard arrangement, as shown
(Figure 3.1). Each component performs a separate and important function
in the drilling process. Periodic reference to Appendix II will be
necessary.

3.3.2   Drillpipe

The drillpipe acts as a conduit for the drilling fluid and transfers power
to the drill bit. It is relatively flexible and usually maintained in
tension to preserve the verticality of the borehole. Two sizes are
available in the JPT package (Appendix III; list). It can be seen from
the list that the 150 m of the smaller pipe (8.89 cm dia.) and 300 m of the
larger drillpipe (12 cm dia) is available for use by either. The smaller
pipe is more suited to use with the DHH system where a continuous

FIGURE 3.1   DIRECT CIRCULATION DOWN-HOLE ASSEMBLIES

DRILLPIPE

SUB

DRILL COLLARS

STABILISER

ROCK BIT

SINGLE PASS OPERATION.

DRILL COLLARS

SUB

HOLE OPENER

STABILISER

ROCK BIT
(7⅝ ").

PILOT HOLE
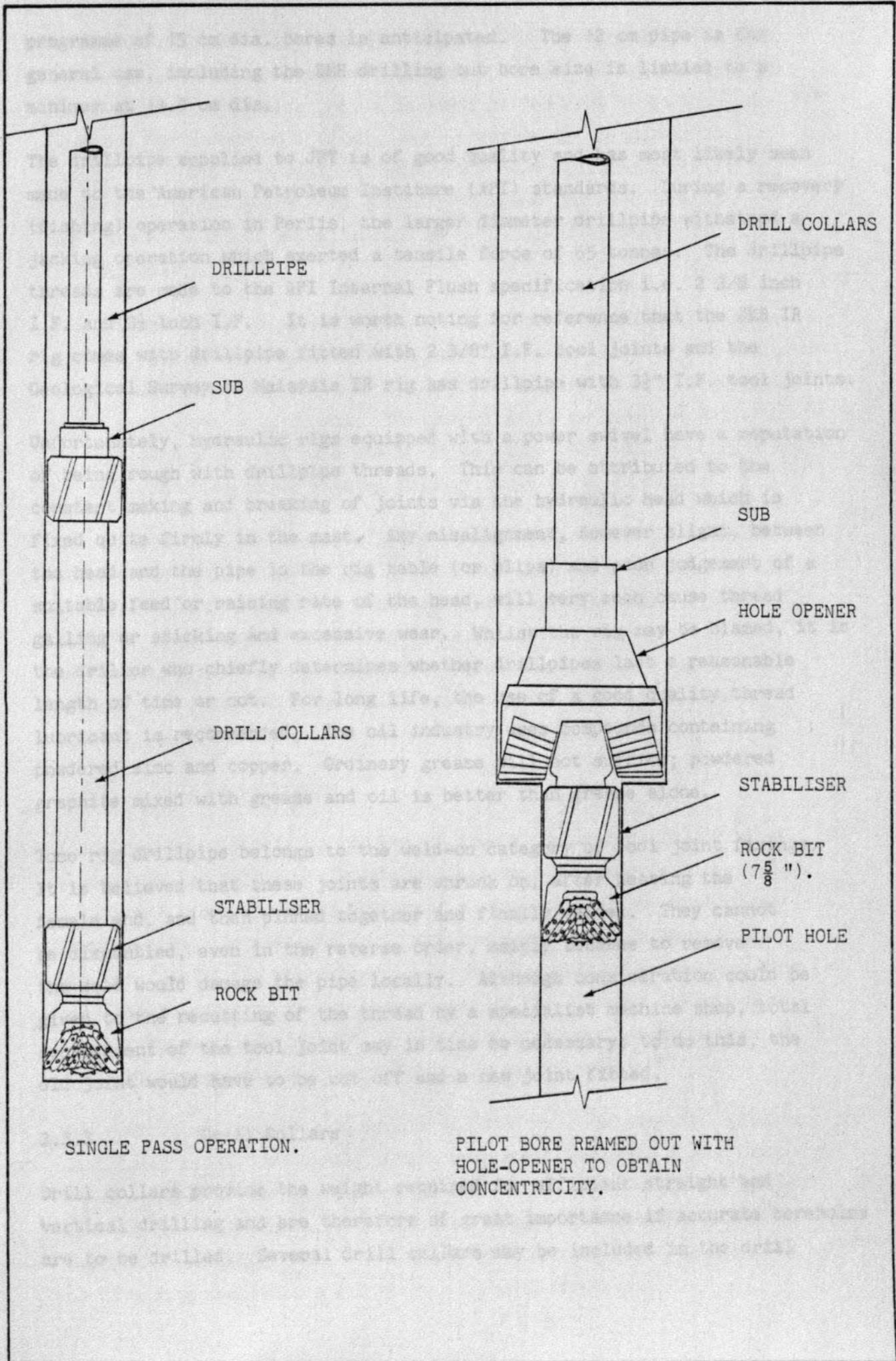
PILOT BORE REAMED OUT WITH
HOLE-OPENER TO OBTAIN
CONCENTRICITY.

programme of 15 cm dia. bores is anticipated. The 12 cm pipe is for general use, including the DHH drilling but bore size is limtied to a minimum at 14.9 cm dia.

The drillpipe supplied to JPT is of good quality and has most likely been made to the American Petroleum Institure (API) standards. During a recovery (fishing) operation in Perlis, the larger diameter drillpipe withstood a jacking operation which exerted a tensile force of 65 tonnes. The drillpipe threads are made to the API Internal Flush specification i.e. 2 3/8 inch I.F. and 3½ inch I.F. It is worth noting for reference that the JKR IR rig comes with drillpipe fitted with 2 3/8" I.F. tool joints and the Geological Survey of Malaysia IR rig has drillpipe with 3½" I.F. tool joints.

Unfortunately, hydraulic rigs equipped with a power swivel have a reputation of being rough with drillpipe threads. This can be attributed to the constant making and breaking of joints via the hydraulic head which is fixed quite firmly in the mast. Any misalignment, however slight, between the head and the pipe in the rig table (or slips) and poor judgement of a suitable feed or raising rate of the head, will very soon cause thread galling or sticking and excessive wear. Whilst the rig may be blamed, it is the driller who chiefly determines whether drillpipes last a reasonable length of time or not. For long life, the use of a good quality thread lubricant is recommended. The oil industry uses compounds containing powdered zinc and copper. Ordinary grease will not suffice; powdered graphite mixed with grease and oil is better than grease alone.

Tone rig drillpipe belongs to the weld-on category of tool joint fixings. It is believed that these joints are shrunk on, after heating the female end, and then pinned together and finally welded. They cannot be dismantled, even in the reverse order, mainly because to remove the weld would damage the pipe locally. Although consideration could be given to the recutting of the thread by a specialist machine shop, total replacement of the tool joint may in time be necessary; to do this, the old joint would have to be cut off and a new joint fitted.

3.3.3 Drill Collars

Drill collars provide the weight required for efficient straight and vertical drilling and are therefore of great importance if accurate boreholes are to be drilled. Several drill collars may be included in the drill

string to achieve optimum weight requirements. For optimum results, quoted weight requirements vary between 500 and 5,000 kg per inch of hole diameter, depending on the hardness of the rock to be drilled. However, for larger hole sizes, the optimum weight requirements are beyond the lifting capacity of most water bore drilling rigs and a compromise is necessary. To generally achieve the best results, the maximum possible weight should be utilised consistent with rig lifting capabilities.

The JPT have four 20 cm dia. drill collars from the original package and two 16.5 cm dia. collars which were fabricated later. The smaller collars are made from 12 cm drillpipe core encased by a 16.5 cm pipe which was filled with cement. The larger drill collars are suitable for use with a minimum size bit of 25 cm dia.; the smaller collars may be used with bits sizes ranging from 19 cm up to 25 cm dia.

Where conditions are ideal, all the weight required by the bit is obtained by drillcollar weight alone; the drillpipes are then held back and remain in tension. Oil well drillers very often use 100 m of drill-collars in their drill string to achieve this. However, even with perfect weighting arrangements, deep bores can deviate by as much as 45° off vertical. To overcome the tendency for the bit to move off course, stabilizers are used in the drill string.

3.3.4   Stabilizers

Blade or wing stabilizers (30 cm dia.) were included in the JPT rig package whilst smaller stabilizers could be fabricated locally; if so, a 'spiral' blade design is preferred to the existing straight blade or wing type. Because the drill collars are not run in tension and the function of the stabilizer is to hold the collars centrally, some wear can be expected on the outer edges of the blades. These can be dressed successfully by welding with mild steel rod to build them up; they are then topped with hard facing to resist wear.

The reaming of bore PM 3 in Perlis was difficult because the straight stabilizer blades frequently became caught in fractured ground with a result that torque was constantly high and the rig winch oil seals were blown. Subsequently, the spaces between the straight blades on two of the existing units were joined by a rounded thick-section plate to form ring stabilizers and these gave good results.

3.3.5 Subs (Substitutes)

The purpose of a sub is to connect the various sections of the drillstring together. Subs are supplied to suit any combination of thread type and size and are mostly made to API specifications with dimensions in inches. A 'pin' thread is male and a 'box' thread is female. Subs used to join kelly to drillpipe and drillpipe to drill-collars are usually 'box' on top and 'pin' below. Subs to join drillcollar or drillpipe to a bit are usually box on top and box below.

The JPT drillpipe is fitted with API. IF series tool joints and the drill collars with API regular threads; all rockroller bits also have API regular threads. Machining details of the two thread systems are given (Appendix V). Previous experience shows that the average machine shop cannot successfully make API subs unless they specialize in this type of work.

3.3.6 Non-Return Valves (NRV)

When airdrilling, a NRV is used in the drill string in or just above the bit and stops ingress of cuttings and water into the drill string when the compressor is switched off. Without it, there is the possibility that the bit or the airways to the bit bearings may become blocked and this would mean that the whole drillstring would have to be withdrawn from the bore. Both down-the-hole hammers incorporate a NRV device but they are not available for JPT rockroller assemblies. Some bit manufacturers offer a simple butterfly type NRV with their bits which should be procured when available. Alternatively, special subs which incorporate a NRV device can be purchased. Subs suitable for range 2 and 3 bit threading shown later (Table 3.3) would be necessary.

3.3.7 Rockroller Bits

There are two main types of rotary bit, the drag and the rock roller type. Rockroller bits having long, widely spaced teeth can drill the soft formations which are also drillable by drag bit. Very hard rocks, which cannot be touched by drag bits, can be drilled effectively by rock-roller bits having short, closely spaced teeth (i.e. hard formation bits). Rockbits in the medium to hard formation range are more suited to the meta sedimentary rocks of Peninsular Malaysia.

Rockroller bits are built to withstand tremendous strain and are very
ruggedly built. Recommended drilling weights vary from 180 kg per cm
of bit diameter (soft formation type) up to 1450 kg per cm. of bit
diameter to suit the hardest rocks.   If the 7 5/8" diameter rockroller
bit is used as an example, it can be seen that depending on bit design,
weights varying from about 3.5 tons to 26 tons can be safely applied.
Rockbits are available to suit the full range of strata from alluvium
to the hardest rock. Manufacturers' catalogues show a bewildering variety
of bits, each with slightly different designs; variations in bearings,
teeth, inserts, lubrication systems and circulation apertures may confuse
if they have to be ordered by a person who is unfamiliar with the
equipment. The supplier will need various basic details before he can
make an offer. These details and some reasons for particular choices,
are given below:

Bit Diameter

The bit required must pass through standard casing (conductor or
permanent type) and must then make a hole which in some cases will need
to accept another casing. Table 3.2 shows some casing, bit sizes and
clearances which may have been used in the JPT drilling work. When bit
size has been decided on, it may be found that one particular manufacturer
does not make that size or it is out of stock. He may offer the next
nearest size which may or may not be suitable.

Formation Type

Basically bits for soft formation have long sharp teeth and for hard
formation, shorter teeth in greater numbers. In between, tooth
configurations are offered to suit multi-layered strata i.e. soft to
medium formation, medium to hard formation, etc. Because of the great
numbers of bits on offer, it is useful to refer to the code published
by the International Association of Drilling Contractors (IADC)
when checking bit catalogues and returned tenders. The comparison
charts in Appendix VI show the IADC Code for bits on offer from the
major manufacturers.

50

Table 3.2   JPT CASINGS/BITS MINIMUM CLEARANCES

Casing Size O.D.	Bit Size Available to drill hole to accommodate this casing	Bits available for drilling through this casing
inches	inches	inches
13 3/8	14 3/4	12¼
10 9/16	12¼	9 5/8
8 5/8	9 5/8	7 7/8, 7 5/8, 7 3/8
6 5/8	7 7/8, 7 5/8	6, 5 7/8
4½	6, 5 7/8	-

Dimensions are inches (1 inch = 25.4 mm)
Majority of casing and all bits used for oil and water bore construction are manufactured to imperial measurements.

1. The 13 3/8" dia. conductor casing is only intended to be set into rockhead by a maximum of one or two metres.

2. The 10 9/16" dia. casing may be used as conductor but its prime use is intended for pump chamber (upper bore casing). Long sections of hole in hard rock to accommodate this casing must be drilled by a stiff bottom hole assembly comprising 8" drill-collars 12" stabilisers and a 12¼" Bit.

3. For long sections of hole required to accommodate 6 5/8" dia. casing, the 6½" dia. drill collar must be used (especially in hard rock). Preferred bit size is 7 7/8" or 7 5/8", although 7 3/8" bit has been frequently used.

4. Larger clearances are sometimes necessary in difficult conditions and for gravel packed bores thus:

    12¼" Bit for 8 5/8" casing
    9 5/8" Bit for 6 5/8" casing

It should be remembered that the properties of certain strata are
not universal. The limestones in Perlis are of two different ages
(Chuping and Setul) and each require a different bit.

Steel Tooth or Tungsten Insert

The steel tooth bit is usually about one third or one quarter the
price of the insert bit but the latter should give three or four times
more metreage. In a deep oil well, the difference in cost could be
saved by not having to pull the bit out so frequently in order to change
it. The JPT have managed quite well to date with steel tooth bits,
although one 'insert' bit should later be tested for comparison purposes.

Mudflush or Air Circulation

Alluvial drilling has got to be by mud flush but some sedimentary rocks
may be hard but have soft components. Therefore JPT use both hard
and soft formation rock roller bits suitable for mudflush.

Special airdrilling rock roller bits are offered by some companies.
These bits incorporate an air cooled bearing system and these bits are
found to give better results that dual purpose bits. The latter, which
have airways to the bearings which can be plugged off if the bit is
used for mud drilling, are perhaps less successful. Other bits, described
as multipurpose, are in fact primarily designed for mud flush and have a
short life when used in air drilling.

Centre or Jet Circulation

It has to be decided if a bit is to be supplied with one large hole at
the bottom to pass the circulation material or if it is to be of the jet
type, which usually contains three small diameter holes.
The advantage of the centre circulation bit is that larger quantities
of fluid or air may be passed through the bit without appreciable pressure
losses. This type is more suited to the JPT mud pump whose pressure
is relatively low. However, centre circulation bits may not be offered
for every bit size and in this case, jet type bits are acceptable provided
their nozzles are removed.

Jet bits give superior bottom hole cleaning due to the high velocity
of the fluid directed to the rock face. This leads to a faster penetration
rate as cuttings are quickly removed and not re-ground. The nozzles
mentioned above come in various diameters so that they can be selected
to suit available pump pressures.

The special airbits mentioned above have somewhat restricted discharge
orifices. This is to create a small differential pressure in order to
divert air to the bearings. Such bits may be acceptable when fitted
with large to medium size nozzles.

Thread or Shank Size

Bits are supplied universally with standard API. Regular threads according
to a bit size. Reference should be made to Table 3.3.

Table 3.3   Bit Threads

Range	Bit diameter (inches) Up to and including 4½ inch.	Threading 2 3/8 API. REG.
1	4 5/8 - 5	2 7/8 " "
2	5 1/8 - 7 3/8	3½ " "
3	7 5/8 - 9	4½ " "
4	9½ - 14 3/4	6 5/8 " "
5	15 - 26	6 5/8 or 7 5/8 " "

Note: JPT has subs to suit each of the above sizes.

Rockroller bits are very seldom repaired and nothing can be done for a
bit with worn bearings. Rebuilding of bit teeth by hard face welding is
possible but may not be worth the effort if the remaining bearing life
is short. Rehabilitation is time consuming and the work must be precisely
executed in order to obtain an even tooth height. For the best results
the bit should be submerged under water with only one row of teeth exposed
and in this way, bearings will not be damaged by heat.

3.4 Temporary Casings

The main uses for temporary casings are as follows:

- to seal off unconsolidated strata (alluvium) above hard rock so that drilling by airflush is possible and to case off unstable alluvium especially near the surface

- to case off unstable or caving sections within hard rock

- to case out water during airdrilling

- to act as conductor casing to start off any bore

- in airlift pumping, temporary casing can be used as eductor pipe and in 'fishing' operations, it is used as a wash-over pipe. It can also be used in isolating upper strata in drill stem tests.

No temporary casing was included with the original rig package and the casing listed in Appendix III has been manufactured locally to British Standard 879 and JPT now has sufficient temporary casing to allow the rigs to work independently. At the same time, various casing handling tools and fittings have been made. These include:

- casing head adaptors to connect swivel head to the casing (8 5/8" and 6 5/8" casings)

- casing shoes-rotary fitted with tungsten teeth (8 5/8" and 6 5/8" sizes)

- drive shoes-bevelled (13 3/8", 8 5/8", 6 5/8" sizes)

- casing clamps to fit each casing size

- lifting bail for 13 3/8 casing

- tapered slips to suit Tone spider bowl sizes 8 5/8" and 6 5/8"

With the exception of the 10 9/16" O.D. casing which has 'V' threads and collars, temporary casing has a parallel square form thread and the outer diameter is flush (i.e. flush joint).

FIGURE 3.2 REDUCING CASING DIAMETERS (TELESCOPIC BOREHOLE)

Normally, a hole is drilled to accept the casing but in soft formation, the casing can often be rotated (if equipped with a rotary head and shoe) or driven down by percussion. Such practice is not always possible due to the hardness of some strata and because of resistance resulting from wall friction. Often casings used in this manner become stuck in the bore and have to be jacked out at a later date.

The list of temporary casing in Appendix III indicates an excess of smaller size casing (6 5/8" dia.) over larger diameters; this is because rarely are deep, very large diameter bores required. The casing sizes stocked also allow a telescopic borehole configuration as shown (Figure 3.2). Precautions should be taken to prevent ingress of cuttings into the annulus between the different size casings as these may otherwise become locked together. A neat fitting flange, or washer, should be fitted around the smaller casing in each case.

Damage to temporary casing threads is common, especially through careless handling during loading and transport and drivers and assistants must be made aware of this. Damaged threads are difficult to screw together and usually damage other, perfect mating threads. Minor repairs are possible but badly damaged or worn ends need to be cut off completely and the whole end re-screwed at a specialist workshop. Repairs to casing shoes with inserts can be carried out on site; old broken inserts can be removed by heating-up and new inserts brazed in their place.

3.5   Borehole Components

3.5.1   General

The components of a permanent borehole or well assembly are discussed here as they are part of the drillers equipment. The components of a borehole assembly come in a variety of tubular materials ranging from stainless steel to plastic, with a large range of diameters and wall thickness. A variety of bore design configurations are possible and some are shown later, in Chapter 5. The main components of a borehole are:

- an upper bore or well casing (UWC) which acts as on a pump chamber or housing

- a lower bore or well casing (LWC) comprising the slotted pipe/screen and any necessary blank casing.

FIGURE 3.2   REDUCING CASING DIAMETERS (TELESCOPIC BOREHOLE)

$13\frac{3}{8}$" O.D. CASING.

$10\frac{3}{4}$" O.D. CASING PASSES
THROUGH $13\frac{3}{8}$" CASING.

$8\frac{5}{8}$" O.D. CASING PASSES
THROUGH $10\frac{3}{4}$" CASING.

$6\frac{5}{8}$" O.D. CASING PASSES
THROUGH $8\frac{5}{8}$" CASING.

6" OPENHOLE (UNLINED).

WILL ACCEPT $4\frac{1}{2}$" FINAL
SIZE CASING (AND $4\frac{3}{4}$"
DRILLPIPE).

In alluvial boreholes, the UWC is larger in diameter than the LWC whilst in hard rock areas, a LWC may not be necessary. In both alluvial and hard rock types, the borehole assembly may be a single string casing of the same diameter. Minor components which may also be necessary are bail plugs, centralisers, reducers, and a dropset or hanger system and casing caps.

3.5.2   Bore Casings

The JPT groundwater section has in stock several years supply of bore casings at both 10" (254 mm) and 6" (152 mm) nominal diameters. This casing pipe has bevelled ends suitable for welding. An advance commitment to the use of sizes and types of casing pipe has some disadvantages since it produces some reluctance to take advantage of other materials and to use other sizes closer to those needed for optimum borehole design. However steel casing is safe for unknown or exploratory drilling conditions.

Verticality of the upper bore casing is very important and care has to be taken when welding to ensure straightness. The casing pipes have been prepared at the mill with 35° chamfered ends and are ready for use. Casing pipe ends cut on site by gas burning will be inaccurate and will not be suitable for further use as pump chamber unless they are refaced at a workshop. However, a gas cut pipe is better used as part of a piezometer casing where straightness is not too important. Alternatively, it may be used so that the cut end is positioned uppermost on a borehole casing assembly with the inaccurate end sticking above the ground. The careless transport and unloading of casing can cause ends to dent inwards; casing should be inspected for this defect before welding, otherwise the drilling bit may not pass the defective joint.

Lower bore casing of 152 mm diameter is often used between bore screens to serve as a blank against fine sands or impermeable strata. The distance required between screens is unlikely to be exactly the same as a standard casing length and so it will need to be cut as accurately as possible on site. Straightness in this case will not be so critical because the adjacent screen has some flexibility and is able to take up slight inaccuracies.

FIGURE 3.3   DROP-SET CASING LOWERING SYSTEM

3.5.3   Reducers and Dropset/Hanger Systems

A reducer is required to connect one size of casing to another of
different diameter where the bore or well assembly is to be run-in in
one string. Reducers should be fabricated to the specification shown
in Appendix VII. Conical shaped reducers are specified because development
tools are more easily able to pass into the small diameter (LWC) pipe.

Upper and lower bore casings are not always inserted into the bore as
a single string. In the other common bore construction technique, the
UWC is installed first and the rest of the bore drilled through the upper
casing. A smaller diameter casing-screen assembly (the LWC and screen)
will then be suspended or hung off from the UWC. To do this, a lowering
device in the form of either a left hand/right hand system or a bayonet
type fitting is suitable; this device is termed a dropset. Dropset
casing fittings are normally prepared on site to suit local conditions
although prepared casing ends should be manufactured in advance and
a few stocked on site or in the stores. Figure 3.3 gives a suitable
design.

3.5.4   Centralisers

Where an artificial gravel pack is to be placed opposite a screen or
an envelope of cement is to be introduced around the bore casing, then
the casing/screen needs to be positioned concentrically in the bore.
Commercial centralisers are available but are expensive. At JPT sites,
a welding set is always available so it is simpler and cheaper to weld
centralising strips where necessary onto the casings as these are run
in the bore. Appendix VIII shows the required designs.

Centralisers are normally used at every other casing joint but this
can be varied. Centralisers should not be attached to upper bore
casings as these often need to be moved during verticality tests.
The exception to this rule is for certain special applications when
the upper bore casing needs to be cemented in position accurately.
The position of centralisers should be decided on after examination
of the caliper log.

FIGURE 3.3   DROP-SET CASING LOWERING SYSTEM

LOWER 'DROP-SET' WITH
DRILLPIPES OR TEMPORARY
CASING.

BAYONET FITTING (MALE)
WITH SPIGOT FITTING

CUT TOP OF CASING
TO FORM 'J' SHAPE.

STEEL AND RUBBER FLANGE

WELD 'LANDING RING' TO
BOTTOM OF 10" CASING IF
LOWER CASING NEEDS TO
HANG OFF BOTTOM

SLOTTED PIPE OR SCREEN AS
REQUIRED. CAN EITHER SIT ON
BOTTOM OF BORE OR MAY HANG.
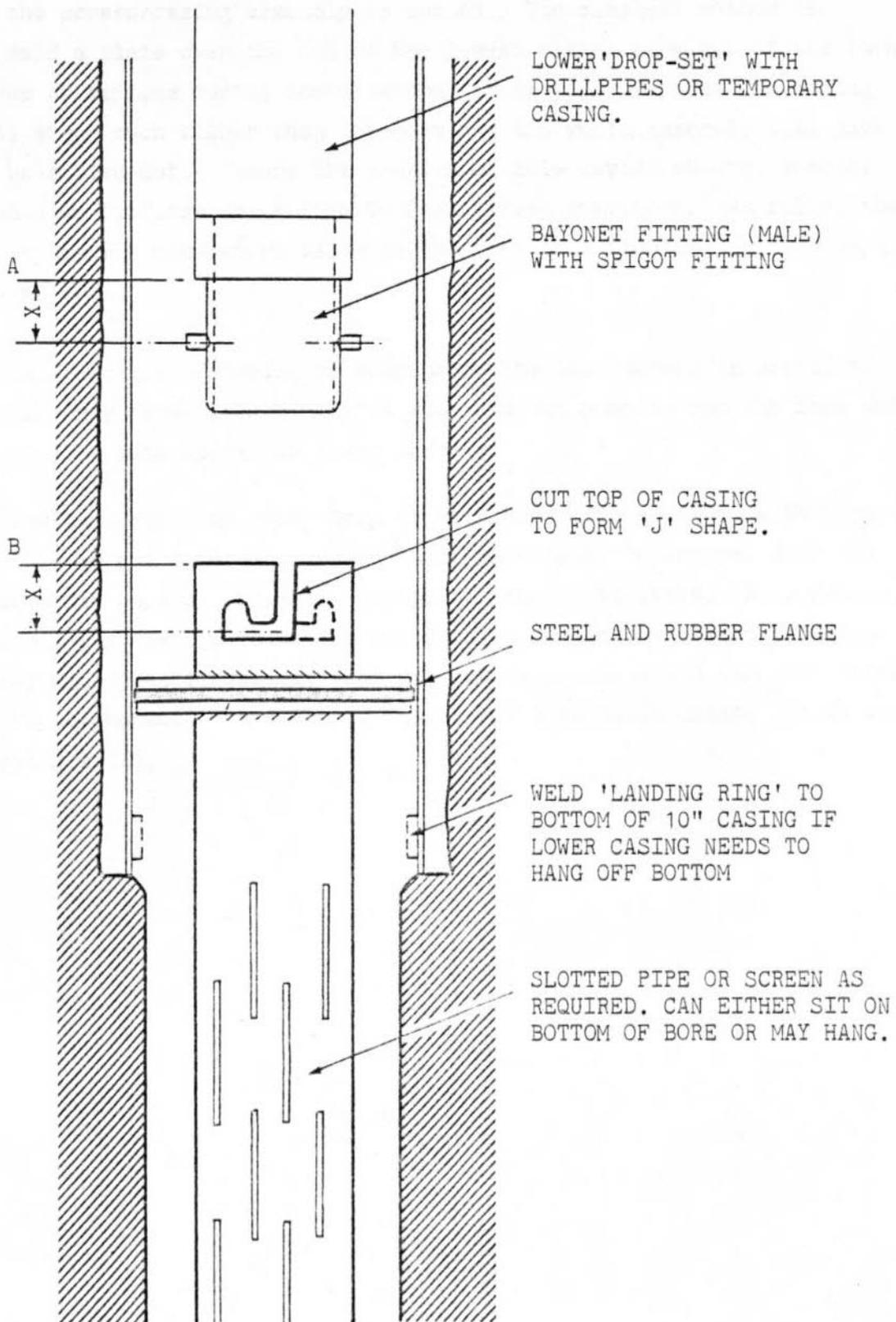
EXPLANATION:

BAYONET OR 'J' LATCH ASSEMBLY SHOULD BE MATCHED SET. FACES A AND B
SHOULD BUTT IN COMPRESSION AND DISTANCES 'XX' SHOULD BE EQUAL.
(CENTRE SPIGOT = CENTRE OF SLOT).

3.5.5   Bail Plug, Casing Sump and Casing Caps

Bore casing assemblies for alluvial conditions require that the base
of the screen/casing assembly be sealed. The simplest method is
to weld a plate over the end of the lowest casing pipe but if the bore
caves or bridges during installation, it is possible that the casing
will stand much higher than intended and the whole assembly will have
to be pulled out.   Where the problem of hole caving exists, special
wash-down fittings are available from screen suppliers. Basically, they
incorporate a non-return valve in the form of a floating ball or spring
loaded ball.

A blank section of casing or sump below the last screen is useful to
contain any fines including silt and sand not pumped from the bore which
could otherwise block the lower screens.

Following completion, each bore or well should be equipped with a cap.
If this is not done, some object will inevitably be dropped down the
unattended bore by those who delight in such activities. As a result,
the rig may need to return to the site to remove the object from the
bore; with plastic casing, this may not be possible and the bore willhave
to be abandoned.   A suitable design for a lockable casing cap is given
(Appendix IX).
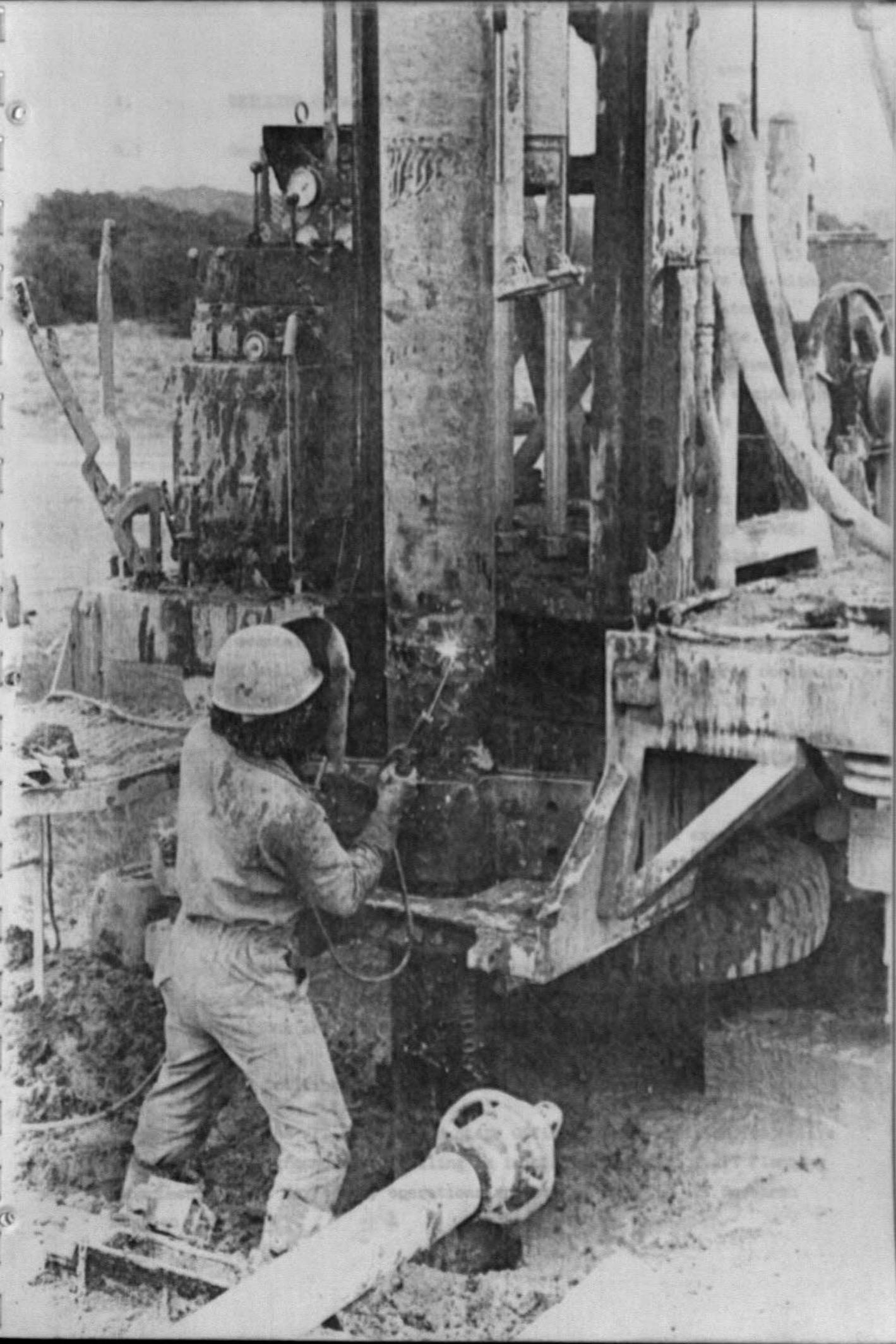
4. DRILLING OPERATIONS AND PRACTICES

4.1 General

4.1.1 Introduction

The process of drilling is to a large extent a matter of experience.
A driller will gain experience on the site over a number of years and although
training courses may be available, most knowledge is gained by watching
and observing others and by actually doing various jobs on the site.
A driller in the UK usually enters into drilling after the age of twenty
by which time he may have served an apprenticeship in mechanical engineering.
Apart from experience and a 'feel' for the job, common sense is a pre-
requisite for the making of a good driller.

Most drillers start their careers doing the dirty, heavy and less desirable
jobs on site such as cleaning mudpits, mixing mud, cleaning and greasing.
Meanwhile, chances occur for the trainee to take part in the handling
of drill strings during running-in and out of the bore ('tripping')
and to be put in charge of the mud pump. Certainly they will do all the
jobs on site eventually. Once aptitude is shown for the job, then the
senior driller will occasionally let the trainee look after the rig controls.
On average, it takes three or four years to become a driller in charge
and from then, the driller should become wiser and more experienced.
In the JPT, the time scale for progression from trainee to senior driller
has been somewhat shortened.

Drilling is often unpredictable and no two holes drilled are exactly the same.
Precise programmes and instructions for operating a rig properly and
efficiently under all conditions cannot therefore be given and instead,
the driller reacts according to his experience.

The following sections deal with the various operations of drilling and
constructing water bores (often called wells). Much is common sense. Advice
and recommendations are given where appropriate.

4.1.2 JPT Drilling Organisation

Liaison between the JPT Federal and State Offices on the location, objective
and financing of groundwater drilling is initially arranged by JPT Planning
Department whilst day to day operations are run through the JPT Research
Station, Ampang.

FIGURE 4.1   FLOW CHART-SUPPLY AND REPAIR

The drilling section requires the following back-up support at state level:

- storage space for heavy drilling equipment, enclosed (lockable) stores for spare parts, and a shed or covered area for bentonite drilling mud

- arrangements for site access and liaison with the land owners

- preparation of the drilling sites including digging mud pits, clearing the site, laying down necessary hardcore, laying temporary culverts and arranging water supply to site

- supply of fuels, oils, grease, cement and small hardware.

- arrange to supply two labourers to supplement the rig or pump test crew and a night watchman and guard at week ends

- to arrange minor mechanical repairs or assist crew in locating workshops

- obtain necessary spares to cover breakdown of equipment

- provide a 3 tonne truck at times when the groundwater group vehicle needs to perform long journey or is broken down

- provide a field car for occasional use by technical staff or when rig crew vehicle is being repaired.

The well equipped JPT Central Workshops at Ipoh can handle major repairs; recently both rigs were overhauled there and their hydraulic cooling systems modernised. An experienced chargeman at Central Workshops is now familiar with the drilling equipment and test pumping plant. He is available on request to attend to breakdowns on site which cannot be handled by the JPT drilling crews or the mechanics from the state JPT offices.

The general organisation of the JPT groundwater and drilling section is given (Figure 4.1). This shows arrangements for the provision of back-up and repair services to the field drilling teams.

FIGURE 4.1   FLOW CHART–SUPPLY AND REPAIR

Boxes in flow chart:

- IPOH PLANT-HIRE
- LABOUR (STATE)
- PUMPTEST TEAM (FIELD)
- IPOH TRANSPORT
- STORES (STATE)
- IPOH WORKSHOPS — M.E.
- RIG 2 (FIELD)
- IPOH WORKSHOP CHARGEMAN
- WORKSHOP (STATE)
- AMPANG RESEARCH STATION — GROUNDWATER OFFICE
- RIG 1 (FIELD)
- TEST-PUMPS AGENT
- D.I.D. OFFICE (STATE)
- ISUZU AGENT
- STORES (AMPANG)
- CONSUMEABLE -SUPPLIERS
- MUDPUMP COMPRESSOR AGENT
- PLANNING SECTION K.L.
- WORKSHOP (AMPANG)
- TONE AGENT
- TRANSPORT (AMPANG)
- TONE JAPAN

Legend:

MECHANICAL REPAIRS – MAJOR

MECHANICAL REPAIRS – MINOR

FIGURE 4.2   TEMPORARY CANAL CROSSINGS

4.2   Site Access, Preparation and Layout

4.2.1   General

Site location is a matter of common sense.   Once the general area has been
chosen, an exploration bore site can be conveniently positioned in the
vicinity. A site off the road, away from electricity wires and needing the
least preparation is all that is required for the majority of exploration
bores whilst the siting of a test or production bore is a different matter
and the end use has to be considered. An irrigation bore has to be positioned
so that it can command the proposed irrigation area without wasteful uphill
pumping and associated civil works. An engineer from the State JPT office,
together with a hydrogeologist or another person from the groundwater staff
or the drilling supervisor, needs to visit each site and agree on the
borehole position; notes regarding access difficulties and alternative sites
should be made in case a land owner raises objections to drilling in his
land or access proves impossible.

4.2.2   Site Preparation

               Access and Ground

To enable the rig to reach the drill site, it is often necessary to widen
and strengthen some tracks sufficiently to accommodate the rig and also
to build up hard rig standing. This cannot be done by tipping loose
clayey materials. A base course of large stones topped with small rocks
and fill is needed. To avoid damage to crop land, the minimum area
required for rig hard standing should be built.

Drainage channels and irrigation canals invariably run alongside roads
and often there is a need to cross them. Concrete culvert pipes topped
with hard-fill will carry the weight of the drilling rig. It is also
worth considering using the drillers bore casing as a temporary solution
to crossing shallow drains (Figure 4.2). In irrigated areas it is often
difficult to find waste ground which is suitably situated for a drill
site so there is no alternative but to position the site on cropland.
It is then necessary to make sure the ground can take the weight of the
drilling rig. On wet padi land, a substantial thickness of hardcore
(not clayey material) will have to be laid. Each site will be slightly
different but attention should be paid to utilizing adjacent hard ground

FIGURE 4.2   TEMPORARY CANAL CROSSINGS

A
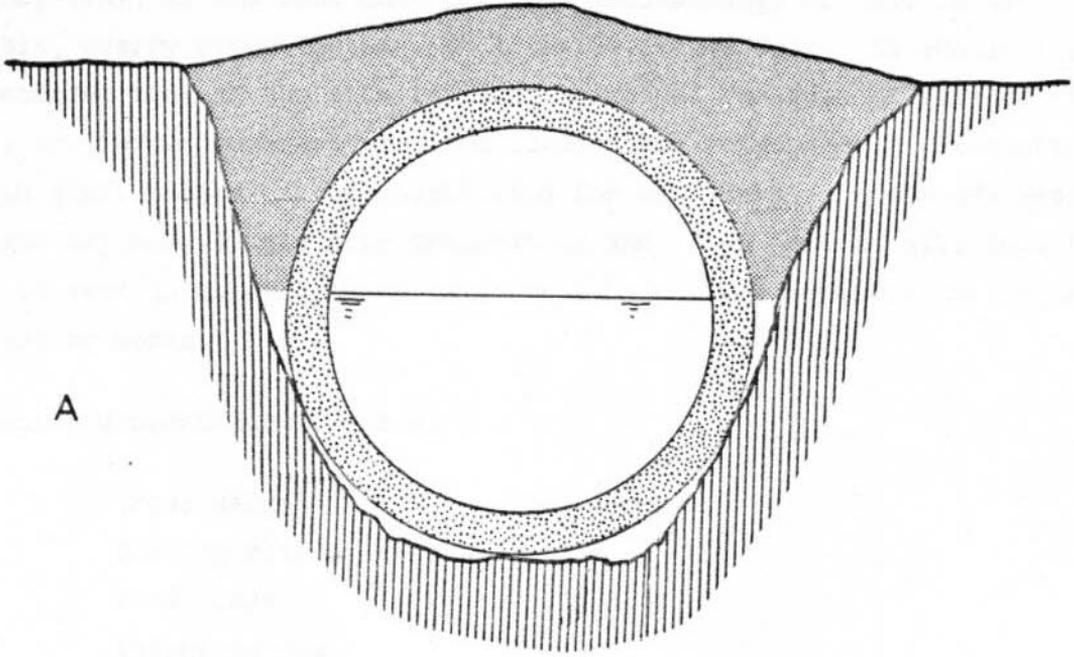
Explanation

The Drilling Rig and Supply Truck often has to pass
over canals and drains to reach the site.
Standard round section concrete culvert pipe (A)
should be used for deeper channels.
Shallow depressions may be filled with either 6"
or 10" plain end steel casing (B)
The pipes used for both methods may be recovered
later.

B

FIGURE 4.3   TYPICAL SITE LAYOUTS
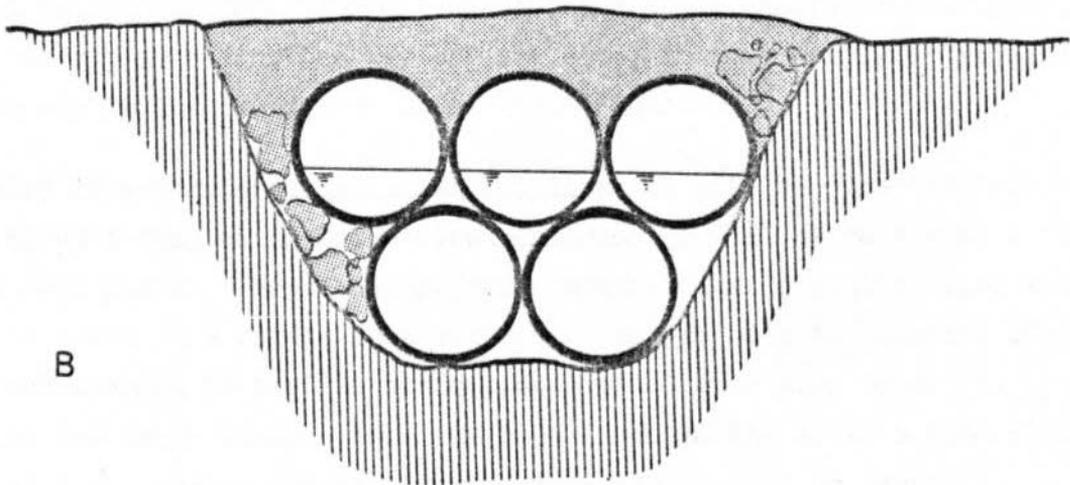
(a road hard shoulder, for example) for accommodating part of the rig;
in that way, expense incurred on fill material and compensation is minimised
(Figure 4.3).   It has been found that quarry waste, a mixture of rock
and sandy-clay, is the best material for hardstanding; if this is not
available, quarry stone topped with laterite serves well. It should also
be remembered that if the site is later abandoned (because of absence of
water), the farmer may want his land cleared and reinstated.   Excavator
mats and steel plates can be substituted for hard core. In the dry season,
crop land may need little site preparation and often none at all; this fact
should be kept in mind if there is to be a long delay between site inspection
and start of works.

Pertinent rig specifications are:

Gross weight	-	24 tonnes
Turning radius	-	8.8 m
Wheel base	-	5.15 m
Weight on rig front wheels	-	approx. 8 tonnes
Rig height (mast folded)	-	3.73 m
Rig width	-	2.52 m
Rig length	-	10.52 m

Site Arrangement

When planning a site for an airdrilling operation, it should be remembered
that any water discharged from the bore will have to be drained away;
the rig is therefore best positioned on ground which is slightly elevated.
In all situations rig, compressor and other plant should be positioned so
that the rig is facing the way off the site; in that way later manoeuvering
by the rig in its own debris is avoided (Figure 4.3).

If water is encountered during airdrilling, it will be directed from the
bore along a channel in which flow measurements will be made with a 'V'
notch weir plate. The discharge measurements taken from the plate will
only be taken as a guide; more accurate readings will be possible if the
approach channel to the 'V' notch plate is 1.0 m or more in width.
To stop the water issuing from the bore flooding the site, a bund 30 cm
high at 1.5 m radius around the conductor casing will be required.

FIGURE 4.3   TYPICAL SITE LAYOUTS

ROAD TARMAC.

P. W. D. RESERVATION (HARD SHOULDER).

RIG 24 TONNE

COMPRES-SOR

MUD PIT

MUD PIT

OFFICE TENT

DRILLPIPE & CASING
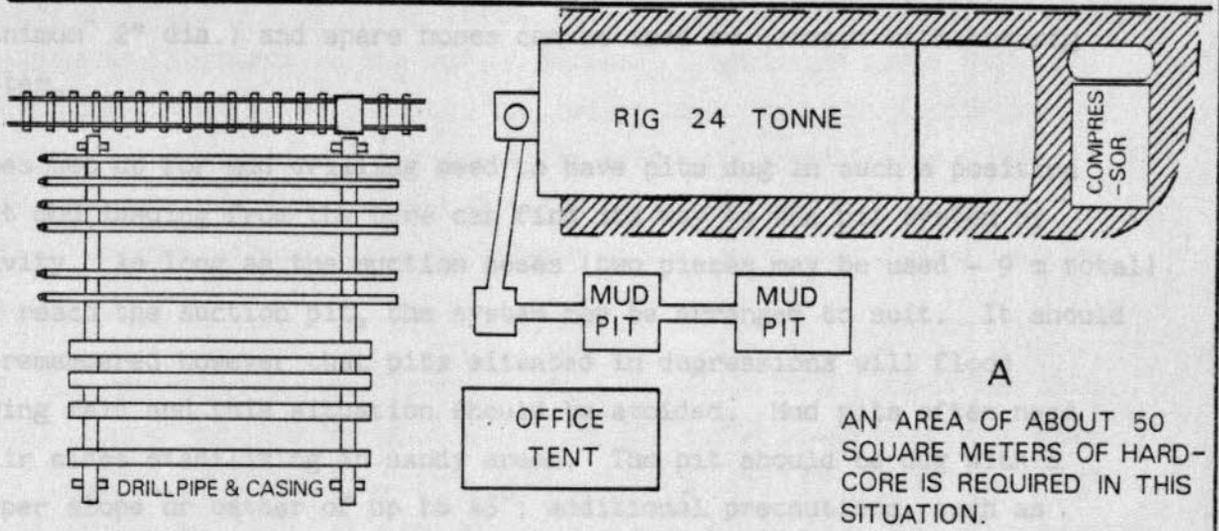
A

AN AREA OF ABOUT 50 SQUARE METERS OF HARD-CORE IS REQUIRED IN THIS SITUATION.

ROAD TARMAC.

P. W. D. RESERVATION (HARD SHOULDER)

COMPRES-SOR

DELIVERY ROUTE FOR 3 TONNE TRUCK

RIG 24 TONNE

MUD PIT

MUD PIT

OFFICE TENT

DRILLPIPE & CASING

Notes:

To cut site preparation costs drillsites should be planned for minimal hard core requirements and encroachment on crop lands.

Roadside sites face problems with canals and drains, as well as danger from overhead electricity cables.

Thickness of hardcore may be 40 cm on wet padi land for the Rig, to 10 cm or none in the dry season.
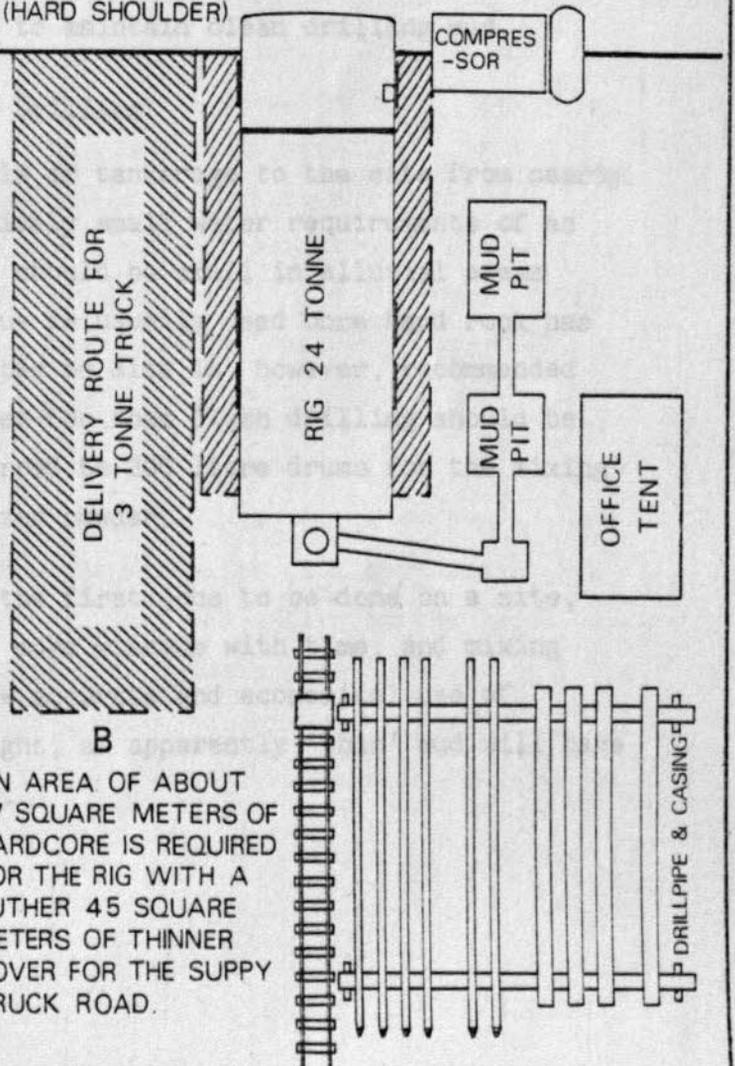
B

AN AREA OF ABOUT 37 SQUARE METERS OF HARDCORE IS REQUIRED FOR THE RIG WITH A FUTHER 45 SQUARE METERS OF THINNER COVER FOR THE SUPPY TRUCK ROAD.

Turf and clayey soil from the drainage channel area should be suitable for this.

If the site is congested, the auxiliary compressor may be positioned conveniently some distance away from the rig. Standard waterpipe (minimum 2" dia.) and spare hoses can be used to connect with the rig system.

Sites set up for mud drilling need to have pits dug in such a position that mud issuing from the bore can find its way to the pit system by gravity. As long as the suction hoses (two pieces may be used - 9 m total) can reach the suction pit, the system may be arranged to suit. It should be remembered however that pits situated in depressions will flood during rain and this situation should be avoided. Mud pits often need their sides stabilizing in sandy areas. The pit should be dug with a proper slope or batter of up to 45°; additional precautions, such as cement rendering and the addition of woven bamboo matting, may be necessary. Polythene sheets used for pit lining have met with limited success. It is worth remembering that a long meandering channel connecting the bore head to the settling pit will collect a lot of cuttings; if the channel is cleaned regularly, this will help to maintain clean drilling mud.

Water Supply for Drilling

Water supplies from local dug wells or tankerage to the site from nearby rivers are adequate for the relatively small water requirements of an alluvial drilling site. Mud loss should be small in alluvial areas and the airflush drilling technique is usually used once hard rock has been reached. A spare tank of water on site is, however, recommended during mud flush operations. Water for foam flush drilling should be stored similarly and then transferred to 200 litre drums for the mixing of the foaming agents and stabilizer powder.

Mixing of drilling mud is one of the first jobs to be done on a site, the reason being that mud becomes more viscous with time, and mixing in advance will result in the more accurate and economical use of the mud material. If left overnight, an apparently 'thin' mud will have thickened considerably by morning.

Ground Bearing Strength

Midjudgement in estimating ground bearing capacity is common and may lead to vehicles becoming bogged down. However, the Isuzu truck (rig carrier) has an inherent weakness in its transmission system and the combination of high gearing and a delicate clutch will not allow any attempt at shunting backwards and forwards in the normal manner. Experience shows that if clutch burn-out is to be avoided, the driver must stop the engine and prepare to jack up the rig using the rig hydraulic system. Once the truck is raised off the ground, suitable fill material such as steel matting, should be laid under the wheels and a track constructed back to firm ground.

It is not necessary to hard core the area where the drill pipes are laid out although a path may be laid alongside the bogie (pipe carrier) track. Where site access is particularly difficult, the drillpipe and casing should be brought onto the site before the rig and in that way, the supply truck may use the hardstanding built for the rig.

Stores and Office

The site stores and office are usually erected side by side. The store generally holds boxes containing spares and fittings, with subs and clamps stored on timbers or on the floor, upon metal decking. Bentonite and mud additives are kept off the floor and under cover on a wooden platform. The office will contain a table and chairs and will be situated to provide a good view of the drilling operations. The site geologist, drilling supervisor and consultant staff may use the office for their discussions, report writing and sample logging. The office is not a public shelter and non-JPT personnel should politely but firmly be refused admittance.

As soon as a rig and equipment is on site, the need for a watchman arises. The practice to date is for the state JPT to supply one of their labourers to look after the rig. This man will know the local authorities and is in a better position to guard the equipment.

4.2.3   Rig Foundations and Levelling

Foundation (jack) timbers under the rig levelling system should be adequate
to support the rig's weight and to bear the full working load of the rig.
The rear jack timbers bear most of the load and special care must be taken
to see that the surface area of the timbers is adequate. A minimum of
1.5 m^2 of timber in contact with the ground for each jack is adequate for
the Tone rig. This timber layer should be dug-in about 10 cm below soil
surface and firmly bedded down; additional timbers laid on top of the
bottom layer may be of smaller area. Care should be taken to see that
the timbers fit centrally under the jacks. The chocking of timbers by
odd stones and wood is no use and the levelling of the ground is
considered a better solution.Setting up of the rig should be one of the
first jobs on site as this will allow time for 'bedding' in of the timber
supports. The weight of the rig should be taken off the truck tyres for
otherwise the rig will rock and sway; it is better therefore to ensure
that each wheel is off the ground by at least 5 cm.

If a borehole is to be straight and vertical, precautions should be taken
from the very beginning to start the bit on a true path. Checking for
rig alignment and verticality should be done with diligence and care.
A rotary table driven kelly rig is usually checked for verticality by
hanging a drillcollar on the kelly line (or travelling blocks) and when
this hangs centrally in the rotary table, the mast is considered to be
straight. Further checks are made by using a spirit level on the top
of the rotary table.

Top drive (power swivel) rigs (like the Tone rig) are better levelled in
another way. Checking the kelly or top drillpipe for verticality on this
type of rig can be subject to error as clearance between the swivel
carriage guide runners and the guide rail exists as well as clearance
at table level between pipe and bushings.   Therefore spirit level should
be used first on the guide rail of the rig in both directions (left to
right and front to rear) with further checks at the kelly and table.
Daily checks at the start of shift are also necessary, more frequently
in the unlikely event that rig jacks are visibly leaking.

A bedding in period, which might last whilst the first batch of mud is being mixed, will allow foundation timbers to settle in. A second check for verticality should be made before drilling commences. Care should also be taken when setting up the rig on very dry, black cotton type soils which, when wetted, may cause uneven settlement at the jack timbers; additional checks are therefore needed from time to time.

4.3   Drilling Operations

4.3.1   Spudding In

For mud flush operations, the conductor pipe or conductor box (the conductor box has a horizontal flow pipe attached to it) is normally set with the aid of the rig. A 3 m length of temporary casing is placed in a 2 m deep drilled hole and the next size bit is run in and another metre drilled. The casing is then pushed with the aid of the drillhead into the smaller hole where a tight fit is effected. A typical example for a 7 5/8" diameter exploration bore is as follows:

- drill down to 2.0 m with a 9 5/8" bit and run in 3.0 m of 8" diameter casing

- continue drilling with a 7 5/8" bit to about 3.0 m and then use the kelly or a laykey in drillpipe slot and push the casing to a convenient depth into the shallow hole

- wash down the bit and clean out the hole and continue drilling; if necessary, a conductor box can be fitted.

The operation takes only a few minutes so there is no need to follow the bad practice of setting a large diameter (final size) conductor casing of, say, 13 3/8" diameter for the pilot hole. Two sizes should be used if a large diameter bore is later to be drilled. If leakage occurs from behind the conductor casing the casing could be pushed further down and a short piece connected to it.

It should be standard practice when alluvial drilling to fill the bore with mud whilst the drill string is pulled (or tipped) out. This is carried out by operating the various valves on the mud system so that mud is directed to the conductor casing. A pipe is simply inserted into the flow pipe on the conductor box or may be screwed onto a special fitting (Appendix VII). The latter system suits the Tone rig design as at running speed, the mud pump output would be excessive for this application and pipe may fly out.

4.3.2   Drilling Practice

General

Alluvium: The bit requirements for drilling alluvium are clearly defined;
either drag or long tooth rockroller bits with bentonite mud circulation.

Hard Rock: Hard consolidated strata required the use of mud or air
circulation with a rockroller type bit with shorter teeth or the use of the
DHH system with air flush.

Overburden: The perfect bit suitable for drilling superficial deposits
or overburden over hardrock has not yet been designed.

Overburden

The overburden bit needs to pass through various unconsolidated strata
including a weathered or broken rock zone, and into rockhead proper before
surface casing can be set. To achieve this, a series of compromises have
to be made in bit choice. The dragbit may suit 90% of the strata but
will be of no use in the harder transient zone whilst a rockroller bit
with small teeth, suitable for drilling the bedrock would most likely
become 'balled up' if extreme care was not taken in the clay sections.
Often one type of bit has to be run first followed by a second, different
type. A compromise is also needed when considering the flushing medium
in the overburden. Because of the limitations of the rig compressor
and the absence of a foam pump, drilling by airflush in these deposits
is often troublesome. If water is very close to the site, it can be
pumped into a tank at the side of the rig and then pumped directly down
the bore without the need of a pit system. This method is preferred over
all others.   The preferred flushing methods in overburden are given
(Table 4.1).

Table 4.1   Suitable Flushing Methods in Overburden

Strata	Thickness (m)	Flushing System found easiest
Overburden	0 - 12	air flush
(Clayey)	greater than 12	foam or water flush
Overburden (loose sand and gravel)	0 - 10	water flush
	greater than 10 m	mud flush

Bit Use

Use of the dragbit in hard formation, even for a few centimetres, maylead to breakage of the tungsten inserts. Prolonged use causes undesirable vibrations and may lead to mechanical failure or burst oil seals and hoses.

Care is necessary with any rockroller bit which has passed through striky clays into hard rock as the bit may have become balled up. Non-rotating rollers on the bit will develop flats if used for a long period in this condition.

Extreme care is necessary in drilling the first few centimetres of hard rock with the rockroller bit. In particular, the surface of hard limestone beneath overburden is rarely horizontal but rather it is sloping or pinnacle shaped. A bit which is pushed too hard will slide down the slope and the bore will be crooked at best and may not later accept the conductor casing. It is recommended therefore that a stiff bottom hole assembly with stabilizer and heavy drill collars be used in these conditions.

Caving and Casing Installation

When airdrilling alluvium, it is not always possible to clean out the bore perfectly before inserting the conductor temporary casing. Some caving of clayey material actually helps in sealing the annulus between the hard rock and the casing and indeed sometimes, clay needs to be dropped down the bore for this reason.

When caving of the bore is excessive, 'stuck-up' casing may be pushed with the rig pulldown system. Severe caving of the drilled bore can be rectified by cleaning out the bore with mud or resorting to a 'drill and drive' system. To do this, the bit should pass through the bottom of the casing to clean out two or three metres before another joint of casing is added and pushed down. The drillpieps may be left in the bore by hanging them on the lay-key.

FIGURE 4.4   CASING ALIGNMENT

Pull down of about 7-8 tonnes may tilt the rig. On occasions extra force
may be necessary, so the DHH may be used between the casing (which should
be protected by a hardwood block) and the drillhead. Pulldown is applied
and the hammer operated carefully. Casing so inserted would need jacking-
out afterwards so the system should really be only used for permanent
casing installations.

Penetration in Overburden

Penetration rates when airdrilling using rock roller bits and dragbits
in overburden are often misleading since apparent low penetration rates
relfect not the hardness of the strata but the difficulties in clearing
the bit of cuttings plus general bore cleaning problems.

With overburden, airdrilling samples at each metre may not be possible
as cuttings may be retained down the bore. Those recovered will be
contaminated and too mixed for accurate description.

4.3.3   Casing Assemblies

Both permanent bore casing assemblies and overburden surface casings
into rockhead, utilising welded casings from JPT stock, need to be
welded-up straight to comply with verticality and bit clearance
limitations.

Casing alignment is of great importance and a long straight edge
(one metre long or more) should be used for this. The straight edge
is pushed against both pieces of casing in several directions and
when the casings are lined up with each other, they can be tack welded.
Further checks should then be made before final welding (Figure 4.4).

Suitable welding rods (to suit the type and thickness of steel) should
be kept in dry, oil-free conditions. When more than one run of weld
is applied, the slag must be cleaned off thoroughly before another layer
is placed. The practice of welding straps across welded joints as
additional strengtheners is basically acceptable. If holes have been
burnt in the top of casing to accommodate lifting slings, then those
holes should be plated over on the outside to prevent gravel and sand
entering the borehole. It is common for most people working on drilling
site to regard themselves as expert welders, and while most people can
stick two pieces of steel together with little practice, the chances of
them remaining together are doubtful. Welding is an art which requires

FIGURE 4.4   CASING ALIGNMENT

WELL CASING.

STRAIGHT-EDGE (AT LEAST ONE METRE LONG) MUST BE USED TO CHECK CASING ALIGNMENT BEFORE WELDING.

CHECK ALIGNMENT FROM ALL SIDES THEN TACK-WELD FIRST.

SPIDER BOWL AND SLIPS (OR CLAMPS) SET LEVEL IN DRILLTABLE.

NOTE:
1. THE USE OF A SPIRIT LEVEL FOR CHECKING ALIGNMENT IS INACCURATE AND IS NOT RECOMMENDED.

2. ALL CASING SHOULD HAVE SQUARED AND BEVELLED ENDS.

3. FLAME CUT ENDS NEED TO BE MACHINED BEFORE RE USE.

35° CHAMFER

2mm FLAT

EXISTING WELL CASING - END DETAILS.

FIGURE 4.5   BIT WEAR RATE

plenty of experience; four members of the JPT drilling crew have
attended a course in theory and practice of welding.

4.3.4   Weight on the Bit and Rotation Speed

Two of the important functions of a drilling operation which are performed
entirely at the discretion of the driller are control over the weight on
the bit and the speed of rotation. In general, it can be said that clays
and similar lithologies are best drilled at the higher speeds and harder
rocks at the slower end of the range. However, the combinations of speed
and weight are in practice infinitely variable and some harder rocks
for example, react favourably to faster speeds. Fast rotation, however,
may be detrimental to bit life and it is known that if the rotation speed
is high and insufficient weight is being applied to a rockroller bit,
then the bearings will wear out first, leaving the teeth intact. The aim
should therefore be to rotate the drill string with weight on the bit
so that an optimum drilling rate is achieved. A rockroller bit having
both worn out teeth and bearings is usually proof of good drilling
practices. (Figure 4.5).

4.4   Measurement

4.4.1   General

Accurate measurement of drill string, bore casing assembly and drilling
and reaming depths is imperative whilst inaccurate measurements lead
to erroneous sampling and variety at situations which may be difficult
to remedy later. The following are dependant on measurement accuracy:

- Setting of conductor/surface casing
-    "   " temporary casing
-    "   " bore casing and screen assembly
-    "   " packers
- Success of recovery (fishing) operations
- Placement of cement

To enable proper records to be kept, the drilling supervisor should
keep a site day book in which an account should made of all down-hole
tools including drawings and dimensions of each component. In addition,
quantities of drillpipe, casing (temporary and permanent) number of
and type of subs, air pipe and all other tubular goods, should be noted:
Appendix X.

FIGURE 4.5 BIT WEAR RATE
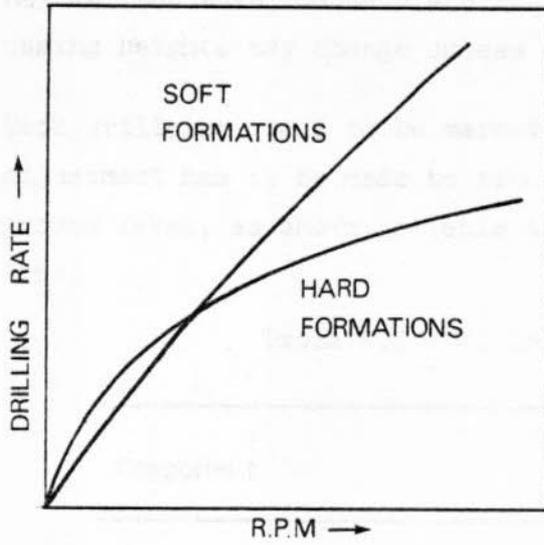
THE EFFECTS OF ROTARY
RPM ON DRILLING RATE.
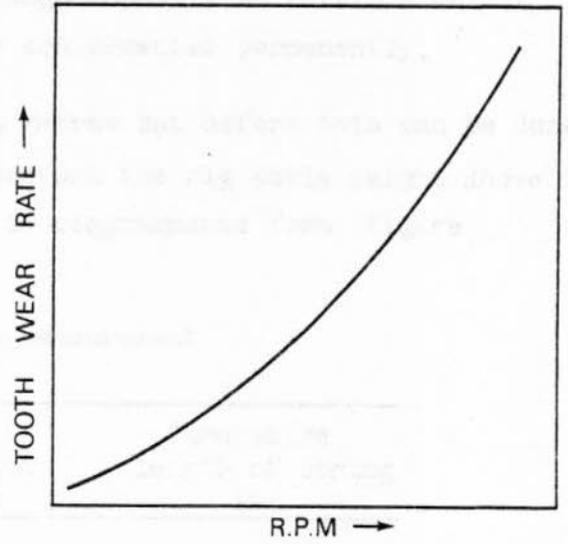
TOOTH WEAR INCREASES
AS RPM IS INCREASE
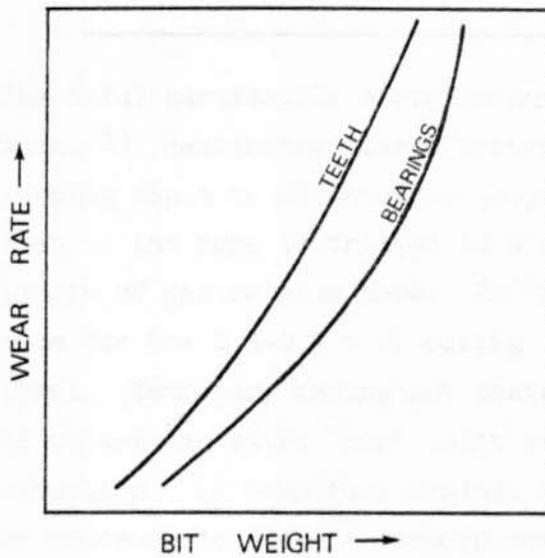
BIT TEETH AND BEARINGS
WEAR OUT FASTER WITH
INCREASED DRILLING
WEIGHT.

4.4.2 System of Measurement

Drillstring and Casing

The top of the rig table should be used as a datum; original ground level may be lost when channels are cut or through deposits of cuttings whilst casing heights may change unless casings are cemented permanently.

Each drillpipe needs to be marked off in metres but before this can be done, adjustment has to be made to take into account the rig table height above ground level, as shown in Table 4.2 and in diagrammatic form (Figure 4.6).

Table 4.2   Drillpipe Measurement

Component	Length (m)	Cumulative length of string (m)
Bit	0.19	0.19
Sub	0.32	0.51
Kelly-first drillpipe	6.00	6.51
Subtract height of drill table from original ground level	-1.13	5.38

Therefore, top of first drillpipe is 5.38 m above datum.

The total permissible error on any depth measurement should not be more than ±1 centimetre; large errors cause numerous problems. Bore or reaming depth to accommodate temporary casing has to be predetermined, that is the bore is drilled to a depth which is suitable for the total length of casing plus shoe. In the calculations, allowance has to be made for the 0.3-0.5 m of casing which normally remains above ground level. Temporary casing not seated firmly at the base of the bore is of no use; an extra 'pup' joint would be required to remedy this situation. If temporary casing, when landed on the bore base is found to be stuck-up too far, it should not be cut. Either some of the casings will have to be pulled out and others of a different length substituted (to give the desired stick-up) or the bore deepened.

FIGURE 4.6   DRILLPIPE   MEASUREMENT

TOP OF DRILLPIPE
5.38m.

5.0m MARK

4.0m MARK

3.0m MARK

2.0m MARK

1.0m MARK

ZERO

TABLE

DRILLPIPE 6m

DRILL-STRING LENGTH 6.51m

TABLE HEIGHT 1.13m

SUB   0.32m

BIT   0.19m
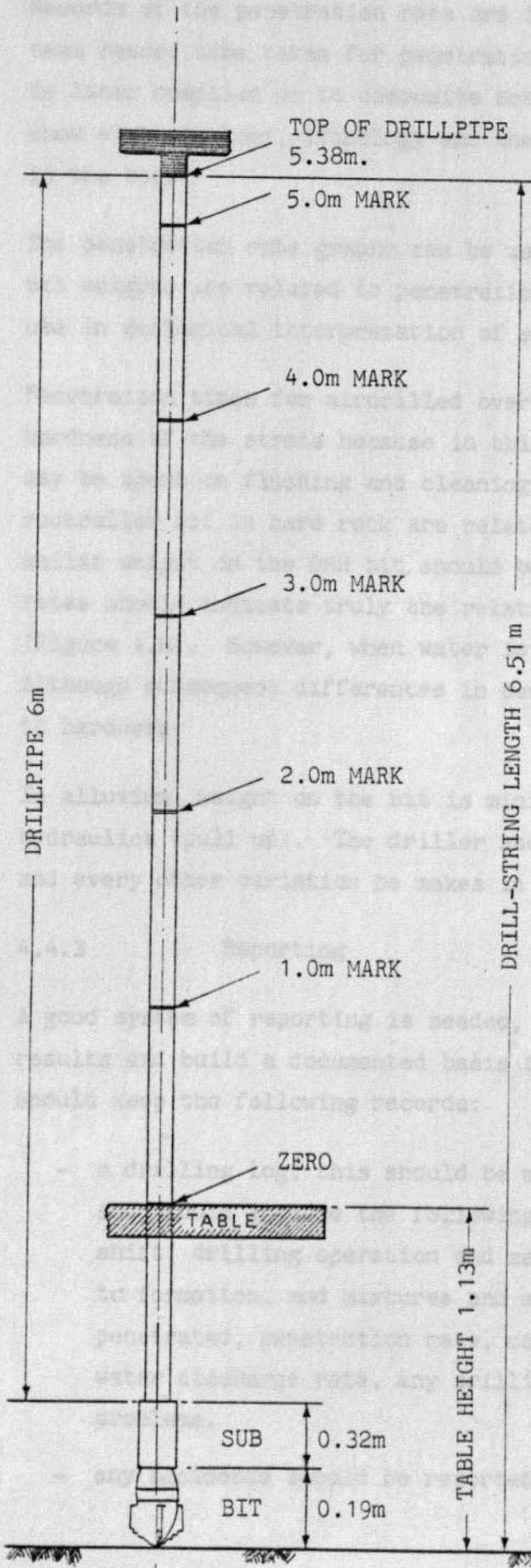
EXPLANATION:

1. DRILLTABLE IS THE DATUM FOR MEASURING DRILLPIPE.

2. TOTAL-UP LENGTH OF FIRST DRILLPIPE (KELLY), SUBS AND BIT AND SUBSTRACT TABLE HEIGHT (ABOVE ORIGINAL GROUND SURFACE).

3. TOP OF THIS PIPE IS 5.38m, SO 6m MEASUREMENT ON THE NEXT PIPE SHOULD BE MARKED ON 62cm FROM THE BOTTOM OF THAT PIPE.

ORIGINAL GROUND LEVEL ON SETTING UP RIG.

Penetration Records

Records of the penetration rate are invaluable. The JPT drilling team record time taken for penetration of each metre and this information is later compiled on to composite borehole logs (Appendix XI) which show electric logs, lithology and the points where water was encountered in the bore.

The penetration rate graphs can be used to show dramatically how required bit weights are related to penetration (Figure 4.7) and are of considerable use in geological interpretation of strata cut.

Penetration times for airdrilled overburden may not be related to the hardness of the strata because in this phase of drilling, extended time may be spent on flushing and cleaning problems.Penetration rates using a rockroller bit in hard rock are related to variable weight on the bit whilst weight on the DHH bit should be low and constant and DHH penetration rates should indicate truly the relative degree of rock hardness (Figure 4.8). However, when water is struck, the DHH will slow drastically although subsequent differences in penetration rates should still be related to hardness.

In alluvium, weight on the bit is minimised by holding back with the rig hydraulics (pull up). The driller should record this type of information and every other variation he makes in weight on the drilling bit.

4.4.3   Reporting

A good system of reporting is needed, to allow technical analysis of results and build a documented basis for future operations. The driller should keep the following records:

- a drilling log; this should be made daily by the driller
  and should include the following details: time on and off
  shift, drilling operation and method, tools used, mud loss
  to formation, mud mixtures and additives, depths, formation
  penetrated, penetration rate, casing installed, water levels,
  water discharge rate, any drilling problems and any machine
  problems.

- any accidents should be reported.

Figure 4.7 PENETRATION GRAPH OF BORE PT 1 PADANG TERAP.

EXPLANATION

ALL THE DRILLING ON THIS BORE WAS CARRIED OUT USING A DRILL COLLAR AND A 7 3/8" ROCK ROLLER BIT.

THE SECTION 0-11M WAS EVENTUALLY REAMED-OUT BY 12¼" DRAG BIT AND 10" CASING INSERTED.

PENETRATION OF THE STRATA FROM 0-18M WAS AIDED BY DRILL STRING WEIGHT ONLY.

THE SECTION OF STRATA 18-24M NEEDED RIG PULL DOWN WHICH RANGED FROM 2-4 TONNES.

SECTION 24-60M NEEDED 5 TONNES PULL DOWN TO ACHIEVE REASONABLE PROGRESS. (TOTAL WEIGHT ON BIT WITH PIPES, COLLAR AND DRILL HEAD - 7 TONNES).

NOTE: A PULL DOWN OF 5 TONNES APPEARS TO BE MAXIMUM - OTHERWISE RIG LIFTS AND TILTS OFF JACK FOUNDATIONS.

PENETRATION RATE MINUTES/METRE

DEPTH IN METRES
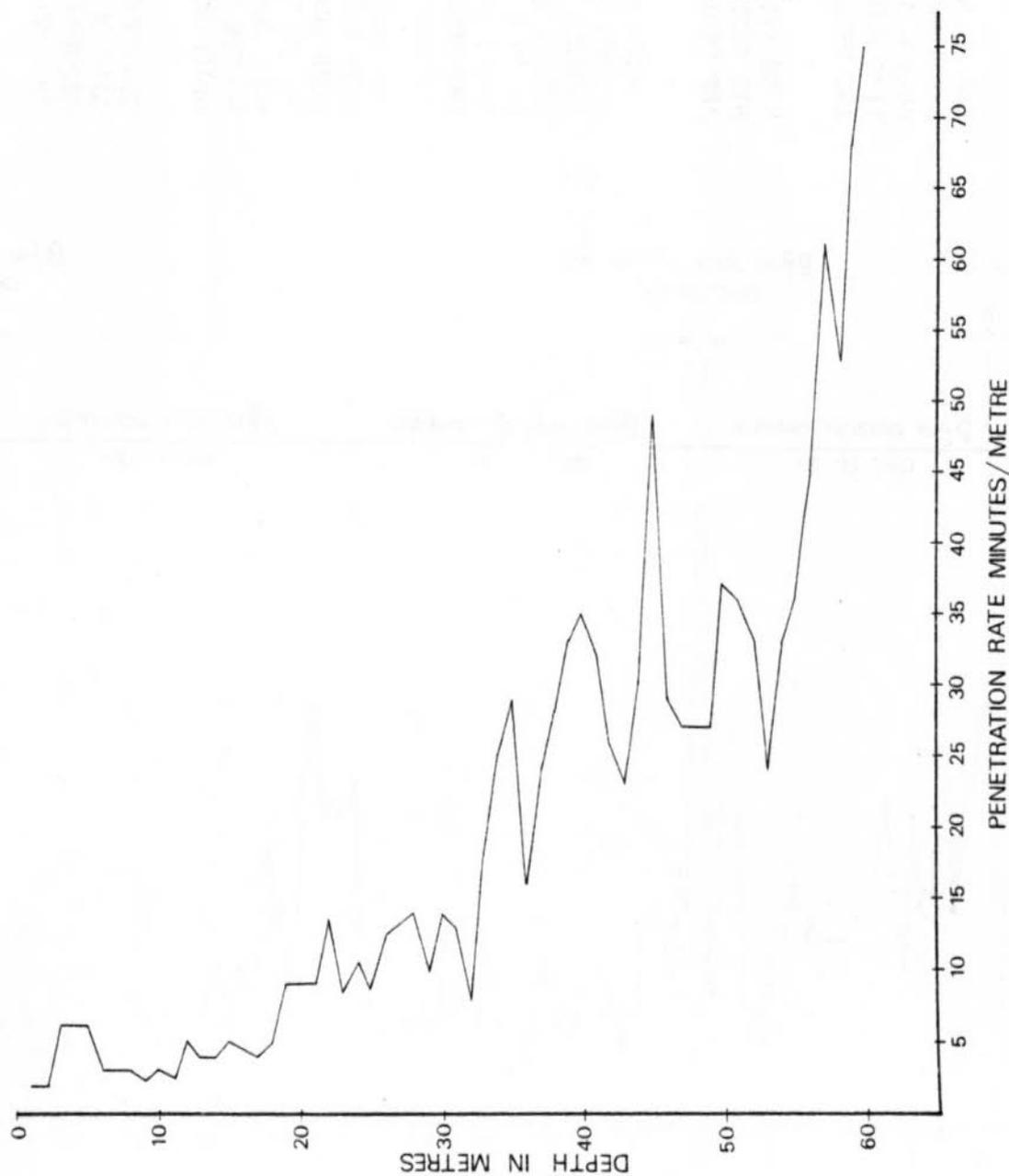
Figure 4.8   PENETRATION GRAPH OF BORE PT 2 PADANG TERAP.

EXPLANATION

SECTION 0-5M WAS DRILLED BY A DRAG BIT THROUGH SOFT OVERBURDEN WHICH GRADUALLY GOT TOO HARD FOR THAT TYPE OF BIT. THIS SECTION WAS THEN CASED OFF WITH 10" CASING.

DRILLING CONTINUED WITH 7 3/8" HARD FORMATION ROCK ROLLER BIT USING DRILL COLLAR AND UP TO FIVE TONNE PULL DOWN (PLUS WEIGHT OF TOOLS). AS THE STRATA GETS HARDER PENETRATION RATES SLOW DOWN (OVER 5-60M). THIS SECTION WAS DRILLED OVER A PERIOD OF 16.5 HOURS. THE HOLE WAS THEN CASED TO 60M WITH 6" CASING.

THE SECTION 60 TO 107M WAS DRILLED USING A MISSION A4315 D.H. HAMMER WITH 5¼" BUTTON BIT OVER A PERIOD OF 10.0 HOURS. WEIGHT ON BIT WAS CONSTANT 0.5 TONNE. TOWARDS THE BOTTOM OF THIS SECTION LEAKING CASING TOE ALLOWS WATER AND CAVING INTO THE HOLE FROM ABOVE 60M. CASING WAS THEN CEMENTED AFTER PLUGGING HOLE AT 62M.

THE SECTION 107-110M WAS DRILLED BY A 5¼" ROCK ROLLER BIT OVER A PERIOD OF 2.0 HOURS. WITH FIVE TONNE PULL DOWN (PLUS DRILLPIPE WEIGHT) PENETRATION WAS POOR.

THE SECTION 110 TO 150M WAS DRILLED OVER A PERIOD OF 11.0 HOURS WITH A MISSION A4315 D.H. HAMMER WITH 5¼" BUTTON BIT. BECAUSE OF STICKY CONDITIONS, BACK PRESSURE IN THE ANNULUS SLOWED PENETRATION TOWARDS THE BOTTOM.

DRILLED BY 8¼" IN DRAG BIT

DRILLED BY 7⅞" IN ROCK ROLLER BIT

DRILLED BY 5¼" IN MISSION HAMMER

DRILLED BY 5¼" IN ROCK ROLLER BIT

DRILLED BY 5¼" IN MISSION HAMMER

DEPTH IN METRES

PENETRATION RATE MINUTES / METRE
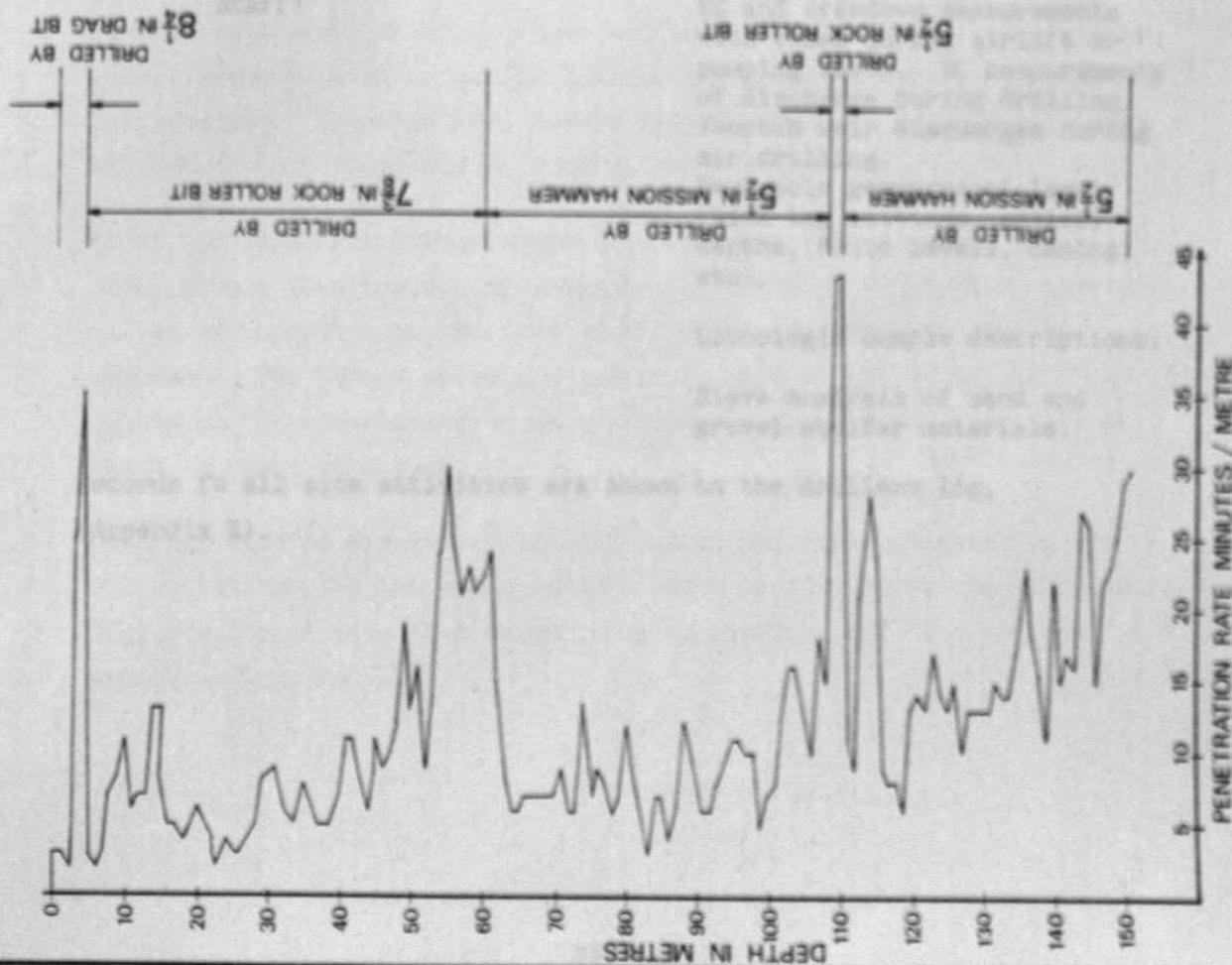
- machine problems must be reported so that repair and
  maintenance may be carried out as required.

If the shift system is operated, the driller leaving the site should
inform the oncoming driller of the situation. Any problems should be
recorded in a log book and the oncoming driller should sign this to
acknowledge that he is aware of them.

The primary responsibilities in record keeping between technical
hydrogeological and drilling staff are shown below (Table 4.3).
Inevitably, there is overlap and mutual assistance. Generally, records
(or at least a copy) should be available on site until the bore is
complete.

Table 4.3   Site Records

Staff designation	Records to be kept
Chief driller, driller	Driller log, penetration rate, bit record, casing record, water cut, mud loss, mud viscosity, weight.
Technician, hydrogeological staff (assisted by drilling staff)	EC measurements with depth, time during drill stem tests. EC and drawdown measurements with times during airlift or pumping tests. EC measurements of discharge during drilling. V-notch weir discharges during air drilling. Down-hole geophysical logs (with log settings, scales, depths, fluid levels, casing, etc).
	Lithologic sample descriptions.
	Sieve analysis of sand and gravel aquifer materials.

Records fo all site activities are shown on the drillers log,
(Appendix X).

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4.5   Sampling

4.5.1   General

The importance of sampling even in apparently homogeneous formations
cannot be overlooked. Good samples recovered at regular intervals,
considered in conjunction with a well prepared driller's log which
shows penetration rates as well as observations such as changes in
the colour of the mud or air returns, loss of circulation and drilling
difficulties, give an invaluable guide to the hydrogeologist when he
designs the production bore.

The size of cuttings depends on the type and the state of wear of the
bit. A worn bit with flat teeth makes smaller cuttings and has a tendency
to grind cuttings into powder. A bit designed for harder formations, if
used in soft clays, will tend to ball up or at best cut slowly.

Proper cleaning of the bit by adequate jet action of the circulatory
medium on the bottom of the hole removes cuttings as soon as they are
cut and does not allow them to hang around to be ground up and crushed.

4.5.2   Airflush Samples

Samples recovered during airflush drilling should arrive at the surface
within seconds of being cut if optimum uphole velocities in the annulus
are obtained. Occasionally, due to hole enlargement and partial loss
of circulation, there may be a slight time delay.

Drill cuttings from hammer operations manifest themselves in the
form of dust or a mixture of water and grit/chips. In softer materials,
pieces of formation in the form of chippings are rare but dust is
abundant. The harder materials generally show as chips ranging from
2-3 mm to those measuring 10 mm by 15 mm and about 5 mm thick, all of
which is mixed with dust.

Chipping size is also controlled by weight and rotation speed of the
bit as well as the bit design and diameter besides rock type and hardness.
Bigger sizes of bits have larger tungsten inserts and they obviously
produce bigger cuttings.

These samples are easy to obtain. Several buckets or trays are placed around the conductor casing and under the deflector plate of the drill table. Samples should be recovered from these each metre and the recepticals emptied. The samples should be placed in the sample box unwashed.

Samples obtained from the overburden section by air flush may not be of much use and it is expected some may be lost.

4.5.3   Alluvial Samples

A geologist clearly prefers an uncontaminated and representative sample of alluvial strata and although these can be obtained by undisturbed sampling techniques and by the use of cable-tool drills, most drilling work in alluvium is by the rotary mud flush technique.

It may be difficult to interpret cuttings recovered from mudflush holes mainly because these are often mixed up and out of sequence. In deep boreholes, a considerable time lag occurs between the cutting of a sample and its arrival at surface and this must be allowed for when assigning a true depth to a cuttings sample.

Some strata are ground up so finely that the cuttings mix with the mud and become part of it. A large cutting may take longer to reach the surface than does its immediate neighbour. Often cuttings do not reach the surface and will remain down-the-hole suspended in the mud or stuck to the sides of the bore. It is not uncommon in deeper holes in clayey strata for cuttings to disintegrate on the way up to the surface, due perhaps to be combined action of the drillpipe abrading the hole wall and the effects of water on the clay. Thickening of the mud is a sign that clay cuttings are contributing to viscosity. The use of polymer fluids instead of bentonite mud is one way to stop these clays breaking down.

Apart from sample mixing, disintegration and delay, the mud flush technique gives less than perfect samples because of the difficulty of separating and settling the cuttings from the viscous drilling fluid The average exploration bore is drilled under the following typical

conditions:

- a bore of 7 5/8" dia. is constructed by using 4 3/4" drillpipes
  and mud with viscosity range 36-40 secs (Marsh Funnel). Mud
  pump output is 850 l/min. Penetration rate through sandy section
  is four minutes per metre.

It can be deduced that:

Volume of 1 metre x 7 5/8" hole $\qquad$ = 0.028 m^3
and

Volume of mud circulated during the
drilling of the 1 metre section of
bore is :

4 min x 850 l/min $\qquad$ = 3.4 m^3

Volume of average sample retained $\qquad$ = 0.001 m^3 or 1 litre

From the above facts, it may be deduced that the ratio of retained sample
volume to the volume of mud circulated is about 1:120.

For a specific interval penetrated by the bit, the inherent difficulties
of abstracting all the drilled material from the mud are considerable;
recovery of all the cuttings could only be achieved by collecting all
the mud discharged over the period of drilling and decanting cuttings
from it. In the sample shown, a suitable tank would need to hold both
3,500 litres of drilling mud and an equal volume of water for dilution
purposes; clearly this is not practical and a compromise has to be made.

Suggested sampling methods are:

- collect samples 'little and often', for each metre drilled
- hold a very fine sieve (200 mesh) under the mud return flow
  pipe for a few seconds at a time and constantly empty contents
  into a bucket
- use several buckets to catch the sample and mud together and
  allow settlement; dilute if mud is very viscous
- trap cuttings in a long baffled trough set into the mud
  channel system

If borehole conditions for the removal of cuttings are adequate
(i.e. mud condition and UHV), then the geologist should be able
to correct for sample mixing and delay. The driller should certainly
inform the geologist of any bore condition that could give erroneous
samples. It may be assumed that pilot bores drilled at 7 5/8" dia.
with the Tone rig will normally not suffer from UHV problems.

A sample box should have compartments about 12 cm square.
Samples are laid in the box unwashed according to some fixed sequence.
A 'book fashion' sequence is suggested; left to right from the top and
so on to the next line down. When a sample is not recovered for some
reason, the appropriate compartment should be left empty.

4.5.4   Undisturbed Sampling

The technique of taking so-called undisturbed samples or cores is
used mainly in soil investigation programmes for foundation
calculations. The method uses a thin wall tube which is driven
or pushed hydraulically into the ground at specific intervals.
A soil investigation unit would normally drive protective temporary
casing down to the sampling point and clean out the casing until
virgin strata was exposed. The tube is then driven its full length
into the strata (usually 0.5 to 1.0 m penetration).

The undisturbed sampling tube is rated in inches of diameter
(i.e. U2, U3, U4) and is really designed for clayey soils or very
cohesive sands. Such simple tubes do not incorporate any method
of retaining the sample in the tube, but rather rely on packing of
the formation to the tube or expansion at the core as occurs
with some clays.

The JPT sampler (U3) incorporates a piston within the tube which is
positioned at the bottom of the tube and moves up on top of the core
as the tube is pressed into the ground until, when fianl depth
is reached, the 'piston rod' locks in the tube head. Any tendency
for the core to slip out on withdrawal creates a vacuum within the
tube thus creating favourable conditions for core retention.

In the consultants experience, the sampling tubes mentioned above are
incapable of retention of the non-cohesive, unconsolidated sands and
gravels which form good aquifers; rather such sands and gravels can only
be sampled by the bailer method. The fact that the sampling conducted
in possible aquifer zones at Bukit Gantang and Cankat Jong with sampling
tubes was mainly successful in core recovery indicates (even before core
extrusion and examination) that the material sampled can be of little
potential as an aquifer. Good core recovery indicates a cohesive clay
rich material.

It is recommended, however, that when such tube sampling is attempted,
the bore is properly cleaned of cuttings and cavings. After it has
been circulated clean, the bore must be kept full of mud whilst the
drill pipes are removed. It is not envisaged that casing the bore to
each sampling interval would be practical. In fact sampling under mud
has been proved to be feasible in an uncased bore.

4.6   Testing

4.6.1   Bore Preparation for Logging

Electric logging of the bore produces, amongst other things, an accurate
and final check of the strata and from the log, the final decision
regarding the position of screen will be made.

For logging purposes the configuration of the hole should be known,
including the size and depth of any casing; the weight and viscosity
of the fluid in the hole is also often asked for. Logging is preferably
carried out immediately after the hole is drilled; either the equipment
should be on hand before the pipes are pulled out or if there is going
to be a short delay, the drillers can rotate near the bottom of the bore
with the pump running slowly until the logger arrives. Whenever the
drill string is removed from the bore (except for air drilled holes),
the gun line from the mud pump should be directed into the conductor
casing and mud should be pumped into the hole at a rate equivalent to
the volume of the drillpipe being withdrawn. If this is carried out, the
hole should not cave.

FIGURE 4.9   DRILLSTEM TEST APPARATUS AND METHODS

Occasionally, tight sections of the hole cause sticking of the drill-
collars coming up. If this happens, the swivel head should be re-
connected and the drill string reamed out of the tight spot with the
pump on. If this is not done, a piston effect will be created down
the hole which may cause collapse of the strata lower down. This,
and bridging, should be checked by the drillers before logging begins.

If hole conditions are poor, some logs (gamma) can be taken from within
the drillpipe in which case the bit should be at least three metres
off the bottom.

4.6.2   Drillstem Tests

Water sampling techniques must ensure that the actual sample recovered
is formation water, not drilling water. This is usually done by withdrawing
the sample continuously and monitoring its Electrical Conductivity (EC)
until it is both stable and different from that of drilling fluid filtrate.

Sampling methods generally termed drillstem tests, can be destructive
or non-destructive in relation to the hole. Non-destructive sampling is
usually done as drilling proceeds downwards and destructive after
completion to full depth. Sample extraction is usually by airlifting
in drillpipe via short screen. Techniques are:-

- drive point non-destructive, used in soft formations;
  drive screen on drill pipe through hole bottom and airlift;

- ratholing: non-destructive, used in harder formations; drill
  smaller hole in borehole base and place screen and packer
  on drill pipe; air lift;

- collapsing: destructive, used soft formations; drill to
  total depth, place screen on drill pipe opposite formations
  to be sampled and airlift until hole collapses around screen;
  sample and pull out.

Drillstem testing methods are shown (Figure 4.9) and an account of JPT
testing at Alma (near Bukit Mertajam) is given below.

At Alma bore A 1, 29 m of alluvium was cut; the alluvium contained
a reasonable thickness of sand. Six inch temporary casing was inserted
into rockhead and the bore was continued a further 30 m in granite.

FIGURE 4.9   DRILLSTEM TEST APPARATUS AND METHODS

Left diagram labels:

Compressed air →
→ Water discharged

- 7 3/8" dia borehole
- 4 3/4" dia drillpipes
- 1/2" dia airpipe
- Mud in Annulus

CLAY

AQUIFER / FINE SAND

- 6 5/8" O.D. Slotted pipe
- Pipe plug
- Mud in Sump

Right diagram labels:

Compressed air →
→ Water discharged

LIMESTONE

- 7 7/8" dia borehole
- 4 3/4" dia drillpipes
- 1/2" dia airpipe
- Mud in Annulus

SHALE

- Tapered plug (Rubber covered) Seated in borehole reduction

AQUIFER / SANDSTONE

- 4 1/2" O.D. Slotted pipe
- 5 7/8" dia pilot hole

Water sampling method suitable for alluvium.
Unconsolidated material collapses around slotted
casing.

Water sampling method suitable for consolidated strata.
Method depends on tapered plug being forced into
bore reduction to obtain tight seal.

Although the hard rock section of the bore did not yield water during drilling, the bore did fill up over a weekend. The water was later discharged and sampled; electrical conductivity (EC) was 20,000 micromhos. A procedure termed drill stem testing was then carried out in the bore. This can be used where aquifer salinity is suspected and where some confirmatory test can perhaps avoid the need to construct and pump a screened bore. A 5.5 m length of slotted 6 5/8" o.d. casing, complete with bottom plug, was positioned opposite the aquifer sand. The slotted pipe is usually lowered down on drillpipe, but in this case, temporary casing was used instead. Any water entering the screen, after the drilling mud is removed, is then airlifted out for sampling. Initially, EC was about 3,500 micromho; it then stabilized at about 2,000 micromho. The bore was then abandoned because of the rather brackish water present. A second bore (A 2) was drilled but this penetrated less deeply into the granite. Drill stem testing was used to sample two separate aquifers; both showed high salinities and the bore was abandoned.

With care, the drill stem test can be performed at any depth but different methods of sealing the upper hole from the test zone may have to be adopted to avoid 'mixing' of water from different aquifers. The method adopted, whereby a 6 5/8" O.D. slotted pipe is run into a 7 3/8" O.D. hole, depends on the collapse of the aquifer sand against the pipe. A different approach may be needed on more consolidated aquifers (Figure 4.9).

4.6.3   Verticality Testing
                Introduction

The checking of the verticality of pump casing is part of the construction phase of borehole drilling. The reason for a straight and vertical borehole is that lineshaft turbine pumps operate better under these conditions. Although the pumps will tolerate non-vertical conditions, straightness is of prime importance. British standards for verticality allows a maximum deviation of 8 cm in 30 m. All production boreholes, especially those equipped with plastic casing, should be checked.

Programme

Before a casing-screen assembly is lowered, it should be ascertained
that at least the top part of the hole (the pump casing zone) is
reasonably straight. Verticality tests in 'open hole' conditions
are not usually carried out, especially where there are alluvial type
materials present. This is because hole diameter is variable (caused
by erosion, and wall cake, or dangerous hole conditions).

A method of assessing the hole verticality before the bit is pulled from
hole is now described. It is assumed the rig is correctly set up and
is straight and vertical and has not moved since drilling began. The
following operations are carried out:

- remove the kelly bushes or the drillpipe guide and lift the
  bit off the bottom
- if the drillpipes in the hole lie to one side, then the
  lower section of hole is probably off vertical
- pull the bit up to where the bottom of the pump casing
  will eventually be. Ensure the bit is opposite harder
  consolidated material, if possible, and observe the deviation
  of the drillpipe at the drill table. Rough estimates can be
  made of verticality from this by considering the verticality
  test shown below.

If the upper section of the bore appears to be fairly straight, then casing
can now be run in and a preliminary check of verticality carried out.
The toe of the casing is cemented and the main test performed as described
below.

Verticality tests should be witnessed by an engineer or hydrogeologist
(a test conducted by a contractor without supervision should not be accepted)
If the bore verticality is satisfactory, any necessary gravel or formation
support may be placed around the upper bore casing. Gravel must, of
course, be placed from all directions and the casing must not be moved
afterwards. After gravel has been placed, the final verticality
test should be done. The figures obtained should be recorded and a
copy should be retained on site. A specimen form is shown in
Appendix XII.

Method

The 'bobbin and string' method is used for checking verticality.
The system entails lowering a properly centred bobbin (two close
fitting discs separated by a smaller body about 60 m long) down the
bore in increments equal to the suspension height (from the suspension
pulley to the top of the casing). The distance the string (in fact
a 3 mm dia. wire) moves off centre is measured and calculations for
the deviation at depth are made. The system is shown in Figure 4.10
and the procedure described below.

The equipment required is as follows:

- bobbin for 25.5 cm ID casing would be 245 cm OD by
  60 cm long

- slim pliable wire rope (3 mm dia.) about 60 m long.

- small hand operated winch (drum approximately 30 cm long
  by 10 cm diameter)

- suspension pulley, which could be already on the rig at
  the crown blocks or specially made and supported by a
  bracket fixed at a convenient place. The pulley must be
  fixed securely and not move laterally.

The method requires the pulley to be fixed at a height equal to whatever
the test intervals are to be (to keep the arithmetic simple). For
example, casing may be in 6.0 m lengths and tests required at each
3.0 m level to the bottom of the pump chamber. Therefore the pulley
will be suspended at exactly 3.0 m above the casing top. For the Tone
rig a simple fitting is screwed on to the power swivel sub. (see Figure
4.11). The procedure is:

- the north point is permanently marked on the casing (by
  paint and saw cut)

- the bobbin is centred precisely in the centre of the casing
  (without touching anywhere) by levelling the rig

- when centred (the string in the middle) the bobbin is
  lowered down the bore - three metres exactly

- the string is then checked to see if it has moved off centre.
  If so, the deviation is measured, in millimetres, in two

FIGURE 4.10 — VERTICALITY MEASUREMENT BY BOBBIN AND STRING METHOD.
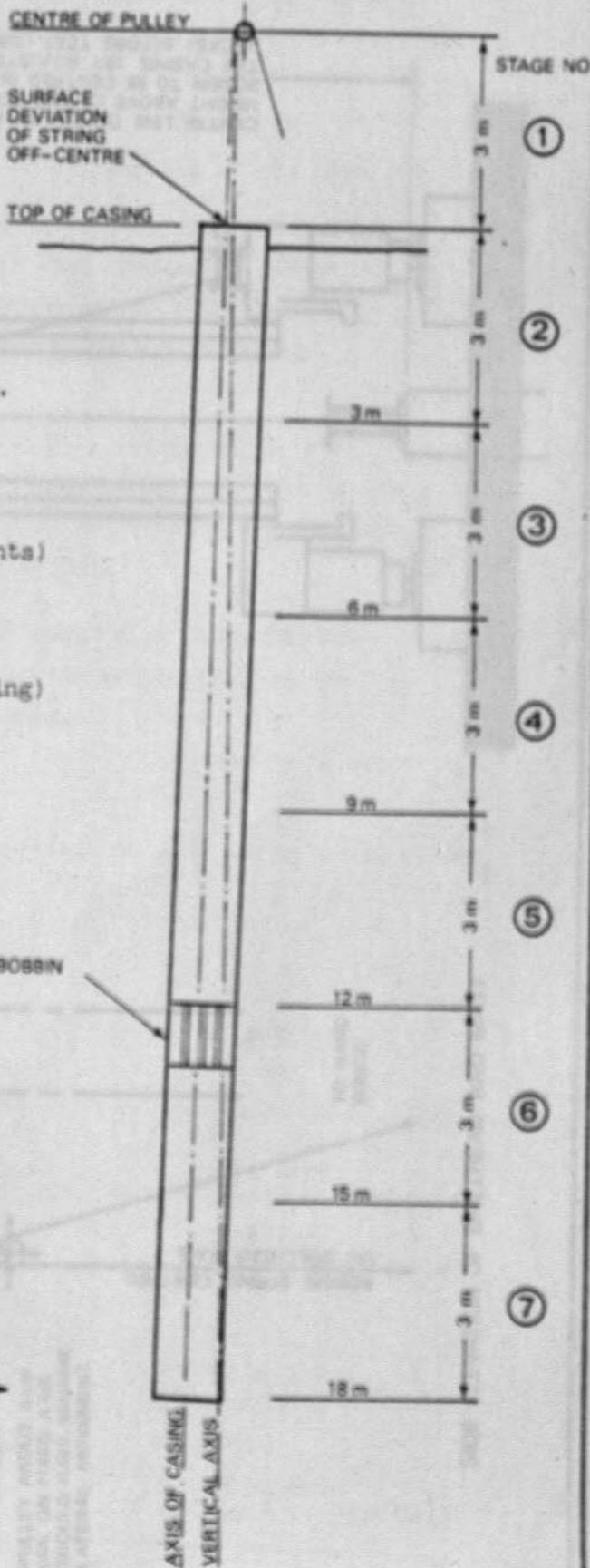
Example:

Pulley suspension height is 3 m.
Bobbin is at depth 12 m.
String at the surface deviates
by one cm. (one way)

Deviation at 12 m

= 1 cm x 5 (No. of 3 m increments)
= 5 cm + disc factor

Note:

The disc factor is half the
difference between hole (or casing)
ID and Bobbin OD.

CENTRE LINE OF PULLEY AT FIXED
HEIGHT ABOVE CASING TOP (SAY 3m)
BOBBIN TO BE CENTRED IN TOP OF
THE CASING (BY ADJUSTING RIG
JACKS) BEFORE TEST COMMENCES.

DRILLHEAD

MAST

TO HAND WINCH

CENTRE OF DRILLHEAD

BOBBIN STRING CENTRED ON DRILLHEAD AXIS

SPECIAL SUB EQUIPPED WITH PULLEY, SCREWED TO POWERSWIVEL ADAPTOR SUB.

PULLEY ABOUT 6cm DIA. ON FIXED AXIS SHOULD HAVE MINIMAL LATERAL MOVEMENT.

SIDE ELEVATION OF DRILLHEAD AND MAST
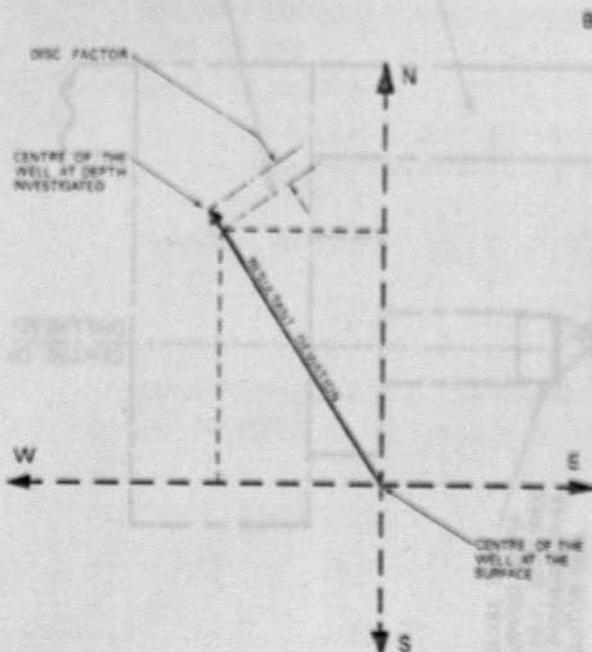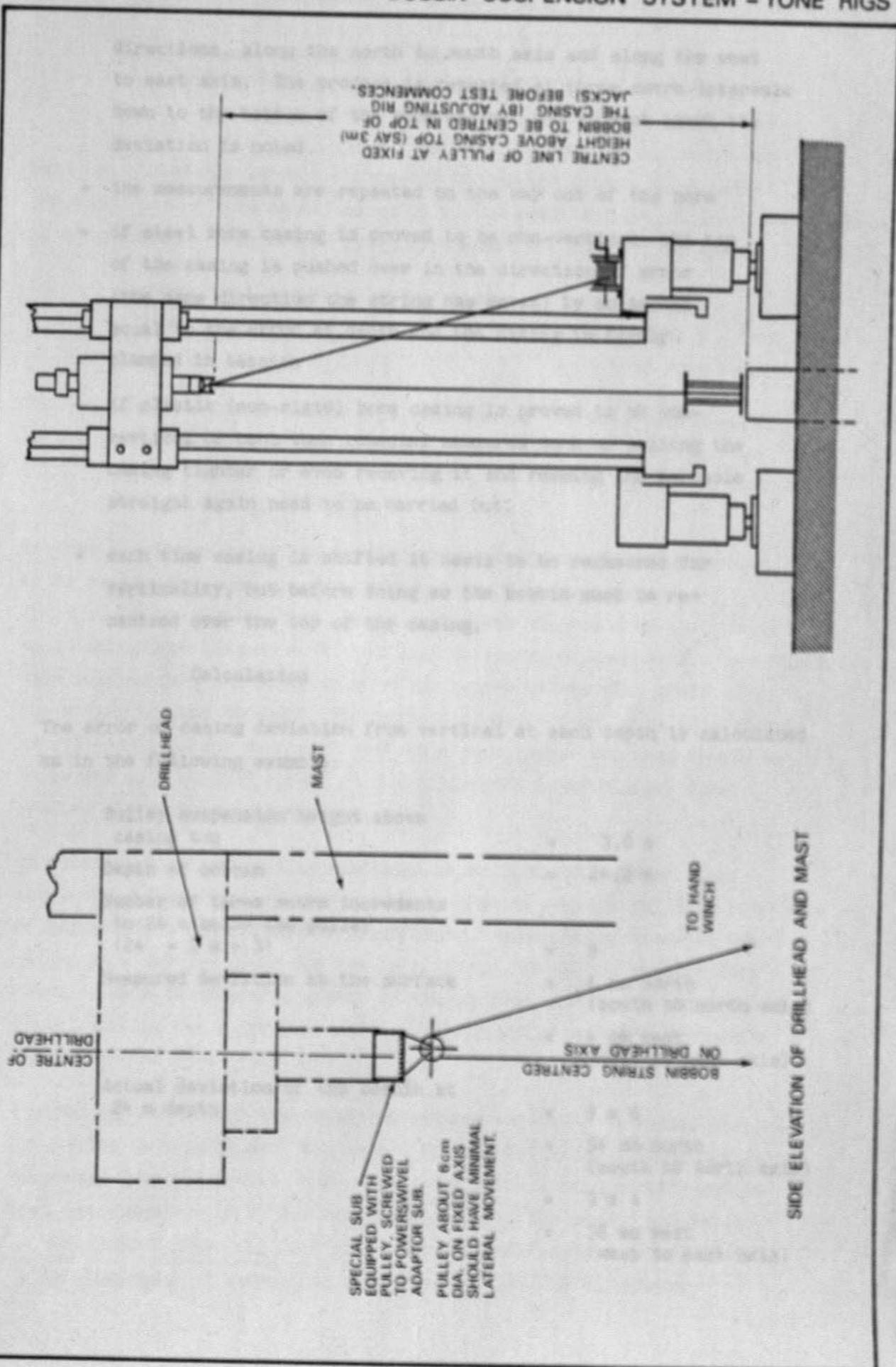
directions, along the north to south axis and along the west
to east axis. The process is repeated at three metre intervals
down to the bottom of the pump casing, and at each level the
deviation is noted.

- the measurements are repeated on the way out of the bore

- if steel bore casing is proved to be non-vertical, the top
  of the casing is pushed over in the direction of error
  (the same direction the string has moved) by an amount
  equal to the error at depth and the casing is firmly
  clamped in tesnion

- if plastic (non-rigid) bore casing is proved to be non-
  vertical or bent then remedial measures such as pulling the
  casing tighter or even removing it and reaming the borehole
  straight again need to be carried out.

- each time casing is shifted it needs to be rechecked for
  verticality, but before doing so the bobbin must be re-
  centred over the top of the casing.

Calculation

The error or casing deviation from vertical at each depth is calculated
as in the following example:

Pulley suspension height above casing top	= 3.0 m
Depth of bobbin	= 24.0 m
Number of three metre increments to 24 m below the pulley (24 ÷ 3 m ÷ 3)	= 9
Measured deviation at the surface	= 6 mm north (south to north axis)
	= 4 mm west (west to east axis)
Actual deviation of the bobbin at 24 m depth	= 9 x 6
	= 54 mm north (south to north axis)
	= 9 x 4
	= 36 mm west (west to east axis)

Resultant deviation of the
bobbin at 24 m depth (Deviation^2) $= 54^2 + 36^2$

$= 64.90$ mm

$= 6.5$ cm (north west)

Half the difference between the casing ID and the bobbin OD is called
the disc factor; this should be added to the resultant deviation of the bobbin
to compensate for the bobbin lying up against one side of the casing.

Resultant deviation of the casing
at 24 m depth

$= 6.5 + (25.5 - 24.5 \quad 2)$

$= 7.0$ cm (north west)

The resultant deviation of the bobbin and hence the resultant deviation
of the casing can be plotted (Figure 4.10).

Aids to Measurement

So that the deviation of the bobbin string can be measured accurately,
it is recommended that a transparent plastic disc be made up.
The disc (about 3-6 mm thick) would be located centrally on the casing
by locating pegs (Figure 4.12). A slot in the disc about half a centimetre
wide leading from the outer edge to the centre of the disc would allow
the string to pass through. The whole disc would need to be able to move
around freely in the casing to meet this condition. The disc should be
inscribed with circles spaced at one millimetre intervals and with
heavier lines at each centimetre.

Verticality tests showing non-straight upper bore casing conditions
should have supplementary checks made by drawing out the relative positions
of column pipes and casings on graph paper. Where there is doubt that
column pipe may not clear the casing properly, it is recommended that a
trial be made of inserting a pump of the correct size in the hole before
gravel packing the upper bore casing and certainly before constructing
the production bore head works.

Another aid is a plumb line that can be used initially to ensure that
the pulley is exactly over the centre of the casing top. It should be
suspended from the pulley, the position of which should be adjusted so
that the plumb bob is in the central position. The bobbin and cable
is then substituted. In this way initial centralisation errors due
to an unbalanced or assymetric bobbin can be largely eliminated.

FIGURE 4.12   CASING TOP – MEASURING DISC – VERTICALITY TEST.

INSCRIBE
DISC AT
5° INTERVALS

AFFIX PLASTIC SCALE.
ZERO PRECISELY LINED
UP WITH DISC CENTRE.

THREE EQUALLY SPACED
LOCATING PEGS TO SUIT
CASING.

SLOT   0.5cm WIDE

DIAMETER : 4 cm GREATER THAN CASING I.D.
THICKNESS : 5 – 10 mm.
MATERIAL : CLEAR PLASTIC.
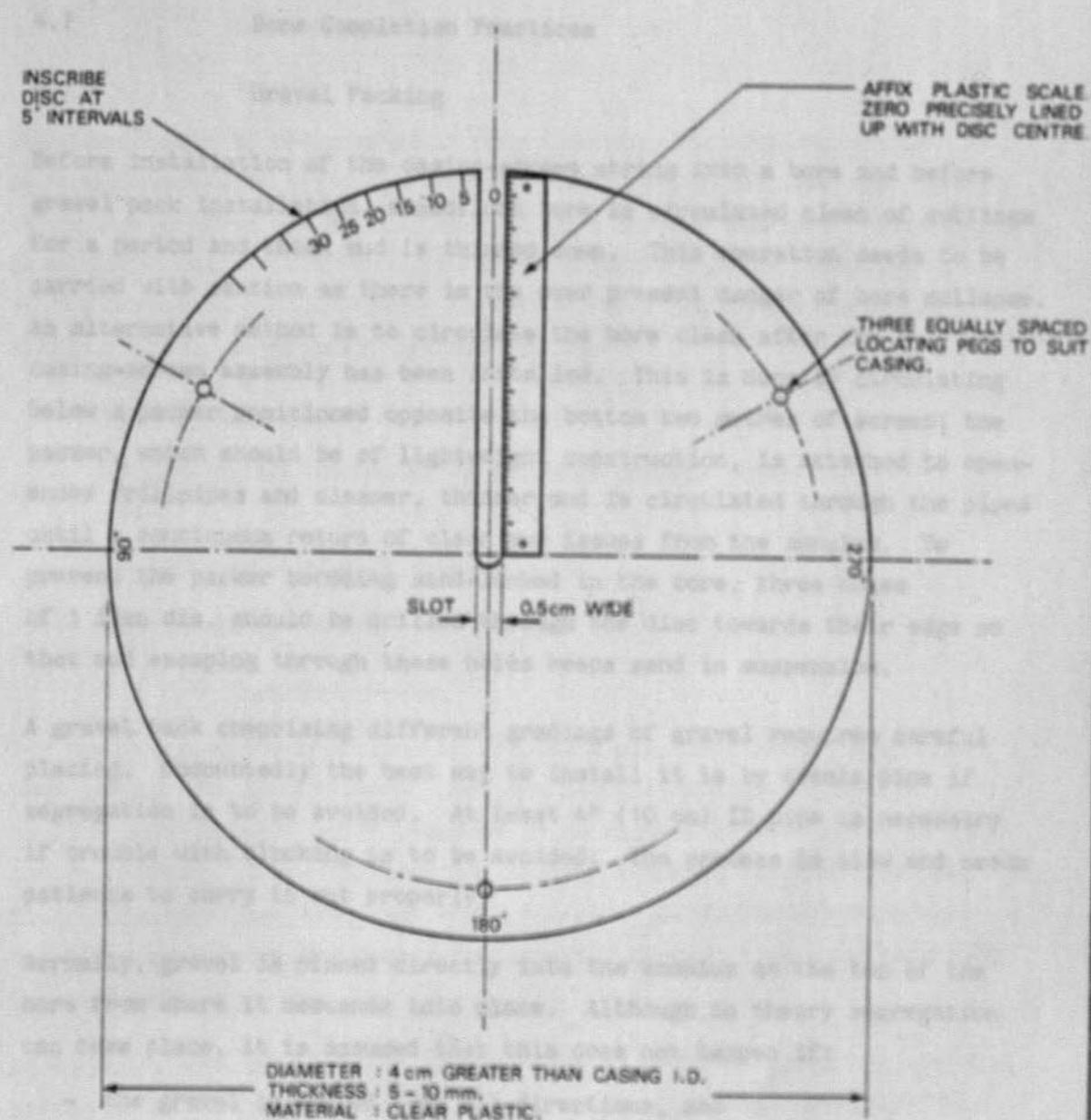
Method:

1. Disc is located on casing top by close fitting pegs.

2. String passes through slot in disc as bobbin is lowered down well. Slot in disc follows path of string. Disc must therefore be able to rotate freely (but not loosely) at casing top.

3. Deviation error at depth may be calculated directly from surface reading. (Only single direction is required with this method).

4.7   Bore Completion Practices

4.7.1   Gravel Packing

Before installation of the casing-screen string into a bore and before
gravel pack installation, a mudflush bore is circulated clean of cuttings
for a period and thick mud is thinned down. This operation needs to be
carried with caution as there is the ever present danger of bore collapse.
An alternative method is to circulate the bore clean after the
casing-screen assembly has been installed. This is done by circulating
below a packer positioned opposite the bottom two metres of screen; the
packer, which should be of lightweight construction, is attached to open-
ended drillpipes and cleaner, thinner mud is circulated through the pipes
until a continuous return of clean mud issues from the annulus. To
prevent the packer becoming sand-locked in the bore, three holes
of 1 inch dia. should be drilled through the disc towards their edge so
that mud escaping through these holes keeps sand in suspension.

A gravel pack comprising different gradings of gravel requires careful
placing. Undoubtedly the best way to install it is by tremie pipe if
segregation is to be avoided. At least 4" (10 cm) ID pipe is necessary
if trouble with blocking is to be avoided. The process is slow and needs
patience to carry it out properly.

Normally, gravel is placed directly into the annulus at the top of the
bore from where it descends into place. Although in theory segregation
can take place, it is assumed that this does not happen if:

    - the gravel is placed from all directions, and
    - the gravel is placed in a continuous non-stop operation.

It is recommended that water be introduced into the gravel stream during
installation and, at the same time, the bore be pumped lightly. The pumped
water may be used for mixing the gravel if it is not too dirty. Before
gravel reaches the level of the reducer, the upper bore casing (UWC)
must be pulled tight and the main verticality test performed. When
this has been done, the casing is positioned accurately and reclamped
(in tension) and the rest of the gravel is installed. This verticality test
if often neglected and as a result some pump casings are not to the required
straightness and verticality. It is up to the drilling supervisor and
hydrogeologist to insist that this verticality test and realignment
is carried out in their presence.

4.7.2   Development
             General

The development of the production bore involves the cleaning of the
bore and removal or all drill cuttings and drilling mud, and wall cake
in particular from the aquifer zone. Where screens has been installed,
development will seek to so agitate the granular aquifer formation
at the screen face as to remove formation fines and form a permeable
stable filter. Development methods include:

- surging, backwashing

- overpumping and isolation of discrete aquifer zones by
  packer

- air lift and air-water jetting

- addition of mud breakdown chemicals

             Hard Rock Bores

For hard rock aquifers drilled by JPT using air, development needs have
been small.   It is considered that the natural inclination of the water
to flow into the well under pressure is sufficient in most cases to keep
the bore clean. After drilling has ceased, flushing has continued for
a period until clean water has been produced. During this period, air
delivery to the bore has been intermittently stopped to create back flow
to the formation.

Bores which have been drilled in hard rock by mudflush or by the airflush
system in lost circulation zones (e.g. Perlis limestone) need more than
the standard 'cleaning out' operation as in these cases mud or air plus
cuttings are bound to have entered the formation at joints, cracks and
fissures and it is necessary to remove the invaded material.

A large proportion of the debris will flow out with the water when the
bore is airlifted or pumped. The amount removed will depend mainly on
how much drawdown is induced in the bore by pumping, that is, what the
final differential pressure is. Whilst water and cuttings issue from the
main fissures without too much of a problem, the small cracks and fissures
may remain blocked and will not contribute to bore yield.

FIGURE 4.13   DEVELOPMENT TOOLS

To clean out these zones, efforts need to be made to localize the pumping or sucking action during development so that only a small section of bore wall is worked on at a time. The obvious way to do this is by a double packer system (Figure 4.13) where water can be drawn out of the strata over a short distance.

System operation is given by the following hypothetical situation:

- a bore is completed to 100 m depth and has a SWL of 20 m. When pump tested at 60 l/s, it shows a specific capacity of, say, 10 l/s/m (with a drawdown of 6.0 m).

- a drawdown of 6 m exerts a differential pressure of 0.6 kg/cm^2, i.e. the water in the aquifer is entering the bore at that pressure or less. Drilling debris may have entered the formation at a pressure greater than this, especially if mud has been used or if the bore has narrowed.

- The 0.6 kg/cm^2 pressure differential exerted by pumping would not be sufficient to suck out the cuttings and debris blocking the smaller fissures, but when a packer system is operated, at a zone isolated at say 55 m depth, then a pressure differential of 3.5 kg/cm^2 could be created simply by air lifting all the water from the packer column pipe assembly (or a drillpipe - packer assembly). Back washing (reversing the flow of water) would be necessary to accomplish the cleaning out process.

There are several types of packer available commercially. They are mainly expanding packers operated hydraulically or pneumatically and most are designed to operate in smaller diameter holes so that rock permeability can be measured. Although an expanding packer is the ideal, a 'flanged' packer can be made to work successfully, especially when it can be closely seated against the bore wall. A borehole caliper log may allow a suitable site to be chosen for the packer.

The point should not be missed that the well-known method of development by 'over-pumping' is in effect another way of creating extra drawdown and producing a greater differential pressure across the bore wall.

FIGURE 4.13   DEVELOPMENT TOOLS

AIR-PIPE

DRILL PIPE (EDUCTOR)

FLANGE
STEEL AND RUBBER

PIPE WITH LARGE
APERTURES
LENGTH BETWEEN
FLANGES 2-3m

FLANGE BLANK END
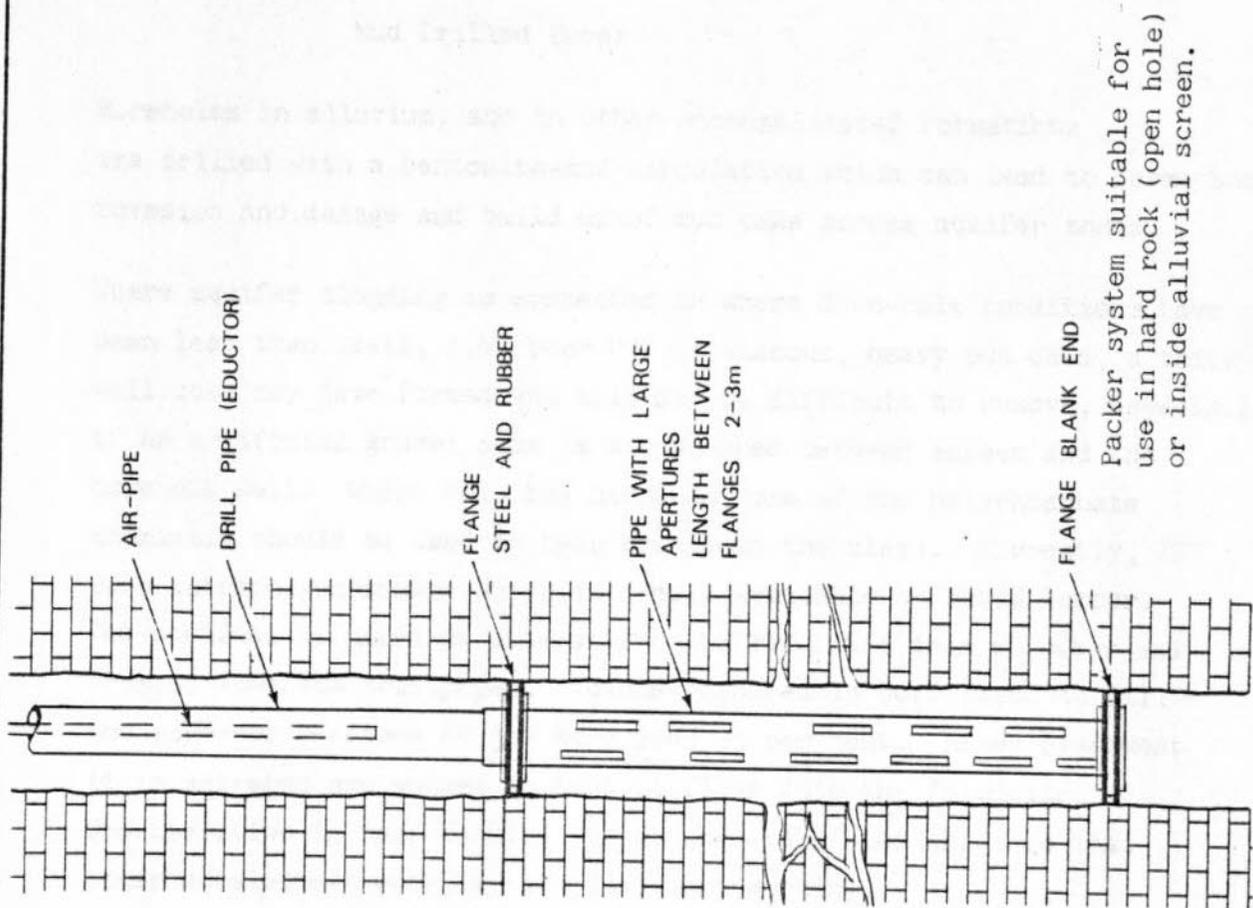
Packer system suitable for
use in hard rock (open hole)
or inside alluvial screen.

DRILLPIPE

WELL-CASING

SCREEN
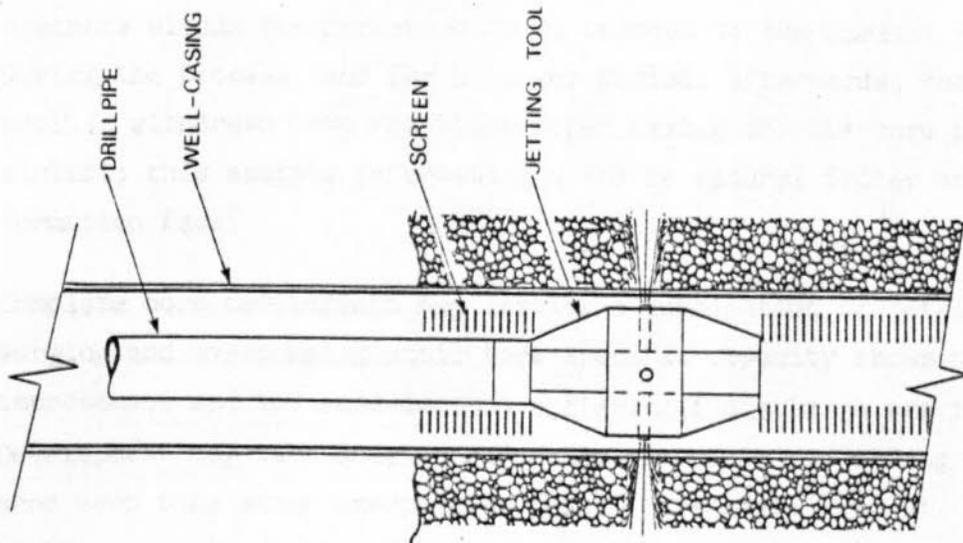
JETTING TOOL

Jetting tool suitable for
working inside screened or
slotted pipe using air or
water.

Mud Drilled Bores

Boreholes in alluvium, and in other unconsolidated formations are drilled with a bentonite-mud circulation which can lead to formation invasion and damage and build up of mud cake across aquifer zones.

Where aquifer clogging is suspected or where down-hole conditions have been less than ideal, i.e. poor UHV or viscous, heavy mud used, a thick wall cake may have formed and this may be difficult to remove, especially if an artificial gravel pack is sandwinched between screen and the borehole wall. Where this has happened, one of the polyphosphate chemicals should be used to help breakdown the clays. Currently, JPT uses tetrapolyphosphate which is freely available in Kuala Lumpur. The chemical is mixed on site at 2 kg to 200 litre drum of water and tremied down the drillpipes. Volume required is sufficient to fill the screened sections of the bore plus 20 per cent. After placement it is agitated and surged so that it flows into the formation. The operation is best carried out at the end of the shift so that other development work may continue next morning.

When screens are set in alluvial aquifers, drilling mud and wall cake is removed by use of a high velocity jetting tool fitted with four 4.7 mm diameter nozzles and used in conjunction with the rig compressor to jet across each screen. A system of rotary jetting of high pressure air against the screen not only cleans each slot, but will allow debris to pass through the screen and to blast off formation wall cake; it can also vigorously agitate the surrounding formation and allow finer elements within the formation to be removed by the airlift system. During the process, and for a longer periods afterwards, the jetting tool is withdrawn into the blank upper casing and the bore pumped by airlift; this assists in creating a stable natural filter at the screen-formation face.

Complete bore development may involve a combination of jetting, airlift surging and overpumping until bore specific capacity shows no significant improvement and the sand-content criteria of discharge are met. Development may take some considerable time with re-jetting producing sand each time after overpumping phases have stabilised it, but should be continued until no more sand show is obtained. The bore can then be step-tested for pump selection purposes.

20 Q-H
η% HP
70 14
60 12
10 HP 50 10
40 8
30 6
20 4
10 2
0 0 0

0 50 100 150 m³/h

0 200 400 IMP GPM
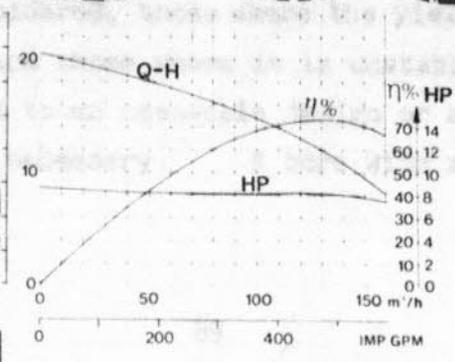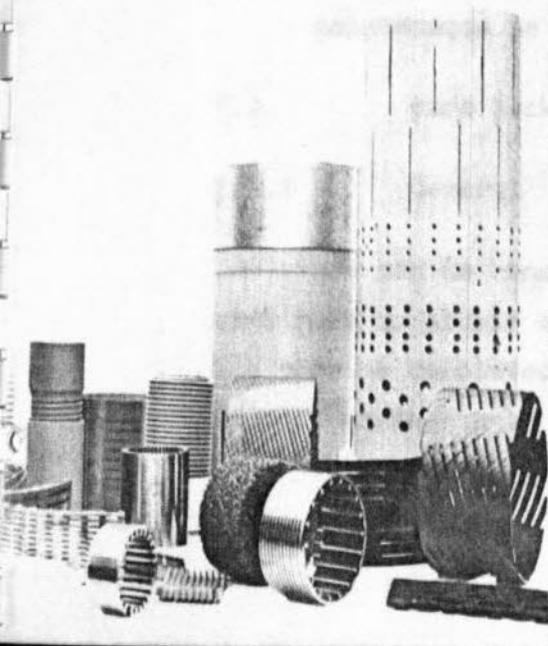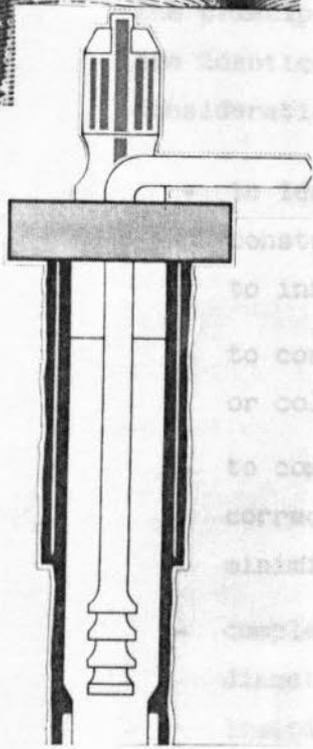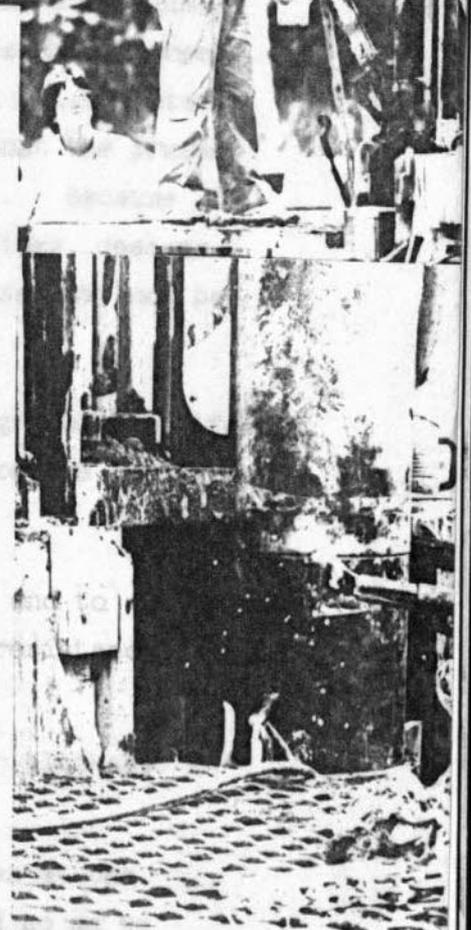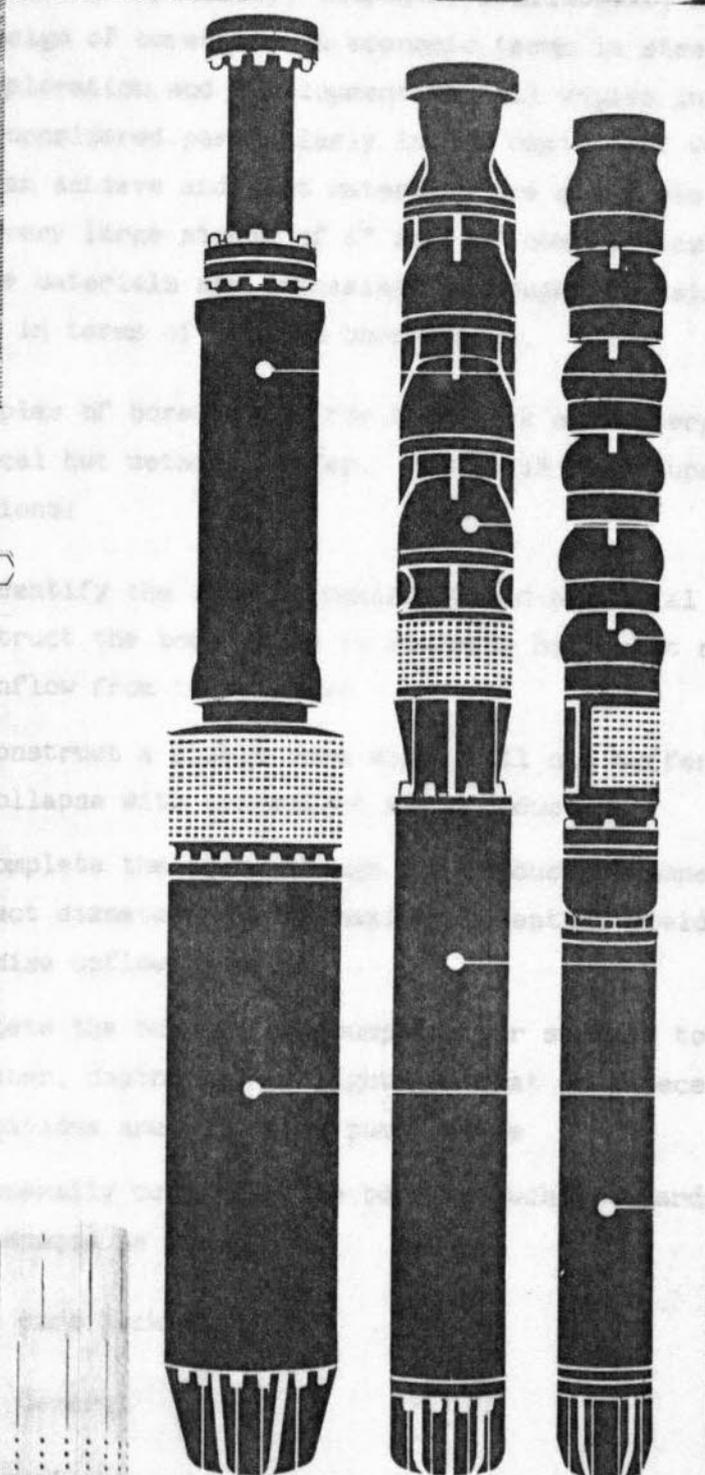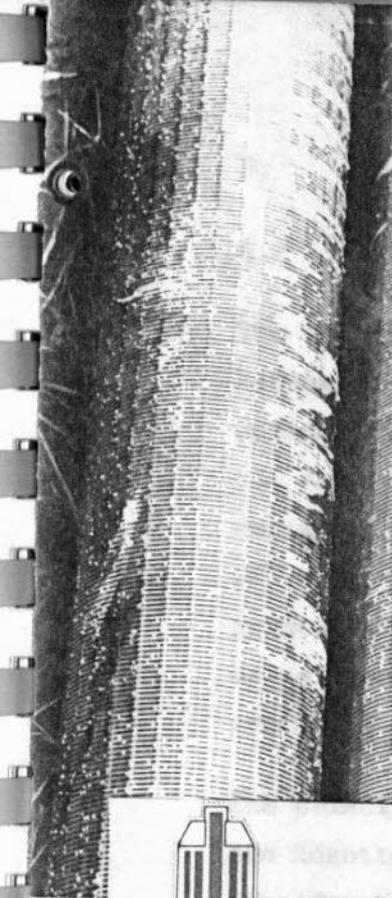
5. PRODUCTION BORE DESIGN

5.1 Introduction

The design of production bores (often called wells) is a compromise
between drilling capability, component availability and economics.
Optimum design of boreholes in economic terms is stressed elsewhere
(in the Exploration and Development Manual) whilst in this chapter,
design is considered particularly in the context of what the present
JPT rigs can achieve and what materials are available. Because JPT
possesses very large stocks of 6" and 10" nominal casings, designs
using these materials are emphasised although such sizes may not be
preferred in terms of optimum bore design.

The principles of bore design for hard-rock and intergranular aquifers
are identical but details differ. Design is based upon the following
considerations:

- to identify the zone of maximum yield potential and to
  construct the bore so as to minimise hydraulic resistance
  to inflow from these zones

- to construct a stable bore which will not suffer blockage
  or collapse with consequent yield reduction

- to complete the bore through the production zones at the
  correct diameter for the maximum potential yield so as to
  minimise upflow losses.

- complete the bore in the pump-chamber section to such
  diameter, depths and straightness that no unnecessary
  limitations are placed on pump choice

- to generally construct the bore to such standards that
  maintenance is low.

5.2 Hard Rock Bores

5.2.1 General

Two types can be considered, those where the yielding section of the
hard rock is stable and those where it is unstable. That is, can
the bore be completed to an open-hole design or are some formation
support arrangements necessary.   A bore with a major yield zone

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could be unstable because of localised fracturing and weathering, and yield may deteriorate during its active lifetime. On the other hand, strata with well distributed minor fissures may often be considered as stable and an open-hole design considered.

Open-hole means on uncased bore, below the pump casing, which has been designated stable. The pump casing may also be situated in stable rock but there is always a chance that without the casing, the odd piece of rock could fall and trap the pump.

5.2.2   Stable Hard Rock Bores

Invariably, an explanatory borehole will precede any production bore design, because of gross uncertainties as to bore yield and yielding zone in hard rock. This is simply illustrated by Figure 5.1 which shows estimated test yields (not production yields) in various geological formations. For the following discussion, a test discharge of less than 10 l/s is considered to be a failure bore; criteria for failure is however dependent on presumed end use of the bore.

For the best hard rock formations such as the Permo-Triassic Limestones (Chuping Formation) there is about a 50% chance of getting a successful production bore (>10 l/s) from an exploratory drilling; about $2\frac{1}{2}$ exploration bores will be therefore needed for every successful production bore. In the Ordovician Limestones (Setul), 3 exploration bores are needed per production bore. In the extreme case of Triassic Sandstones, success rates may drop to 6% and hence 16 exploration bores might be needed!   It is therefore clear that exploratory bores have to be drilled before any production design can be considered.

A production bore for irrigation is the end requirement, the hard rock should be presumed stable and a pilot or exploration bore drilled at the full diameter that would be required for an open-hole producing section. If successful, the upper part of the bore can later be reamed to accommodate a pump chamber casing. Small to medium drilling diameters available with the JPT equipment are 5 7/8 inches and 7 5/8 inches and bores drilled with these would be suitable for yields up to about 18 and 35 to 40 l/s respectively. Very few stable hard rock bores can be expected to exceed this yield and so the available diameters are appropriate.

FIGURE 5.1   FORMATION 'FAILURE' PROBABILITIES

FIGURE 5.1 — FORMATION 'FAILURE' PROBABILITIES

Axis labels:
- Vertical: WELL YIELD, Q (l/s) (for 7.5 m drawdown)
- Horizontal: PROBABILITY OF YIELD EXCEEDING STATED VALUE (%)

Curve labels: Triassic Sandstones / Carboniferous Shales / Sandstone; Ordovician Limestone (Setul); Permo-Triassic Limestone (Chuping); Kelantan Alluvium (approx)

FIGURE 5.2 STABLE HARDROCK BORE DESIGNS
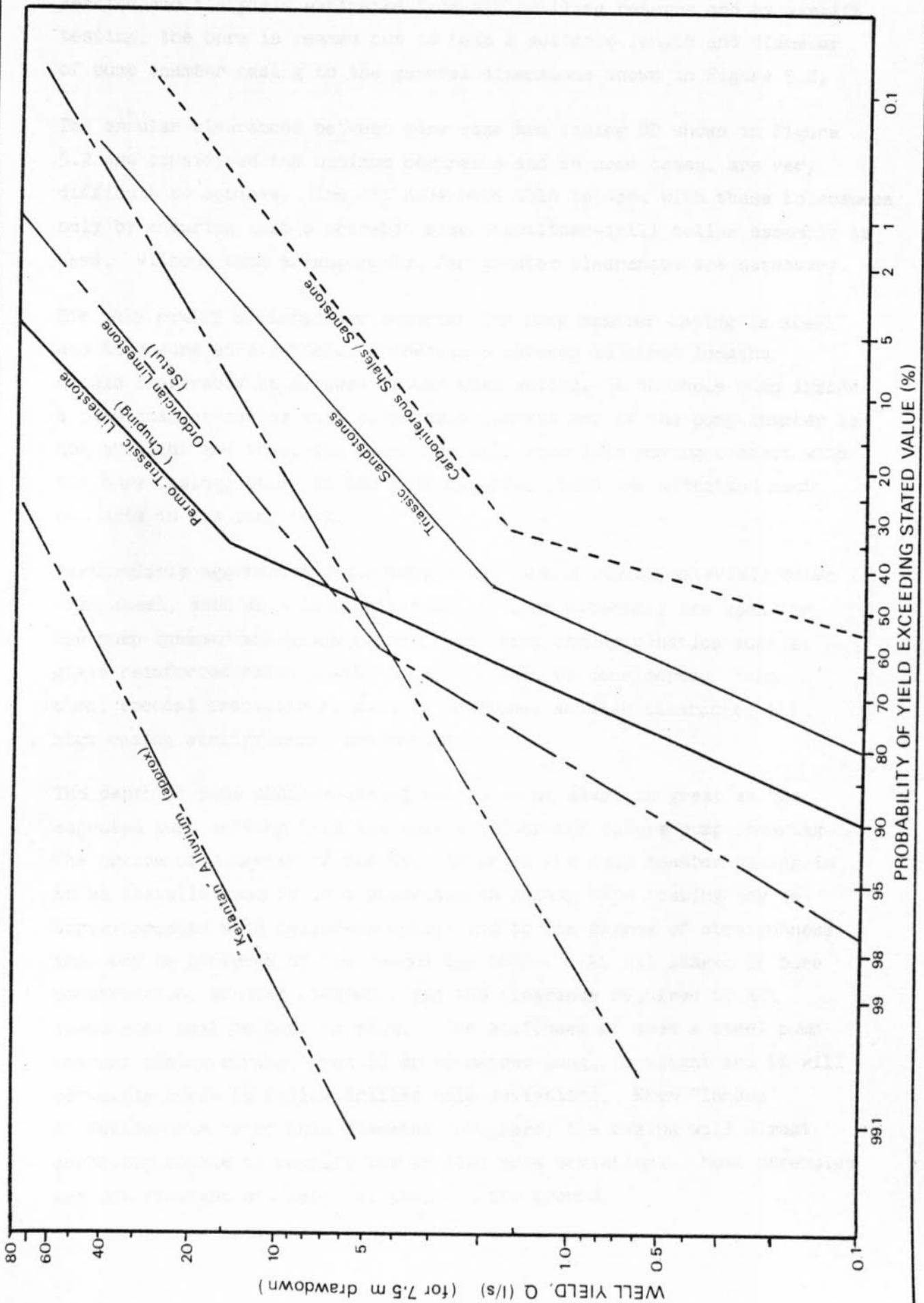
After a suitable diameter bore has been drilled through the producing
section and its yield estimated from air drilling returns and by airlift
testing, the bore is reamed out to take a suitable length and diameter
of pump chamber casing to the general dimensions shown in Figure 5.2.

The annular clearances between bore size and casing OD shown in Figure
5.2 are considered the minimum desirable and in some cases, are very
difficult to achieve. The JPT have been able to work with these tolerances
only by ensuring that a near-bit size stabilizer-drill collar assembly is
used. Without such arrangements, far greater clearances are necessary.

The only really satisfactory material for pump chamber casing is steel
and to ensure straightness, connections between adjacent lengths
should preferably be screwed rather than welded. A borehole pump inside
a pump chamber casing will invariably vibrate and if the pump chamber is
not straight and true, the pump body will come into moving contact with
the bore casing; steel is the only material which can withstand such
contacts in the long term.

Particularly aggressive groundwaters may demand casing materials other
than steel, such as a inert plastic. If such materials are used for
the pump chamber and blank casing, only very strong plastics such as
glass reinforced resin plastics (GRP) should be considered. Even
then, special precautions, such as increased annular clearances and
high casing straightness, are needed.

The depth of pump chamber casing has to be at least as great as the
expected pump setting plus any safety factor for future pump lowering.
The choice of diameter of the hole in which the pump chamber casing is
to be installed should be appropriate to casing type (casing may be
screw-threaded with collar-coupling) and to the degree of straightness
than can be achieved by the reamed out hole.   At all stages of bore
construction, annular clearance and the clearance required by all
components must be kept in mind.   The stiffness of even a steel pump
chamber casing string, when 30 or 40 metres long, is slight and it will
certainly curve to follow drilled hole deviations. When "landed"
on bottom-hole or on hole diameter shoulders, the casing will almost
certainly buckle to magnify the drilled hole deviations. Most boreholes
are not straight and vertical holes in the ground.

FIGURE 5.2 STABLE HARDROCK BORE DESIGNS
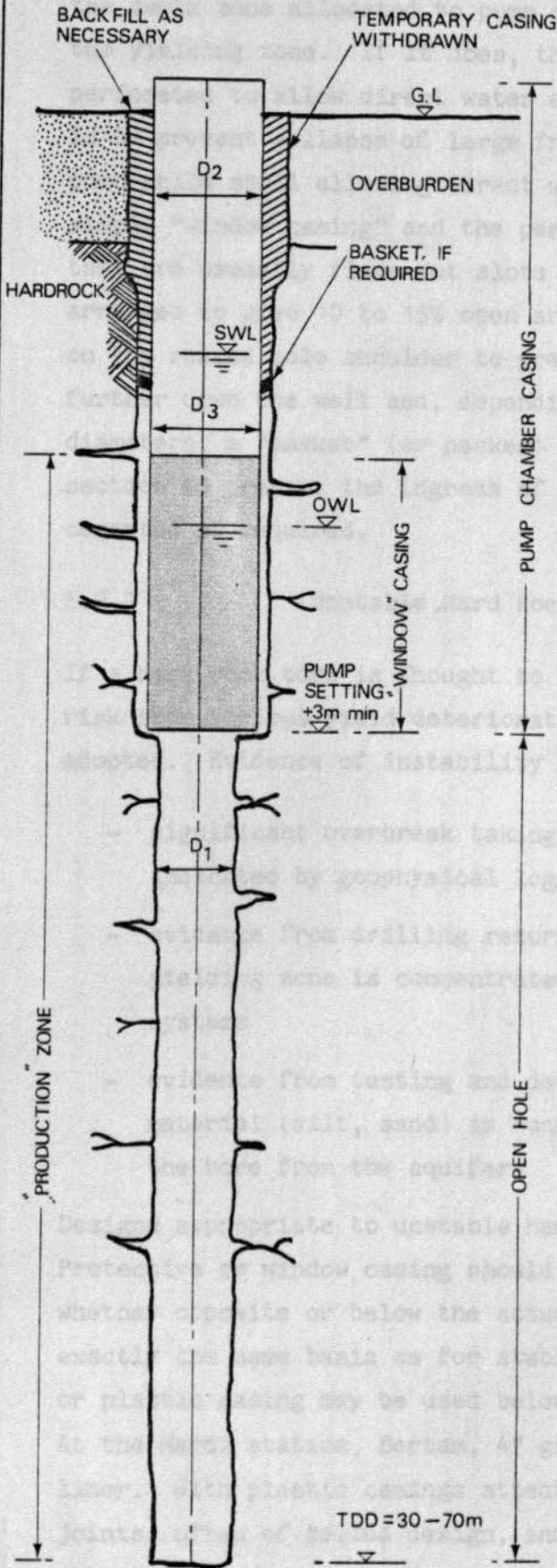
Diagram labels:
BACKFILL AS NECESSARY
TEMPORARY CASING WITHDRAWN
G.L
D2
OVERBURDEN
BASKET, IF REQUIRED
HARDROCK
SWL
D3
PUMP CHAMBER CASING
OWL
"WINDOW" CASING
PUMP SETTING +3m min
D1
"PRODUCTION" ZONE
OPEN HOLE
TDD = 30 – 70m

Recommended Diameters

Discharge, Q (l/s)	Open Hole diam. (mm) D_1	Pump Casing ID. (mm) D_2	Pump Casing Nominal dia. (ins). D_2	Minimum Reamed hole diam. (mm) plus Equivalent bit size (ins). D_3
1–8	149	156	6	194 (7 5/8)
18	149	206	8	251 (9 7/8)
30	194	256	10	311 (12½)
40	194	256	10	311 (12½)
60	251	311	12	381 (15)

Note:

Open hole can always be re-reamed through pump chamber casing. Backfill may be cement just above basket.

156 Available JPT bit and casing sizes.

A stiff drill assembly including stabilisers must be used for these designs.

FIGURE 5 3   UNSTABLE HARDROCK BORE DESIGNS

The last major consideration in stable hard rock bore designs is whether
the depth zone allocated to pump chamber casing coincides with part of
the yielding zone. If it does, then the pump casing has to be partly
perforated to allow direct water entry. The function of the perforations
is to prevent collapse of large fragments of formation on and into the
pump while still allowing direct water entry. Its technical name is
simply "window casing" and the perforations in it can be quite rough;
they are ususally flame-cut slots 5 to 15 mm wide and 100 to 150 mm long,
arranged to give 10 to 15% open area. Such casing is usually "landed"
on the reamed hole shoulder to prevent any collapsed material falling
further down the well and, depending on the up-hole and temporary casing
diameters, a "basket" (or packer) is sometimes fitted above the slotted
section to prevent the ingress of loose overburden; this basket may be
cemented if required.

5.2.3   Unstable Hard Rock Bores

If a hard rock bore is thought to be prone to collapse or otherwise at
risk from serious yield deterioration, special design measures must be
adopted. Evidence of instability in the bore includes:

- significant overbreak taking place during drilling, or
  indicated by geophysical logging

- evidence from drilling returns or testing data that the
  yielding zone is concentrated in a few major fissure
  systems

- evidence from testing and development that granular
  material (silt, sand) is continually being brought into
  the bore from the aquifer.

Designs appropriate to unstable hard rock bores are given (Figure 5.3).
Protective or window casing should be provided for the producing section,
whether opposite or below the actual pump chamber, which is provided on
exactly the same basis as for stable bore designs; plain-welded casing
or plastic casing may be used below the pump chamber if required.
At the Mardi station, Bertam, 4" galvanised water pipe was used as a
liner. With plastic casings attention has to be paid to the larger size
joints, often of belled design, and the reduced inside diameters of such
material.

FIGURE 5.3   UNSTABLE HARDROCK BORE DESIGNS
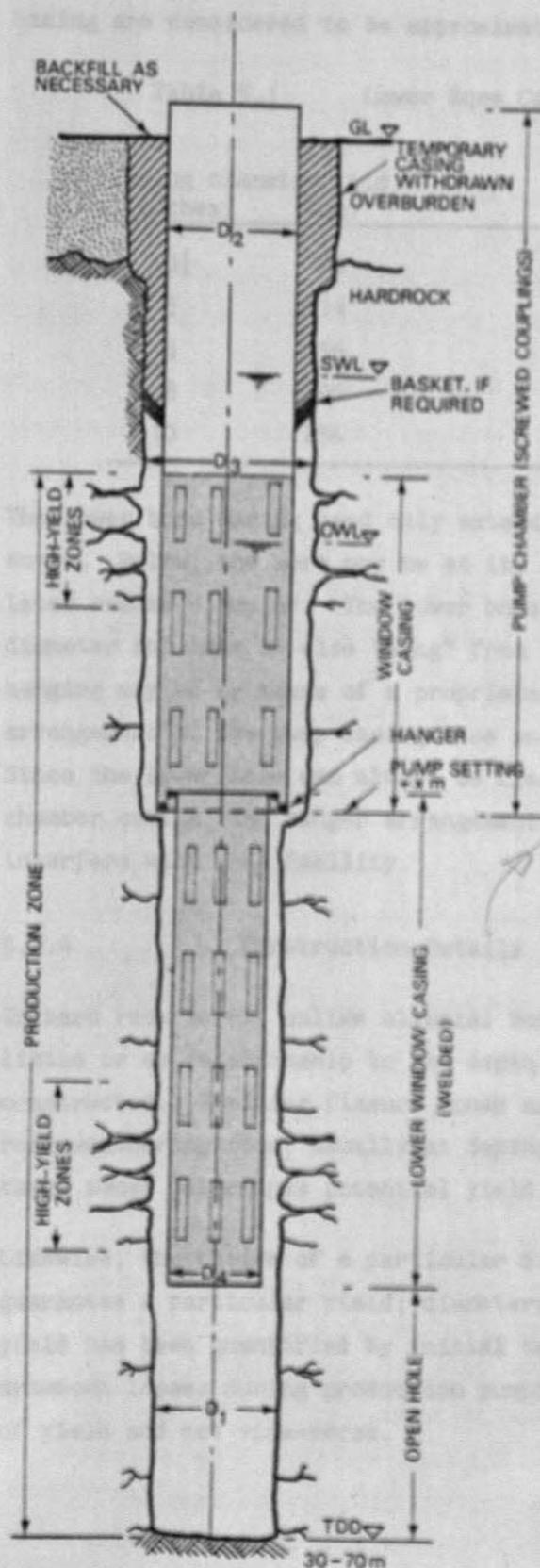
FIGURE 5.3   UNSTABLE HARDROCK BORE DESIGNS

Recommended Diameters

Discharge, Q (l/s)	Open Hole diam. (mm) D_1	Pump Casing ID (mm) D_2	Pump Casing Nominal diam. (ins) D_2	Minimum Reamed Hole Diameter (mm) plus equivalent bit size (ins) D_3	Lower Casing Nominal diam. (ins) D_4	Pump Casing Setting (m) X
1-8	149	156*	6	194 (7 5/8)	4	3
18	149	206	8	251 (9 7/8)	5	3
25	194	256	10	311 (12¼)	6	3
30	251	256	10	311 (12¼)	8	3
50	251	311	12	381 (15)	8	3
60	251	311	12	381 (15)	8	6

Note:

Lower bore can be re-reamed, cleaned or cased through pump chamber casing. Backfill may have to be cement just above basket if drilling clearances are large.

156 Available JPT bit and casing sizes.

*Preferred; lineshaft pumps with discharge 6- 16 l/s can fit into 156 mm casing.

The upflow-losses limiting discharges for smooth-walled, slotted steel casing are considered to be approximately as shown (Table 5.1).

Table 5.1   Lower Bore Casing - Desirable Discharges

Casing diameter (i.d.)		Maximum desirable discharge
(inches)	(mm)	Q, (l/s)
3½	90	15
5	114	18
6	156	25
8	206	50
10	256	80

The lower bore casing need only extend to cover the unstable yielding zones. Below, the bore may be at its original drilled diameter or at a later reamed diameter. The lower bore casing can be landed on a reamed diameter shoulder or else "hung" from the bottom of the pump chamber casing; hanging may be by means of a proprietary casing hanger or by a simple welded arrangement at the pump casing shoe and lower casing head (Figure 5.3). Since the lower hole can always be cleaned or re-reamed through the pump chamber casing, the hanger arrangement should be detailed so as not to interfere with this facility.

5.2.4   Construction Details

In hard rock bores, unlike alluvial bores, actual yield obtained bears little or no relationship to the depth or diameter to which a bore is constructed. Yielding fissure zones are found almost at random in the rock weathering zone, usually at depths less than 60 m; the quality of these zones determines potential yield.

Likewise, the choice of a particular diameter for construction will not guarantee a particular yield; diameters are simply chosen after potential yield has been quantified by initial testing and are chosen to minimise drawdown losses during production pumping. Diameter is a consequence of yield and not vice-versa.

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For all hard rock bores therefore, an exploratory or pilot hole is drilled through temporary or conductor casing, at the exploratory diameter suitable for the desired production bore yield i.e. 5 7/8, 7 5/8 or 9 7/8 inches (149, 194 or 251 mm). Air drilling yields would be noted to assess both the overall yield potential and vertical distribution of yielding zones; these would be confirmed by geophysical logging, particularly caliper logging and the rock assessed as stable or unstable. At least an airlift test, and preferably a pumped step test would be carried out to quantity the bore's ultimate production yield and pump setting.

One this had been carried out, if the yield was deemed adequate, a production bore completion diameter could be determined, as from Figures 5.2 and 5.3. The sequence of operations would then typically be as follows:

- ream the hole to accept pump chamber casing and upper window casing, to the necessary depth and diameters. Reaming should be carried out with a 'hole opener' type of bit with a pilot stabiliser, to preserve straightness and verticality

- if the existing pilot bore diameter is deemed adequate for eventual open-hole or lower window casing completion, this bore may be temporarily plugged (just below eventual pump casing shoe setting) during the reaming process, to prevent reaming debris from filling the lower hole. Such a plug can be a wooden bung or a sand-cement sandbag which can later be drilled out.

- if the lower hole has itself to be reamed out, this can either be done through the pump chamber casing or directly after completion of reaming the upper hole. The drilling-through technique is sometimes essential in order to obtain adequate up-hole drilling fluid velocities from greater depths (by reducing the apparent hole annulus). However, when pump chamber window casing is used, there is a danger of lower hole reaming cuttings may lodge in the space between the casing and the upper borehole wall and so reduce the eventual yield. If the annular reduction technique has to be adopted, it is recommended that unperforated temporary casing is used to blank-off the upper producing zones during reaming.

- On completion of reaming and cleaning out of the lower bore if necessary, the permanent pump chamber casing and window casing can be installed. It should not be centralised in the hole, but adjusted within the annular space, to optimise pump chamber straightness and verticality as measured by verticality surveys. If the annular clearance is significant, a cement basket may need to be fitted outside the casing, above the production zone, to prevent downward movement of collapsed weathered rock and overburden. For substantial annular clearances (above 25 mm), it may be necessary to place some cement just above the basket to strengthen the isolating seal. The remainder of the backfill (any material) can then be placed to the surface; its function is mainly to preserve the pump chamber casing in its straight and vertical condition.

- After cement set, any required lower bore casing can be placed and seated on its hanger arrangement. A specially designed tool (usually called a drop-set latch which utilises the principles of a light-bulb socket) will be necessary to back-off the setting tool string from the lower bore casing.

- The completed production bore should then be develped by the most vigorous means available, including overpumping combined with intermittent positive backwashing. A full bore test would later be carried out to confirm the details of the production pump selection.

5.3   Casing and Straightness Standards

Various unsuitable tubular goods are considered suitable for use as bore casing. They can be used in special circumstances, but the particular precautions required and the risks involved must be recognised. It is considered appropriate here to consider particular bore or well casing requirements.

The stresses acting upon properly installed bore casing, once in place, are slight by say structural engineering standards but stresses generated during handling and installation and due to improper emplacement, can be several orders higher. In particular, the installation of plastic casing is often troublesome and the driller may need to subject the material to high and possibly destructive stresses.

FIGURE 5 4   CASING STIFFNESS AND STRAIGHTNESS

In normal groundwater conditions, only steel casing should be considered
for pump chamber use; other materials can be considered for lower bores
casing if some form of formation-support backfill is provided. Alternative
materials for pump chamber require additional clearance and drilling
allowances and special straightness precautions which are generally
costly.

In addition to the material used, other factors are of importance. Waterworks
quality steel tubular pipes often appear much cheaper than special bore or
well casing. The reasons for this are twofold:

- casing wall thickness is usually greater than that of pipe
  since external pressures are more difficult to resist than
  interval pressures and rigidity is more important

- standards of coupling alignment, and hence coupled unit
  straightness are much higher for casing than for pipe
  (Figure 5.4).

Casing joints for pump casing are factory prepared, screw-threaded
joints certified to a bore casing standard. Welded pipe joints could
be used for lower bore casing and screen where straightness and
verticality is much less important.

Traditional steel casing standards are based on either the American
Petroleum Institute's (API) oil well casing standards API 5A (casing),
API 5B (couplings and threads), API 5L (linepipe), or the British
Standards Institution (BS) water-well casing standard BS 879. All are
considered to be somewhat excessive in their requirements, the API
in terms of wall thickness and coupling outer diameters required, and
the BS in terms of its rather special thread forms. The Australian
water well industry has recently formulated a compromise, between the
American and British standards, with adequate wall thickness (stiffness)
for water wells, a reasonable thread form and a less bulky coupling
termed 'slimline'.

Various casing standards are shown, in Appendix XIII. When using
these tables, attention should be paid to the type of joint, its
dimensions and how suitable   or appropriate these are to desired
clearances in the bore. A suitable casing wall thickness for Malaysian
conditions is 5-6 mm below 125 mm OD and 6.5-7.5 mm thickness above that.

FIGURE 5.4   CASING STIFFNESS AND STRAIGHTNESS

DEVIATED HOLES
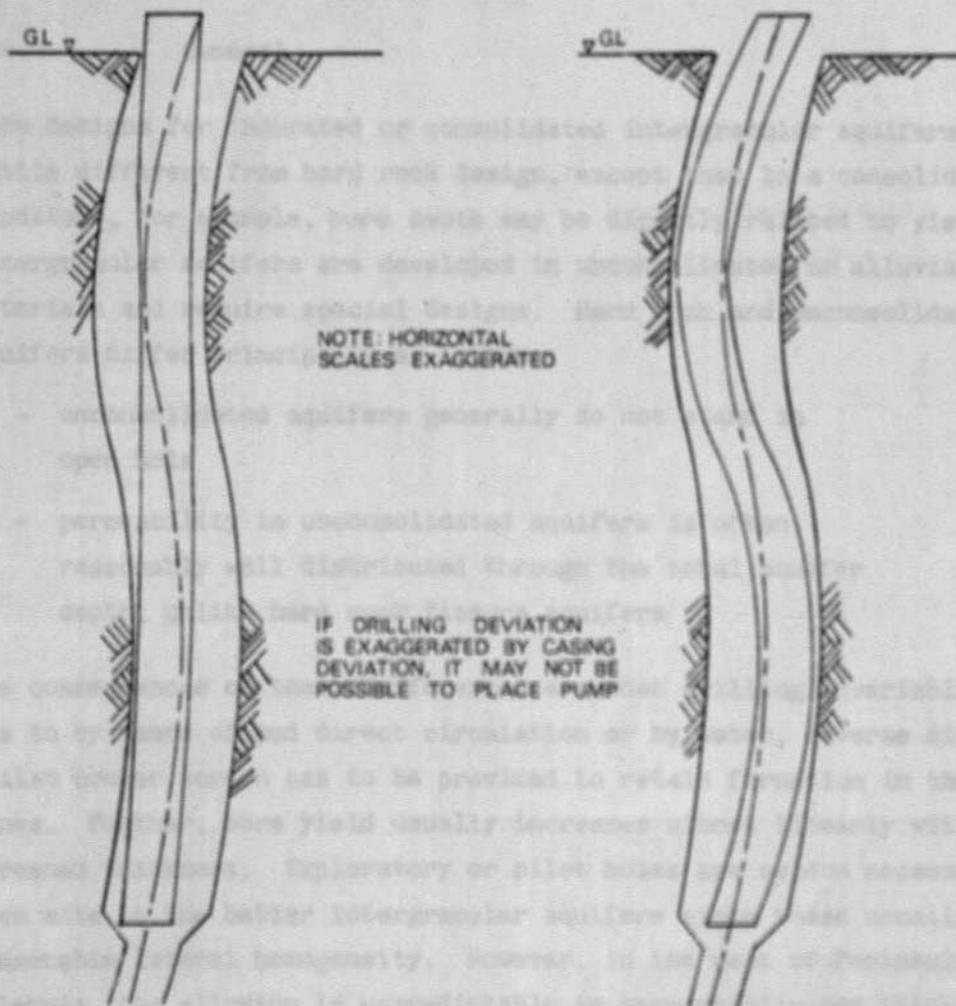
NOTE: HORIZONTAL
SCALES EXAGGERATED

IF DRILLING DEVIATION
IS EXAGGERATED BY CASING
DEVIATION, IT MAY NOT BE
POSSIBLE TO PLACE PUMP

"STIFF" CASING
(MINIMISES DEVIATIONS)

"FLEXIBLE" CASING
(EXAGGERATES DEVIATIONS)
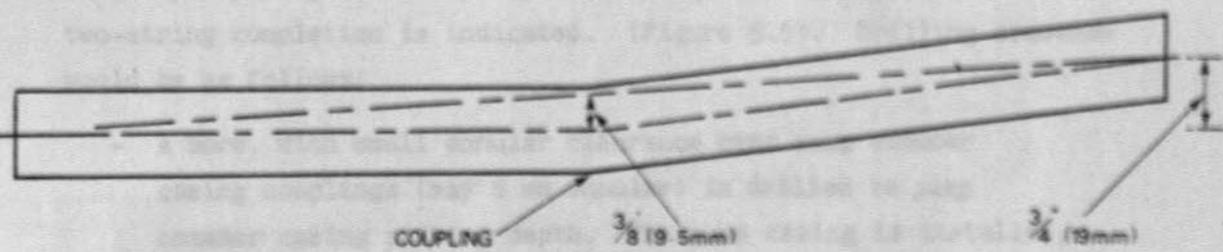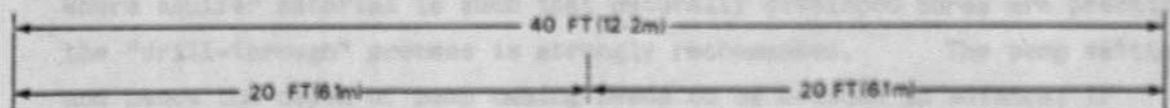
CASING ALIGNMENT STANDARDS
(A.S. 1396, BS 879)

5.4   Bores in Intergranular Aquifers

5.4.1   General

Bore designs for indurated or consolidated intergranular aquifers are
little different from hard rock design, except that in a consolidated
sandstone, for example, bore depth may be directly related to yield.
Intergranular aquifers are developed in unconsolidated or alluvial
materials and require special designs. Hard rock and unconsolidated
aquifers differ principally as follows:

- unconsolidated aquifers generally do not stand in
  open hole

- permeability in unconsolidated aquifers is often
  reasonably well distributed through the total aquifer
  depth, unlike hard rock fissure aquifers

The consequences of these differences are that drilling invariably
has to by means of mud direct circulation or by water, reverse circulation,
whilst proper screen has to be provided to retain formation in the yielding
zones. Further, bore yield usually increases almost linearly with
screened thickness. Exploratory or pilot holes are seldom necessary at
each site in the better intergranular aquifers since these usually possess
reasonable lateral homogeneity. However, in the west of Peninsular
Malaysia, the alluvium is unpredictable in permeability and thickness
and exploratory bores are certainly necessary before large diameter
production bores or test-wells can be considered.

5.4.2   Bore Configurations

Where aquifer material is such that naturally developed bores are practical,
the "drill-through" process is strongly recommended.   The pump setting
and hence the depth of pump casing needs to be decided in advance; if
this depth partly encroaches upon total aquifer depth, then a standard
two-string completion is indicated. (Figure 5.5). Drilling sequence
would be as follows:

- a bore, with small annular clearance over pump chamber
  casing couplings (say 8 mm annular) is drilled to pump
  chamber casing setting depth. The pump casing is installed,
  landed on the bottom and annular collapse encouraged by
  pumping out.

FIGURE 5.5 NATURALLY DEVELOPED ALLUVIAL BORE DESIGNS
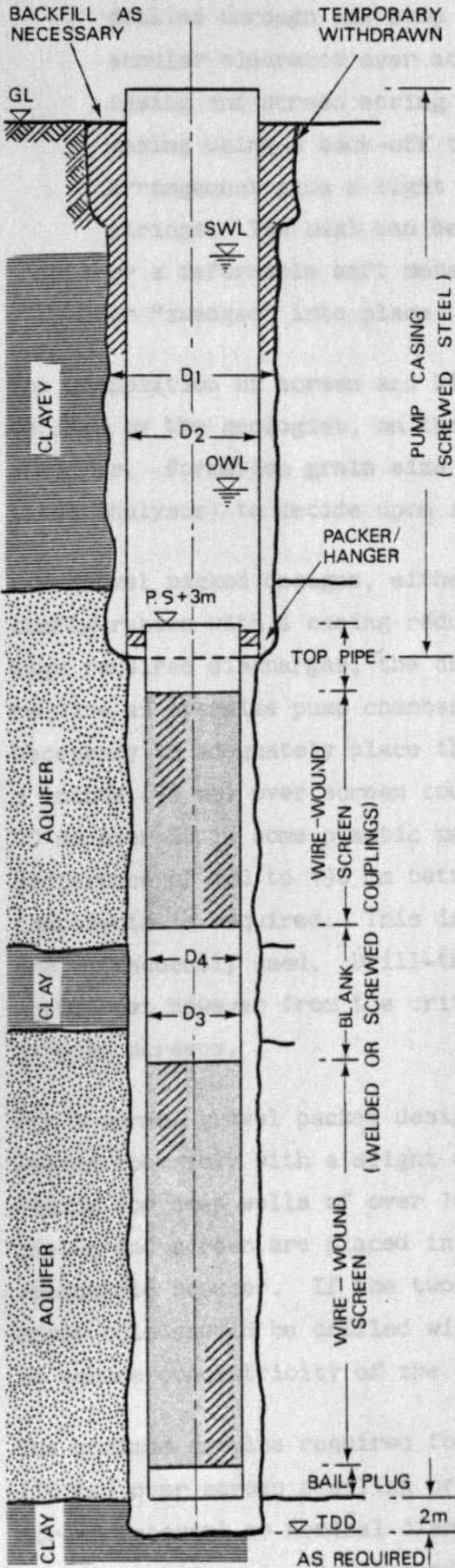
Recommended Diameters

Discharge, Q (l/s)	Upper Hole diam. (mm) plus equivalent bit size (ins). D_1	Pump Casing ID. (mm). D_2	Lower Hole diam.(mm) plus equivalent bit size (ins). D_3	Screen nominal diam. (mm). D_4
1-8	194 (7 5/8)	156	149 (5 7/8)⁺	100
15	251 (9 7/8)	156-206	149 (5 7/8)	100
18	251 (9 7/8)	206	149 (5 7/8)	125
25	251 (9 7/8)	256	194 (7 5/8)	150
30	311 (12¼)	256	251 (9 7/8)	200
50	356 (14)	311	251 (9 7/8)	200
>60	356 (14)	311	292 (11½)	250

Note:

Total screen lengths to be determined from desired discharge and economic design criteria.

Pump casing may need lower end plug-cementing to prevent washout when drilling on through.

156 Available JPT bit and casing sizes

+ Smallest Available.

- the lower hole for the screen and lower casing string is
  drilled through the pump casing, with least possible
  annular clearance over actual coupling diameters. The
  casing and screen string is installed through the pump
  casing using a back-off tool, a fabricated hanger
  arrangement plus a tight seal between the two casing
  strings. The seal can be a push-fit rubber arrangement
  or a deformable soft metal (lead) ring which is expanded
  or "swedged" into place.

The disposition of screen and blank casing in the lower string is normally
decided by the geologist, on the basis of sample and geophysical log
analysis. Formation grain size should be checked on site (mechanical
sieve analysis) to decide upon screen slot sizes.

For gravel packed designs, either a drill-through or a single-string
configuration with a casing reducer could be adopted. However, for
high required discharges, the drill-through technique would usually
require an oversize pump chamber casing to accommodate the annulus
necessary to adequately place the gravel pack; this should be at least
3 inches (75 mm) over screen couplings and since these can be 30 to
40 mm over ID in some plastic materials, an excessive diameter
difference of 180 to 190 mm between the nominal bores of the two
components is required. This is rare and so drill-through gravel packs
are infrequently used. Drill-through configurations can easily be
worked out however from the criteria already given, but using flush-
jointed screens.

For a normal gravel packed design, the hole is drilled in one or two
passes (possibly with a slight diameter reduction just below pump
casing for deep wells of over 100 m). The pump casing and lower bore
casing and screen are placed in a single string, connected by a
concentric reducer. If the two-pass, two-diameter system is used, the
upper hole should be drilled with a hole-opener or two-stage bit,
to ensure concentricity of the two holes.

The minimum annulus required for placement of gravel is 3 inches
(75 mm) over screen coupling or just less than 4 inches (100 mm) over
screen interval or nominal diameters. Two inches (50 mm) over pump
casing couplings is also considered a minimum to allow the gravel to
pass downwards.

FIGURE 5.6   GRAVEL PACKED ALLUVIAL BORE DESIGNS

After the single string casing has been lowered and hung from the
surface with a 2 m end-float beneath it (to prevent screen string
buckling), the gravel is immediately emplaced (section 4.7.1).
The screen string is fitted with centralising devices to preserve
its concentricity within the hole, but none are fitted to the pump
chamber. As gravel placement has been completed to above the reducer
connection, the pump chamber is positively tensioned from the rig to
preserve its verticality. Backfill in the pump chamber annulus may be
any suitable or sealing material, although in practice clay fill is
almost impossible to place to an adequate density.

The bore is immediately developed by localised airlift surging and
overpumping and acceptance/production pump selection tests carried out
as before. Typical configurations for this form of completion are
illustrated on Figure 5.6.

FIGURE 5.6   GRAVEL PACKED ALLUVIAL BORE DESIGNS
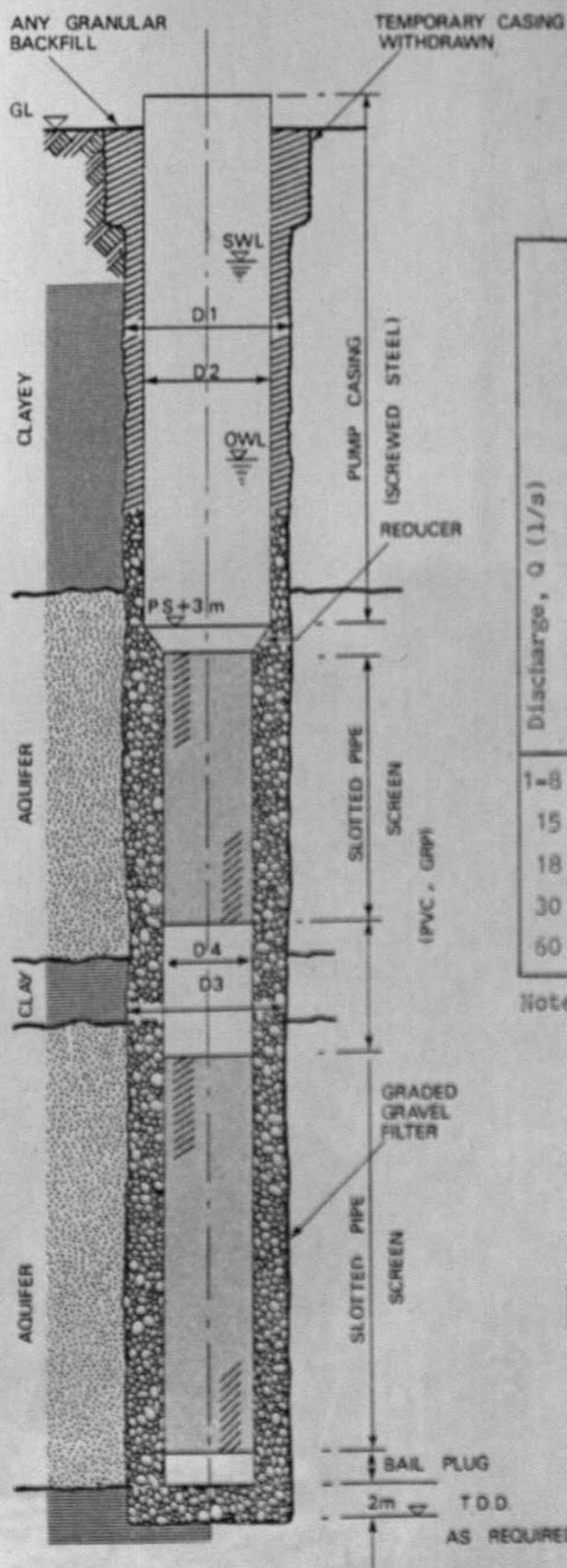
Recommended Diameters

Discharge, Q (1/s)	Upper Hole diam. (mm) with equivalent bit size (ins). D_1	Pump Chamber ID. (mm). D_2	Lower Hole diam. (mm) with equivalent bit size (ins). D_3	Screen Nominal diam. (mm). D_4
1-8	244 (9 5/8)	156	244 (9 5/8)	100
15	311 (12½)	206	311 (12½)	100
18	311 (12½)	206	311 (12½)	125
30	406 (16)	256	356 (14)	150
60	457 (18)	311	406 (16)	200

Note:

Total screen lengths to be determined from desired discharge and economic design criteria.

- 12½ ins. is about smallest feasible R.C. Drilling diameter.

- Drag bits for larger R.C. Drilling can be made up to any desired diameter.

156 Available JPT bit and casing size.

8. AREA DRILLING AND F...

8.1 Introduction

8.1.1 Strategy

Despite examination of maps, geol...
drilling investigations, the init...
type, anticipated problems and be...
area have often been wrong. Are...
techniques have been shown to co...
to require hard rock drilling an...
and state of knowledge of Malaya...
that drilling techniques and equi...
to suit the ever changing si...
shows...
handl...
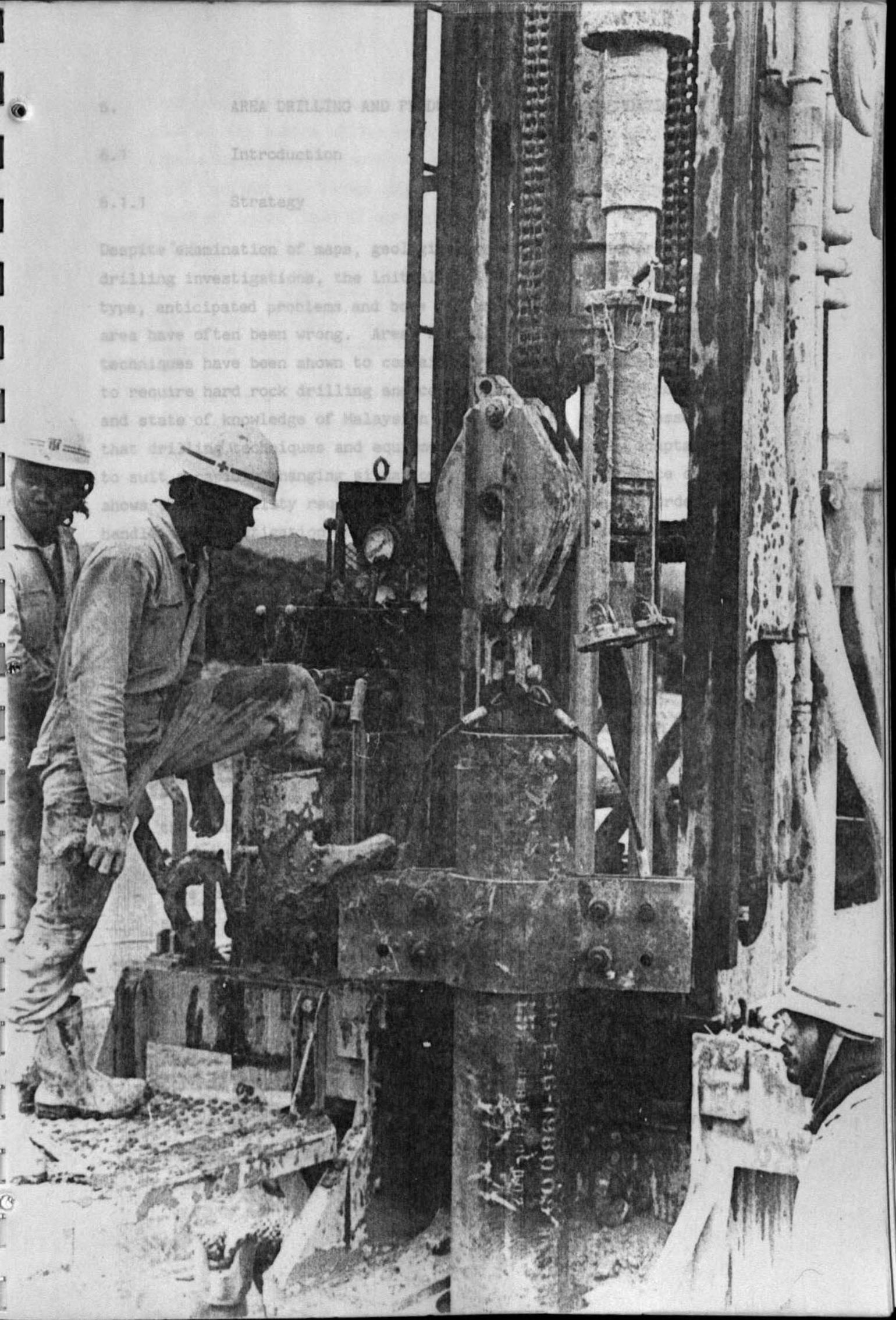
6. AREA DRILLING AND PRODUCTION BORE RECOMMENDATIONS

6.1 Introduction

6.1.1 Strategy

Despite examination of maps, geological reports and data from previous drilling investigations, the initial choices made about drilling type, anticipated problems and bore design in a given JPT investigation area have often been wrong. Areas for alluvial drilling and completion techniques have been shown to contain very thin alluvium and therefore to require hard rock drilling and completion. In present conditions and state of knowledge of Malaysian conditions, it appears essential that drilling techniques and equipment should be readily adaptable to suit a rapidly changing situation. The following sequence of events shows the versatility required of the drilling section, in order to handle the investigation of one site, at the Mardi research station at Bertam, in Seberang Prai. A summary of events during the drilling of bore MB 1A which was originally projected to be a screened bore completion in alluvium, is given below:

- set conductor casing and mix mud

- start hole with dragbit and continue through alluvium; unexpected hard strata is encountered at shallow depth

- dragbit is pulled and rockroller bit substituted. The hard strata turns out to be ferruginous band within the alluvium. Eventually bedrock is reached and after penetrating a few meters, drilling is stopped.

- bore is logged and a recommendation is made for a single string casing assembly including screen

- bore assembly is lowered, no gravel pack is required but gravel is used to stabilize upper clays and to stop this clay from dropping down the annulus and blocking the screened section

- bore is developed by jetting with high pressure air

- discharge from the alluvium is very low, due to high clay content of the sand aquifer. Bore assembly is retrieved from the bore and the bore collapses.

- because a two metre long casing sump (6" line pipe) has broken-off at the bottom of the bore and the bore has collapsed, the decision is made to move the rig a few metres rather than clean and fish out the broken pipe. Redrilling the alluvium nearby took no longer than it would have taken to clear the collapsed bore.

- since it was now known that a hard band existed within the alluvium, a dragbit could not be used and therefore mud and a medium formation rockroller bit was employed.

- this bit was not really suitable for the alluvium, became 'balled up' with clay on two occasions and had to be pulled out. Once the hard rock was reached, drilling continued without problems to a depth where casing was to be set

- A string of welded linepipe was set into rock head in order to exclude the unconsolidated deposits and to act as pump chamber

- drilling mud was then blown from the casing and a hard formation rock roller bit, designed for airflush, was used with compressed air to drill a further hard rock section of the bore. Yielding fissue systems were found in the hard rock (the Sg. Petani Formation)

- because the strata encountered became very hard and progress was slow, the rock roller bit was pulled from the bore and a down-the-hole hammer (DHH) substituted.

- after completion of drilling to final depth, an attempt was made to log the bore; unfortunately shaly strata below the casing became unstable and a piece of rock bridged the bore

- to stop further caving, a special slotted lining was set in the bore opposite the troublesome areas

- the bore was then logged and the hard rock yielding section was airlift pump tested.

The difficulties highlighted here illustrate the need for flexibility in order to handle the drilling conditions. Even whilst drilling this simple section of strata, the driller has had to compromise with his choice of drilling bits and methods.

Table 6.1 shows some of the areas drilled by the JPT and the preferred drilling methods. It must be understood that only a few kilometres from the designated areas, drilling conditions may change drastically.

6.1.2   Exploration and Production Bores

The objectives of the JPT groundwater section have been to carry out groundwater exploration and to develop production bores where water was found available. It has therefore long been recognised that a bore or well of production status will invariably follow an exploration (or pilot) bore and will use design concepts and aquifer parameters derived from that exploration bore.

In some parts of the world, in particulr in the vast alluvial plains of Pakistan, India and Bangadesh, there are thick alluvial deposits, often hundred of metres deep. In such areas, thousands of high capacity production bores have been sunk without any need for exploration on or near the production site. The boundaries of such areas are fairly well defined and virtually all bore drilling carried out would be considered successful.

In Malaysia, groundwater is not so freely available. River systems here are less extensive and the predominance of 'hard' rocks make prediction of groundwater occurrence haphazard. Further, the un-consolidated deposits found along the coastal and riverine plains do not appear to have been transported far, nor sorted and hence they are not 'clean'. Such strata often comprise granite wash deposits of coarse granular quartz and feldspar fragments which high kaolin clay-silt contents which render them very poor quality aquifers. Because of this, the aquifer potential of many so called alluvial plains in the west of Peninsular Malaysia, is low. Because of poor aquifer quality in these areas, pilot or exploration bores are necessary in all new areas.

Average hard rock distances were drilled in Kedah and Perlis by the program as is shown in Table ... ... indication that the average drilling and air lift rates from the exploratory bores; average distances bore rates produced, in about ... ... Clearly, it is necessary ... ... for purposes of a more efficient exploration ... ... and the majority of exploration bores would not be considered for production rotation.

A similar table (Table 6.3) shows data ... drilling and flushing with best contact discharges and ... shale deposits. The preferred distances, ... is most often drilled, cannot provide high-class ... in ...

6.7 PREFERRED DRILLING METHODS

6.7.1 General

From the information obtained from ... ... work and from other sources, it is now possible to set forth ... ... contents in the ... areas are given in the following sections. Whilst generally these variations are dependent on the distances ... ... the DTH type bores are operating at ... ... apparatus, some distance-controlled methods and equipment are best used.

Large time-consuming costs ... ... the use of ... more ... ... dismisses. The ... ... distances ... ... on a different basis as follows:

- Distance ... ... Cost based on a figure of ... ... per ... drilling ... ... per-metre drilled penetration.

- Hard ... ... Cost based on a figure of ... hungers per unit drilling ... cross sectional area of drilled bore metre.

Typical costs are shown (Table 6.4).

TABLE 6.1 PREFERRED DRILLING METHODS

State	Area	Formation drilled by DHD	Driller's Classification of Strata	Preferred Drilling Method	Preferred Flushing System (Superficial deposits)	Preferred Flushing System (Hard Strata)	Preferred Bit Type (Superficial deposits)	Preferred Bit Type (Hard Strata)
Perlis	Wang Bintong and part of Padang Meliwati	Setul Limestone	H.R.	D.H.R.	W or M	A	R.R.	D.H.R.
	Hulu Ayer	Chuping Limestone	C.Lr.	R.R.	M	M or A	D or R.R.	R.R. or D.H.R.
	Tasul Tinggi part of Padang Meliwati	Setul Shale/Sandstone	H.R.R.	D.H.R.	A or R.R.	A	A or R.R.	D.H.R. or R.R.
Kedah	Padang Terap	Setul Shale/Sandstone	H.R.	D.H.R.	A	A	D or R.R.	R.R.
Perak	Kuputo Bahru	Silurian	S.A.	S.R.	M	-	D or R.R.	R.R.
	"	Shale /Sandstone	H.R.	D.H.R.	M	R.R.	B or R.R.	R.R.
	Bukit Merajam	Silurian	S.R.	R.C.	M	A	B or R.R.	-
	Bukit Pulau	Granite	H.R.	D.H.R.	A	A	D or R.R.	D.H.R.
	Bukit Pulau	Silurian	S.R.C.	R.C.	A	A	D or R.R.	R.R.
Perak	Kledger	Granite	H.R.	D.R.R.	A	A	R.R. or D.H.R.	D.H.R.
	Bukit Gantang	Silurian	H.R.	R.C.	A	M	D or R.R.	-
	Tebuk Entar	Silurian	S.R.C.	R.C.	A	M	D or R.R.	-
Pahang	Sungai Temau	Granite/Meta Shales	H.R.C.	D.H.R.	A	A	R.R.	D.H.R.
Kelantan	Pasir Puteh	Silurian	S.R.	R.C.	M	A	D or R.R.	R.R.
		Granite/Meta Shales	H.R.C.	D.H.R.	M	A	R.R.	D.H.R.

Key:
R.R. = Hard Rock, D.R. = medium Rock, D.H.R. = down-hole-hammer, R.C. = Rotary Pad, A = air, M = Mud, W = Water.
R.R = Rock Roller Bit, D = Drag Bit.

6.1.3   Results of JPT Drilling Work

Average hard rock discharges of bores drilled in Kedah and Perlis
by the JPT and JKR in 1981-1983 are shown (Table 6.2). The data
indicate rather low average drilling and air lift yields from 41
exploratory bores; average discharge (dry bores excluded) is
about 6 l/s. Clearly, if success were defined (for irrigation
purposes) as a bore yield exceeding 10 l/s, success rate is low and
the majority of exploration bores would not be considered for
production status.

A similar table (Table 6.3) shows data from alluvial test bores,
with the resultant discharges and comments on their potential.
The results indicate a thin, very low permeability alluvium which
is most areas drilled, cannot provide high yield irrigation bores.

6.2   Drilling Recommendations

6.2.1   General

From the information gathered from the JPT and JKR work and from
other records, broad outlines for exploration and production bore
construction methods in various areas are given in the following
sections. Whilst generally, configurations and designs discussed
in Chapter 5 are followed, recommendations are biased to using the
JPT Tone rigs and existing stocks of 10" and 6" bore casing. Where
appropriate, suggestions for improved methods and equipment have
been made.

Large diameter bores in hard rocks are expensive and exploratory
bore results should be used to give a production design to minimum
diameters. Soft rock and hard rock drilling costs are often quoted
on a different basis as follows:

Alluvial drilling	Cost based on a figure of x Ringgit per cm of diameter drilled per m.
Hard drilling	Cost based on a figure of y Ringgit per unit cross section area of drilled bore per m.

Typical costs are shown (Table 6.4).

TABLE 6.2   HARD ROCK DRILLING AND AIR LIFT TESTING - KEDAH AND PERLIS

Borehole No. Informal ISM	Total Depth (m)	Yielding Zone	Static Water Level bgs (m)	Test Date	Discharge Q (l/s)	Drawdown Sw (m)	Specific Capacity (l/s/m)
KEDAH - PADANG TERAP							
PT 1	T109	60	Semanggol Formation meta shale/sandstone	8.8	18,11,83	5.2	8.59	8.81
PT 2	T102	151	"	1.75	4,12,81	2.3	10.49	0.22
PT 3	T103	77	"	5.65	17,12,81	2.0	14.51	0.28
PT 4	T104	60	"	2.9		5	10.95	0.46
PT 5	T105	66	"			11.55		
PT 6	T106	66	"	8.08		10.55		
PT 7	T107	62.5	"	8.8	2,3,82	3.0	12.3	0.24
PT 8	T108	66	"			09		
PT 9	T109	61	"	1.9	27,1,82	4.5	12.04	0.37
PT 10	T110	125	"	5.3		10.71		
PT 11	T111	63	"	2.1		12.55		
PT 12	T112	60	"	5.6	16,2,82	6.2	10.26	0.61
	420	26	"	1.8	4,6,79	6.4	17.06	0.35
	402	38	"		29,6,79	13.75		
	537	33	"	4.5	28,10,79	8.25	16.5	0.13
	539	50	"	1.98		1.5	9.64	0.29
	540	59	"	5.85	26,12,79	5.9		0.4
PERLIS - BUKIT TEMIAK							
TT 1	BT14	60	Kubang Pasu or Singa Formation	4.28		deep		
TT 2	T115	60	"	3.2		deep		
TT 3	T116	216	"	-		dry		
TT 4	T117	60	"	2.57		(1.4)	2.2	3.18
TT 5	T118	100	"	-		10.55	10.09	0.55
PERLIS - PADANG MELAWAET							
PM 1	T119	54	Kubang Pasu Formation	3.33	28,4,82	5.7	10.17	0.56
PM 2	T120	130	"	3.65	13,4,82	5.5	10.24	0.63
PM 3	T121	64	Setul Limestone	8.21	5,5,82	7.8		3.18
PM 4	T122	88	"	8.68	19,6,82	5.5		0.55
PM 5	T123	100	"			45.55		
PM 6	T124	115	"			11.25		
	65		"			19.05		
	770	65	"			19.05		
	781	55.5	"			11.55		
	782	60	"			19.45		
	783	20.5	"			9.55		
	784	61.5	"			9.55		
	785	60	"			17.55		
	795	49.5	"			16.55		
	783	49.5	"			19.25		
	796	49.5	"			17.55		
PERLIS - MATA AYER							
MA 1	T130	78	Chuping Limestone	4.36	6,5,82	7.8	5.82	1.2
MA 2	T131	106	"	5.09	12,5,82	7.9	5.24	1.25
MA 3	T132	64	"	2.3	18,5,82	7.7	6.45	1.2
MA 4	T133	60	"	3.5		4.08		

Notes:

*   JKR/GSC boreholes in Kuala Nerang/Batu Chin area
**   Discharge from 2-3 hr. air lift test
(2,1) Drilling discharge
bgs   below ground surface

TABLE 6.3 ALLUVIAL DRILLING : AIR LIFT DISCHARGE

Borehole No. Informal	GSM	Total Depth (m)	Aquifer; Target	Static Water Level bgl (m)	Test Date	Discharge (l/s)	Drawdown (m)	Specific Capacity (l/s/m)
SEBERANG PRAI - ALMA								
A 1	1128	55	Alluvium; weathered bedrock	-	3.9.82	*1.5	large	-
A 2	1129	41	Alluvium; weathered bedrock	-	8.9.82	*1.8	-	-
SEBERANG PRAI - BERTAM (HARDI)								
(1) NB 1	1136	54	Alluvium			(1.3)	-	-
PENANG - BALIK PULAU								
(2) BP 1	1134	97	Eluvium-coastal alluvium	1.0	4.10.82	*3.8	18.31	0.21
(3) BP 2	1135	101	Eluvium-coastal alluvium	1.9	15.10.82	*5.5	14.5	0.38
PERAK - ENGGOR								
E 1	1113	100	Eluvium; weathered granite quartz residual	-	-	(<0.1)	-	-
PERAK - BUKIT GANTANG								
BG 1	1140	40	Eluvium-Alluvium	0.45	11.12.82	*1.0	5.07	0.2
BG 2	1141	21	Eluvium-Alluvium	-	-	(0.1)	-	-
PERAK - CANKAT JONG								
(4) CJ 1	1142	42	Alluvium	-	22.1.83	<0.1*	-	-
CJ 2	1143	96	Alluvium	-	Not tested	-	-	-
CJ 3	1144	66	Alluvium	1.69	8.1.82	2.3*	19.21	0.12

Note:

(0.1) drilling discharge

2.3* Discharge from 2-3 hr. airlift test

bgl below ground surface

1 Screens 21-24 m

2 Screen 40-49 m

3 Screen 42.5-45.5 m and 51-54 m

4 3 m Screen set successively over intervals 9-12 m and 15-18 m.

Table 6.4 Hard and Soft Rock : Indicative Drilling Costs

Bore diameter (cm)	Rock type	Cost per m ($)
15	soft	60
15	hard	100
30	soft	120
30	hard	400

6.2.2   Hard Meta Sedimentary Rock Drilling

Exploration Bore Construction

These rocks are extensive in Peninsular Malaysia. It can be seen (Table
6.2) that average yield is low. The chances are that a high yielding bore
is unlikely and the minimum exploration drilling diameter is likely to
be of suitable size for the diameter required by a subsequent production
bore. A suggested sequence of operations is as follows:

- set 2-3 m of 8" dia. conductor casing

- drill with air, through overburden into sound rock;
  bit size 7 5/8"

- ensure temporary casing is set firmly into rock head;
  average penetration into rock is 2-4 m. Do not set
  casing too deeply into the rock as most water is found
  in the top few metres

- continue drilling with 5 7/8" or 6" bits to final depth

- conduct airlift test or decide on further action required
  on the basis of water discharge observed during drilling

- if sufficient water is present, pull back temporary casing.
  If discharge is high, ream bore out or, usually, insert
  production casing i.e. 6" line pipe, welded joints. Clean
  bore out afterwards.

- if insufficient water for irrigation, consider possible use to
  JKR or leave as a piezometer. If not, backfill bore and place
  concrete plug at 1.0 m depth.

'Overburden' is a superficial deposit; not truly alluvium but may be in-situ weathered rock. In the meta-shale areas, the overburden is clayey in nature and airdrilling is possible. Out of 23 such sites, 20 were airdrilled from the surface; average overburden thickness was 8 m, and 16 m was the deepest. The Tone rig compressor was boosted by a second unit and occasionally foam was poured down the drillpipes, especially while drilling the deeper overburden. Sampling in the overburden will not be complete for each metre. This is because of sticky conditions, poor UHV and perhaps lost circulation zones. If overburden is deep and whenever water is situated close to the site, water flush drilling is preferred as sampling and drilling is mainly trouble free. Water flow past the site allows waterflush drilling without a pit system. Alternatively water may be pumped by the centrifugal pump to a tank at the rig and sucked from there.

The most suitable bit for the overburden is the dragbit but for dry shallow deposits, the rock roller bit is best. Rock head may be too hard for the dragbit to penetrate (e.g. MB 1A) and the rockroller would then be required. The drill string should be equipped with a drill collar as, when passing from soft to hard rock, there is a danger of bore deviation. Without the drill collar, a 9 5/8" bit may be necessary.

The choice of whether to use temporary casing or insert the final, production casing immediately is a matter of judgement. Previous experience in the area, or plans to have a piezometer on the site will help in making the decision.

Deep alluvium over hard rock (Mardi Bertam) will need mud for drilling whilst in most situations, the hard rock drilling is best carried out using the DHH although in 'wet' bores, backpressure may cause premature abandonment of the method. Where a rockroller bit has to be used in hardrock a medium/hard formation type is preferred.

Production Bore Construction

Out of the 23 bores drilled in the meta-sedimentary shale-sandstone rocks, only one was considered worth reaming out to accept 10" pump chamber casing. The potential discharge of the remainder could be accommodated within a 6" pump casing and such bores have been completed that way. A operations sequence for a production bore is given below:

- Consider specific capacity of bore as indicated by short
  preliminary yield test, but assume lower specific capacity
  values in deciding a production yield. Define location of
  yielding fissures from drillers log. This is important as a
  pump chamber casing positioned wrongly, may seal off some of
  the aquifer and even if it is slotted, an over-ambitious estimate
  of pumping capacity may de-water the upper part of the fissure
  aquifer. For production bore design consider alternatives
  shown earlier (Figure 5.2).

- pull back temporary casing and prepare to ream bore out to
  accommodate 10" nominal bore casing

- drill with 15" dragbit or 14 3/4" rock roller bit to set 13 3/8"
  conductor casing

- with 8" drill collar, 12" stabilizer and 12¼" dragbit or soft
  formation rock roller bit, drill through overburden using foam
  or water if necessary. Many of the drill cuttings may not reach
  surface and will fall down the pilot bore

- be prepared to change bit type for 12¼" rock roller suitable
  for hard formation and ream pilot bore to desired depth; see
  below for preferred system

- during reaming, pump chamber casing must be prepared; slot
  lower casing if necessary and fix any cement basket device
  required

- run in and weld casing assembly to bottom of reamed section;
  check verticality of casing

- clean out lower bore with foam using original pilot hole bit.
  If a part of the lower bore requires a 6" drop-set lining, then
  this section must have the 7 5/8" pilot hole bit and the 6"
  drill collar pass through it before drop set installation is
  attempted

- cement casing if necessary; see below

- conduct final pump test and cap the bore.

FIGURE 6.1   WINGED HOLE OPENER FOR ALLUVIUM

If overburden contains gravel, the reaming operation may require either that 13 3/8" conductor casing is set into rock head (about 0.5-1 m should be sufficient) or else the reaming should be carried out entirely under bentonite mud.   If mud is used, some losses can be expected initially but afterwards, cavings from the overburden often blocks the pilot hole and circulation is regained.

The drilling of the rock head section is most important as it is at this point most bore deviation problems occur. In horizontal bedded sedimentary deposits, this problem is small but in Malaysia, the majority of the metasedimentary shales and sandstone strata encountered are steeply dipping. to ensure bore concentricity and to minimise deviation during reaming, the operation described above is best performed with a 'hole-opener' (Figure 6.1). JPT do not possess this tool bit its purchase is recommended.

Slotted pipe to be used against cracked rock should have fairly large apertures cut in it. The cement basket (or packer) mentioned above may be required if loose overburden has been encountered; such a device acts as a barrier to ingress of caving material. The bore designs in Chapter 5 show situations where a basket is required.

If a hole-opener has been used for reaming, then the enlarged bore might be expected to be as straight and vertical as the original pilot bore. Even with a conventional rockroller bit, a proper drill collar/ stabilizer arrangement should ensure straightness, if not verticality and concentricity, and the installation of the permanent pump casing should present no difficulty. However, the casing needs to be carefully checked for alignment before each casing joint is welded. After installation, the casing assembly needs to be positioned so that the best straightness and verticality is achieved. On long assemblies this is carried out by pulling on the casing slightly (but keeping the bottom piece seated), clamping at the surface and then cementing or backfilling the annulus.

After reaming, the required cleaning should be straight forward if foam is used; air alone may be ineffective with the Tone rig compressor. Attention should be paid to hard rock development techniques.

FIGURE 6.1   WINGED HOLE OPENER FOR ALLUVIUM

STANDARD TONE 12½"
DRAG BIT.

CUT DRAGBIT HERE.

60cm APPROX

PILOT BIT 7⅝"
SOFT FORMATION
EITHER ROCKROLLER
OR DRAGBIT.
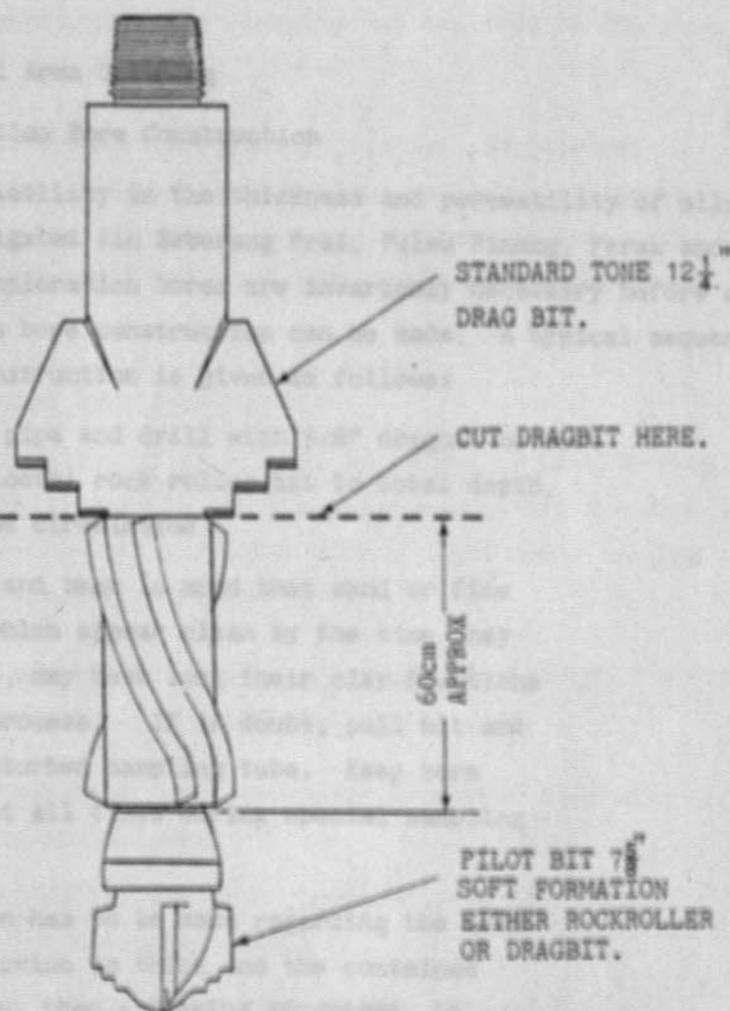
EXPLANATION:

1. PILOT BORE SHOULD BE REAMED OUT WITH HOLE-OPENER TO ENSURE CONCENTRICITY.

2. CUT 'NOSE' OFF STANDARD TONE DRAGBIT AND WELD-ON SPIRAL SUB AS SHOWN ABOVE.

3. SPECIAL A.P.I. JOINTS ARE NOT NECESSARY. BOTH SUB AND OLD BIT MAY BE WELDED IN POSITION (PILOT BIT HAS LONG LIFE).

Placement of cement in the annulus between borehole wall and casing
is rarely necessary for irrigation bores but is standard practice for
drinking water bores.

6.2.3   Alluvial Area Drilling

Exploration Bore Construction

Because of extreme variability in the thickness and permeability of alluvial
deposits so far investigated (in Seberang Prai, Pulau Pinang, Perak and
southwest Kelantan), exploration bores are invariably necessary before any
decisions on production bore construction can be made. A typical sequence
of exploratory bore construction is given as follows:

- set 8" conductor pipe and drill with 5/8" dragbit or soft
  formation (long tooth) rock roller bit to total depth,
  using drilling mud circulation

- sample carefully and bear in mind that sand or fine
  gravel samples, which appear clean by the time they
  reach the surface, may have lost their clay fractions
  in the drilling process.   If in doubt, pull bit and
  run in a U3 undisturbed sampling tube. Keep bore
  filled with mud at all times during special sampling
  and logging

- a careful decision has to be made regarding the next
  step. If the alluvium is thick and the contained
  sands appear clean, then a reaming programme, to
  accommodate large pump chamber casing, may be needed.
  If coring by 43 tube and geophysical gamma logging
  indicate very low sand permeabilities, then consider
  abandonment of the site.

Bentonite should be mixed several hours before use and the mud should
have a viscosity of between 36-40 seconds (Marsh Funnel). The pit and
channel system should be as earlier indicated (section 2.1.9); water
should be immediately available to mix mud, in case of mud loss.

Do not run the mud pump for too long with the bit in one spot otherwise
the bore will erode; caving and sample contamination will result.

If for some reason the upper section of the bore caves or collapses altogether, cleaning out may be found difficult without casing off the enlarged section of the bore. This may mean running 8" temporary casing down past the caving area and cleaning out the rest of the bore with a 7 5/8" bit.

In alluvium, final drilled depth is usually rockhead or bedrock; the exception to this rule perhaps is where deep salinity is expected. In most places investigated, rock head has been either granite or the meta-shale sequence; at Telok Intan, soft claystones were effective bedrock.

Production Bore Construction

The reaming operation in alluvial conditions is generally trouble free. The dangers of eccentricity through using a conventional bit for reaming are much less but never-the-less a dragbit with a pilot head, similar to the hole opener, is preferred (Figure 6.1).

Two basic bore designs are used; one uses a natural development technique whilst the alternative requires an artificial gravel pack.

A typical construction sequence for a naturally developed bore of production type is given as follows:

- pull out the 8" conductor used for the pilot bore and substitute a 13 3/8" conductor casing

- ream bore with 12½" wing bit to pump chamber setting depth plus one metre; pull out

- run pilot bit (7 5/8" dia.) back down bore, to a depth at least 6 m lower than the projected base of the bore casing-screen
  or
  ensure that the pilot exploration bore is open by plumbing with weighted plumb-line

- run in one piece casing assembly and test for verticality; set casing in clamps.

- evacuate mud from the bore by gently airlifting at the bottom
  of the pump chamber; the aquifer material should then begin to
  collapse against the screen. Slowly move jetting development
  tool down to the bottom of the casing assembly. After the
  initial downward pass of the development tool, rotate the
  tool upwards slowly and develop each screen thoroughly.
  A final (downward) pass, to clean out the bottom screens
  which may have become partly filled with sand will be necessary
- pump for a period with test pump to ensure sand free running
  at design discharge.

The construction for a production bore which is to be artificially
gravel packed is somewhat different, as follows:

- pull conductor used for pilot or exploration bore and set
  13 3/8" conductor casing
- ream pilot bore using 12¼" wing bit to a depth 6 m greater
  than anticipated maximum depth of the bore casing-screen
  assembly. Ream out with 15" drag or wing bit to pump casing
  setting depth plus two metres; pull out.
- run in a one piece type casing-screen assembly. Check pump
  chamber casing for verticality, set in clamps and induce
  graded gravel pack by pouring gravel into annulus from all
  sides in a non-stop operation
- develop as before and backfill annulus with gravel as required.
  Follow special gravel packing instructions (section 4.7.1).

Alternatively, for smaller diameter gravel packed bores or for naturally
developed bores in known producing areas, the following system is
recommended:

- drill single pass with 12¼" bit to required pump chamber
  casing setting and run in 10" casing; clamp after checking
  verticality
- drill lower bore using 7 5/8" bit for natural development,
  or 9 7/8" bit for thin gravel pack. Ensure bore is to correct
  depth for bore casing-screen assembly and run in lower casing
  on bayonet or LH/RH threading system.

FIGURE 6.2 GRAVEL PACK INSTALLATION 2 - STRING WELL ASSEMBLY

The lower bore casing (LWC) for the natural development will have a
close fitting flange positioned on the top joint. This will sit
about a metre up in the 10" pump casings when the lower end of the
screen sits on the bottom of the bore (Figure 3.3). The LWC for
gravel packing needs to be connected with a temporary casing so that
a gravel pack may be safely installed (Figure 6.2). Development
should take place until all gravel settlement has finihsed and then
the temporary casing may be disconnected. The ten inch casing in all
cases should be held at the surface in clamps under tension until
development is complete.

6.2.4   Limestone Drilling : Setul Type

               Exploratory Bore Construction

Drilling in the Setul limestone in Perlis, by both JPT and JKR,
has had only a moderate success. In the JPT drilling, out of four bores,
only one was considered worth converting to a 10" diameter production
bore.

The Setul limetone is very hard even at rockhead. There does not seem
to be any softening by weathering, although the first metre or two
may be broken. The overburden may be gravelly and may require to be
drilled with mud. Because of the hardness of the Setul, importance
has to be paid to verticality and straightness especially when drilling
at the base of the overburden and into the fresh rock. Pilot bore
drilling recommendations are made, thus:

- set 8" conductor and drill with dragbit or rockbit
  to rockhead, using water or mud circulation. Ensure
  that a hard formation rock bit (7 5/8") and drill
  collar is used to drill into the rock; do not over-
  weight bit for the first half metre. Make hole for
  temporary casing about 2 m into the rock

- run temporary casing and continue drilling at 6" dia.
  by air flush with DHH

- monitor the electrical conductivity (EC) of any water
  discharged, especially where the Setul is drilled near
  the coast (e.g. Kangar)

- proceed as suggested in section 6.2.2 regarding any
  conversion.

10" PUMP CHAMBER

6" TEMPORARY CASING

BACK-OFF JOINT (BAYONET)
OR USE L.H./R.H. THREAD.

CEMENT PLUG
(AFTER DEVELOPEMENT).

6" BLANK AND SCREEN

CENTRALISER

GRAVEL PACK

CASING OVERLAP

EXPLANATION:

1. GRAVEL PACK THE WELL VIA THE CASING
   ANNULUS.

   DEVELOP SCREENS WITH TEMPORARY CASING
   CONNECTED AND BACK OFF AFTER GRAVEL HAS
   COMPLETELY SETTLED.

2. FOR NATURAL DEVELOPED WELL DESIGN (WITHOUT
   GRAVEL PACK) A PACKER COMPRISING STEEL AND
   RUBBER FLANGES SHOULD BE FITTED BELOW
   BACK-OFF JOINT.

3. CASING OVERLAP NEEDS TO BE A MINIMUM OF
   1.0m FOR BOTH SYSTEMS.

Where overburden conditions are suitable, a quicker alternative method
is possible:

- drill directly through conductor casing with Dresser T6 DHH
  fitted with a 7½" bit; a 6" drill collar must be fitted
  immediately above the hammer

- penetrate about 2 m into the rockhead and case.

Note that the hammer will not operate perfectly in the clay material
but once the rock is reached, the hammer will perform well at a
penetration rate of about 5 min/m.

Production Bore Construction

The drilling or reaming of large diameter production bores in Setul
Limestone with the Tone rig has proved difficult. The following
reports, extracted from the May 1982 progress report of the JPT
Groundwater Section, adequately describe the problems encountered during
the drilling of bores WB2 and PM3 in Perlis. These reports also give
recommendations on bore construction techniques and equipment
modifications.

Wang Bintong (Setul Limestone WB 2)

The bore, the first of the Setul limestone drillings, was eventually
abandoned because the ground in the vicinity of the rig caved due to
the effects of the drilling operation. The occurrence of pits and
depressions several meters away from the rig is very unusual and is
ascribed to a general disturbance of an irregular channelled karstic
surface developed upon the Setul and infilled with clay and pisolitic
material.

During the drilling, the loose overburden was cased off with 10" casing.
Unfortunately the casing hardly penetrated competent rock, and compressed
air possibly entered the fissured zone and caused some disturbance.
At 18 m penetration, a fissure containing a mud-gravel mix was
encountered and whilst drilling through this zone, quite a lot of
gravel caved and was excavated before temporary casing could be placed
in the bore. At 53 m penetration, another fissure, also containing
a sand-gravel-mud mixture, was encountered. This mixture too was in
a fluid state and a fair amount of material was again excavated.

However the volume of the material lifted to the surface was insignificant when compared to the greater volume of the depressions formed on the karstified surface. The conclusion is that the rock is heavily fissured, that the fissures are plugged with unconsolidated and saturated material and are directly connected to the surface. Obviously, natural solution processes continue in the area as settling is incomplete. We have learned subsequently that similar depressions have appeared in the region in the past.

The drilling of WB2 has demonstrated that a conductor casing has to be positioned properly into rock-head and that the drilling of the first two or three metres into the hard rock will take several hours to complete; only then can the conductor be set. It is apparent that loose overburden will not stand whilst air is used for flushing and that water or mud is essential. Once conductor casing has been set, air can be used as usual but mud may subsequently be necessary if large infilled fissures are encountered.

Padang Melangit (Setul Limestone PM 3)

Because of the problems encountered at Wang Bintong, the rig was set up with a larger area of base timbers to allow rig support in case of ground disturbance. A convenient water supply in a nearby canal made it easy to use water for flushing (otherwise mud pits would have been necessary). Rockhead was found to be 4.5 m approx. and a 7 3/8" bit was used to drill on to 10.5 m. Six inch casing was then set and the hole continued at 6" diameter to 72 m with the DHH. Back pressure due to inflow of water at 56 m reduced the penetration rate. Therefore, as a comparative trial, a 5 7/8" rock bit was run-in to demonstrate conventional rotary drilling under hard rock conditions.

The penetration rates achieved are shown (Figure 2.14). They demonstrate in particular, the slow start, where the bit had to be controlled so that it did not 'slide' down the sloping rock head, and the improved rate of penetration at about 6 to 10.5 metres when a drill collar/stabilizer and extra weight could be safely added. From 10.5 m onwards, the DHH showed its ability until it was slowed because of back pressure problems. At this stage, only higher pressure air could have helped in improving penetration. However, the rock roller drilling was shown to be slower still, even though the bit carried six times more weight on it (with correspondingly more wear to mechanical components) than does the DHH.

Figure 6.3 CONVERSION OF EXPLORATORY BORE TO TEST-PRODUCTION BORE

On the basis of a short airlift test, the decision was made to ream out the exploration hole to accommodate a 10" pump chamber set to about 22 m. To allow a 12½" rockroller bit to ream the rock in safety, 13 3/8" casing had to be set into rock head and in order to make the hole into the rock head to accommodate this casing, a 15" bit had to be borrowed from a private drilling contractor.

Hole opening, from 7 3/8" dia. to 15" dia. from ground level to 5.5 m or one metre into rock, was extremely slow and took a full day. The reaming of the 7 3/8' dia. hole (from 5.5 m to 10.5 m), and the 6" dia. hole (from 10.5 m to 21.5 m) at 12½" dia. took 6 days of work! Figure 6.3 shows the bore construction and tools used.

A total of six or seven days of work to convert an exploration hole into a test production bore (including the installation of 10" casing and the cleaning out of the pilot hole below) is excessive. In addition, the strain on the rig's hydraulic system and head motor was such that similar exercises, carried out in very hard rock, could eventually lead to serious damage to the machine or at least to a shortening of component life. This judgement is based on careful supervision of the operation, during which time particular attention was paid to the high torque required to rotate the larger size bits in a cracked hard rock. Already, high pressure oil seals have blown in a hydraulic motor on both rigs because of excessive torque.

It is concluded as follows:

- that the rig would find it difficult to complete a large number of similar large diameter hard rock bores in Setul limestone using the present equipment

- the same difficulty will be expected during the projected drilling in granite rocks

- alternative equipment will be required for any development drilling of 10" TP bores in the Setul or in granites

The rig can adequately complete exploration bores of 6" cased diameter in rocks such as the Setul. However, if numbers of 10" cased diameter production bores were eventually needed, new equipment would have to be bought. This would need to include a 700 cfm x 250 psi compressor,

Figure 6.3 CONVERSION OF EXPLORATORY BORE TO TEST-PRODUCTION BORE.

a DHH suitable for drilling up to 12¼" dia., 10" and 12¼" button bits, a 7 7/8" x 12¼" hole opener equipped with replaceable rollers subbed 6 5/8" REG. PIN-UP, hard formation rock bits of 7 7/8" 12¼",and 15" diameter and foam pump capacity 0-30 l/min at 300 psi.

The practice of reaming a hole in a cracked and fissured formation, from say 6" to 12" diameter, with an ordinary tricone rock roller bit can lead to difficulty. The bore produced often is eccentric and hence the possibility of deviating away from the original exploratory hole exists. To overcome this, tools known as hole openers are used. They have a lower pilot bit which follows the original pilot (or exploration) hole and the upper section of the tool usually consists of three wings each equipped with a single roller rock cutters. Normally, a 7 7/8" hole could be opened to 12¼" dia. but not to 15". If the latter diameter was required, another hole opener of 12¼" to 15" size would be required or alternatively one having two tiers of cutters of different diameters. For DHH drilling only a limited range of tools are available and the hole opening process is often a combination of DHH and conventional rock roller drilling. Very often, it is easier to drill a new hole close by with a bigger hammer and hence avoid the reaming-out operation.

It can be seen that penetration rates for DHH drilling are often four times better than rock roller drilling. However the DHH method cannot be used where unconsolidated materials remain uncased; this often prevents the use of the DHH in the rock head zone, at least until casing has been set. Therefore the above list has to contain equipment sufficient to allow substitution of hammer for equivalent diameter rock roller operation where appropriate. The reaming out the PM 3 was extremely slow and the following facts are pertinent:

- a rock bit considered suitable for a hard formation is usually designed to take a load of up to 1,450 kg for each centimetre of diameter. Hence a 7 3/8" dia. bit could take a maximum weight of about 26 tonnes

- The rig's hydraulic pulldown arrangement allows about 6 tonnes weight on the bit at shallow depth. In applying this weight, torque is in themiddle range for homogeneous rock. When cracked or broken rock is encountered, weight on the bit is reduced to give a drilling action that does not give an unduly high torque which is potentially damaging to the rig.

- a 12¼" dia. bit is a little more than twice the diameter
  of bit used in an exploration bore (typically 6") yet
  has four times the area of rock to cut. However, the
  6 tonne pulldown available gives only about 227 kg
  weight per centimetre of diameter

- observations conducted during the reaming of PM 3
  showed that only an average of 2.0 tonnes total weight
  on the 12¼" rock roller bit was possible, otherwise high
  torque was produced (which resulted in a burst oil seal).

It can be concluded that in very hard rocks, larger diameter production
bore drilling by rock roller could progress at only one tenth of the
rate produced by a bit half the size. Therefore the DHH technique should
be employed whenever possible.

6.2.5   Limestone Drilling : Chuping Type
               Exploratory Bore Construction

The Chuping limestone in Perlis contains a substantial aquifer which is
used by JKR and by the Chuping sugar estates. The JPT have recently
drilled four bores into the Chuping, three of which were reamed to
accept production bore 10" pump casing. Bore success in the Chuping
is quite high, with the possibility of bore yields of 10-30 l/s
(Table 6.2).

The rock is unstable near surface and can present difficulties with
caving and lost circulation. Average thickness of overburden in the
Mata Ayer area of Perlis is 30 m and this comprises both loose sandy
or silty sections and, often, shattered rock. A suitable exploratory
bore drilling sequence is given, as follows:

- set 8" conductor

- drill with mud through overburden/alluvium into sound rock.
  Use a 7 5/8" bit with drill collar. Ensure adequate drilling
  mud reserves.

- Penetration into rock should be to about 10 m before preparing
  for temporary casing insertion. The rate of mud loss, inevitable
  in this section, should be observed.

- run in temporary casing. Empty mud from bore and drill with
  6" bit (a DHH is unlikely to be necessary) to final depth;
  proceed with caution

- conduct yield test or decide on further action after
  considering both the discharge of water during drilling and
  the possibility of an aquifer existing behind the temporary
  casing

- if bore is to be converted to a large diameter production bore,
  follow recommendations shown in section 6.2.2. If bore has
  limited potential, equip with a 6" casing assembly as described
  previously.

JPT has drilled one bore complete Chuping bore with air but with difficulty;
JKR has drilled several by air but because of difficulties, it has become
their policy to use mud.

The main aquifer potential is in the rock close to rock head.
Unfortunately, the aquifer is very dirty due to the presence of loose
deposits in the karstic, fissured rock; these deposits are likely to
be connected to the overburden. This troublesome upper zone can be
sealed off so that deeper drilling can attempt to find a lower and
cleaner fissured.   If this strategy proves successful then the
upper zone can be permanently sealed off.   If the lower zone is shown
to be non-productive, the upper zone behind the casing has again to be
considered for development.

If circulation is lost during the mud drilling phase, the driller
should be prpeared to lose several pits of mud. To drill blindly for
a few metres is prepared, but there is great danger of hole collapse
in the upperhole if the mud level drops. Casing must be firmly set
into sound rock before airdrilling commences.

final drilling depth is uncertain but is usually within 50 m of the
rockhead. One bore has been taken down to 170 m but mud loss was not
reported below 90 m depth.

Very fresh (unhydrated) drilling mud should not be employed as in this
state, it may continue to swell and block the aquifer permanently.

Production Bore Construction

Trouble has been experienced by both JPT, JKR and private drilling
contractors, in completing production bores in the Chuping Limestone.
The principal methods are those recommended generally for hard rocks
but with emphasis on a few extra precautions as follows:

- overburden drilling has to be carried out using mud

- the bore will collapse when any temporary casing is pulled.
  To avoid this, the bore should not be filled to the surface
  with drilling mud as is the normal procedures; instead, natural
  bridging of the pilot hole through caving, helps in gaining
  mud returns and allows a straightforward reaming operation.

- the Chuping limestone aquifer is often incompetent near the
  superficial rockhead zone. Pump chamber depth should be such
  that much of the loose unstable rock is sealed off, without
  completely isolating the aquifer. Hopefully, cleaner
  fissures encountered further down will prove sufficient
  to contribute to bore yield. If not, efforts are needed
  to minimise ingress of unstable material in the upper aquifer
  zone. Two JPT bores in Mata Ayer rely on so-called 'clean'
  fissures for their supply; one bore has a slotted dropset
  lining positioned opposite the unstable or 'dirty aquifer'.

- there is evidence that pumping of the Chuping aquifer tends
  to pull in large quantities of silty material, and in so
  doing cause disturbance to the overburden/alluvial deposits.
  Subsequent settling then may force clayey particles into the
  annulus around the window or protective slotted casing and
  cause blockage. To avoid this, it is advisable to have slots
  of about 4-6 mm in the casing; wire-wound screen is susceptible
  to blockage and should not be used.

A bore design using a gravel stabilizer pack behind the slotted window casing may help to relieve the problem. Here are the alternative construction requirements:

- after setting pump casing, ream bore from the casing toe at 9 5/8" dia. to two metres below the unstable zone; this should be done with mud, before the lower hole is cleaned out

- install the dropset slotted liner (window or protective casing) by using bayonet or LH/RH system

- induce gravel stabilizer around slotted liner and cap the gravel with cement plug

- develop bore until sand free; do not use suction methods of development on this particular aquifer othewise the gravel may block off.

Cementing the pump casing at its base has been considered as a method of overcoming silt ingress but JKR drilling staff report that silt is sometimes drawn through lower fissures and cementing efforts are to some extent wasted.

Development by overpumping and airlift within the bore are probably the best methods. Prior to pump testing, the pump should be run at varying discharges up to its maximum to monitor and clean the bore.

The test pump must not be stopped quickly if large quantities of sand are being discharged, otherwise the impellers will become sand-locked and the pump will need to be withdrawn. Rather, pumping should seek to produce sand free discharge before pump rate is increased to a next higher rate.

6.2.6   Drilling in Granite Areas

In areas where granite has been encountered (at Alma near Bukit Mertajam, at Bukit Gantang near Taiping and near Pasir Putih, Kelantan) the formation above the rock usually comprises thin alluvial sands and gravels; nowhere has the granite exhibited groundwater potential. On the west coast, granite appears to be more weathered

and the first few metres is often drillable by a rock roller bit.
The granite cut in bores near Pasir Putih in Kelantan is extremely hard
and fresh.

It is recommended that drilling should be with mud flush whilst drilling
the upper hole through the alluvium whilst a down-the-hole hammer should
be used once casing has been set. Production bore drilling should take
into account the recommendations made for the other hard rocks.

7.   MISCELLANEOUS

7.1   Yield Tests and

7.1.1   Yield

Whilst drilling the main formations, any aquifer intersected as a continuous returns, the
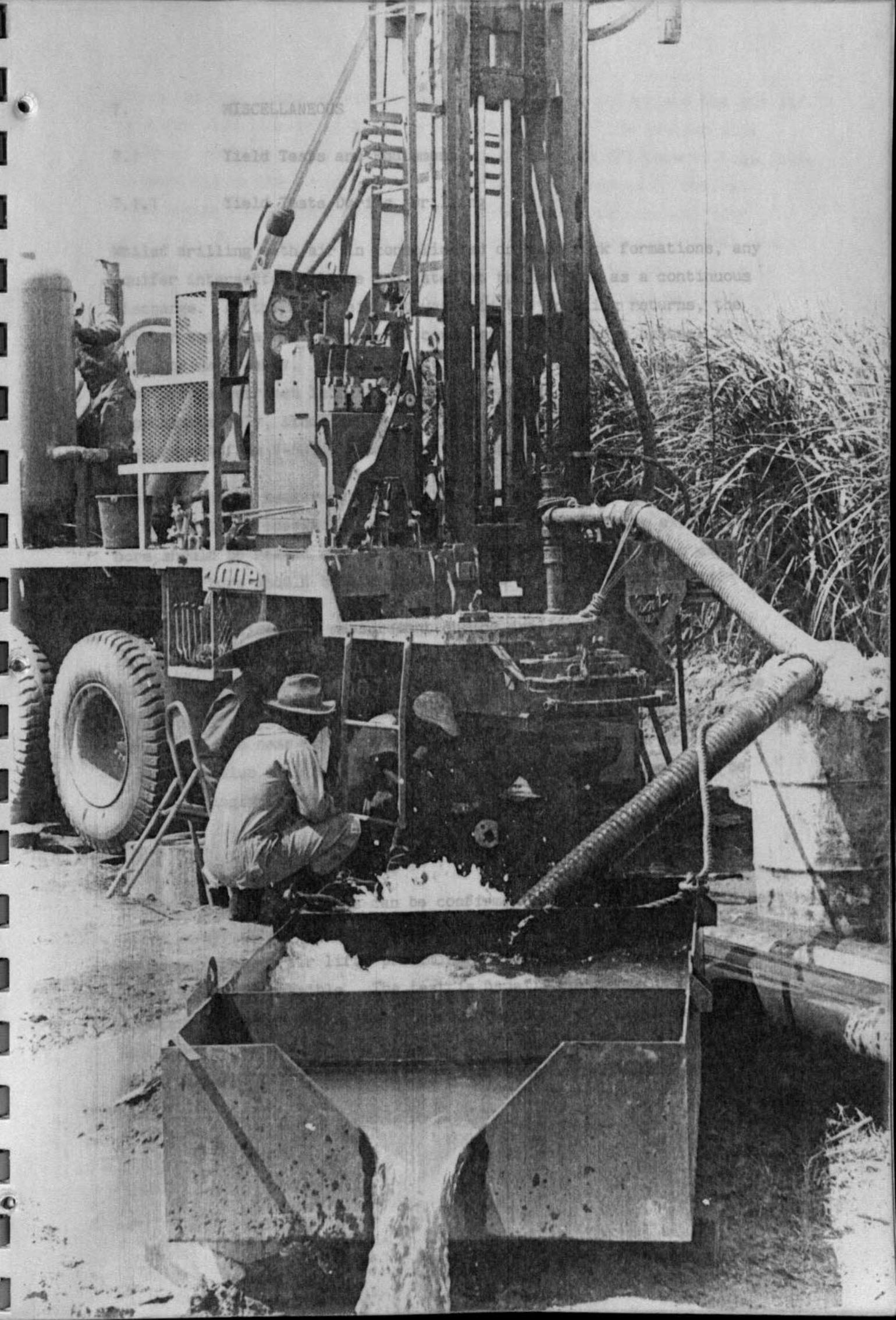
7.   MISCELLANEOUS

7.1   Yield Tests and Equipment

7.1.1   Yield Tests During Drilling

Whilst drilling with air in consolidated or hard rock formations, any
aquifer intersected will be indicated at the surface as a continuous
discharge. At the first sign at water in the drilling returns, the
driller builds a bund around the conductor casing and a channel to
lead the water away. The discharge is then monitored by passing the
flow over a weir set into the channel; readings obtained are considered
approximate only, since the hydraulic conditions governing discharge
measurement from V-notch weirs are only approximately met.

These discharge measurements are then used to formulate the next part
of the drilling operation, in particular to decide if the exploratory
bore should be reamed out to accept a larger, production pump casing
or if the bore should be abandoned because of insufficient yield.

Clearly, the discharge measurement during drilling is most useful
but it must be remembered that yield is partly determined by bore
and drillpipe diameter and bore depth. Low to medium water discharge
from a large annulus (i.e. small drillpipes and large diameter bore)
could indicate near or total drawdown conditions. On the other hand,
a small annulus will have a limiting discharge and drawdown will be
correspondingly less.

7.1.2   Airlift Tests

Previous yield indications can be confirmed by a preliminary yield test
using an air lift device or small borehole pump. Standard JPT practice
is to perform an 'air lift' preliminary yield test on each bore (alluvial
or hardrock) if possible. The test is usually carried out at a low
constant discharge for up to 3 hours; drawdown is measured periodically
and the EC of the discharge checked.   If results from this test are
good, the exploratory bore will be later pump tested with a turbine pump.

FIGURE 7.1   AIRLIFT TERMINOLOGY

Often the bore diameter within the uncased rock is 5 7/8" and the air lift
educator pipe (the drill pipe) is 4 3/4" diameter. The eductor pipe
diameter would normally be considered ample but the API tapered tool joint
threads reduce the ID to 2 11/16". The air pipe used is ½" nominal
bore making the largest dia. over the air pipe joints (socket) 3/4"
or more. Obviously, there is then an insufficient cross-sectional area
to give high discharges; the maximum flow observed with this system is
8 l/sec, well above the average bore discharge in the JPT drilling
programme.

The efficiency of an air lift, like all machines, depends on correct
design and it is essential therefore that certain matters receive careful
consideration. It has been found that air lift operation is determined
by the ratio of submergence of the air pipe to the total lift and the
ratio of air supplied to water raised; the relative sizes of eductor
and air pipe also have to be considered. The term 'submergence' (S)
is used to denote the distance to which the air pipe is placed below
the working water level (Figure 7.1). The lift (L) of the installation
is the vertical distance water is carried from working water level to
where it is finally educted. The total lift is the submergence plus
the lift distance.

The minimum recommended ratio of submergence (S/S+L) x 100%) has been
found to be about 60-70% for general applications but lower values are
used on deeper installations, beyond 100 m. Too great a submergence
of the air pipe below the water level will 'kill' the compressor.
The depth of the eductor pipe, however, should be about 6.0 m greater
than the air pipe but experience in the field has shown that 2 m is
possible. If necessary, an eductor pipe fitted with packer can be placed
very much deeper than the air pipe and by this method, the bottom section
of hole can be tested with the upper part isolated.

FIGURE 7.1   AIRLIFT TERMINOLOGY

AIR DELIVERY PIPE →

EDUCTOR PIPE

GROUND LEVEL

S.W.L.

DRAWDOWN

WORKING
WATER LEVEL

LIFT (L)

TOTAL HEAD 100%

SUBMERGENCE (S)
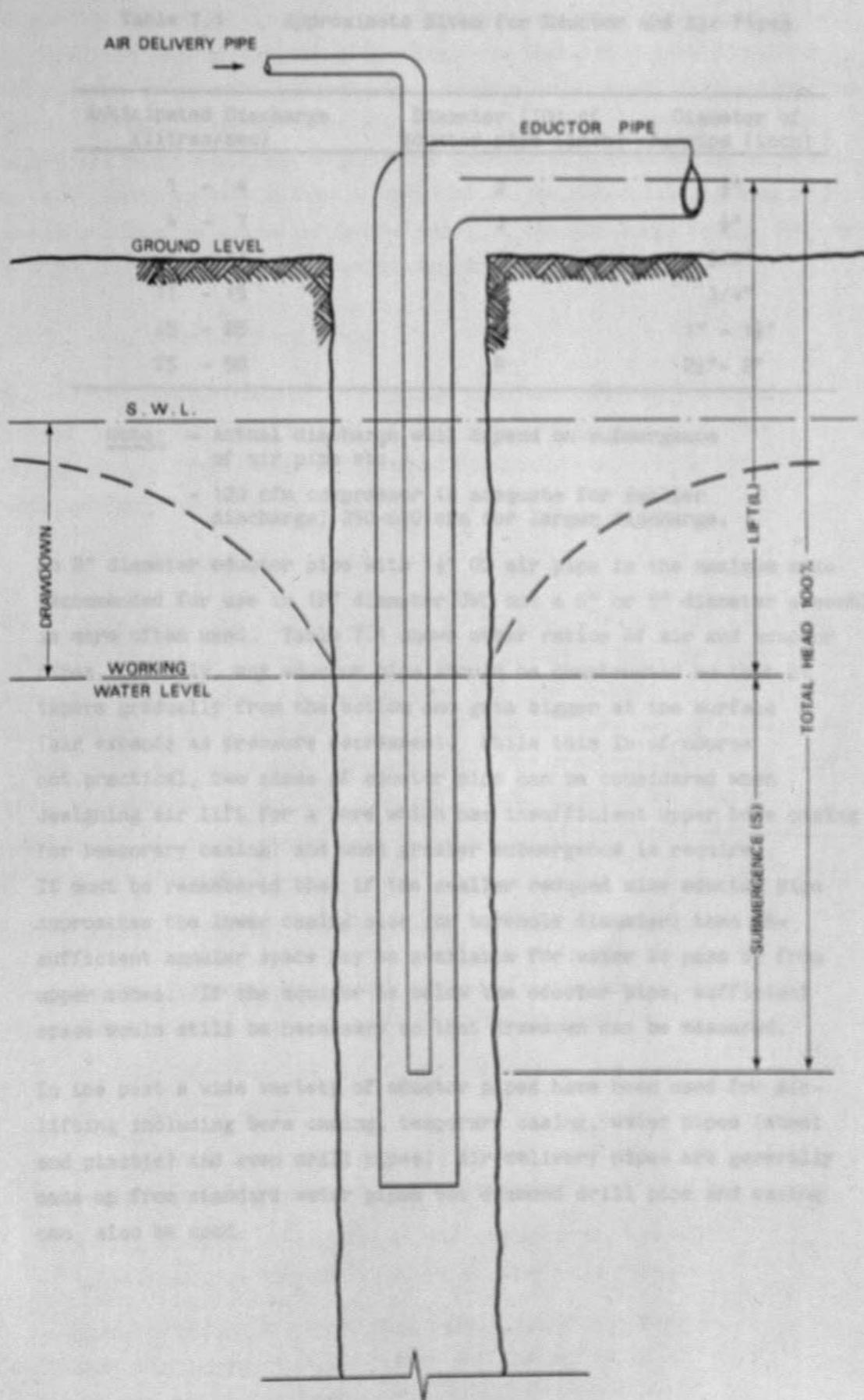
Table 7.1   Approximate Sizes for Eductor and Air Pipes

Anticipated Discharge (litres/sec)	Diameter (ID) of Eductor pipe (inch)	Diameter of Airpipe (inch)
1 - 4	2	½"
4 - 7	3	½"
7 - 11	4	3/4"
11 - 15	5	3/4"
15 - 25	6	1" - 1½"
25 - 50	8	2½"- 2"

Note: - Actual discharge will depend on submergence
of air pipe etc.

- 120 cfm compressor is adequate for smaller
discharge; 350-600 cfm for larger discharge.

An 8" diameter eductor pipe with 1½" OD air pipe is the maximum size
recommended for use in 12" diameter UWC but a 6" or 5" diameter assembly
is more often used. Table 7.1 shows other ratios of air and eductor
pipes. Ideally, any eductor pipe should be constructed so that it
tapers gradually from the bottom and gets bigger at the surface
(air expands as pressure decreases). While this is of course
not practical, two sizes of eductor pipe can be considered when
designing air lift for a bore which has insufficient upper bore casing
(or temporary casing) and when greater submergence is required.
It must be remembered that if the smaller reduced size eductor pipe
approaches the lower casing size (or borehole diameter) then in-
sufficient annular space may be available for water to pass by from
upper zones. If the aquifer is below the eductor pipe, sufficient
space would still be necessary so that drawdown can be measured.

In the past a wide variety of eductor pipes have been used for air-
lifting including bore casing, temporary casing, water pipes (steel
and plastic) and even drill pipes. Air delivery pipes are generally
made up from standard water pipes but diamond drill pipe and casing
can also be used.

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Whilst tables and charts should be consulted regarding ideal combinations
of pipes and compressors, many operators use whatever suitable eductor
and compressor is available and make use of a roll of stiff alkathene-type
water pipe to deliver air down the hole. In this way the pipe can run-
in freely to any depth and adjusted in seconds to suit drawdown conditions.
In all cases, the air volume is adjusted at the compressor by a gate valve
and if possible by a smaller needle valve at the discharge head. The use
of fine valve allows optimum operating conditions to be attained.

7.1.3 Borehole Test Pumps

The JPT Groundwater Section is equipped with two line shaft borehole
turbine pumps; the smaller unit is just able to fit into a 6" bore
casing and the larger pump is suitable for installation in a 10"
bore casing.

BP 45-4 Pump

The 6" bore test pump is difficult to work with. The maximum discharge
rating of 15 l/s is higher than usually necessary. The pump has a large
diameter column pipe of 4" nominal bore and with sockets of 5.1" OD and
installation of this component into a 6" nominal bore casing results in
a very small annular space. Consequently, the preferred method of water
level measurement by electric sounding is not possible and instead,
water level has to be measured by airline, a system often troublesome
and usually inaccurate.

During pump installation, the following points should be remembered:

- the airline must be securely fastened to the top of the
  pump or to the bottom of the first column pipe

- the distance from the end of the airline to the surface
  datum must be known

- to prevent failure, two airlines should be attached, to
  opposite sides of the column pipe assembly

- during lowering or raising of the column pipe, the air
  lines should be kept taut otherwise they will rupture

- when screwing the column pipe together, threads must
  butt tightly but the lower pipe must be backed up
  and not allowed to turn.

- because of the flat-belt drive used by the pump and the
  light weight pump base, the unit has a tendency to vibrate
  excessively. Therefore it needs to be firmly fastened to
  base timbers which should have already been well bedded
  into the ground

- the pump has no clutch and 2 men are needed to start the
  motor; because there is no clutch, the discharge valve must
  be closed.

10M-50 Pump

This 10" borehole pump has a larger annular clearance (7½" max. column
pipe dia. in 10" ID casing) which allows the use of the electric sounding
tape for water level measurements in the pump casing annulus. General
installation recommendations, listed below, should be adhered to.

General Instructions on Installation
of Turbine Test Pumps

The advice and recommendations given in the manufacturer's instruction
manuals regarding pump installation should be followed. Because a
test pump has to operate in less than perfect conditions, special
precautions are necessary to avoid serious damage to pump components
and allow trouble free operation.

A footvalve is installed between the pump intake strainer and the pump
body. This is necessary in order to avoid flooding and surging in the
annulus when the pump is stopped at the end of a test. Without it,
the initial water level recovery readings will be misleading. A bore
development technique known as back-washing is sometimes used as
a method of agitating the aquifer. By alternately overpumping the
bore and stopping the pump quickly, a washing action is effected.
If the pump is to be used for this type of work the footvalve should
be left off.

The line shaft of the pump extends from the surface to the pump body
and is centred every 3.0 m (for the 10" pump) by a 'spider bearing'.
Because of high rotational speeds up to 2,500 rpm, the bearing within
the column pipe and the pump body will wear out very quickly unless
the shafts are perfectly straight.   Manufacturers quote a tolerance

FIGURE 7.2   LINESHAFT PUMP HEAD ALIGNMENT

of straightness within 0.010" (0.25 mm) over a 3 m shaft length as a
working figure; they advise a straightening operation on any shaft not
within this limit. Such an operation is complicated and troublesome
and cannot be carried out on site; a lathe bed, 'V' blocks and dial
gauges are needed. There is little chance of the shafts becoming
bent during operation of the pump, but if extreme care is not taken
in their loading, unloading and installation, they quickly will be.
The shaft should never be dropped, stood upon or handled roughly;
it should be transported and stored on site in the special heavy duty
box made for this purpose.

The manufacturers of the 6" pump (Gadelius) advise smearing soap on the
surface of the shaft where it comes into contact with the spider bearing
as a method of alleviating drag and friction on start up. The Worthington
10" pump like most open shaft pumps, requires lubrication before start
up; a funnel is attached to the discharge head for this purpose.

Column pipe must not be used as a roller or lever and care should be
taken during handling to avoid thread damage. After firmly seating the
spider bearing, the column pipe should be tightly made up using thread
lubrication compound. Oil and grease should not be allowed to contaminate
the rubber on the spider bearings.

Once installed, the pump discharge head has to be connected to the top
column pipe. Ideally the pump assembly should hang perfectly central
and vertical in the bore casing. This is not always the case in practice
and the column pipe may be slightly off vertical as a result of bore
deviation. This is not serious if deviation is not beyond accepted limits
(7.5 cm in 30 m); it will be necessary however to ensure that the discharge
head is fixed exactly at right-angles to the pump axis. On no account
should the discharge head be bolted down to the pump base frame without
ensuring that the head is at right angles to the axis of the pump.
If necessary, the discharge head may be shimmed slightly or the whole
pump base-frame wedged so that alignment is ensured (Figure 7.2).

Impeller setting (clearance) is variable and depends on installation
depth; clearances are shown in the pump installation manuals. For both
pumps, the impellers are raised by adjusting the lineshaft at the
surface.

FIGURE 7.2   LINESHAFT PUMP HEAD ALIGNMENT

Labels in figure:

DISCHARGE HEAD

PUMP BASE

TIMBER

MOVE PUMP ASSEMBLY OVER GENTLY INTO THE MOST VERTICAL POSITION. DO NOT FORCE

COLUMN PIPE

SHIM WHERE NECESSARY (EITHER PLACE)

A B

90°

90°

1

2
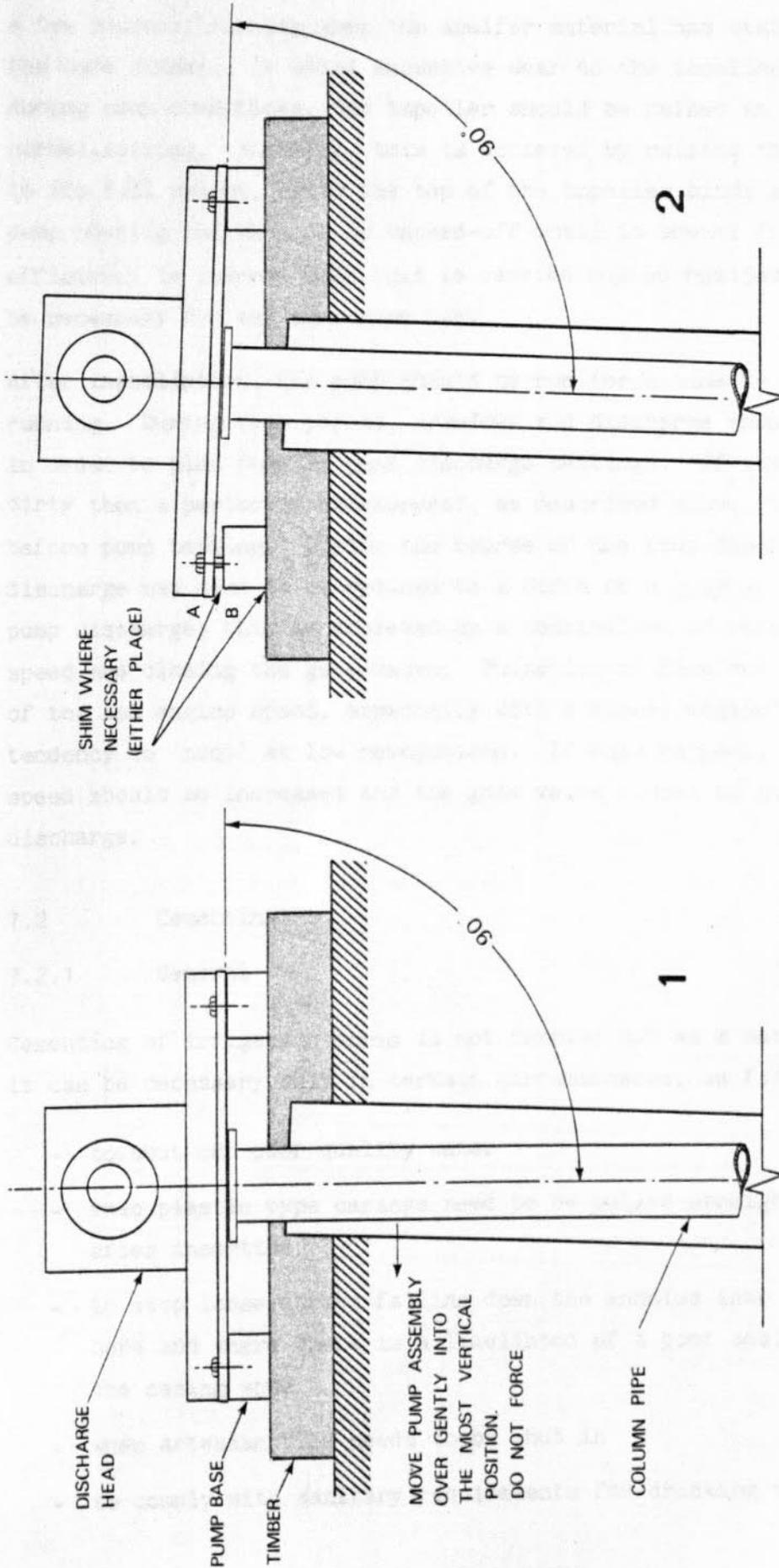
Explanation:

The lineshaft test pump will not tolerate crooked hole condition which causes the column pipe to bend. If necessary the pump may be positioned off-centre to allow vertical setting (1).

An inclined pump setting is allowable as long as the discharge head is set at right-angles to the pump's axis (2).

The whole pump-engine base should be tilted to attain the required inclination, or, the discharge head may be shimmed - but only on either side of the pump-engine axis (to comply with engine drive-shaft universal joint operating instructions).

During the course of initial pumping and even after prolonged development, some bores may pump silt or sand. The condition usually clears up after a few hours of running when the aquifer material has stabiliser against the bore screen. To avoid excessive wear to the impeller and housing during such conditions, the impeller should be raised in excess of the normal setting. Normally, this is achieved by raising the impeller to its full height, until the top of the impeller binds against the pump housing and then it is backed-off until it breaks free. Pump efficiency is lowered when this is carried out so readjustment will be necessary for any long pump test.

After installation, the pump should be run for a time to ensure smooth running. During this period, drawdown and discharge should be noted in order to plan pumping test discharge settings. If the water is very dirty then a period of development, as described above, is necessary before pump testing. During the course of the step discharge test, discharge may need to be reduced to a fifth or a quarter of maximum pump discharge; this is achieved by a combination of reducing engine speed and closing the gate-valve. Pulsation of flow may be the result of too low engine speed, especially with a diesel engine which has a tendency to 'hunt' at low revolutions. If this happens, the engine speed should be increased and the gate valve closed to give the desired discharge.

7.2   Cementing

7.2.1   General

Cementing of irrigation bores is not carried out as a matter of course; it can be necessary only in certain circumstnaces, as follows:

- to shut out poor quality water
- when plastic type casings need to be pulled straight after insertion
- to stop loose strata falling down the annulus into the bore and where there is a likelihood of a poor seal at the casing shoe
- when artesian flow needs to be shut in
- to comply with sanitary requirements for drinking water supply.

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FIGURE 7.3   BORE PLUGGING DEVICES

7.2.2   Bore Plugging

Prior to cementing, the exploration or pilot hole may need to be isolated from the upper zone; this is specially important in flowing artesian zones. Several methods can be used, as detailed below:

- a soft, dry wooden plug whose diameter is exactly the bit size at the lower end, and up to three centimetres greater than bit size at the other end, is set in the pilot bore as close to the reamed section or shoulder as possible. The idea is that the wooden plug is forced tightly into the hole and once in position it swells. the plug is placed by drill pipe which has a nail or spike fitted to a sub (Figure 7.3). After the spike disengages from the wooden plug, a bucket of sand is normally thrown down the hole or clay tamped down on to of the plug to form a good seal. The length of the plug should be at least twice the hole diameter so as to avoid turning in a fissure or enlarged section. The setting of the wooden plug can also be done prior to reaming. This will allow a better chance for reaming out by mud which may be necessary if loose overburden is present.

- another method of blocking a pilot hole is to drop a round boulder down the hole after it has been reamed out. On top of this is thrown enough large gravel to fill-up 15 cm of hole above the boulder. After large gravel, fine gravel is introduced to raise the level another 15 cm and on top of that about 15 cm of sand-clay can be used instead of gravel and sand, but it must be packed tightly on top of the boulder.

- backfill all the hole just below the upper bore casing with sand and fine gravel.

If any of the methods described above were used in more demanding conditions, a three or four metre long plug of cement should be placed and allowed to set before the main batch of grout is inserted.

Most pilot holes do in fact get blocked during reaming operations; this is mainly due to cuttings and cavings produced during reaming not being excavated from the hole. Some of these blockages are secure, as returns from reaming with mud flush circulation are often observed. In those circumstances, the blockage will serve as well as the other methods mentioned above.

FIGURE 7.3   BORE PLUGGING DEVICES

LEFT HAND THREAD

FILL WITH SAND AND GRAVEL

3. Inverted tapered soft-wood plug jammed into bore by pulling back against gravel.

FILL WITH SAND AND GRAVEL

STEEL SPIKE

2. Tapered Soft-wood plug forced into bore

Soft boulder or cement filled ball

1. Soft boulder or cement filled ball
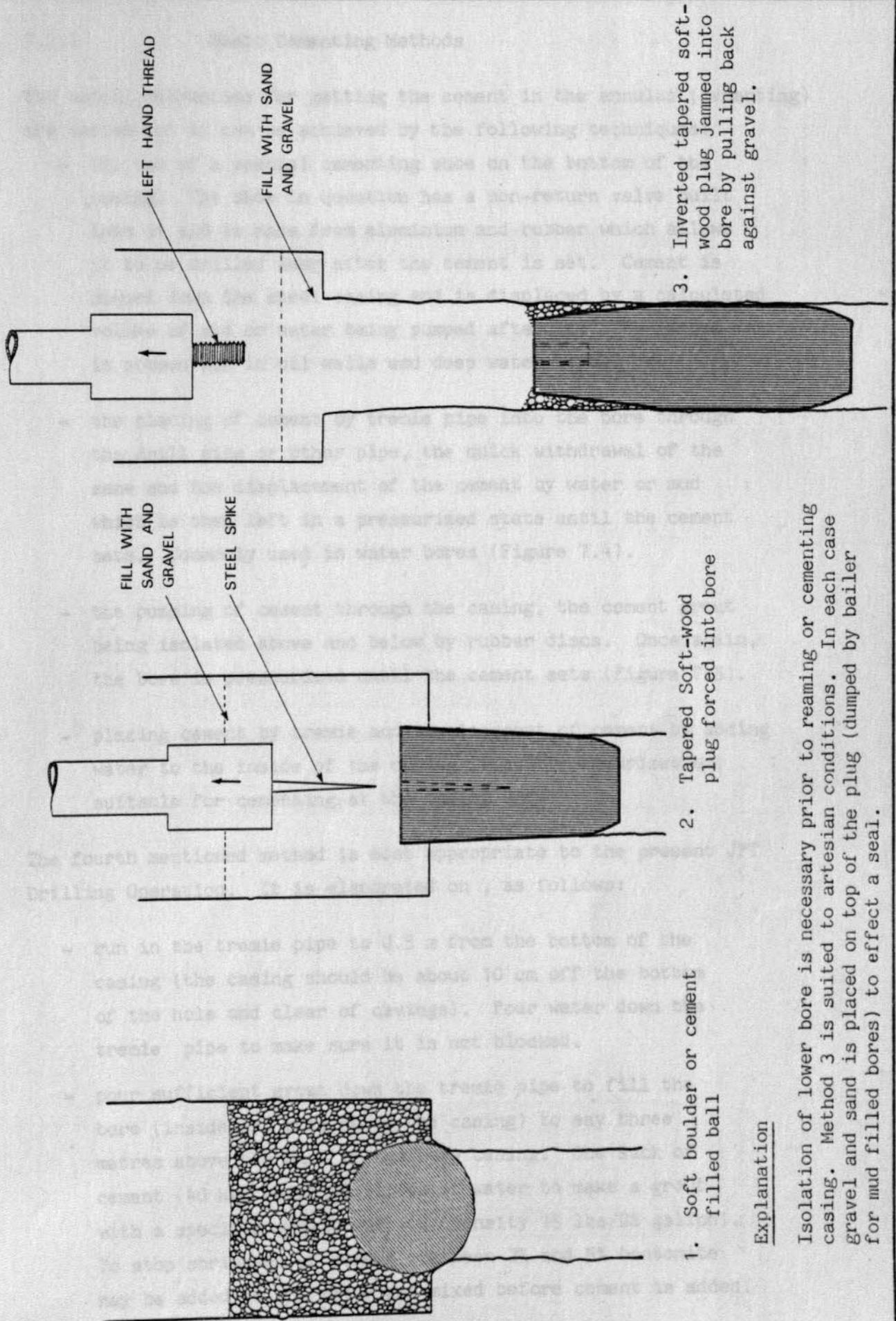
Explanation

Isolation of lower bore is necessary prior to reaming or cementing casing. Method 3 is suited to artesian conditions. In each case gravel and sand is placed on top of the plug (dumped by bailer for mud filled bores) to effect a seal.

FIGURE 7.4   SIMPLE CEMENTING METHOD : SHALLOW WELL

7.2.3   Basic Cementing Methods

The actual mechanisms for getting the cement in the annulus (cementing)
are varied but it can be achieved by the following techniques:

-   the use of a special cementing shoe on the bottom of the
    casing. The shoe in question has a non-return valve built
    into it and is made from aluminium and rubber which allows
    it to be drilled away after the cement is set. Cement is
    pumped down the steel casing and is displaced by a calculated
    volume of mud or water being pumped after it. The method is
    in common use in oil wells and deep water bores.

-   the placing of cement by tremie pipe into the bore through
    the drill pipe or other pipe, the quick withdrawal of the
    same and the displacement of the cement by water or mud
    which is then left in a pressurized state until the cement
    sets. Commonly used in water bores (Figure 7.4).

-   the pumping of cement through the casing, the cement grout
    being isolated above and below by rubber discs. Once again,
    the bore is pressurized until the cement sets (Figure 7.5).

-   placing cement by tremie and displacement of cement by adding
    water to the inside of the casing without pressurization;
    suitable for cementing at the casing shoe.

The fourth mentioned method is most appropriate to the present JPT
Drilling Operation. It is elaborated on , as follows:

-   run in the tremie pipe to 0.5 m from the bottom of the
    casing (the casing should be about 10 cm off the bottom
    of the hole and clear of cavings). Pour water down the
    tremie pipe to make sure it is not blocked.

-   pour sufficient grout down the tremie pipe to fill the
    bore (inside and outside of the casing) to say three
    metres above the base of the bore casing. One sack of
    cement (40 kg) needs 15 litres of water to make a grout
    with a specific gravity of 1.8 (density 15 lbs/US gallon).
    To stop shrinkage of cement, between 3% and 5% bentonite
    may be added to the water and mixed before cement is added.

FIGURE 7.4   SIMPLE   CEMENTING   METHOD - SHALLOW   WELL

CEMENT DISPLACED
BY WATER OR MUD

CLOSE VALVE
AFTER CEMENT IS
DISPLACED

CASING HEAD

LEVEL OF DISPLACED
CEMENT

DISPLACEMENT FLUID
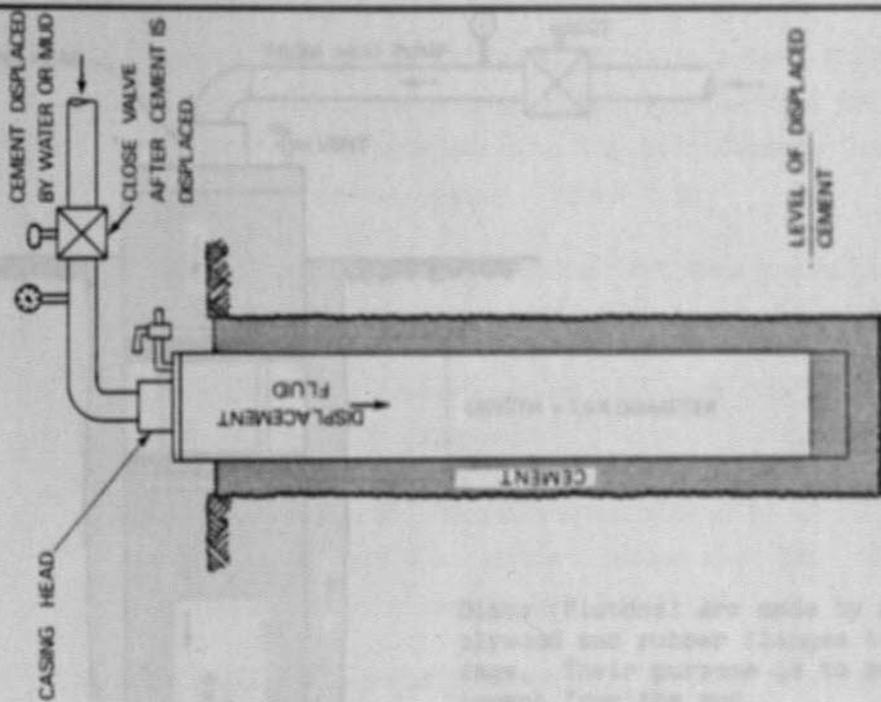
CEMENT

Displace cement in casing into annulus
by pumping in measured amount of fluid
and close valve. Seat casing on the
bottom after cementing. Pressure is
maintained until cement sets.

CEMENT PUMPED
OR POURED DOWN

LEVEL OF
CEMENT

CEMENT

MUD

2" WATER OR
DRILL PIPES
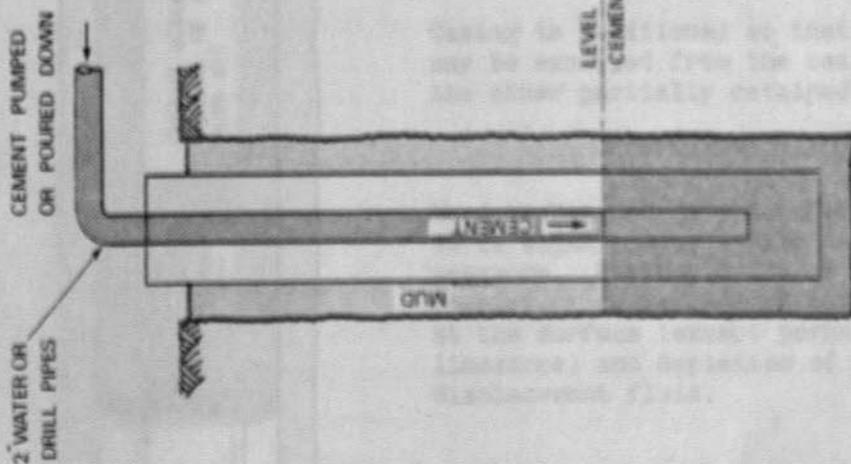
Run 2" pipes (or drillpipes)
and pump cement to bottom
of the hole. Pull pipes out
quickly and wash them out.

Note:

Cement can be pumped down by using separator discs
(top and bottom of cement) instead of through the pipe.

FROM MUD PUMP

CASING HEAD

MUD
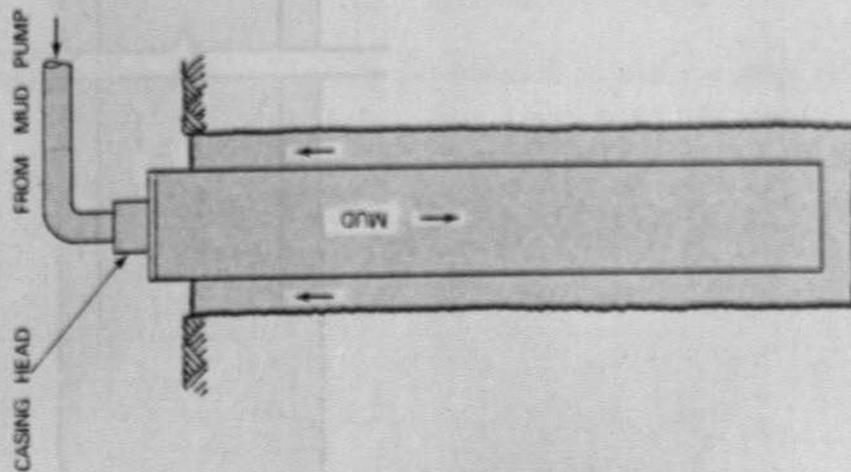
Set casing off bottom
of hole. Flush annulus
with mud.

FIGURE 7·5 CEMENTING – DISC METHOD

CASING HEAD

FROM MUD PUMP

VENT

LENGTH = 1.5 X DIAMETER

CEMENT VOLUME EQUALS
VOLUME OF ANNULUS
PLUS 10%
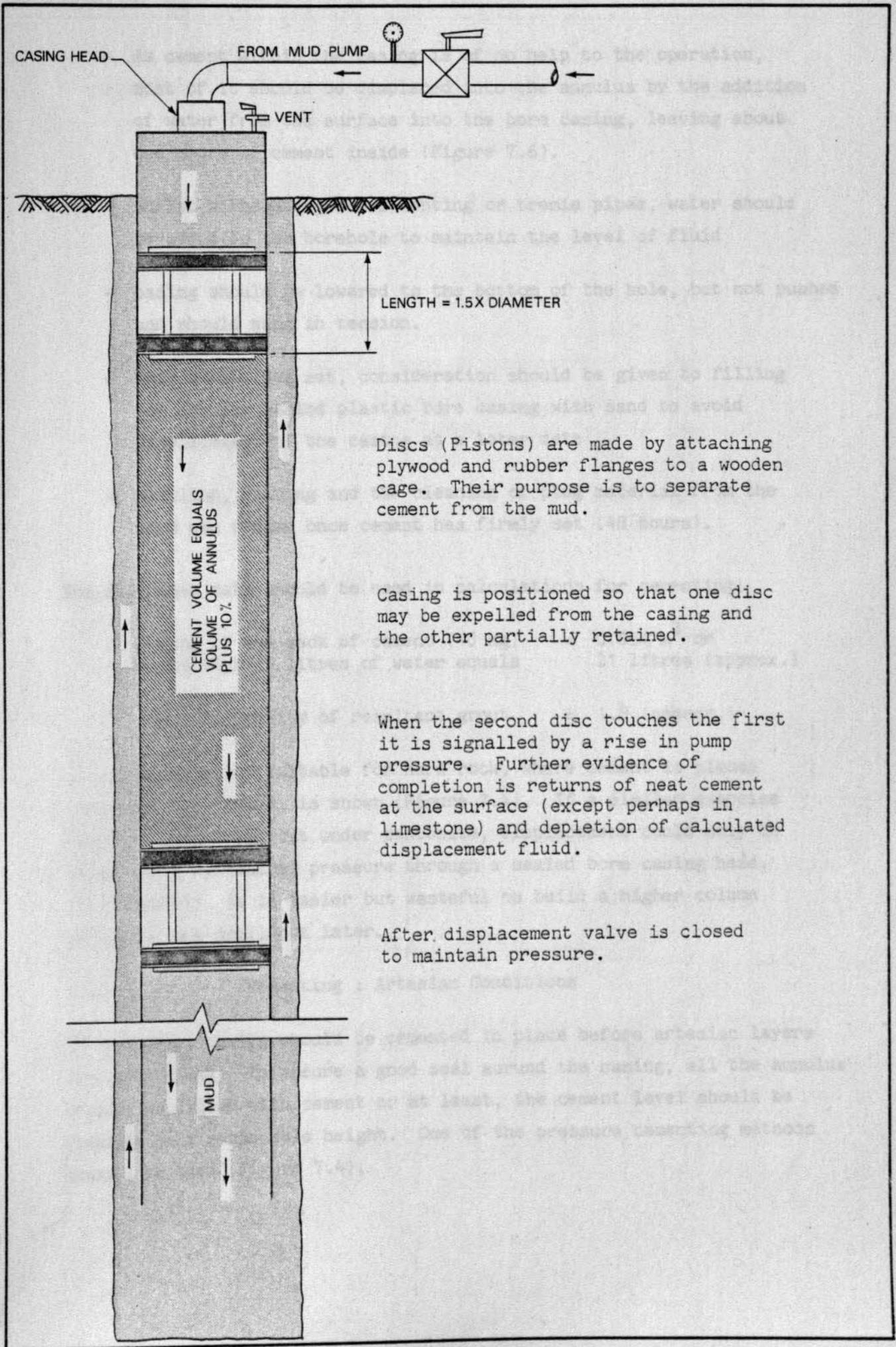
Discs (Pistons) are made by attaching
plywood and rubber flanges to a wooden
cage. Their purpose is to separate
cement from the mud.

Casing is positioned so that one disc
may be expelled from the casing and
the other partially retained.

When the second disc touches the first
it is signalled by a rise in pump
pressure. Further evidence of
completion is returns of neat cement
at the surface (except perhaps in
limestone) and depletion of calculated
displacement fluid.

After displacement valve is closed
to maintain pressure.

MUD

FIGURE 7.6   NON - PRESSURISED CEMENTING METHOD

- As cement within the casing is of no help to the operation, most of it should be displaced into the annulus by the addition of water from the surface into the bore casing, leaving about one metre of cement inside (Figure 7.6).

- whilst withdrawing the cementing or tremie pipes, water should be added to the borehole to maintain the level of fluid

- casing should be lowered to the bottom of the hole, but not pushed and should hang in tension.

- once cement has set, consideration should be given to filling the annulus behind plastic bore casing with sand to avoid displacement of the casing at a later date

- drilling, reaming and the cleaning of plug material from the bore can resume once cement has firmly set (48 hours).

The following data should be used in calculations for cementing:

Volume of one sack of cement (40 kg)   = 0.031 m^3 or
mixed with 15 litres of water equals   31 litres (approx.)

Specific gravity of resultant grout   = 1.8 (approx.)

A cementing method suitable for hard rock, where cement is placed underwater by tremie, is shown (Figure 7.4). If a similar exercise needs to be carried out under bentonite, displacement could only be affected by mechanical pressure through a sealed bore casing head. Alternatively, it is easier but wasteful to build a higher column of cement and drill-out later.

7.2.4   Cementing : Artesian Conditions

If possible, casing should be cemented in place before artesian layers are penetrated. To ensure a good seal aorund the casing, all the annulus should be filled with cement or at least, the cement level should be brought to a reasonable height. One of the pressure cementing methods should be used (Figure 7.4).

FIGURE 7.6   NON -PRESSURISED CEMENTING METHOD
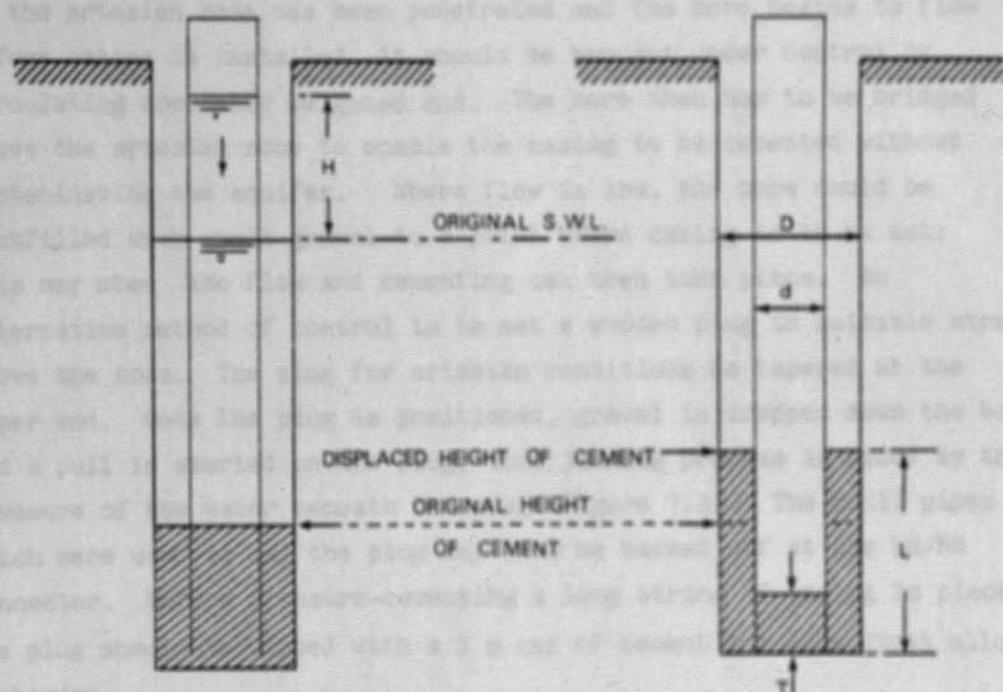
D = hole diameter
d = casing diameter
L = required length of cementing
T = required plug thickness
H = applied head of water

Required volume of grout :

$$\frac{\pi}{4}(D^2-d^2)L \;+\; \frac{\pi}{4}d^2\,T$$

Applied head of water (H) = 1.8 (L-T)

Required volume of water = 1.8 (L-T) $\frac{\pi d^2}{4}$

Notes:

(1)   40 kg sacks of cement mixed with 15 lt. of water
       has a volume of 0.031 m³ (31 lt) and an approx.
       gravity at 1.8.

(2)   Lower casing to the bottom after dispalcement.

FIGURE 7.7   FISHING LARGE DIAMETER PIPES

If the artesian zone has been penetrated and the bore begins to flow before casing is installed, it should be brought under control by circulating specially weighted mud. The bore then has to be bridged above the artesian zone to enable the casing to be cemented without contaminating the aquifer. Where flow is low, the bore could be backfilled with small gravel to a point where casing is to be set; this may stem the flow and cementing can then take place. An alternative method of control is to set a wooden plug in suitable strata above the zone. The plug for artesian conditions is tapered at the upper end. Once the plug is positioned, gravel is dropped down the bore and a pull is exerted on the plug, this jamming process is aided by the pressure of the water beneath the plug (Figure 7.3). The drill pipes which were used to set the plug may then be backed off at the LH/RH connector. Before pressure-cementing a long string of casing in place, the plug should be topped with a 3 m cap of cement and this first allowed to harden.

7.3   Fishing or Recovery Operations

7.3.1   Equipment

It is not usual for a small drilling organisation to stock all possible recovery ('fishing') equipment. Often, this has to be borrowed from other organisations and contractors or else special tools are made up to suit the job in hand.

Two sets each of tapered tap and releasing over-shot are held by the JPT. The tap is suitable for connecting with the inside of the drill pipe and the drill collar whilst the over-shot is suitable for operating over the 4 3/4" drill pipes only. Because the diameter of the fishing tools is 8", they need to operate in a minimum bore diameter of 9 5/8", a situation which is not always possible. Other ancillary fishing equipment in stock includes spider bowl and slips to suit 4 3/4" and 6 5/8" pipe, a trip-hammer and hydraulic jacks.

General fishing tools as described above meet normal site needs, but the recovery of large diameter casing is most often undertaken with custom made tools. Figure 7.7 shows a simple fishing method suitable for picking up large diameter casings. A tool which can pick up small pipe from within a large diameter bore is shown in Figure 7.8. Recovery of a DHH bit can be achieved by a tool as indicated in Figure 7.9.

FIGURE 7.7   FISHING LARGE DIAMETER PIPES.

FIGURE 7.7   FISHING LARGE DIAMETER PIPES.
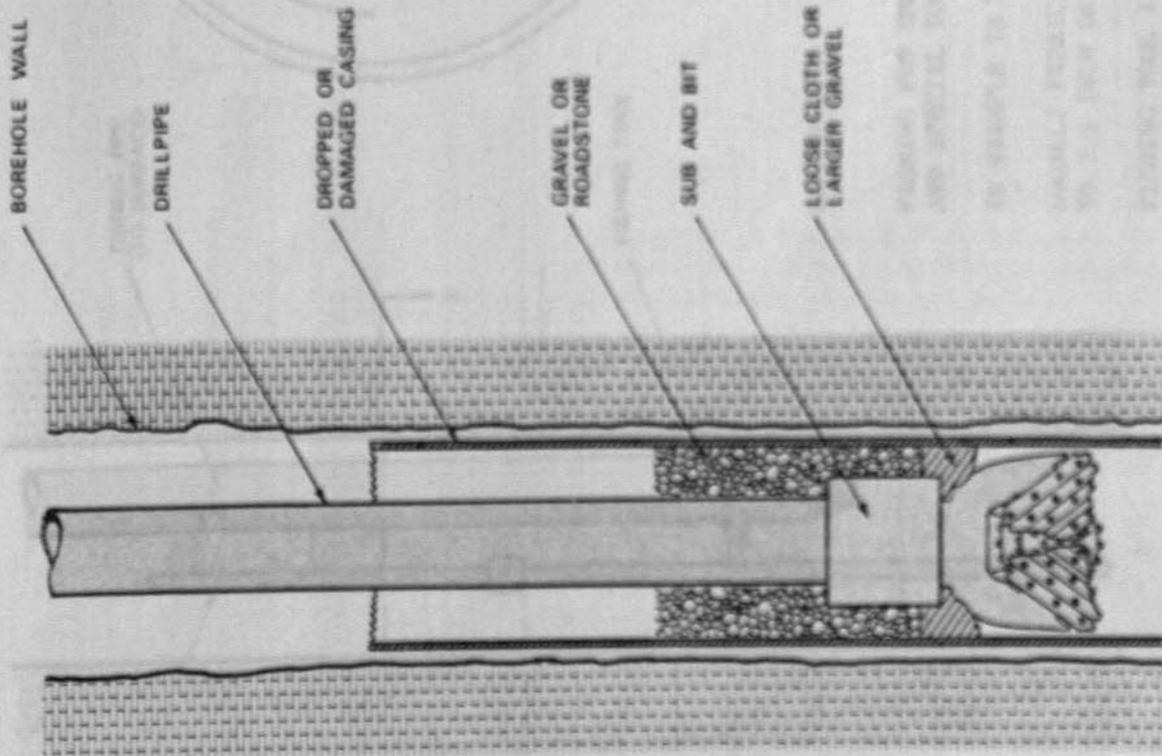
EXPLANATION

FISHING TOOLS TO RECOVER LARGER DIAMETER PIPES AND TEMPORARY CASING ARE NOT NORMALLY AVAILABLE.

A SIMPLE RECOVERY METHOD WHICH RELIES ON JAMMING A CLOSE FITTING SUB OR BIT INTO THE CASING (FISH) AND THEN EXERTING A PULL ON THE DRILLPIPE, IS OFTEN SUCCESSFUL.

TO JAM THE BIT INSIDE THE CASING, CLOTH IS LOOSELY WRAPPED AROUND THE TOP OF THE BIT AND GRAVEL IS DROPPED DOWN THE CASING TO FILL UP 0.5 - 1.0 m.

TO SEAL THE SPACES BETWEEN THE BIT COMES LARGER PIECES OR ROCK MAY BE INSERTED INSTEAD OF THE CLOTH.

TO ABORT THE FISHING EXERCISE THE BIT MAY BE MOVED DOWNWARDS (AND TURNED) AND THE COMPRESSOR SWITCHED ON.

BOREHOLE WALL

DRILLPIPE

DROPPED OR DAMAGED CASING

GRAVEL OR ROADSTONE

SUB AND BIT

LOOSE CLOTH OR LARGER GRAVEL

FIGURE 7.8   FISHING SMALL DIAMETER PIPES.

'FISH' ORIGINALLY LIES AT THE SIDE OF THE BOREHOLE AND THEN IS SWEPT INTO PREPARED SLOT IN FISHING TOOL.

SLOT FORMED TO SUIT O.D. OF PIPE (FISH).

SECTION ON 'X X' (ENLARGED)

FISHING PIPE (TO SURFACE)

FISHING TOOL

BROKEN OR DROPPED PIPE

TOOL RAISED TO CATCH UNDER COLLAR

EXPLANATION

FISHING FOR SMALL DIAMETER PIPE IN A LARGE DIAMETER HOLE IS DIFFICULT AND SPECIAL TOOLS ARE NOT USUALLY AVAILABLE.

AN EXAMPLE IS SHOWN OF HOW 1" WATERPIPE CAN BE RECOVERED FROM A 10" BORE.

LOCALLY FABRICATED PLATE, SHAPED TO SCOOP THE FISH INTO A SLOT IS WELDED TO 3.5 INCH DRILLPIPE OR SUB.

FISHING TOOL IS LOWERED BELOW COLLAR ON PIPE (FISH) AND TURNED CLOCKWISE AND THEN RAISED.

FIGURE 7.9   FISHING TOOL FOR D.H.H. BIT

DRILLPIPE

CONNECTOR SUB
(3.5 REG BOX BY 3.5 I.F. BOX)

SHROUD – TAPERED
TO SUIT BORE DIA
(WELDED TO SUB)

PREPARED SPIKE
SANDWICHED
BETWEEN DRILL
PIPE AND SUB
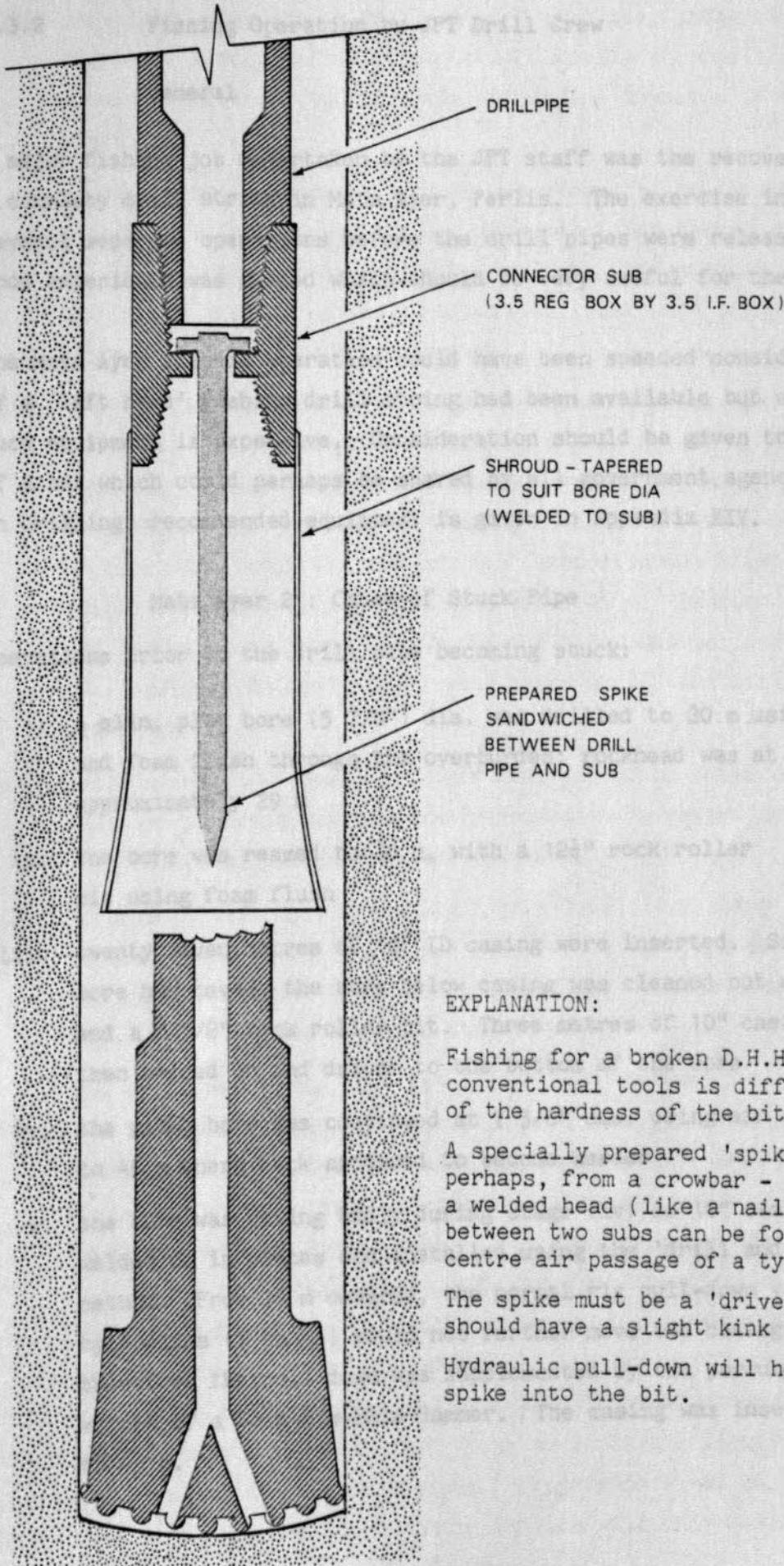
EXPLANATION:

Fishing for a broken D.H.H. bit with
conventional tools is difficult because
of the hardness of the bit metal.

A specially prepared 'spike', made
perhaps, from a crowbar - fitted with
a welded head (like a nail) - sandwiched
between two subs can be forced into the
centre air passage of a typical bit.

The spike must be a 'drive' fit and
should have a slight kink in the middle.

Hydraulic pull-down will help force the
spike into the bit.

7.3.2   Fishing Operation by JPT Drill Crew

             General

A major fishing job undertaken by the JPT staff was the recovery of
a complete drill string in Mata Ayer, Perlis. The exercise involved
several separate operations before the drill pipes were released.
Good experience was gained which should be very useful for the future.

The Mata Ayer fishing operation could have been speeded considerably
if a 'left hand' fishing drill string had been available but unfortunately
such equipment is expensive. Consideration should be given to the purchase
of a set which could perhaps be shared by all government agencies involved
in drilling; recommended equipment is given in Appendix XIV.

             Mata Ayer 2 : Cause of Stuck Pipe

Operations prior to the drill pipe becoming stuck:

   i.   a slim, plot bore (5 7/8") dia. was drilled to 30 m using air
        and foam flush through the overburden; rockhead was at
        approximately 29 m

  ii.   the bore was reamed to 30 m, with a 12¼" rock roller
        bit using foam flush

 iii.   twenty seven metres of 10" ID casing were inserted. Since the
        bore had caved, the bore below casing was cleaned out using foam
        and a 7 5/8" rock roller bit. Three metres of 10" casing was
        then welded on and driven to the bottom of the bore

  iv.   the pilot bore was continued at 7 5/8" dia. using air and foam
        to 45 m where rock appeared to become harder

   v.   the bore was caving badly during stage (iv) so 10" casing was
        welded on in pieces and installed using the 'drill and drive'
        method. From 36 m onwards, the normal rig pull-down via the
        hydraulics (7 tonne) would not further move the casing and
        therefore the pull down was supplemented by the percussive
        effect of a Down-the-Hole Hammer. The casing was inserted
        to 45 m.

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vi.   an attempt was made to drill on at 7 5/8" dia, using air
      flush and a rock roller bit, but bore caving started again.
      Attempts were made to drive the 10" casing down but it was
      stuck.

         The formation from 29 m to 45 m appeared to be fractured
      limestone with lime sand filled fissures. The harder components
      of the limestone broke down when handled, into angular particles.
      During the process of casing insertion, lime sand often flowed
      several metres up into the casing.

vii. all drilling operations in Padang Terap and Perlis (hard rock areas)
      had up to this point, been conducted solely by air or foam flush
      methods. It was then decided that bentonite mud should be used
      to continue the drilling of bore MA 2, to give better control
      of bore wall condition and caving. Bentonite was mixed and
      circulated and drilling continued below 45 m. Because of heavy
      mud losses encountered within the first few metres, mud viscosity
      was increased by addition of padi husks until circulation was
      regained.

viii. drilling was continued at 7 5/8" dia. to 132 m; occasional mud
      loss was observed but this was presumed to be caused by leakage
      into the formation just below the casing

ix.   it appears that during the night of 4 June, 1982 heavy rain
      flooded the mudpits (whose mud level was low). However, no attempt
      was made to add bentonite mud to the highly diluted low viscosity
      fluid which by then occupied the mud pits.

x.   the crew lowered the last few drill pipes to near the bottom of
      the bore and flushed the last pipe down using the mud pump.
      The bit then reached 132 m with the kelly in the down position.
      The drill head was then disconnected from the drill string ready
      to accept another drill pipe. It is then reported that the fluid
      inside the drill pipe flowed back out for two or three minutes.
      This indicates that the fluid in the annulus between drill pipe
      and borehole wall was full strength drilling mud, perhaps
      containing some cuttings and cavings. Its weight, perhaps 10-15%
      greater than water, was sufficient to force the lighter fluid
      out from inside the drill pipes. Experience shows us that the
      heavier fluid descending in the annulus will only stabilize when

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FIGURE 7.10   HOLE COLLAPSE

sufficient fluid has been expelled from the drill pipe.
The stabilized fluid level in the annulus very often and
certainly in this case, is much lower than the natural or static
water level of the formation. In this case, groundwater flows
into the annulus until its natural piezometric level is reached.
In hard rocks this process does not matter too much apart from
the dilution of the drilling mud. In fact, the process happens
each time drill pipes are pulled out of the bore unless their
volume is continuously replaced by the addition of drilling mud.

The stability of alluvium or loose incompetent formation
is guaranteed by a column of mud. The removal of this mud
column or any severe reduction in its density, allows groundwater
ingress and the collapse of incompetent materials (Figure 7.10).

Borehole collapse often allows the formation to jam around
the drillpipe in the vicinity of the incompetent formation
whilst the viscous mud acts as a barrier in preventing the descent
of caving material to fill the annulus to the bore bottom.

xi. the crew had no previous experience of this situation and did not
know what had happened. When they coupled a new drill pipe, they
found the drill pipe to be stuck. Following unsuccessful attempts
to free the pipes, the crew decided that perhaps the mud was the
cause. They therefore forced compressed air down the drill pipe.
This action obviously made matters worse since it removed any
remaining mud from the drill pipes and hole and allowed unstable
angular limestone gravel to fill the annulus and enter the drill
pipe via the bit. At this point, the jet nozzles within the bit
became blocked making circulation impossible.

MA 2 : The Recovery ('Fishing') Operation

A 'fishing' operation is often the result of the failure of the drill
string or casing assembly, especially in deep oil wells.

Water well drilling operations also suffer to a lesser degree from this
problem. Fishing may also be necessary when something is dropped down
the bore or, in the case of bore MA 2, through a combination of severe
drilling conditions and inexperience.

FIGURE 7.10   HOLE COLLAPSE.
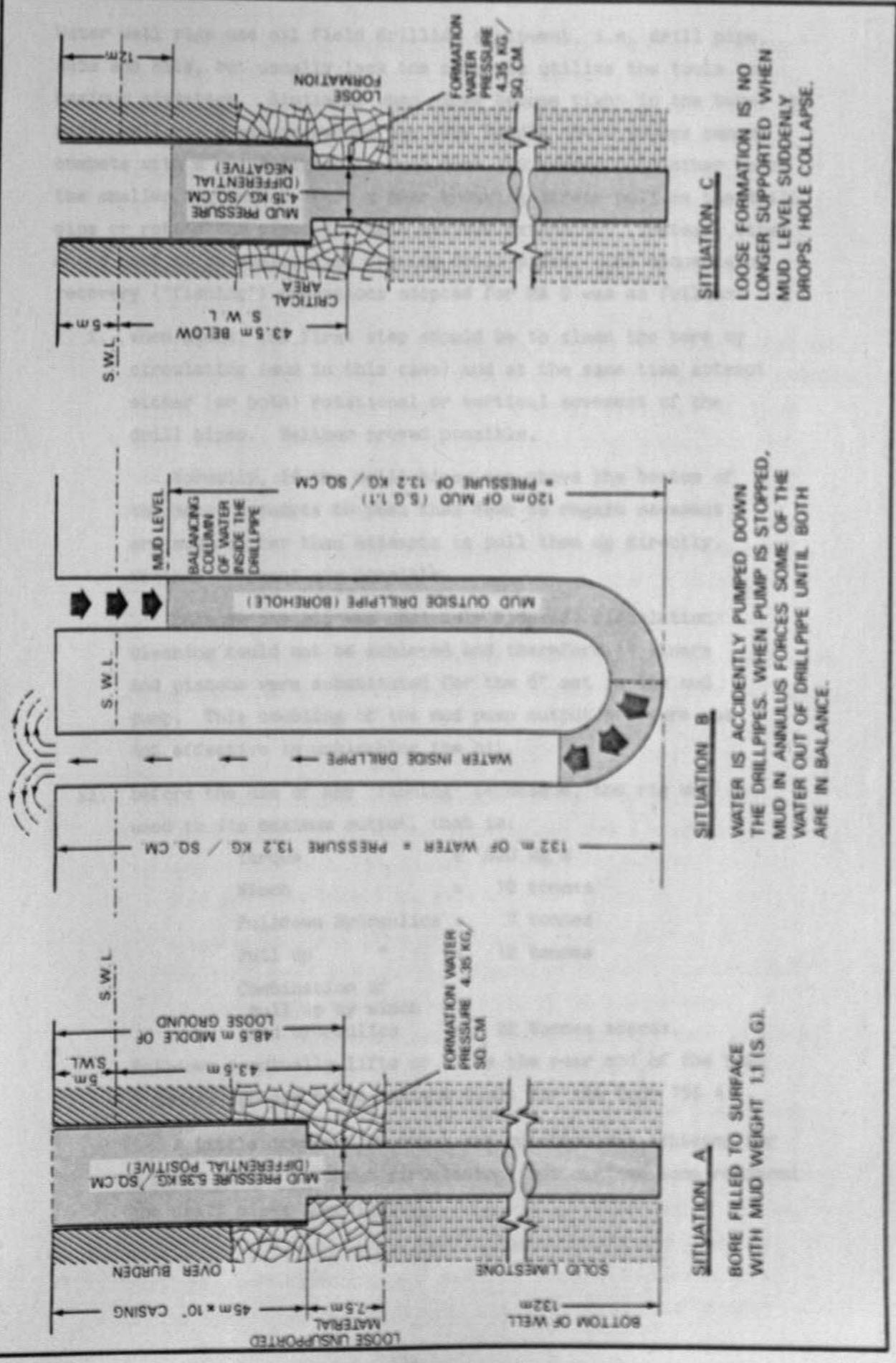
Water well rigs use oil field drilling equipment, i.e. drill pipe, subs and bits, but usually lack the power to utilize the tools to maximum advantage. Similarly when pipes become tight in the bore, the water well rig whose drawworks can only handle 10-12 tonnes cannot compete with a rig designed to pull over 100 tonnes. In other words the smaller rig cannot exert a near breaking strain pull on the drill pipe or rotate the pipes to their maximum extension. Instead, other means need to be employed in freeing drill pipes. The sequence of recovery ('fishing') operations adopted for MA 2 was as follows:

i. when stuck, the first step should be to clean the bore by circulating (mud in this case) and at the same time attempt either (or both) rotational or vertical movement of the drill pipes. Neither proved possible.

 Normally, if the drill pipes are above the bottom of the hole, attempts to push them down to regain movement are much better than attempts to pull them up directly. Neither movement was possible.

 Because the bit was obviously blocked, circulation/ cleaning could not be achieved and therefore 4" liners and pistons were substituted for the 6" set in the mud pump. This doubling of the mud pump output pressure was not effective in unblocking the bit.

ii. before the use of any 'fishing' technique, the rig was used to its maximum output, that is:

Torque	=	620 kg m
Winch	=	10 tonnes
Pulldown Hydraulics	=	7 tonnes
Pull up "	=	12 tonnes
Combination of pull up by winch and hydraulics	=	22 tonnes approx.

Pulldown eventually lifts or tilts the rear end of the rig; 7 tonnes appears to be maximum limit for the Tone 750 A.

 A little downward movement and rotation was achieved for a short period (without circulation) but cavings soon rendered the drill pipes immobile.

iii. Part of the Tone rig package includes a drive hammer (or monkey')
     assembly. The hammer weighs about 68 kg and can slide up and
     down a special pipe equipped with a drive ring at each end.
     Percussive effect is through the rigs winch rope, after removal
     of the travelling block, to give fast single line action.
     The stroke length is 1.5 m. By coupling the hammer assembly
     between the stuck drill pipe and the power swivel, the hydraulic
     pull down can be operated in either direction at the same time
     as the hammer.

     Afterwards, a similar exercise was carried out using a Mission
     A 6315 DHH borrowed from JKR. With this assembly, downward movement
     only is possible. It was hoped that the high frequency of blows
     (up to 900 per minute) with hydraulic pull down would free the
     drill pipe or at least vibrate cuttings out of the bit to allow
     circulation to be restored. Neither effort had any effect.

     Another similar percussive option would have been the use
     of a 'piling extractor' although none was available locally.
     This might be considered as a future recovery method.

     Throughout the efforts mentioned, bentonite mud was maintained
     in the borehole to surface level, to prevent any further caving.

iv. before initiation of long fishing operations, the following
    additional operations were carried out:
    - an unsuccessful attempt was made to turn the pipes with
      the combined force of the power swivel and a large pipe
      wrench over which was placed a 6 m extension pipe;
      five men then pushed the pipe

    - a spider bowl and slips were placed around the top of
      the drill pipe and two jacks operated to exert approximately
      30 tonnes thrust to the underside of the spider bowl.
      At the same time the winch and hydraulics were used to their
      maximum pull. The attempt was not successful.

v. following the failure of these efforts, the decision was made to
   recover the drill string by the 'wash over' method. This is
   essentially a process of cleaning the annulus between drill pipe
   and bore hole wall of all caving material. A string of casing,
   of a size smaller than the bore diameter and bigger than the
   drill pipe, is fitted with a shoe, is rotated downwards and
   at the same time, mud is flushed through. Temporary casing

FIGURE 7.11 BORE M.A.2 FISHING OPERATION

of 6 5/8" OD and 6" OD was the ideal size for use in the
7 5/8" bore containing the 4 3/4" diameter stuck drill pipes.

The shorter the string of wash-over pipe used, the easier
and safer would be the cleaning operation. As the top of the
'fish' was at 124 m, then ideally a similar length of wash-
over pipe would be required to reach it. However, this amount
of temporary casing was not imediately available and because
the use of a shorter wash-over string was preferred, it was
planned to unscrew the drill pipe within the bore hole.
To carry out this operation so that the greatest length of
drill pipe may be recovered, it is normal practice to exert a
heavy pull on the drill pipes and then back off (turn anti-
clockwise). After several attempts, a drill pipe joint at 34 m
b.g.l. backed off. The re-tightening of the drill pipes back
into the stuck string (tighter than previously) eventually allowed
45 m of drill pipes to be recovered. The situation is shown
(Figure 7.11).

Since it is often found that less drill pipe is recovered
after each attempt, certain precautions should be observed
each time the drill pipes are run back into the bore. Firstly,
all grease is removed from both male and female threads and
each joint is screwed together with a little fine sand sprinkled
in the threads. The joint is then tightened under power so that
it is tighter than joints within the string still down the
bore hole.

vi. the wash-over casing pipe was then washed and reamed down the bore
from 45 m to approx. 99 m b.g.l. in 3 m joints. Troublesome
circulation loss was experienced over the 45 m - 50 m zone where
the wall case was disturbed by the casing. At 99 m, abrasion
of the casing against the problematic 45-50 m zone allowed
caving to take place and the wash-over casing became stuck.

Rig power alone could not free the wash-over casing but
hydraulic jacks were successfully used; about 5 m of jacking,
in 30 cm stages, was necessary. At this stage, the whole wash-
over casing string was pulled out to check and re-dress the
casing shoe.

FIGURE 7.11   BORE M A 2: FISHING OPERATION

STUCK DRILL PIPE

POSITION AFTER WASH-OVER
OPERATION
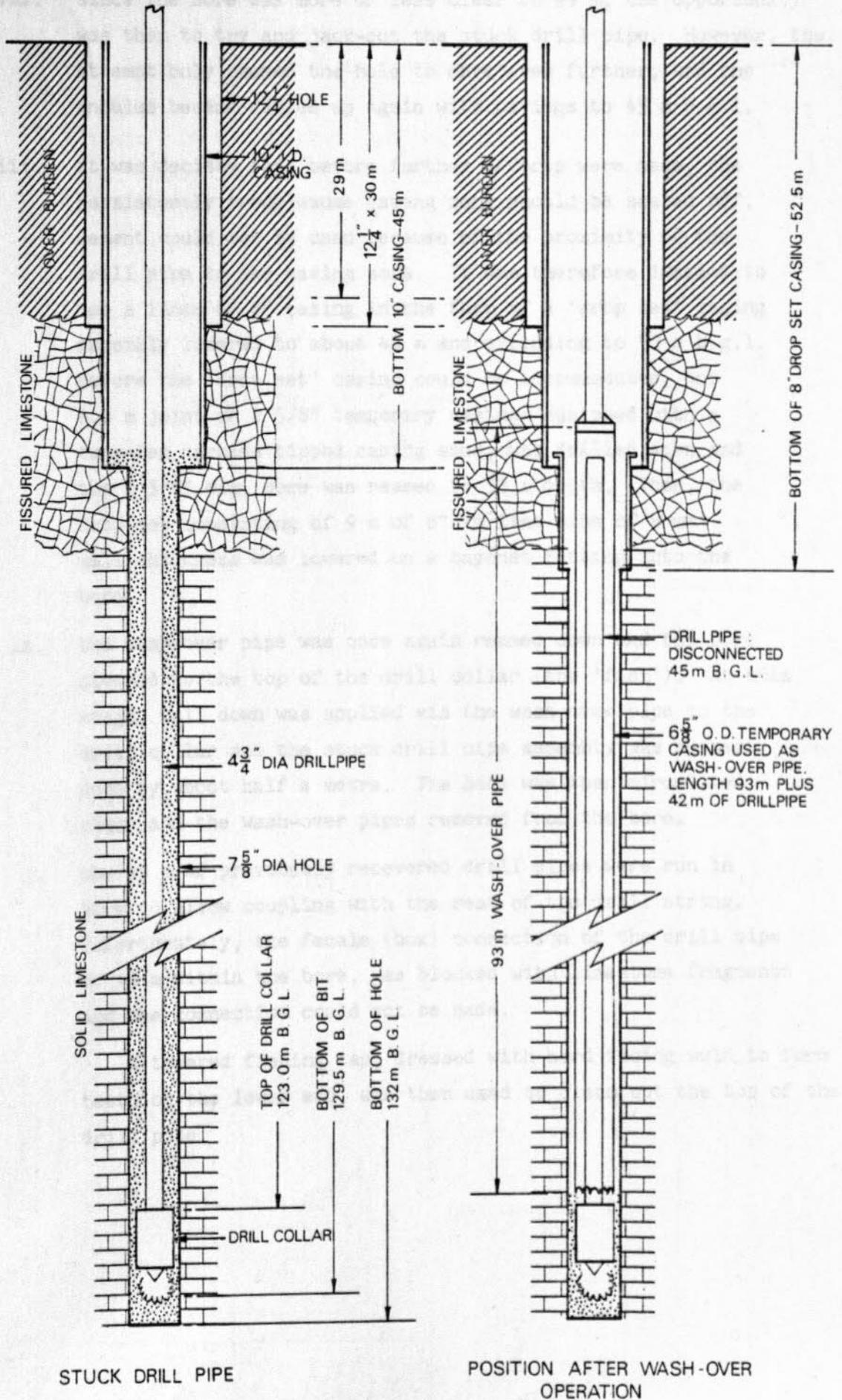
vii. since the bore was more or less clear to 99 m, the opportunity
was then to try and jack-out the stuck drill pipe. However, the
attempt only caused the hole to cave even further, and the
annulus became filled up again with cavings to 45 m b.g.l.

viii. it was decided that before further efforts were made, the
persistently troublesome caving zone should be sealed off.
Cement could not be used because of the proximity of the
drill pipe to the caving zone. It was therefore decided to
use a liner of 8" casing in the form of a 'drop set' casing
assembly lwoered to about 44 m and extending to 53 m b.g.l.
Before the 'drop set' casing could be accommodated, one
6.0 m joint of 8 5/8" temporary casings equipped with a
tungsten carbide tipped casing shoe, was drilled down and
the 7 5/8" dia. bore was reamed to 53 m depth. Then, the
drop set consisting of 9 m of 8" ID line pipe of 8 mm
wall thickness was lowered on a bayonet fitting into the
bore.

ix. the wash-over pipe was once again reamed down and the bore
cleared to the top of the drill collar (the 'fish'). At this
stage, pull down was applied via the wash-over pipe to the
drill collar and the stuck drill pipe assembly was pushed
down by about half a metre. The bore was then circulated
clean and the wash-over pipes removed from the bore.

x. the 45 m of previously recovered drill pipes were run in
bore to allow coupling with the rest of the drill string.
Unfortunately, the female (box) connection of the drill pipe
at 45 m within the bore, was blocked with limestone fragments
and the connection could not be made.

A tapered fishing tap, dressed with hard facing weld to form
teeth on the lower end, was then used to clean out the top of the
drill pipe.

xi. following drill pipe connection, rotation of the whole
     of the drill string became possible but withdrawal was not,
     since gravel remained in the annulus between drill collar
     and the bore hole wall. This annulus would normally be
     cleaned by a wash-over pipe measuring 7½" OD by 7" ID
     but since this was not available, the jacking assembly
     was re-positioned and the drill string jacked up by 4 m.
     An estimated 65 tonnes total force was needed to free the
     drill pipes even at that stage. The rig was then able to
     take over.

     When the drill collar and bit was eventually recovered,
     it was found to be full of limestone cavings.

xii. the bore was later continued to a depth of 186 m and then
     converted into a production bore hole.

Maintenance

Rig Component Failures and Remedial Actions

Regarding maintenance of the drill rig the rig has

so long, it has certainly met with some of the

some due to mechanical teething trouble but most

single breakdown, possibly poor design

by the manufacturer

continue to give trouble however,

choice of rig carr

8.   MAINTENANCE AND SAFETY

8.1   Maintenance

8.1.1   Rig Component Failures and Remedial Measures

The JPT experience regarding maintenance of the Tone drilling rigs has
at times been frustrating; it has certainly led to major programme
delays. Major breakdowns due to mechanical teething troubles occurred
early in the programme; these breakdowns, possibly due to design
deficiencies, were put right by the manufacturer at his expense.
Some problems persist and continue to give trouble; these are however,
mainly the result of the wrong choice of rig carrier. An account of major
breakdowns and remedies is given below:

Hydraulic Pump Failure

Two plunger pumps failed in succession on one machine and were replaced
free of charge by the manufacturer. The cruciform adaptor, fitted
internally between the plunger pump and geared make-up pump, had failed
each time and on the new pumps, this item was replaced for one different
material. As a result of these hydraulic problems, new operating
recommendations were made by Tone Boring Company as follows:

- the rig engine should be warmed up for five minutes, to bring
  it up to operating temperature. The PTO drive should not be
  engaged during this operation (disengage in cab)

- the swash, controlling the hydraulic pump, should be in the
  half open position before the PTO is engaged

- the hydraulics should be run for ten minutes on light load
  before drilling commences

- the oil in the tank and oil filters should be changed every
  month or every 200 hours

- only Tellus 68 oil should be used

- the variable discharge, plunger pump-gear end should have
  its pressure reduced to 7 kg/cm^2.

- the oil-filter-change warning device should be ignored and
  the filter changed as recommended above.

As part of the general up-grading of the hydraulic system, the water cooled heat-exchanger incorporated in the hydraulics of both rigs was subsequently changed to an air-cooled radiator type. The rigs have suffered no further trouble and the up-graded cooling system appears to be very efficient.

Isuzu Clutch : Gearing

To date, three replacement clutches have been fitted to each rig carrier. The original clutches fitted were apparently 'light duty' whilst subsequent replacements have all been of the 'heavy duty' type.

The reasons given to explain such rapid wear have included poor driving techniques or wrong clutch clearances; attention has been given to these possible reasons and they are rejected. Rather, experience shows the gearing ratio of these trucks to be too high to enable the truck to move-off a rough ground without the driver needing to slide the clutch to some degree; on soft ground, 'wheel spin' is rare and stalling of the engine is common.

Clutch wear may also be related to the facility whereby the transmission clutch is capable of remote operation by the driller from the rear of the rig. When the rig mud pump or compressor needs to be engaged, the driller has to operate the clutch. Between drilling operations, the driller tends to disengage drive to the rig via the remote clutch control, to eliminate the high mechanical noises emitted from the rig drive train. Obviously a poorly adjusted master cylinder and control cable will allow partial contact to occur, a situation leading to clutch plate wear. Remedial recommendations are as follows:

- an alternative low ratio gear box - rear axle transmission could be fitted but the expense would be high

- drivers and rig operators should be continually encouraged to observe the manufacturers recommendation regarding good driving habits and particularly to avoid resting the foot of the clutch. Frequent attention should be paid to clutch clearances (Figure 8.1).

FIGURE 8.1   ISUZU TRUCK (SPZ) CLUTCH ADJUSTMENTS

PEDAL HEIGHT ADJUSTMENT

Adjust clutch pedal height with stopper bolt.
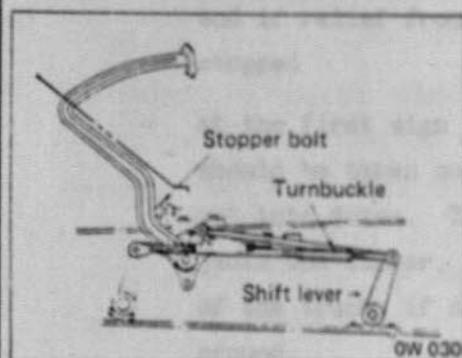
ADJUSTMENT FOR MECHANICAL CONTROL TYPE

(1)   Move the clutch shift lever on the Transmission side until a resistance is felt and hold it in that position (release levers are held in contact with the release bearing).

(2)   Adjust the length of the shift rod with the turnbuckle, so that a clearance of 7mm is provided between the clutch pedal and stopper bolt.

(3)   Release the clutch pedal and release lever, so that clutch pedal free play is automatically adjusted to 25–35mm.

Labels in figure: Stopper bolt, Turnbuckle, Shift lever — OW 030
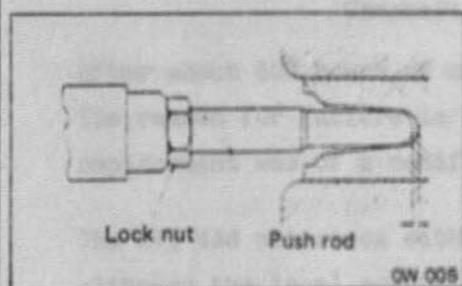
ADJUSTMENT ON HYDRAULIC CONTROL TYPE

Master cylinder

(1)   Disconnect the return spring and loosen the push rod lock nut, then turn the push rod until its end is brought into contact with the piston lightly.

(2)   When push rod is brought into contact with piston, back off the rod 2/3 of a turn and tighten the lock nut.

Labels in figure: Lock nut, Push rod — OW 005

Labels in figure: Clutch pedal free play, 45–55 mm — OW 002

Labels in figure: Pedal height, 195 mm — OW 003
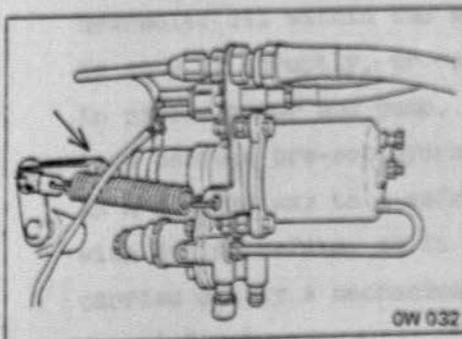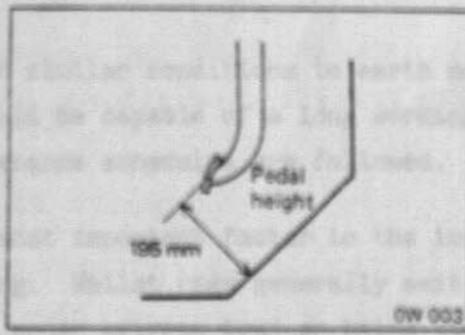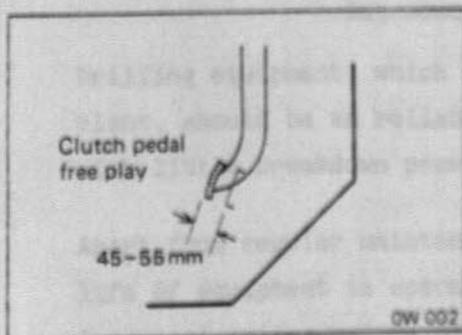
Slave cylinder or Mini-pack

(1)   Remove boot and disconnect return spring.

(2)   With a wrench, loosen push rod by turning it slowly a resistance increases, then back off push rod so that there is between 6–10mm Free play.

Label in figure: OW 032

- the remote clutch control should not be engaged for more time than it takes to slide in the mud pump/compressor clutch control and if relief from noise is desired, the engine should be stopped

- at the first sign of the rig becoming stuck on site, the engine should be taken out of drive and the PTO to the rig hydraulics put into drive. The rig should then be lifted via the hydraulic jacks and timber, plates or hard-core installed under the wheels of the truck; if necessary a track should be laid to harder ground.

Camshaft : Isuzu Engine

After about 600 hours of operation the camshaft on Rig I engine failed. The reason for failure is unexplained but it is significant that the replacement was of a modified design.

The JPT did not stock either spare camshaft or clutch components although the local agents now carry these items.

8.1.2   General Maintenance

Introduction

Drilling equipment, which operates in similar conditions to earth moving plant, should be as reliable and should be capable of a long working life with little breakdown provided maintenance schedules are followed.

Apart from regular maintenance, the most important factor in the long life of equipment is operator handling. Whilst rigs generally emit 'warning' noises before failure when under extreme load or being abused, hydraulic rigs in particular appreciate gentle movement of control levers rather than a sudden snapping action. The reason for this is that hydraulic oil within the system travels rapidly under high pressure and to stop it abruptly, or reverse its direction results in a shock load to pipes, motor and pump. It is not normally possible to exceed design load because pre-set hydraulic unloader valves are fitted and they act in a similar way to a safety valve. However, even these can be tampered with during refits, so it is strongly recommended that re-setting is only carried out by a mechanical engineer who will refer to the manufacturer's manual first.

FIGURE 8.2   SCHEMATIC PIPING SYSTEM - TONE RIG

Comments on certain maintenance problems which have arisen over the
last eighteen months are dealt with below:

Air Receiver Tank : Discharge Hose

The schematic diagram (Figure 8.2) shows the pipework layout on the
Tone rig. The line leading from the compressor receiver tank has been
equipped with a shut-off valve which should be closed when mud is being
pumped. Unfortunately, in the past it has been left open and in one
occasion, mud filled the compressor. To prevent this happening again,
the hose in question should be disconnected when drilling is by mud flush.

Hydraulic Winch : Oil Seal

In difficult drilling conditions involving the use of high torque and
consequent vibration of the drill string, the winch oil seal often fails.
This oil seal, as with many others, is engraved with a part number which
also represents the oil seal size in millimetres i.e. 53.98, 82.55, 9.5
(ID., OD., and thickness); these are available in Malaysia.

Air Cleaner Hose : Isuzu Truck

The rubber pipe connecting the engine air intake to the air filter was
damaged on one machine. After three months of trying to obtain a
replacement both locally and in Japan, the JPT were informed that it is
no longer available. An adequate replacement was therefore fabricated
by the JPT Workshop, Ipoh by using metal trunking connected with short
rubber end fittings.

Mud Pump : Fluid End Maintenance

The mud pump itself is robust and apart from oil changes, required
little other maintenance. The fluid-end is subejct to wear because of
the nature of the pumped fluid i.e. sand laden bentonite. Areas of wear
are:

- Piston rod packings
- Piston rods
- Piston head
- Piston liner
- Valve inserts

FIGURE 8.2   SCHEMATIC PIPING SYSTEM-TONE RIG

MUD PUMP

RELIEF VALVE

SUCTION PIT

SETTLING PIT

AIR RECEIVER TANK

COMPRESSOR

CONNECT AUXILIARY COMPRESSOR HERE

MUD MIXING HOPPER

RELIEF VALVE

OFF-TAKE;
BIT GRINDER
AIR LIFT
FOAM PUMP

INJECT FOAM HERE

DIRECTION OF FLOW ➝

IMPORTANT NOTE.
DISCONNECT FLEXIBLE
HOSE BEFORE STARTING
TO DRILL WITH MUD.

SWIVEL.

STANDPIPE

KELLY

FILL BORE WITH MUD DURING
WITHDRAWAL OF DRILLPIPE

⊠ VALVE

CONDUCTOR CASING

The piston rod packings should not be allowed to leak. Leaking fluid acts as a grinding paste on the rod and results in heavy wear; it is much cheaper to change packings than piston rods. Piston head rubbers will need changing at a rate dependent on use and state of the drilling mud. High sand content may require to change after 200 m of drilling whilst good mud control will allow several times this figure.

To check piston wear, the end-plates need to be removed and each piston tested for movement and visible gaps between piston and liner. Piston liner change frequency depends on the amount of internal leakage past the piston head. Such leaks often allow the liner to be 'mud cut' (i.e. deep channel etched by the sand bearing mud) and they have to be scrapped. Average change period is one liner to three sets of piston rubbers. Valve inserts and valves are also suseptible to mud cutting, especially when the valve is stuck open. The valve covers should be lifted periodically and the pump cleaned and flushed out.

Swivel : Packings

Packings on an air swivel will last indefinitely but for mud use, wear is again dependent on sand content. Leaking packing will cause irrepairable damage to the swivel wash-pipe and eventual damage to the bearings. Maintenance is easy and only entails removal of the swivel cap.

Drill Head : Damper Sub

The drill head is protected by a special splined damper sub during the course of DHH drilling. The sub is also very useful in giving a measure of tolerance to the process of screwing and unscrewing the head from the drill pipe. With it, the whole weight of the head (400 kg) may be positively balanced and thread damage avoided. According to the manufacturer, the damper sub should be used for air only but in view of its usefulness in preventing damage, the drilling section use it constantly during air and mud circulation. The penalty is, however, wear of the internal seals but their cost is low compared with potential savings and it is recommended that it be used and described.

Drill Head Guides

The body of the drill head incorporates brass wear plates or guides which are in contact with the mast runners; they need changing periodically. One rig is now ready for this maintenance.

Dog Clutches

The clutch systems for the compressor and mud pump are simple 'dog' clutch devices which are trouble free unless the control cable is not properly adjusted. If the control cable is adjusted wrongly, the clutch 'claws' which should run freely in a greased groove, become overheated and wear is rapid. The compressor clutch in particular is troublesome, due mainly to it being mounted on a 'floating' type base frame which, if not accurately positioned and tightly bolted down, becomes misaligned.

Hydraulic Pull-down Rams

The rams are substantial and to date have been trouble free. However, because of poor drill table design, cuttings and drilling debris blast past the table and contaminate the rams during air drilling operations. Whilst scraper seals help to clean the ram, and the fundamental fault lies in the table design, efforts should be made to avoid the situation. Drillpipe 'wipers' made from conveyor belt (rubber/fabric) should be fitted beneath the drill table when air drilling and renewed at every site if necessary.

Spares : Hydraulic Components

A few ram seals are stocked in the JPT store. Two complete winch/head motors are available (radial piston type) but there are no hydraulic pumps or control valves. A list of recommended spares suitable for a two rig operation is shown in Appendix XV.

Drill Table : Rig II

The complete drill table, comprising base, laykey plate rod, guide rollers and cuttings deflector plate was lost off the rig en route from Ipoh to K.L. and has never been found. A replacement may be fabricated by copying from Rig I and until this is done, rig II is inoperable.

General Rig and Truck Spares

Rig compressor and mud pump spares are adequate. Chassis and some engine spares (Isuzu) are stocked in small numbers. Drilling consumables such as soft formation rock roller bits in large sizes are sufficient to last several years. Other bit types need constant replacement. Bentonite and additives are available locally whilst screen is stocked in Singapore. Drilling subs can be made to a good standard in K.L.

Hydraulic Hoses

No hydraulic hose failures have occurred but there is a danger that
hoses may be damaged during raising and lowering of the rig mast.
To avoid this, the operator and a second man should watch from both
sides for fouling of the hoses during this operation.

Hydraulic hose is available in most towns. The hose end-fittings
are not re-useable as they are crimped on and complete replacement
hoses will not be available 'off the shelf'. Shopping around to find
a dealer with the hose material and the necessary threaded couplings
will be unavoidable. The stocking of spare hoses in sufficient quantities
to cover all potential needs is not recommended owing to deterioration
of the rubber with time.

Bore Casing

Stocks of 10" and 6" plain end bevelled bore casing are large. At the time
of writing (May 1983) the approximate casing stock position is:

10" nominal bore	-	2,700 metres
6" " "	-	1,650 metres

Judging by the past rate of usage, this amount of 6" casing could last
for four years and the 10" for 10 years. Unfortunately, because of the
difficulties involved in storing such a large quantity, a proportion
of it is bound to be spoiled long before it can be used. It would be
desirable if a proportion of this casing be reassigned to other government
agencies involved in water drilling work.

Stores Procurement

Assuming that stores are fully stocked at the beginning of a drilling
programme, it should be a simple operation to record what is issued to
the field team, so that those parts at least can be replaced. By close
co-operation between the drilling supervisor, the mechanical engineer
and the staff at JPT Ampang, a list of extra items deemed necessary,
and requirements for the future can be given to the chief storeman.

When the opportunity arises (at least annually) and when requirements for spares are requested, the stores department should present a list including among other things:

- spares issued (and not replaced)

- spares required (predicted) for preventive maintenance

- consumables required, such as special oils, filters, packings, mud pump fluid-end spares (piston liners, rods, packing, valves, etc.), rockbits, bentonite and additives, foam, subs and fittings and screen

- additional equipment requirements

Manuals and Spare Parts Books

Lubrication, maintenance and repair particulars are well provided for in the various manuals and books held in K.L. Ipoh Workshops also have copies, and a copy of each publication is held on site.

All new equipment; including test pumps, DHH and welding set, have been supplied with maintenance manuals and parts books, and these have been photocopied for site use.

8.1.3   Drill Pipe and Casing Care

Storage of Drill Pipe and Metal Casing

This material should be handled as follows:

- lay out all the pipes on the drilling site in a convenient position. See that it is clean and ready for use

- it is good practice to ensure that all pipes are clean when leaving the site to be returned to store

- drill pipe and casing should be stored on racks off the ground so that they are out of the mud and water that will invariably collect. Cleaning and greasing of threads is essential for steel pipes before storage.

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Storage of Non-metallic Casing

None of this material should be left in direct sunlight although
fibreglass is moderately tolerant. PVC and other plastic will bend
due to expansion of the side exposed to the sun and under extreme
conditions can even deform over its section.

Doping or Greasing of Tool Joints

It is best to always use a recognised lubricant. For this purpose
copper disulphide or graphite base is the best as it has been developed
primarily for lubricating tool joints. It comes under a variety
of names, one of the most common is 'Kopa-Kote'. Not only does it
alleviate excessive wear and galling on the joints, but also helps to
prevent friction welding of the joints due to the torque built
up in the drill string during drilling.

Lubricant (thread dope) applied to the drill string threads when
running in the hole should be spread evenly over the pin and pin
shoulder, not just placed on one place in the hope it will distribute
itself over the entire threaded area.

Finally it cannot be over emphasized that a few extra minutes of
care can save countless hours of fishing jobs and prolong drill string
life.

Thread Protectors

Each drill string component has been provided with thread protectors
and apart from protecting against damage they serve to guard against
ingress of dirt. This is particularly important with drill pipe
which is to be used for DHH drilling.

When moving drill pipe from site to site, it is important that thread
protectors are installed tightly as several have been lost already
en route. Replacements cost M$60/- each.

8.2   Safety

Safety at work is of paramount importance. It is the subject of
legislation in most countries and it is often a major expense to
an employer. These are a few obvious rules of safety that apply
to drilling. No attempt is made here to list rules in order of
importance and no claim is made that all are contained here.

Common sense is a pre-requisite. It is suggested that each field worker receives a personal copy of the safety measures. It is also recommended that drilling rig crew attend a first aid course.

For the sake of safety, do:

- wear a safety helmet, safety boots and snug fitting gloves
- wear goggles whilst grinding (bit dressing) and gas cutting
- wear shield whilst welding
- wear comfortable snug fitting overalls
- keep a well stocked first aid kit
- keep walk-ways around the rig clear
- keep tools and equipment clean
- keep guards on machinery
- keep generator cable off the ground; string it between poles
- keep a look out for overhead electricity cable whilst moving equipment and keep plant at least 5 m away from electricity cables
- keep site tidy and orderly
- keep fingers away from pipe ends when leading
- use wrench of the correct size; ensure jaws and inserts are in good condition
- ensure that jack timbers are well bedded
- ensure that rig is level before raising mast and that no loose equipment is lying in the mast before raising
- ensure that slings are properly secured to their load before lifting and that the slings are sufficiently strong for the work at hand
- ensure that any load on truck is secure before moving off and that the load overhanging from the truck is well marked
- ensure that high pressure pipe fittings are used on air and mud lines
- ensure that winch rope is in good condition
- ensure that bore casing clamps are tight; run a bead of weld across casing above clamps if necessary.

Do exercise particular care when:

- handling petrol
- handling caustic soda; if in contact, spash copious amounts
  of clean water on area affected
- lifting heavy weights; see later comments
- when charging batteries; no naked flames!
- when breaking out drill pipe joints; stand clear of break
  out tongs or pipe wrench.

Other reminders, warnings and hints for safety include:

- when cranking an engine, do keep your thumb on the same
  side as your fingers on the starting handle
- take care when freeing stuck rock-roller bit cones
  with a hammer as hard metal fragments may fly off into
  your eye; wear goggles
- use both hands when climbing the rig mast, and ensure
  a firm foothold
- use a safety belt when working up the rig mast
- tie jacks back to the drill-table whilst jacking-out drill pipe
  or casing; the jacks may flat apart
- do inspect wire ropes and lifting devices daily
- do care for each other and anticipate each other's actions
  and possible difficulties
- do use common sense.

Some actions are quite clearly dangerous. At the risk of stating
the obvious, do not:

- start rig up with PTO engaged
- raise mast without first looking up; ensure that mast has
  a clearance of 5 m from any electricity line
- touch or lean over a revolving shaft
- operate without guards on rotating equipment
- start compressor with valves open
- store flammable liquids near a welding area
- let grease or oil come in contact with oxygen bottle fittings
- fill petrol tanks whilst the engine is running; do not smoke
  whilst handling fuel or other volatile liquids.

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- overload the supply truck
- set safety valves on compressor beyond that recommended
- stand under suspended loads
- put break-out tong or wrench near the drill pipe if
  the operator has his hand near the rotary control
- play practical jokes on site
- work in half-light or darkness
- push a wrench. It is better to pull but if you need
  to push, keep knuckles clear
- allow junk and items of equipment to accumulate in the
  area of work.

Back injuries resulting from the improper lifting of heavy weights can
be avoided by following some simple rules. These are:

- if the weight appears to be too heavy or bulky to lift,
  get some assistance
- when preparing to lift, stand with your feet apart
  (shoulder width), bend your legs at the knees and
  grasp the item to be lifted.
- with the weight centred between your knees, lift slowly,
  keeping your back as straight as possible
- reverse the procedure when lowering a weighty object.

APPENDIX

GLOSSARY OF DRILLING TERMS

Many terms used in this Manual are seldom seen in standard English
but are common in the oil drilling industry which originated most
of the terminology used. Water bore drilling uses much of the oil
industry equipment and terminology and, because of high involvement
of the USA, a measurement system which is still largely non-metric.
Throughout this Manual, dimensions are given in metric or non-metric
form; many drilling components are only known readily by their size
in inches.

Exaplanation of common drilling terms is given below:

Drill String   : components of the drilling shaft which
                           can include bits, drill collars, subs
                           and drill pipes.

Kelly   : ususally a machined section of hollow
                           pipe with flats or splines which engage
                           in the rotary table of an oil rig. On
                           a rig with a power swivel, it refers to
                           the top drill pipe which is connected
                           to the swivel.

Sub   : connector between two sizes of drill string
                           components

Box   : female thread on a sub

Pin   : male thread on a sub

Tool Joint   : screwed end of a drill pipe

Joint   : refers to a complete length of casing

Conductor   : casing set at the top of the bore to
                           exclude unstable soil or overburden

Casing   : a lining pipe in the bore

API   : American Petroleum Institute

BS   : British Standard

Annulus   : area between drill pipe or casing and
                           bore wall

Mud   : usually, a bentonite clay based drilling
                           fluid

Gun Line   : hose for mixing mud

Spuddin in   : starting the bore.

Circulation	:	the movement of the drilling fluid through the bore hole and rig system. For mud flush drilling, it means the circulation of drilling mud from mud pit, through the mud pump, through the drill string and back up the annulus to the mud pit.
Tripping	:	removal of the drill string from the bore and re-insertion therein.
Driller	:	foreman in charge of the shift
Tool pusher	:	supervisor on drill site
Connection	:	adding a drill pipe to others
Cementing	:	forcing or placing cement grout into the annulus
PTO	:	power take off.
Barrel	:	42 US gallons or 35 IMP gallons
l/sec	:	litres per second
l/min	:	litres per minute
Nominal	:	refers to tubular goods. Is the commonly known casing size, often referring to approximate bore or inside dia. API casing sizes are known by nominal OD sizes.
Blooie line	:	pertaining to discharge or flow pipe when foam drilling.

APPENDIX II   RIG SPECIFICATIONS

Model and Type:

TONE Model "Top-750A" truck mounted hydraulically rotary top head
drive type drilling machine.

Drilling Capacity:

Drilling System	Depth (m)	Size of Drill Pipes
Direct circulation drilling system	750 600 400	2-7/8" 3-1/2" 4-1/2"
Down-the-Hole Hammer drilling system	150	4-3/4"

Vehicle:

Model and Type	-	ISUZU MOTORS Model "SPZ-581" heavy duty diesel truck

*Other detailed specifications refer to manufacturer's catalogue
and General Assembly Drawing of Truck (DWG. No. B5770-025).

Mast:

Type	-	Structural steel channels and L-beams, electrically welded, raised and lowered hydraulically.
Height	-	11.3 m from ground level to center of the head sheave.
Total gross capacity	-	50,000 kg. (110,000 lbs)
Hook load capacity	-	25,000 kg. (55,000 lbs)
No. of sheave	-	3

Drawworks:

Type	-	Planetary gear with band brake
Drum	-	Single drum
Diameter	-	330 mm
Length	-	288 mm
Spooling capacity	-	180 m with 18 mm wire rope
Max. single line pull	-	5,000 kg.
Rope speed	-	0-30 m/min. (bare drum)
No. of lines	-	2
Working pull	-	10,000 kg.

Pull Down:

Type	-	Hydraulic cylinder chain feed
Feed stroke	-	7.5 m
Feed speed:		
High	-	0-17 m/min.
Low	-	0-2.5 m/min.
Max. pull down	-	14,000 kg.

Power Swivel (Swivel Head)

Type	-	Hydraulically rotary top head drive type
Type of chuck	-	Screw chuck
I.D. of drive shaft	-	150 mm
Max. torque	-	640 kg-m at 0-50 rpm
Bit revolution:		
High	-	0-100 rpm
Low	-	0-50 rpm

Mud Pump:

Model and type	-	TONE Model "NAS-6C", heavy duty twin cylinders, double acting type
Max. displacement	-	850 L/min. (225 GPM)
Max. working pressure	-	20 kg/cm^2 (284 psi)

*Other detailed specifications refer to General Assembly Drawing
  of NAS-6C. (DWG. NO. 6106-308)

Air Compressor:

Model and type	-	GARDNER-DENVER COMPANY Model "WEG", two stage, water-cooled type. Reciprocating Piston.
Max. working pressure	-	14 kg/cm^2 (200 psi)
Max. displacement	-	387 cfm.

*Other detailed specifications refer to manufacturer's catalogue
  and General Assembly Drawing of Air Compressor (DWG. NO. C5469-011).

Description	Quantity
Drillpipe (Flush) 12 cm O.D. with Laykey slots. Screwed 3½" A.P.I. I.F. 6.0 m long	100
Drillpipe (Flush) 8.89 cm O.D. with Laykey slots. Screwed 2 3/8" A.P.I. I.F. 3.0 m long	50
Drillcollar 20.3 cm O.D. Flush with Laykey slots. Screwed 6 5/8" A.P.I. REG. 3.0 m long	4
Selection of connector subs to work with each drillpipe and drillcollars. Sizes to suit drillbit range 4 3/4"-15". Size of subs 2 3/8" A.P.I. REG. through to 7 5/8" A.P.I. REG.	2 Sets
Laykeys and breakout ton s to suit drillpipes and drillcollars various sizes	2 Sets
Rockroller bits for hard and soft formations. Various sizes including: 4 3/4, 5 7/8, 6, 7 3/8, 7 5/8, 9 5/8, 12¼, 14 3/4 inches.	2 Sets
Dragbits, tungsten tipped, sizes 6¼, 9 5/8, 12¼ and 15 inches	2 Sets
Down-the-Hole Hammer unit Tone A.D. 150 equipped with 15.2 cm bits	1 Set
Down-the-Hole Hammer unit Dresser T6 equipped with 6" and 7½" bits	1 Set
Hydraulic breakout unit for Tone D.H.H.	1 Set
Undisturbed soil sampling assembly. Tube size 7.75 cm O.D. x 1.16 m	1 Set
Wing stabilizer 30 cm O.D. Screwed 6 5/8" A.P.I. REG. 1.0 m long	4
Wing stabilizer 13 cm O.D. Screwed 2 3/8" A.P.I. I.F. 3 m long	2
Drillcollar 16.5 cm O.D. Screwed 3½" A.P.I. I.F. 6.0 m long (Fabricated locally)	2
Fishing tools (right hand) including taper tap and Die Overshot to pick up 12 cm O.D. drillpipe. Subbed to 3½" A.P.I. I.F.	2 Sets

Description	Quantity
Hydraulic jacks 20 tonne capacity	4
Drillcollar spider and slips	2 Sets
Drillpipe (12 cm O.D.) spider clamps and slips	2 Sets
Drive hammer 150 kg.	2
Lifting plugs various	2 Sets
Pipe wrenches. Various sizes 55 cm to 115 cm length	2 Sets
Chain tongs, various sizes 55 cm to 168 cm length	2 Sets
Composite field tool kit, including special tools for stripping mud pump	2 Sets
Airlift assembly for use with 12 cm O.D. drillpipes	2 Sets
D.H.H. bit grinder kit	2 Sets
Lighting set complete with lamps.	2 Sets
Welding set complete with cables etc. size: 150 AMP Continuous.	1 Set
Water pump 3" centrifugal type complete with suction and delivery hoses	2 Sets
Steel casing 15.6 cm I.D. with bevelled ends. In 5.5 m lengths used as well casing. Original quantity 546 Nos.	300
Steel casing 24 cm I.D. with bevelled ends. In 5.5 m lengths. original quantity 546 Nos.	490
Temporary casing 32.1 cm O.D. flush joint type. Screwed to B.S.	
a) Flush Joint Type - Length 3 m	3
b) " " " - " 1 m	1
Casing as above but 20.7 cm O.D. Length 3 m	24
" " " " " " " 1 m	2
Casing as above but 15.9 cm O.D. Length 3 m	36
" " " " " O.D. Length 1 m	4

	Description	Quantity

Temporary casing 25.5 cm O.D. screwed and socket
type 'V' thread:

screwed and socket type 'V' thread – Length 3 m   6

"   "   "   "   "   2 m   2

"   "   "   "   "   1 m   2

Clamps, lifting pieces, casing heads casing
shoes for all sizes of casing   2 Sets

4 x 4 field vehicles   2

Test pumps (6" & 10")   2

3 ton truck   2

Mining Equipment **DRESSER**
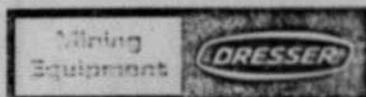
Bit Insert Grinding/Re-Shaping

To assure continuing good performance levels from Dresser button percussion bits, it is advisable to re-shape the tungsten carbide inserts as they wear. After a period of drilling, the buttons tend to develop a flat surface, rather than the original ovoid-rounded shape, and this can slow penetration rates and shorten bit footage. This "flat" enlarges the longer the bit drills. Inspection and experience (noting when penetration rates tend to decrease) can indicate when re-shaping should be done.

When to Re-Shape

Experience has indicated the following as guidelines for resharpening buttons in order to retain drilling efficiency and maximize bit life.

When to Re-Shape Buttons

FORMATION/DRILLING RATE	FLAT SIZE NEEDS RE-SHAPING
Soft Formations — over 40' (12 mtrs) per hour	¼" (6.4mm)
Medium Formations — 25' to 50' (8 to 12 mtrs.) per hour	³/₁₆" (4.8mm)
Hard Formations — Less than 25' (8 mtrs.) per hour	⅛" (3.2mm)

Broken Inserts

Button percussion bits can continue to drill effectively even with a reasonable number of missing inserts. However, in order to minimize possible additional damage to buttons, broken or chipped insert buttons should be ground.

. . . Chipped buttons will continue to function. Sharp edges should be ground smooth to minimize the chance of further damage.

. . . Broken buttons should be ground flush with the bit head to prevent any further breakage which could damage other buttons which are still intact.

Heat Cracks on Buttons

While inspecting a bit for re-shaping, check for rough areas on the buttons that appear like alligator skin. These are fine cracks caused by overheating, and if not ground off can lead to premature button failure.

In order to minimize the chance of further damage, grind the button enough to remove the cracks, re-shaping as necessary. If detected on a normal sharpening schedule, this will require removal of only a small depth of the carbide button.

Chip Relief Maintenance

It is also recommended that while resharpening buttons, the chip relief groove be checked. Grind away any sharp edges that might constrict the passageway, and enlarge the passages if they have become worn.

Quick chip removal is an important factor in maintaining penetration rates and long bit life, and by assuring free passages for chip removal, efficient drilling performance is retained.

Note: To assure safety while grinding, be sure SAFETY GLASSES are worn, and use only grinding wheels approved for the application.)

Grinding/Re-Shaping Guidelines

1. To restore the bit to maximum drilling efficiency, the approximate original shape of the button should be restored.
2. Use a small hand grinder (20,000-25,000 rpm) with a shaped vitrified silicon carbide grinding wheel of 60 to 80 grit and J to L hardness.
3. Grind from the center of the flat, rolling the wheel down the side of the button to remove the edge. Continue until the button is re-shaped to an ovoid or rounded configuration.
4. The re-shaped button will be somewhat smaller than when new, but drilling efficiency will be restored.

Although the gage buttons are most important to re-shape because they are more subject to wear and failure as their efficiency decreases, penetration rates will also be helped if the face button configurations are restored. Therefore, it is recommended that face buttons be re-shaped each time the gage buttons are ground, even though the face buttons may not have worn quite as much as the gage buttons.

FLAT   ORIGINAL SHAPE

SHARPEN TO OVOID SHAPE

A.P.I. REGULAR

SIZE	A	B	C	D	E	F	G	H	K
2⅜	3	3⅜	2⅝	1⅝	2¹¹⁄₁₆	3½	1	5	3
2⅞	3⅜	3⅝	3	2⅛	3⅛	3⅝	1⅜	5	3
3½	3⅝	4⅛	3⅝	2⅝	3⅝	4⅜	1⅝	6	3
4½	4⅜	5⅛	4⅛	3⅛	4⅜	5⅜	2⅛	6	3
5½	5	5½	4⅝	3⅝	4⅞	5⅞	2⅝	4	2
1 6⅝	6	7⅜	6	4⅛	5⅞	6⅞	2⅝	4	2
2 7⅝	6⅝	8⅜	7	4¹¹⁄₁₆	6⅝	8⅜	4	4	3
3 8⅝	7⅝	10	7¹¹⁄₁₆	5¹¹⁄₁₆	7⅝	9⅜	4⅜	4	3

A.P.I. INTERNAL FLUSH

HUGHES & REED I.F.

SIZE	A	B	C	D	E	F	G	H	K
3 2⅜	3	3⅛	2⅝	2⅝	2¹¹⁄₁₆	3½	1⅝	4	2
4 2⅞	3½	4⅛	3⅝	2¹¹⁄₁₆	3¹¹⁄₁₆	3⅝	1⅝	4	2
5 3½	4	4⅝	3¹¹⁄₁₆	3¹¹⁄₁₆	4⅝	4⅝	2⅝	4	2
1 4	4½	5⅝	4¹¹⁄₁₆	3¹¹⁄₁₆	4⁹⁄₁₆	4⅝	2¹¹⁄₁₆	4	2
2 4½	4⅝	6⅝	5⅝	4⅝	5⅝	5⅝	3⅜	4	2
5½	5	7⅝	6⅝	5⅝	6⅞⁄₁₆	6⅝	4⁵⁄₁₆	4	2

1. THREADED PORTION SAME AS 4½″ HUGHES XTRA HOLE &
   5″ REED OBL. STREAMLINE &

2. THREADED PORTION SAME AS 6½″ REED DBL. STREAMLINE &
   5″ HUGHES XTRA HOLE &
   5″ REED XTRA HOLE

3. THREADED PORTION SAME AS 2⅞″ HUGHES SLIM HOLE

4. THREADED PORTION SAME AS 3½″ HUGHES SLIM HOLE

5. THREADED PORTION SAME AS 4½″ HUGHES SLIM HOLE

NOTES:

a) D.I.D. DRILLPIPE HAVE I.F. THREADS.
b) D.I.D. DRILLCOLLARS HAVE REGULAR THREADS.
c) ALL ROCKBITS HAVE REGULAR THREADS.
d) ALL THREADS ARE MEASURED IN INCHES.

Insert Bit Comparison by Type   (TUNGSTEN)

IADC CODE		REED	HUGHES	SECURITY	GRUNER SMITH	VAREL
435	SOFT FORMATION	-	X11	-	-	QMC 9
437		-	J11	-	-	
513		-	-	-	2JS	
515		FP51A	X22	S84	F2	
517		352	J22	S84F		
525		FT52				
527						
532	SOFT TO MEDIUM FORMATION	S53	HH33	-	3JS	QMC 7
535		FP53/FF53A	X33	S86F	F3	
537			J33	S9JA		
542		-	-	-	-	
543		-	-	S83	-	
545		-	-	S89F	-	
547		-	HH44	-	4JA	QMC 77
612		-	X44	-	4JS	
613		FF62	J44	-	F4/F45	
615		Y62JA/Y62BJA	-	M84F	5JA	
617		562	-	M8JA	4JS	
622		FF62B/FF62X	J44C/J55R	-	F5	
625	HARD F.	Y63JA	HH55	M89F/H99TF		
627		563	J55	M89F	F47/57	QMC 6
632		FF63				
635						
637						
713	HARD TO VERY HARD FORMATION	-	-	-	F6	QMC 65
717		-	-	-	7JA	
722		S72	HH77	H84F	F7	
723		FF72	J77	H8JA		
725		Y73JA	-	-		
727		FP73	-	H88	-	
732		Y73RAF	-	H88F		
737		S74	HH88	H9JA		
739		FF74		H99		
742				H99F		QMCH
745		Y83JA	HH99	H10JA	9JA	
747		S83	J99	H100	F9	
812		FF83		H100F		

Mill Tooth Bit Comparison by Type   (STEEL)

IADC CODE		REED	HUGHES	SECURITY	GRUNER SMITH	VAREL
111	SOFT FORMATION	Y11	OCS3A	S3S	DS	
114		S11	X3A	S33S	SDS	
115		-	-	S33SG	-	
116		Y11JD	J1	S33SF	DJ	VJS
118		Y12	-	S33JD	DT	
121		-	OSC3	S3	-	
122		-	S	-	-	
123		Y12T	-	S3T	DTT	
124		S12	J2	A33	SDT	
126		FF12	-	A33F	FDT	
128		Y13	OSC1G	S33F	BHD	VH3G
131		Y13T/Y13G	-	S4	DG	
133		S13	J3	S4T	DGT	
134		S13G	JD3	S44	SDG	
135		FP13	-	S44G	SDGH	
136				S44F	FDG	
137						
211	SOFT TO MEDIUM FORMATION	Y21	OSW/OS4	N4U	V2	V2
212		-	N	-	V2H	
213		Y21G	-	N44N	SV	
214		S21	-	N44NG	S7H	
215		S21G	J4	N44NF	-	
216		FP21	JD4	-	-	
217		-	WO	M4	-	
221		Y22R	-	N4L	T2H	VH2
231		-	-	N44L	ST2	
233		S23	-	-	-	
234		-	-	N44LF	L4	V1
235		S23G	-	H7	-	
236						
311	MEDIUM TO HARD FORMATION	Y31	W7/W7C	H7	L4	V1
312		-	H	-	LAH	
313		Y31G	-	H7T	SL4	
314		-	-	H7T	SLAH	
315		S31G	-			
316		-	J7	H77F	-	VH1
317		FP31G	-	-	-	
319		Y31RAF	-	-	-	
321		-	W7R2	-	-	
329		Y32RAF	HR	H7TSG	-	V2H
332		-	-	H7TSG		
333		-		H77C		
335		-	J5	H77CF		
344		-	JD5			
347						

APPENDIX VI-2   BIT COMPARISON CHART   – AIR DRILLING

VAREL	SMITH	REED	HUGHES	SECURITY	GRUNER	FORMATION
V3S	-	M-12	-	-	GR5	Tooth Bits for Soft Formation
V3M	Q5	-	-	-	GR4	
VH3G	-	M-13	S	S-4M	GR3	
V2	QM	M-21	-	-	GR2	Tooth Bits for Medium Formation
VH2	-	M-23	M	M-4M	GR1T	
V1	-	-	-	-	GR1	
VH1	-	M-32	H	-	GR1H	Tooth Bits for Hard Formation
VQM	QH7	-	HH4	-	-	Hard Formation Tooth Bits with Carbide Gage Row
QHC9	Q-4	M-52	H-33	-	GR44	Insert Bits for Soft Formation
QHC7	Q-5	M-62	H-44	S-8M	GR44	
QHC77	Q-5	M-62	-	H-8M	-	Insert Bits for Medium to Medium Hard Formation
QHC73	Q-5	M-62	-	M-8M	-	
QHC6	Q-6	M-63	H-55	H-8M	GR66	
QHC63	Q-7	M-73	H-88	H-8M	-	
QHCH	Q-9	M-83	H-99	H-10M	GR77	Insert Bits for Very Hard Formation

10"x6" CASING REDUCER

FABRICATE ENDS (SHADED)
FROM 6"(I.P.T) CASING.

MAKE CONICAL FITTING ONLY
6mm THICK STEEL

PREPARE ENDS
FOR WELDING

10" N.B. CASING (I.P.T)

6" N.B. CASING (I.P.T)

10 cm

50 cm

10 cm

35°

FLAT

2mm

WELD-ON 2"N.B PIPE.
SCREW 2"BSP(PARALLEL)

35° APPROX

6" N.B
CASING
(I.P.T)

10cm

30cm

60cm

10" N.B
CASING
(I.P.T)

N.B = NOMINAL BORE

10" CONDUCTOR BOX

6" SCREEN/CASING SET IN 12 BORE:- LENGTH APPROX 50cm.
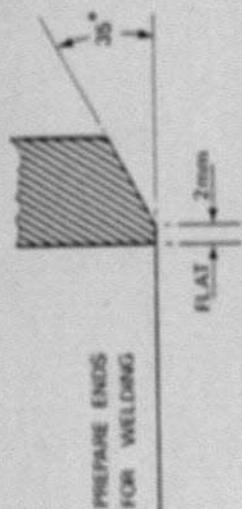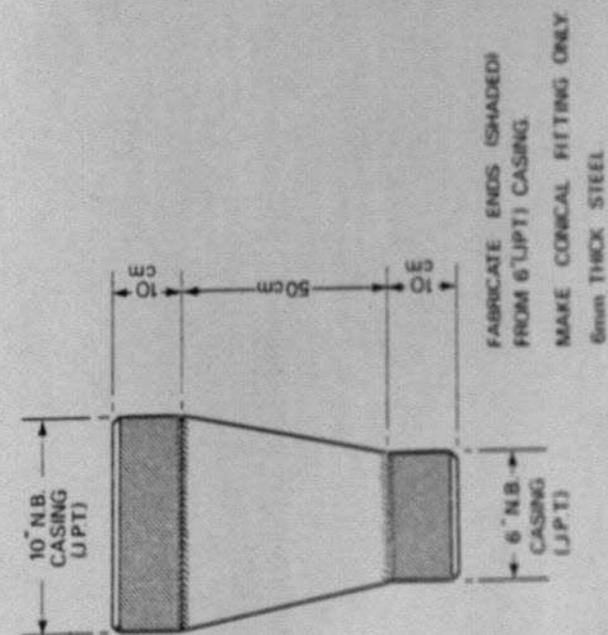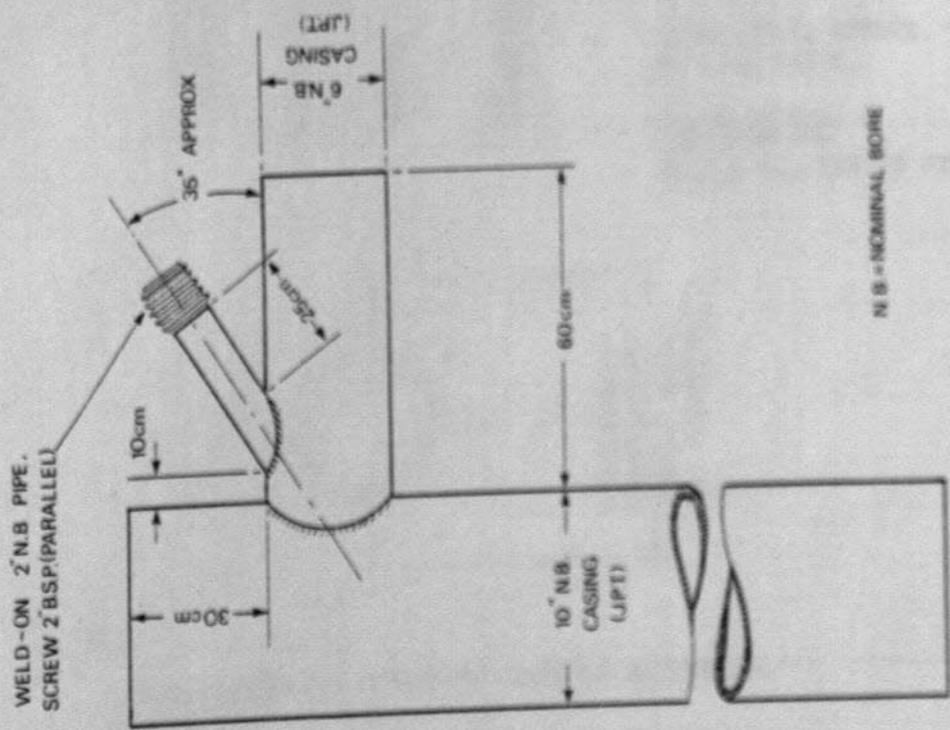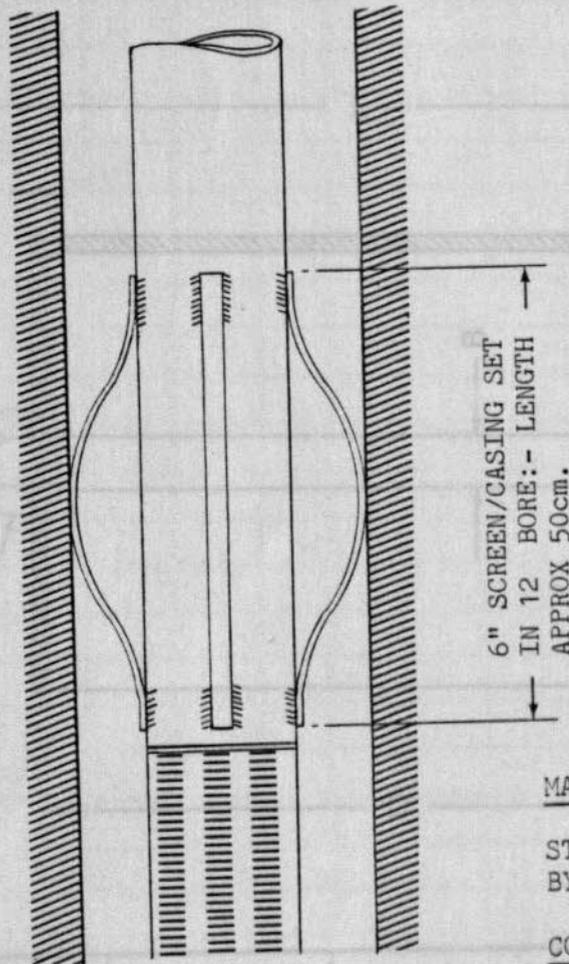
MATERIAL:

STEEL STRIP APPROX. 5 cm WIDE BY 4 mm THICK.

CONSTRUCTION:

WELD 4 no. STRIPS PER SET.

DIAMETER OF CENTRALISER SHOULD EQUAL BIT DIAMETER.
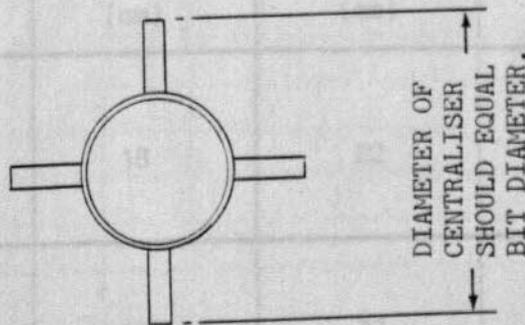
NOTES:

1. CENTRALISERS ARE NECESSARY WHEN AN ARTIFICIAL GRAVEL PACK IS USED.

2. ONCE SCREEN IS HELD CONCENTRICALLY IN THE BORE AND GRAVEL PACKING IS COMPLETE THE CENTRALISER SERVES NO FURTHER PRUPOSE.

3. SPACING OF CENTRALISERS: APPROX. EVERY 9 m OF LOWER WELL CASING. DO NOT USE AROUND PUMP CASING AS IT MAY NEED TO BE MOVED AFTER VERTICALITY TEST.
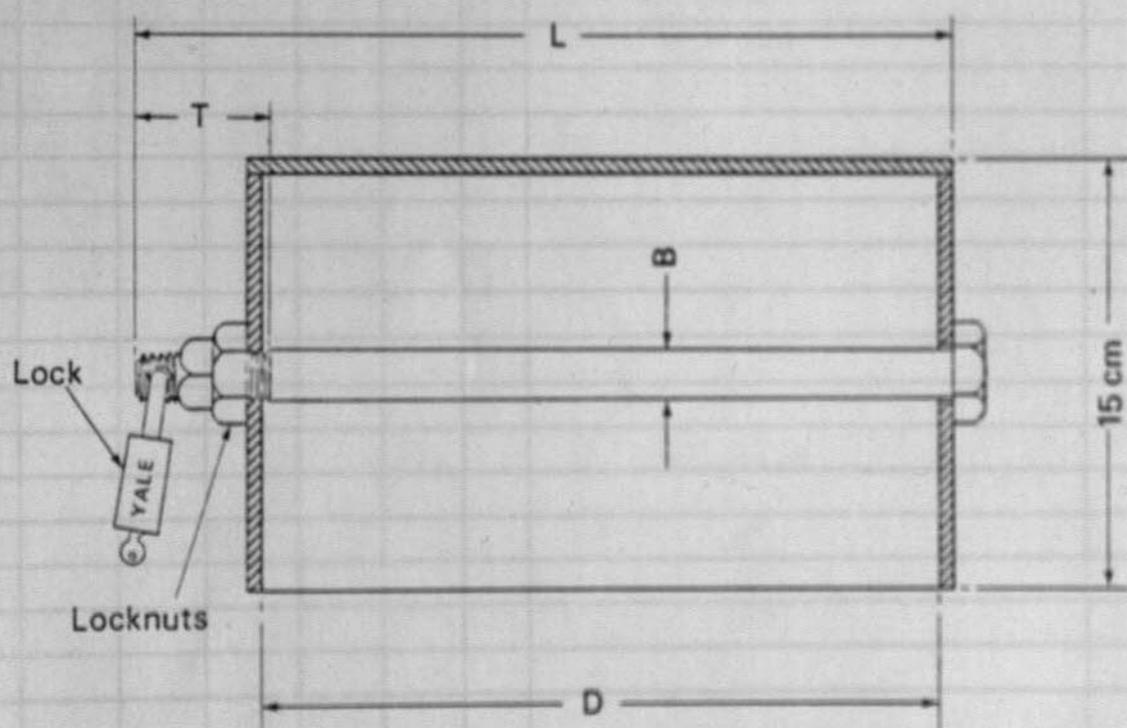
CASING SIZE - NOMINAL BORE (INCHES)	D INSIDE DIA OF WELLCAP (cm)	L LENGTH OF BOLT (cm)	B DIAMETER OF BOLT (mm)	T MINIMUM LENGTH OF BOLT THREADING (cm)
6	18	22	15	5
10	28	33	15	5

NOTES:

1. MATERIAL   : SHEET STEEL, 2.5mm THICKNESS.

2. CONSTRUCTION : WELDED JOINTS.

3. DRILL END OF BOLT 7mm DIA TO ACCEPT LOCK HASP.

DRILLERS LOG

DAILY DRILLING LOG.					SURVEY SHEET			Well NO: Well CO ORDS:		

LOCATION:								DATE:		

RIG:			DRILLING METHOD			SIZE OF MUDPUMP OR COMPRESSOR:				

PIPE NO	MEASUREMENT		DEPTH METERS	TIME		BIT SIZE INCHES	STRATA AND OBSERVATION			CASING -LENGTH -DIA -	90° v-notc
	LENGTH	TOTAL		FROM	TO						

DEPTH END SHIFT										
DEPTH BEGINING OF SHIFT										
TOTAL DRILLED THIS SHIFT										
WATER LEVEL FROM G.I.	TIME							DRILLER:		
	DEPTH							ENGINEER:		

APPENDIX XI   COMPOSITE BORE LOG

COMPOSITE BORE LOG

LOCATION: PADANG TERAP, KEDAH BLOCK

STARTED 13·11·1981, COMPLETED 18·11·1981

DRILLING METHOD: ROTARY AIR FLUSH

YIELD TEST: DATE 18.11.1981.   METHOD: AIR LIFT

TOPO SHEET: KUALA NERANG

GRID REFERENCE: 018 953

REFERENCE POINT (R P) RIG FLOOR

R.P. ELEVATION _____ m (above ground level)

LOCATION MAP
N
PT 1
APPROX 1 : 40,000

(PT 1) GS1101

TOTAL DEPTH	60 m	SWL 10.02m
YIELD 5.2 l/s	EC 480	

REMARKS

GEOPHYSICAL BOREHOLE LOGS

CONSTRUCTION | DRILLING DATA Penet rate m/m yield | DEPTH m | LITHO-LOGICA SUMMARY | CALIPER | NATURAL GAMMA | RESISTIVITY AND SP

SCALES 180 160 120 mm   0 10 20 30 40 50 cps   200 400 600 800 ohm

12¼" ø open hole

10" ø casing

7⅞" ø open hole

tc-5

csg

T.D.

3.3
4.5
5.5
7.6
11.9
14.3
15.3
23.3
23.3
23.3
25
24.6
24.5
24.5

LITHOLOGY LEGEND

Soil

Clay

Shale

Interbedded Shale, Clay & Siltstone

VERTICALITY FORM

VERTICALITY TESTS MALAYSIA D.I.D.	T.W. Borehole No.
Test conducted by : .	Witnessed by :	Location

Suspension height above casing top :	Inside dia. of casing (D) :
Length of Bobbin :	Outside dia. of Bobbin (d) :
Dia of wire (string) :	Clearance factor (D-d)/2 :

Stage	Depth (m)	Distance of string from casing edge at the surface (cm)						Deviation of string from casing centre at surface (cm)		Deviation of bobbin at depth (cm)		Resultant deviation of bobbin (cm)		Resultant deviation of casing (cm)
		West to East			South to North			W-E	S-N	W-E	S-N	Dis-tance	Direct-ion	
		Down	Up	Av.	Down	Up	Av.							
1	0	–	–	–	–	–	–	0	0	0	0	0	–	0
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														

Notes :

DO NOT FORGET TO MARK POSITION OF NORTH ON CASING
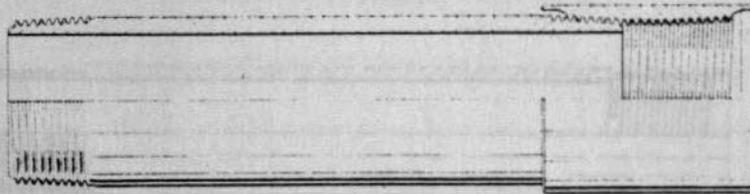
Fig. 1—Screwed and Coupled/Socketed Joint

TABLE A — API CASING — SHORT-THREADED SCREWED & COUPLED JOINTS — Fig 1
API Specification 5A — 32nd Ed — March 1973

Pipe Size O/D in/mm	Wall Thickness in/mm	Bore in/mm	Nom. Wt. with Cplg. lb/ft / kg/m	Coupling O/D in/mm	Coupling Length in/mm	Bit Max to pass thro' in/mm
4½ / 114.3	0.205 / 5.21	4.090 / 103.9	9.50 / 14.14	5.00 / 127.0	6.25 / 158.8	3⅞ / 98.4
	0.224 / 5.69	4.052 / 102.9	10.50 / 15.63			3⅞ / 98.4
	0.25 / 6.35	4.000 / 101.6	11.60 / 17.26			3⅞ / 98.4
5 / 127.0	0.220 / 5.59	4.560 / 115.8	11.50 / 17.11	5.56 / 141.3	6.50 / 165.1	4¼ / 108.0
	0.253 / 6.43	4.494 / 114.1	13.00 / 19.35			4¼ / 108.0
	0.296 / 7.52	4.408 / 112.0	15.00 / 22.32			4¼ / 108.0
5½ / 139.7	0.244 / 6.20	5.012 / 127.3	14.00 / 20.83	6.05 / 153.7	6.75 / 171.4	4¾ / 120.6
	0.275 / 6.98	4.950 / 125.7	15.50 / 23.07			4¾ / 120.6
	0.304 / 7.72	4.892 / 124.3	17.00 / 25.30			4¾ / 120.6
6⅝ / 168.3	0.238 / 7.32	6.049 / 153.7	20.00 / 29.76	7.39 / 187.7	7.25 / 184.2	5⅞ / 149.2
	0.352 / 8.94	5.921 / 150.4	24.00 / 35.72			5⅝ / 142.9
7 / 177.8	0.231 / 5.87	6.538 / 166.1	17.00 / 25.30	7.66 / 194.5	7.25 / 184.2	6¼ / 158.8
	0.272 / 6.91	6.456 / 164.0	20.00 / 29.76			6¼ / 158.8
	0.317 / 8.05	6.366 / 161.7	23.00 / 34.23			6⅛ / 155.8
	0.362 / 9.19	6.276 / 159.4	26.00 / 38.69			6⅛ / 155.6
7⅝ / 193.7	0.300 / 7.62	7.025 / 178.5	24.00 / 35.72	8.50 / 215.9	7.50 / 190.5	6¾ / 171.5
	0.328 / 8.33	6.969 / 177.0	26.40 / 39.29			6¾ / 171.5
8⅝ / 219.1	0.264 / 6.71	8.097 / 205.7	24.00 / 35.72	9.625 / 244.5	7.75 / 196.8	7⅞ / 200.0
	0.304 / 7.72	8.017 / 203.6	28.00 / 41.62			7⅞ / 200.0
	0.352 / 8.94	7.921 / 201.2	32.00 / 47.62			6¾ / 171.5
	0.400 / 10.16	7.825 / 198.8	36.00 / 53.57			6¾ / 171.5
9⅝ / 244.5	0.312 / 7.92	9.001 / 228.6	32.3 / 48.07	10.625 / 269.9	7.75 / 196.8	8¾ / 222.2
	0.352 / 8.94	8.921 / 226.6	36.00 / 53.57			8¾ / 222.2
	0.395 / 10.03	8.835 / 224.4	40.00 / 59.53			8⅝ / 219.1

Pipe Size O/D in/mm	Wall Thickness in/mm	Bore in/mm	Nom. Wt. with Cplg. lb/ft / kg/m	Coupling O/D in/mm	Coupling Length in/mm	Bit Max to pass thro' in/mm
10¾ / 273.0	0.279 / 7.09	10.192 / 258.3	32.75 / 48.74	11.750 / 298.4	8.00 / 203.2	9⅞ / 250.8
	0.350 / 8.89	10.050 / 255.3	40.5 / 60.27			9⅞ / 250.8
	0.400 / 10.16	9.950 / 252.7	45.5 / 67.71			9⅝ / 244.5
	0.450 / 11.43	9.850 / 250.2	51.00 / 75.90			9⅝ / 244.5
	0.495 / 12.57	9.760 / 247.9	55.5 / 82.59			9⅝ / 244.5
11¾ / 298.4	0.333 / 8.46	11.084 / 281.5	42.00 / 62.50	12.750 / 323.8	8.00 / 203.2	10⅝ / 269.9
	0.375 / 9.52	11.000 / 279.4	47.00 / 69.94			10⅝ / 269.9
	0.435 / 11.05	10.880 / 276.3	54.00 / 80.36			10⅝ / 269.9
	0.489 / 12.42	10.772 / 273.6	60.00 / 89.29			10⅝ / 269.9
13⅜ / 339.7	0.330 / 8.38	12.715 / 323.0	48.00 / 71.43	14.375 / 365.1	8.00 / 203.2	12¼ / 311.1
	0.380 / 9.65	12.615 / 320.4	54.50 / 81.11			12¼ / 311.1
	0.430 / 10.92	12.515 / 317.9	61.00 / 90.78			12¼ / 311.1
	0.480 / 12.19	12.415 / 315.3	68.00 / 101.20			12¼ / 311.1
	0.514 / 13.06	12.347 / 313.6	72.00 / 107.15			12 / 304.8
16 / 406.4	0.375 / 9.52	15.250 / 387.4	65.00 / 96.73	17.00 / 431.8	9.00 / 228.6	15 / 381.0
	0.438 / 11.13	15.125 / 384.2	75.00 / 111.61			14¾ / 374.6
	0.495 / 12.57	15.010 / 381.3	84.00 / 125.00			14¾ / 374.6
18⅝ / 473.1	0.435 / 11.05	17.755 / 451.0	87.50 / 130.22	20.00 / 508.0	9.00 / 228.6	17½ / 444.5
20 / 508.0	0.438 / 11.13	19.124 / 485.7	94.00 / 139.89	21.00 / 533.4	9.00 / 228.6	17½ / 444.5
	0.500 / 12.70	19.000 / 482.6	106.50 / 158.49			17½ / 444.5
	0.635 / 16.13	18.730 / 475.7	133.00 / 197.93			17½ / 444.5

Note (i) 60°V thread form.
(ii) Taper 1/16" per inch in diameter.
(iii) All sizes 8 Threads per inch – 3.175mm pitch.
(iv) Maximum bit diameter is the largest standard size bit which will pass through a diameter ⅛" 3.175mm less than the actual bore of the casing.
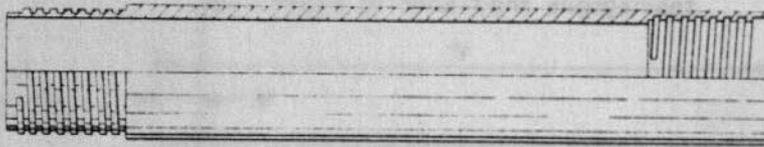
Fig. 2—Flush Butt Joint Casing

TABLE B — B.S. SPECIFICATION 879 WATER WELL CASING
SCREWED FLUSH BUTT JOINTS — Fig 2

Nominal bore in	Tube				Thread	Max Bit to pass thro'
	Outside diameter in mm	Wall thickness in mm	Actual bore in mm	Weight Plain Tube lb/ft kg/m	Thd/in Pitch mm	in mm
4	4½ 114.3	0.312 8.0	3⅞ 98.4	14.0 20.9	4 6.35	3¾ 95.25
5	5½ 139.7	0.312 8.0	4⅞ 123.8	17.4 25.9	4 6.35	4¼ 107.9
6	6⅝ 168.3	0.375 9.5	5⅞ 149.2	25.0 37.2	4 6.35	5⅝ 142.9
8	8⅝ 219.1	0.375 9.5	7⅞ 200.0	33.0 49.1	4 6.35	7⅝ 193.7
10	10¾ 273.0	0.438 11.0	9⅞ 250.8	48.0 71.4	4 6.35	9½ 241.3
12	12¾ 323.9	0.438 11.0	11⅞ 301.6	57.3 85.3	4 6.35	10⅝ 269.9
13	14 355.6	0.438 11.0	13⅛ 333.4	63.1 93.9	4 6.35	12¼ 311.2
15	16 406.4	0.500 12.7	15 381.0	82.0 122.0	4 6.35	14¾ 374.7
18	19 482.6	0.500 12.7	18 457.2	98.8 147.0	4 6.35	17½ 444.5
21	22 558.8	0.500 12.7	21 533.4	114.0 170.0	4 6.35	20 508.0
24	25 635.0	0.500 12.7	24 609.6	131.0 195.0	4 6.35	20 508.0

(i) Square form, parallel thread.
(ii) Maximum bit diameter is the largest standard bit which will pass through a diameter ⅛" 3.175 mm less than the actual bore of the casing.

TABLE C — B.S. SPECIFICATION 879 WATER WELL CASING
SCREWED & SOCKETED JOINTS — Fig 1

Nominal bore in	Tube				Socket		Thread	Max Bit to pass thro'
	Outside diameter in mm	Wall thickness in mm	Actual bore in mm	Weight of Plain Tube in kg/m	Outside diameter in mm	Overall length in mm	Thd/in Pitch mm	in mm
4	4½ 114.3	0.25 6.4	4 101.6	11.3 16.8	5⅛ 130.0	4½ 114.0	10 2.54	3⅞ 98.4
6	6⅝ 168.3	0.312 8.0	6 152.4	21.2 31.5	7¼ 184.0	5 127.0	10 2.54	5⅞ 149.2
8	8⅝ 219.1	0.312 8.0	8 203.2	27.9 41.5	9 5/16 237.0	6 152.0	8 3.175	7⅞ 200.0
10	10¾ 273.0	0.375 9.5	10 254.0	41.6 61.9	11 7/16 291.0	7 178.0	8 3.175	9⅞ 250.8
12	12¾ 323.9	0.375 9.5	12 304.8	49.6 73.8	13⅝ 346.0	7 178.0	8 3.175	10⅝ 269.9
13	14 355.6	0.375 9.5	13¼ 336.6	54.6 81.3	14⅞ 378.0	8 203.0	8 3.175	12¼ 311.2
15	16 406.4	0.375 9.5	15⅛ 357.4	62.6 93.2	16⅞ 429.0	8 203.0	8 3.175	14¾ 374.7
18	19 482.6	0.375 9.5	18¼ 463.6	74.6 110.0	20 508.0	8 203.0	8 3.175	17½ 444.5
21	22 558.8	0.438 11.0	21⅛ 536.6	101.0 150.3	23⅛ 587.0	9 229.0	8 3.175	20 508.0
24	25 663.0	0.438 11.0	24⅛ 612.8	115.0 171.0	26⅛ 644.0	9 229.0	8 3.175	20 508.0

Note: (i) 55° V thread form.
(ii) Taper 1/64" per inch on diameter.
(iii) Maximum bit diameter is the largest standard size bit which will pass through a diameter ⅛" 3.175mm less than the actual bore of the casing.

STEEL SLIMLINE CASING
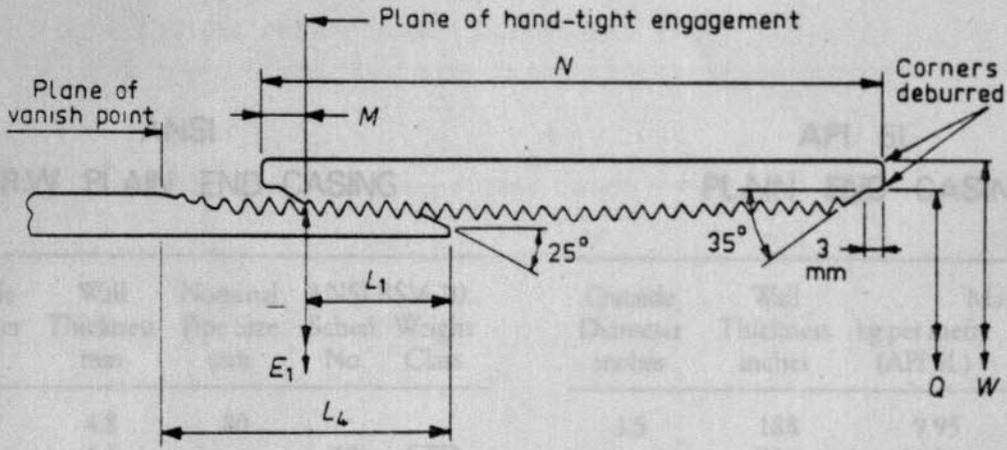
Tube Dimensions					Pitch diameter hand-tight plane	Coupling Dimensions			
Outside Diameter	Wall Thickness	Mass Black	Length, tube to hand-tight plane	Length, tube to vanish plane		Length, face of coupling to hand-tight plane	Finished Length	Outside Diameter	Diameter of Recess
			L1	L4	E1	M	N	W	Q
mm	mm	kg/m	mm	mm	mm	mm	mm	mm	mm
101.6	5.74	13.7	20.85	42.77	98.776	6.56	93.2	109.2	104
127.0	6.35	19.1	22.23	45.31	124.103	7.74	96.3	135.5	129.4
168.3	6.35	25.6	24.33	49.43	165.252	5.75	97.8	177.7	170.7
219.1	6.35	33.6	27.00	54.51	215.901	8.16	107.3	228.4	221.5

The availability of other wall thicknesses is subject to enquiry.

STEEL 'SWELLED NOT CRESSED' CASING
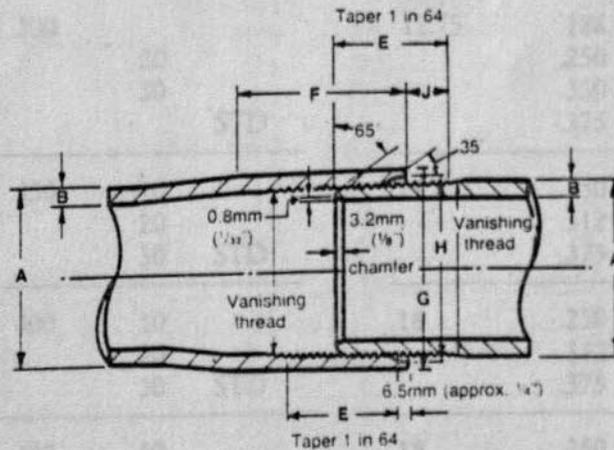
Outside Diameter	Wall Thickness	Mass Black	Total Effective Length of Thread	Minimum Length of Swelled End	Outside Diameter of Swelled End	Diameter of Recess	Thread Exposed at Hand Engagement
A	B		E	F	G	H	I
mm	mm	kg/m	mm	mm	mm	mm	mm
101.6	3.86	9.67	64	102	107	102.4	22±3
127.0	4.76	14.87	70	108	135	127.8	22±3
152.4	4.76	19.05	76	114	160	153.2	22±3

The availability of other sizes such as 203.2 x 6.3 is subject to enquiry.

ANSI E.R.W. PLAIN END CASING						API 5L PLAIN END CASING			
Outside Diameter mm	Wall Thickness mm	Nominal Pipe Size mm	ANSI BS16-10 Sched. No.	Weight Class		Outside Diameter inches	Wall Thickness inches	Mass kg per metre (API 5L)	approx. metres per tonne
88.9	4.8	80				3.5	.188	9.95	100.503
	5.5		40	STD			.216	11.31	88.417
	6.4						.250	13.02	76.805
114.3	4.4	100				4.5	.172	11.92	83.893
	4.8						.188	12.96	77.160
	6.0		40	STD			.237	16.02	62.422
168.3	4.8	150				6.625	.188	19.35	51.680
	6.4						.250	25.55	39.139
	7.1		40	STD			.280	28.22	35.436
219.1	4.8	200				8.625	.188	25.37	39.417
	6.4		20				.250	33.57	29.789
	7.0		30				.277	36.61	27.315
	8.2		40	STD			.322	42.65	23.447
273.1	4.8	250				10.75	.188	31.76	31.486
	6.4		20				.250	42.09	23.759
	7.8		30				.307	51.03	19.596
	9.3		40	STD			.365	60.50	16.529
323.9	4.8	300				12.75	.188	37.77	26.476
	6.4		20				.250	50.11	19.956
	8.4		30				.330	65.35	15.302
	9.5			STD			.375	73.65	13.578
355.6	6.4	350	10			14	.250	55.11	18.146
	7.9		20				.312	67.74	14.762
	9.5		30	STD			.375	81.08	12.333
406.4	6.4	400	10			16	.250	63.13	15.840
	7.9		20				.312	77.63	12.882
	9.5		30	STD			.375	92.98	10.755
457.0	6.4	450	10			18	.250	71.12	14.061
	7.9		20				.312	87.49	11.430
	9.5			STD			.375	104.84	9.538

Typical Fibre Glass Dimensions

Nominal Internal Diameter		Diameter over Joint		Wall Thickness	
ins.	mm	ins.	mm	ins.	mm
6	150	7.75	195	0.14	3.5
6	150	7.75	195	0.16	4.0
8	200	10.00	250	0.18	4.5
8	200	10.00	250	0.24	6.0
10	250	12.00	300	0.20	5.0
10	250	12.00	300	0.26	6.5
12	300	14.25	360	0.24	6.0
12	300	14.25	360	0.28	7.0

Wedge Wire Screen - Diemensions & Weights

Nominal Screen Size (Type of Casing)	Outside Diameter of Screens (ins)	(mm)	Inside Diameter of Screens (ins)	(mm)	Approximate Shipping Weight lb/ft	kg/m
2½ ins API	3.1	79	2.5	63	7	10½
3 ins API	3.5	89	2.9	74	9	13½
4 ins ABC	4.3	108	3.7	93	10	15
4 ins API	4.6	116	4.0	100	11	16½
5 ins ABC	5.1	129	4.5	114	11½	17
5 ins API	5.6	143	5.1	128	12	18
6 ins ABC	6.2	158	5.6	142	13	19
6 ins API	6.7	169	6.1	153	14	21
8 ins ABC	8.1	205	7.5	189	18	27
8 ins API	8.7	220	8.1	205	19	29
10 ins ABC	10.4	263	9.6	244	23	34
10 ins API	10.8	275	10.1	256	25	37
12 ins API	13.0	329	12.2	309	36	54
14 ins API	14.0	358	13.3	338	43	64
16 ins API	16.3	414	15.4	391	50	75
18 ins API	18.0	457	17.2	433	57	84

Specifications below are for a special fishing string which would
be suitable for sharing between JPT, JKR and the Geological
Survey Dept.

Description	Number
4½" (Flush) O.D. heavy duty drillpipe API Grade E equipped with 3½" API Regular left-hand tool joints and having lay-key slots in 6 metre lengths	40
As above but 3 m lengths	2
Lay-Key for above	2
Hoist plug (swivel type) for above	1
Drive rod suit Tone Top 750A drill head screwed 3½" API REG. L.H.*	1
Selection of L.H. fishing tools to pick up 3½" and 4 3/4" flush O.D. drillpipe and inside of 8" drill collar.	1 set

Note:
    *Special fittings to suit JKR and G.S. Swivel
    required to their specs.

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
6	B5405 - 080	SKY-100	Packing	14	8	Jack Ass'y
"	"	SKY-112-1	"	15	8	"
"	"	SKY-100	Back Up Ring	16	4	"
"	"	SKY-112-1	"	17	8	"
"	"	Dust Seal B2401		19	4	"
"	"	DKI 100.114.8.11 Eslight Wear Ring SW 125-20-3		18	8	"
"	"	G-140	O-Ring	20	4	"
"	"	P-18	"	21	8	"
7	B5226 - 334	E0267-055	Bushing	5	8	Frame Ass'y
"	"	D0325-217	Bolt Eye	11	4	"
"	"	M36-3	Nut Hex	27	4	"
8	B5323 - 065	SL04-5018NR	Bearing	14	3	Head Sheave Ass'y
9	B5725 - 268	E0251-414	Bushing	1	2	Cylinder Ass'y
"	"	E0251-415	"	2	2	"
"	"	DKI 60.74.8.11	Dust Seal	17	10	"
"	"	110.126.9.12	Dust Seal	18	10	"
"	"	BR 125 JTS B 2401	Snap Ring	29	2	"
"	"	G60	O-Ring	19	6	"
"	"	G90	"	20	6	"
"	"	G105	"	21	6	"
"	"	G110	"	22	6	"
"	"	G135	"	23	6	"

Note:

Quantities required are for two rig operation.

*Refers to page number in Tone Parts Book.

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
9	B5725 - 268	JIS B 2401 P 60	O-Ring	24	6	Cylinder Ass'y
"	"	P 85	"	25	6	"
"	"	P 115	"	26	6	"
"	"	P 85	Back Up Ring	27	2	"
"	"	P 115	"	28	2	"
10	B5725 - 283	E0251-985	Bushing	1	4	Gearing Ass'y
"	"	S10 4-5016 NR Bearing JIS B 2401 P 8		15	4	"
"	"	G 45	O-Ring	16	12	"
"	"	G 125	"	17	16	"
"	"	OCS-70	Ring	21	16	"
"	"	UPI 60,80,12	Packing	18	20	"
"	"	UPI 90, 110, 12	Packing	19	20	"
"	"	SW-112	Eslight Wear Ring	20	20	"
"	"	60, 74, 8, 11	Dust Seal	22	24	"
"	"	BR 74	Snap Ring	31	8	"
"	"	I-125		23	4	"
11	B5272 - 151	23ASI	Oil Motor	37	1	Gearing Ass'y
"	"	22309	Bearing	38	1	"
"	"	22213	"	39	2	"
"	"	62152	"	40	1	"
"	"	6038 Z	"	41	2	"
"	"	ARX 200 26548	Bearing	42	2	"
"	"	6015 ZZ	"	47	1	"
"	"	SB 200,240,20	Oil Seal	43	10	"
"	"	JIS B2401 G 180	O-Ring	44	4	"
"	"	I-115	Snap Ring	48	1	"
"	"	I-125	"	49	1	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
12	B5275 - 239	D-2705-337	Liner	8	4	Guide Ass'y
"	"	D-2705-338	"	9	4	"
"	"	Mach Screw ASS M6-12		16	72	"
13	C5630 - 717	JIS 2401 P 29	O-Ring	7	8	Piping Ass'y
"	"	90° Elbow 1" BS 3021J-16		8	2	"
"	"	90° Elbow 3/8" BS 30215-06		9	1	"
15	C5722 - 132	D2560-105 Piece, Chuck		9	3	Screw Chuck Ass'y
"	"	E2741-035 Ring, Snap		11	4	"
"	"	JIS B 2401 G 165 O-Ring		15	1	"
16	B5046 - 122	C4049 - 090 Brake Band Ass'y		14	2 sets	Brake Ass'y
"	"	C4049 - 091 "		15	2 "	"
"	"	SC1 D70-05 Spring		16	4 "	"
17	B5136 - 139	6217 LLB	Bearing	32	3	Drum Ass'y
"	"	6219 LLB	"	34	3	"
"	"	6311 LB	"	35	12	"
"	"	22216 B		36	4	"
"	"	SB95, R5, 14, Oil Seal		37	6	"
"	"	SB 100, R5, 13 "		38	4	"
"	"	I-120 Snap Ring "		39	8	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
18	C5591-037	JIS No.120	CHAIN	5	1	Hydraulic Motor Ass'y
19	B5676-408	0-15	Snap Ring	15	12	Lever Ass'y
21	B5045-063	E0251-337	BUSHING	1	4	Valve Box Ass'y
"	"	E2702-077	RUBBER PACKING	15	4	"
"	"	"	LINER	16	4	"
"	"	"	PISTON ASS'Y	21	4 sets	"
"	"	D2841-051	ROD, PISTON	17	4	"
"	"	D2915-023	SEAT, VALVE	18	8	"
"	"	D4057-026	VALVE ASS'Y	20	8	"
"	"	SC2-050-01	SPRING	27	8	"
"	"	JSB SC 050-10 P 100	O-RING	35	4	"
"	"	P 125	"	36	4	"
"	"	P 145	"	37	8	"
"	"	P 210	"	38	4	"
"	"	P 75	"	39	4	"
"	"	1630-V-45	V. PACKING	40	12	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
22	B5185 - 042	PRESSURE GUAGE ASS D4047-004		5	2 Sets	DELIVERY LINE ASS
"	"	VALVE ASS DIAPHRAGM		5-2	2 "	"
"	"	E0540-002	"	5-2-1	2 "	"
"	"	PACKING		5-2-8	2 Nos.	"
"	"	PRESSURE DAMPER TPT 0375		5-3	2 "	"
"	"	E2521 - 541 DAMPER TPT 0375-2		5-3-2	2 "	"
"	"	PRESSURE GAUGE AT 3/8-100 x 80		5-6	2 "	"
"	"	JIS B 2401 G95 O-RING		13	4 "	"
"	"		O-Ring	14	4 "	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
23/24	B5450 - 080	E0251-336	BUSHING	2	4	Crank Disc Ass.
"	"	E1801 - 847	COLLAR	13	2	"
"	"	E1801 - 848	COLLAR	14	2	"
"	"	E2521 - 493	PACKING	17	4	"
"	"	E2521 - 494	PACKING	18	4	"
"	"	E2521 - 496	PACKING	19	2	"
"	"	D2705 - 119 T-LG 0035	LINER	25	4	"
"	"		GAUGE ASS	31	2	"
"	"	T-PW 2000	PACKING	35	4	"
"	"	22313	BEARING ROLLER	38	2	"
"	"	22314	BEARING ROLLER	39	2	"
"	"	6313	BEARING BALL	40	4	"
"	"	SB-80-105-13	OIL SEAL	43	4	"
"	"	5/16/800	GRAPHITE PACKING	55	2	"
"	"	F2521-495	PACKING	63	4	"
"	"	E0251-335 INA NTN	BUSHING	64-1	4	"
"	"	SL01 4844	BEARING ROLLER	64-5	2	"
"	"	JIS B 2401 G65	O RING	65	4	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
26	C5738-006	E2521-211	PACKING	4	4	SAFETY VALVE ASS'Y
"	"	E251-337	PACKING	5	4	"
"	"	E2702-889	RUBBER PACKING	15	2	"
"	"	E2555-552	PIN	6	4	"
27	ASS DWG. No. B5630-954	JIS B2401 P 135	O RING	57	4	PIPING ASS'Y
29/30	B5272-153	E1828-279	COLLAR	12	2	GEARING ASS'Y
"	"	E1828-280	COLLAR	13	2	"
"	"	E1828-287	COLLAR	14	2	"
"	"	E1828-288	COLLAR	15	2	"
"	"	E1828-289	COLLAR	16	2	"
"	"	D1874-076	Clutch, Claw	17	4	"
"	"	6209	Bearing	39	4	"
"	"	6212	"	40	4	"
"	"	6213LB	"	41	4	"
"	"	6309	"	42	4	"
"	"	6310	"	43	4	"
"	"	2214B	"	44	4	"
"	"	NJ 2209	"	45	4	"
"	"	SB 55-72-9	Oil Seal Bearing	46	4	"
"	"	SB 65-90-13"	Bearing	47	4	"
"	"	SB 85-110-13	"	48	4	"
"	"	JIS B 2401-G40	O-Ring	49	10	"
"	"	JIS B 2401-G45	O-Ring	50	10	"
"	"	JIS B 2401-G50	O-Ring	51	10	"
"	"	JIS B 2401-G65	O-Ring	52	10	"
"	"	O-45	Snap Ring	53	4	"
"	"	O-48	"	54	4	"
"	"	O-60	"	55	4	"
"	"	O-65	"	56	4	"
"	"	I-85	"	57	4	"
"	"	I-120	"	58	4	"
"	"	Top-10A	Trochoid Pump	59	2	"
"	"	SV-850	Belt, V	60	14	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
32	B5459 - 131	E1814-521	Collar	3	2	
"	"	E1828-393	"	6	2	
"	"	E1828-284	"	7	2	
"	"	E1828-285	"	8	2	
"	"	E1828-286	"	9	2	
"	"	E1874-077	Clutch Claw	10	2	
"	"	E2562-009	P IN	11	8	
"	"	D4473-110	Coupling AS5	16	2 sets	
"	"	"	Key 12.8.90	17	2	
"	"	"	Key 12.8.56	18	4	
"	"	6313 LB	Bearing Ball	19	2	
"	"	6314 LB	Bearing Ball	20	4	
"	"	222 15B	Bearing Ball	21	2	
"	"	0-63	Snap Ring	22	4	
"	"	0-70	" "	23	4	
"	"	I-125	" "	24	4	
"	"	SB 85-110-13	Oil Seal	25	6	
"	"	SB 90-115-13	" "	26	6	
33	B5676 - 446	E2557-065	Piece Shifter	9	8	
"	"	E2559-186	Pin	10	2	
"	"	E2559-186	Pin	12	2	
"	"	E0267-121	Bushing	14-1	2	
"	"	E0267-132	Bushing	15-1	2	
"	"		Spring	16	6	
"	"	7-7-28 K33-T-28	Key	17	4	
"	"		Set Screw	23	4	

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
34	C5054 - 053	D1185-091	Torque Gauge	3	2	Hydraulic Control Ass'y
"	"	D2596-048	Bit Loadgauge	7	2	"
"	"	DKI-3/8 PT x 3/8 PF	Damper	10	5	"
"	"	DU3/8 x 100 x 350^k	Pressure Gauge	11	2	"
"	"	HG-9210-10-22 Manual	Control	12	2	"
"	"	DMG-06-3D3-40	Valve	14	2	"
"	"	DMG-03-3D60-40	"	16	1	"
"	"	BG-03-32	Relief Valve	19	1	"
"	"	DU3/8 x 100 x 35k	Hirose Pressure Gauge	28	2	"
35	B5643 - 041	E1874 - 075	Clutch Claw	3	4	Pump Ass'y
"	"	E2559-180	Pin	4	2	"
"	"	E2743-346	Ring	5	2	"
"	"	E0267-129	Bushing	11-1	4	"
"	"	E4647-009	Pump ASS	12	2	"
"	"	E2072	Bearing Ball	14	4	"
"	"	6206 ZZ	Bearing Ball	15	4	"
"	"		1-72 Snap Ring	16	4	"
"	"		1-62 Snap Ring	17	4	"
"	"		0-50 Snap Ring	18	4	"
"	"		0-35 Snap Ring	19	4	"
"	"		Spring Roll Pin	20	6	"
"	"	E4473-097	Coupling Ass	28	2 Sets	"
"	"	3V-355	V Belt	32	4	"

Page No.	Ass'y Drg. No.	Parts Drg. No.	Parts Name	Parts No.	Quantity Required	Name of Assembly
36	B5647 – 054	D4473-083	Coupling Ass	9	2 sets	Hydraulic Pump Ass'y
"	"	C5585-132	Gear Pump Ass	10	2	"
"	"	SFN-10-150	Filter Mesh Suction Filter	13	6	"
"	"	SFN-08-150	Mesh Suction Filter	14	6	"
"	"	Teijin 16-18	Axial Plunger Pump	15	2	"
"	"	Taisei LU-10-20	Line Filter	16	20	"
"	"	Nagand Keiki	Damper DKI 3/8 x 3/8	21	2	"
43	C5725 – 105		High Pressure Bushing 3/4 x 3/8	9		Cylinder Ass'y
"	"	JIS B2401-G30	O-Ring	10	4	"
"	"	JIS B2401 G75	O-Ring	11	4	"
"	"	JIS B2401 G85	O-Ring	12	4	"
"	"	DLO 455710	Dust Seal	13	2	"
"	"	UPI 456010	Packing	14	2	"
"	"	UPI 557512	Packing	15	2	"