

**HANDBOOK**  
**ON**  
**BORING & DEEPENING OF**  
**WELLS**



**MINISTRY OF FOOD AND AGRICULTURE**  
**DEPARTMENT OF AGRICULTURE**

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# HANDBOOK ON BORING & DEEPENING OF WELLS



MINISTRY OF FOOD AND AGRICULTURE

DEPARTMENT OF AGRICULTURE

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## FOREWORD

THIS publication is the first of a series of technical publications by the experts on minor irrigation in the Ministry of Food & Agriculture. The need for technical manuals dealing with various problems connected with the implementation of the different types of minor irrigation schemes and their solutions is urgent. Nearly Rs. 300 crores are proposed to be spent on this programme during the Third Plan period. With investment of this magnitude and the extension of the programme to new areas, care has to be taken that every rupee is utilised to the maximum advantage.

Among the sources of irrigation, wells account for 1/3rd of the total area under irrigation in the country. There is considerable scope for the construction of new wells. Simultaneously, the existing wells have to be properly maintained and utilised.

An additional area of 3.8 lakh acres will be brought under irrigation through boring and deepening of about 1.4 lakh wells during the Third Five Year Plan. The techniques and methods of boring and deepening and the equipment used are described in detail in the publication. The economics of the various types of operation have also been indicated.

It is hoped that the hand book will be found useful by the technical staff in the States. It is only by pooling the experience in the States that maximum advantage can be taken of the technical know-how which forms the basis of this handbook.

**K. R. DAMLE**

*Secretary to the Government of India,  
Ministry of Food & Agriculture,  
Department of Agriculture,  
New Delhi.*

New Delhi,  
Date 5-1-1962.

## PREFACE

BORING and deepening of wells are among the most important items of works under minor irrigation for development of ground water resources. Operations involved are of fairly technical nature. Appreciable amount of literature has been available in the country on most parts of the subject, but not at one place in a consolidated form. An attempt has, therefore, been made in this handbook to put together the essential technical information that may be needed for planning and carrying out boring and deepening operations. In compiling the handbook, technical material was obtained from number of sources and also advantage taken of the notes on visits to works and discussions during tours in the various States. A bibliography of the books consulted is given at the end.

The work has been carried out under the guidance of Shri Mahavir Prasad, Irrigation Adviser to the Government of India, Ministry of Food & Agriculture and Shri J. P. Mital, Adviser Irrigation, Ministry of Community Development. Shri O. P. Kumra, Assistant Irrigation Adviser assisted me in drafting portions of the handbook and the Chapter on 'Deepening of Wells by Blasting' is largely his contribution, after making a special visit to the deepening work being carried out in Rajasthan by the Underground Water Board.

The handbook is a first attempt of its kind on the subject and may contain many an error and omission. Suggestions for improving and rectifying the defects will be most welcome and will pave the way for a suitable revision of the handbook at a later date.

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## 1—INTRODUCTION

SINCE the commencement of the Five Year Plans, concerted efforts are being made in the country to develop its irrigation resources from all types of irrigation schemes ranging from big River Valley Projects like the Bhakra-Nangal to small works like the open wells owned by individual cultivators. Increasing importance has been given to the minor irrigation schemes during the last few years, because minor irrigation aims at maximum utilisation of local sources of men and material and yields quick results. Minor irrigation includes a variety of works like open wells, installation of improved water lifting appliances on open wells, tube-wells, filter points, tanks, anicuts, weirs, bandharas, pynes, kuhls, donges, ahars, bundhies, etc. Open wells, however, form the most important item of minor irrigation programme. Individually they are very small works, but collectively they contribute to nearly 1/3rd of the total irrigation in the country. Their popularity has been referred to in history since earliest recorded time and at present the total number in the country exceeds 50 lakhs. They are scattered in almost all parts of the country although their concentration naturally varies from region to region according to the geological sub-strata and groundwater availability. Large numbers of additional wells are being constructed annually under the minor irrigation programme. Prospects for their construction are obviously greater in the alluvial regions, which have more favourable groundwater availability, but large numbers of them also exist and are being constructed further in areas where although groundwater available is not so plentiful, yet the wells provide the only local means of irrigation.

Such being the contribution of open wells to irrigation, it is normal that a sizeable programme of constructing new wells should be undertaken on a continuing basis till full saturation is reached. However, from the point of view of optimum utilisation of resources, it is also important that adequate attention be paid to improving the performance and utility of the existing wells to the extent it is possible and that measures which can accomplish this be given high priority. Boring and deepening of open wells for increasing their discharge is one such scheme. Although the successful boring and deepening operations primarily depend on the type of groundwater formation available, quite a substantial number of wells in various parts of the country is amenable to improvement by such operations. The augmented discharge due to boring and deepening brings more area under irrigation on the same well.

The scheme of boring and deepening has thus two advantages. It brings new area under irrigation with lower order of outlay per acre than what is required in the case of new constructions. Secondly it enables utilisation of the part of the local groundwater source, which would otherwise remain untapped in the normal course. The latter advantage is particularly significant in view of the fact that at present only about 20% of the total annual

replenishable groundwater potential is estimated as being utilised for irrigation in the country. In order that a higher percentage of groundwater may be utilised, only the construction of new open wells and tube-wells may not be sufficient. It will be equally necessary and important to improve the water output of the existing wells wherever additional untapped water source exists.

Like the construction of new wells, the scheme of boring and deepening of wells has been receiving the attention that it deserves under the minor irrigation programme. Its achievements in the past and targets for the future in different parts of the country can be glanced through the graph (Fig. 1) and the statement given below:

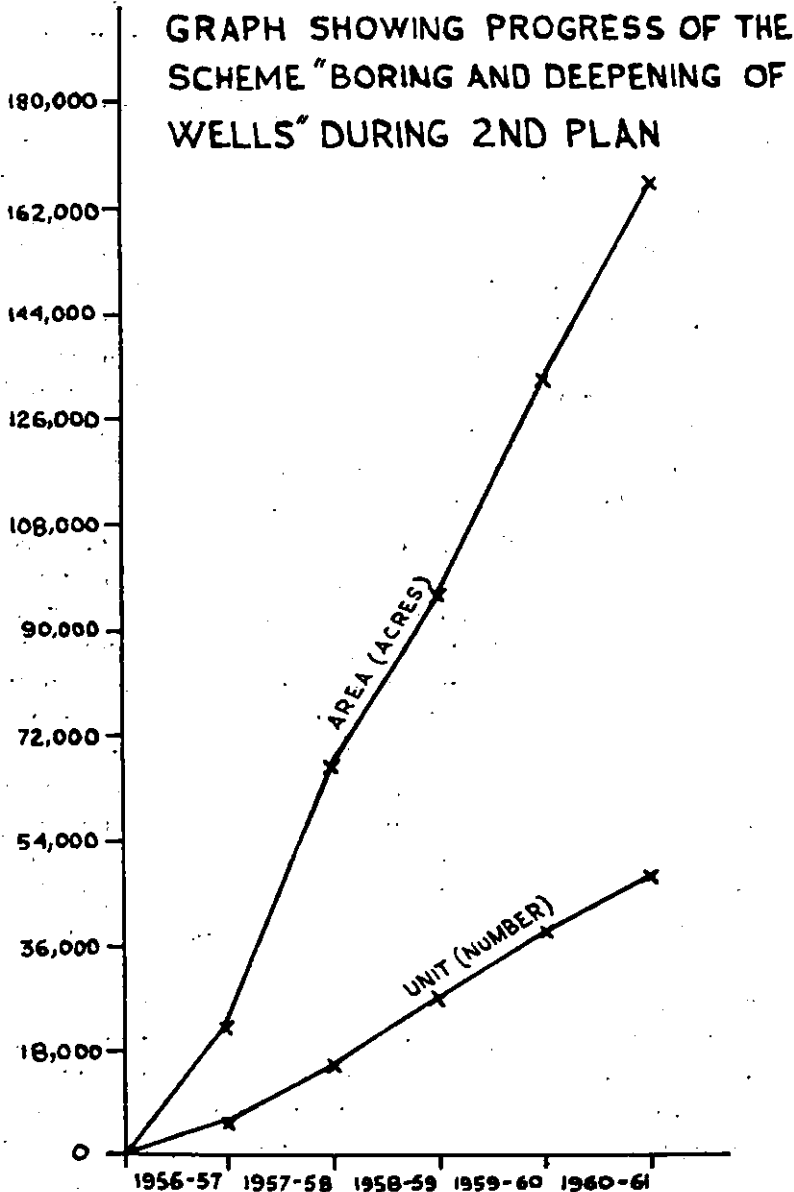


FIG. 1



<b>PROGRAMME OF THE SCHEMES OF "BORING AND DEEPENING OF WELLS" DURING THIRD FIVE YEAR PLAN</b>				
<b>Sl. No.</b>	<b>STATE</b>	<b>Unit</b>	<b>Acreage (000 acres)</b>	<b>OUTLAY Rs. in lakhs</b>
1.	ANDHRA PRADESH	33	5.00	5.00
2.	BIHAR	10,998	54.36	73.80
3.	GUJARAT	9,260	10.76	115.84
4.	MADHYA PRADESH	6,076	30.38	20.00
5.	MADRAS	2,000	20.00	50.00
6.	MAHARASHTRA	34,875	86.75	7.80 (Net)
7.	MYSORE	3,125	3.13	31.25
8.	RAJASTHAN	20,000	20.00	25.00
9.	UTTAR PRADESH	50,000	150.00	74.00
	<b>TOTAL</b>	<b>137,167</b>	<b>380.38</b>	<b>402.69</b>

An attempt has been made in this technical publication to explain the scope and objective of the scheme of boring and deepening and to describe in detail the techniques, methods, equipment, etc., that these operations involve or require. The scope for improving well discharge depends on the local ground-water availability as well as the design and construction of the well. A description of the salient factors pertaining to these aspects is considered essential and is given in the first few pages. The rest of the text deals with the main subject.

## 2—SOURCE OF WATER SUPPLY IN WELLS — ITS ORIGIN, NATURE AND OCCURRENCE

THE source of supply for all wells is invariably the water that accumulates in the sub-surface layers of the earth as a result of rainfall and seepage from surface water sources such as rivers, streams, lakes, depressions, reservoirs, canals, etc. A part of the total surface water that enters the sub-soil is lost to atmosphere through evaporation and transpiration; some of it is retained in unsaturated state by upper layers of the sub-soil through which it passes. The remaining water trickles down to form what is known as 'zone of saturation' overlying an impervious stratum. These processes have continued for long periods of time and as a result have built up a supply of water under most parts of the earth surface. This supply that exists in the zone of saturation, is known as *groundwater* and is tapped by all water wells. The upper surface of the zone of saturation is known as *water table* (Fig. 2).

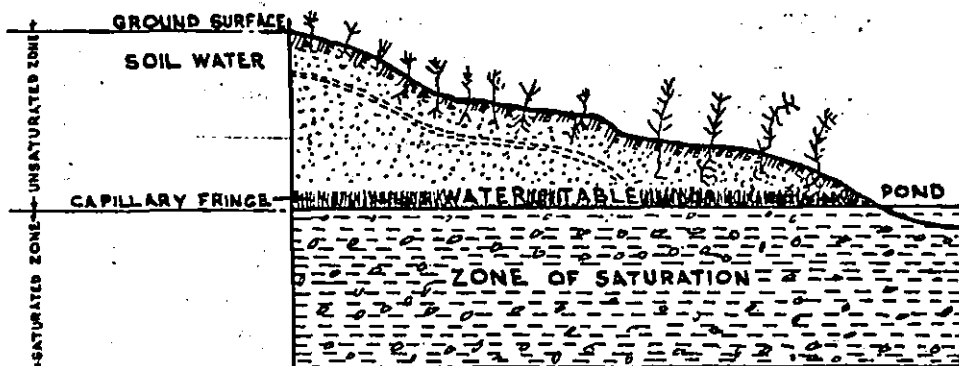


FIG. 2

In loose and unconsolidated formations, the groundwater is contained in the pores and interstices of the sub-soil particles. If, however, the zone of saturation comprises rock formations, the groundwater is mostly contained in the inter-connected joints, bedding planes, fractures, faults, crevices, fissures, etc., available in the rocks. Groundwater except when held in closed basins is never static. It is always moving, though the rate of flow may not ordinarily exceed  $\frac{1}{4}$  to  $\frac{1}{2}$  mile per year, through the inter-connected interstices or joints, crevices, fissures, etc., in the sub-strata, towards outlet points which are normally available in the form of springs, streams, swamps, etc. In this natural state, groundwater is generally 'in balance', that is the amount lost at the discharge points is equal to the total inflow from various resources in the recharge areas. The water table, under this condition remains steady over a period of time, subject to such normal fluctuations that may occur due to alternate, dry and wet season. In some places,

however, the balance is artificially interfered with as in cases of irrigated areas. Here the water table may still be rising on account of application of irrigation water or may be lowering on account of excessive pumping. Even under these conditions, it is possible that a new balance may be established whereupon the water table may again become steady.

Such being the origin and nature of ground water it is obvious that the ground water resources of a region would depend upon: (a) climatic factors, like rainfall, humidity, etc.; (b) topographic factors, such as proximity to hills or mountains, undulation of the surface, direction of the valleys and watersheds, presence of vegetation and forests, etc.; (c) geological features, such as the nature of rocks, system of jointing and bedding planes, their inclination or dip, extent of their weathering and decomposition, presence of faults crevices, fissures, etc; and (d) presence of such features as tanks, reservoirs and canals in the recharge area. A complete appraisal of all these factors, individually and collectively, is important for deciding upon the prospects of any scheme that aims at utilisation of groundwater.

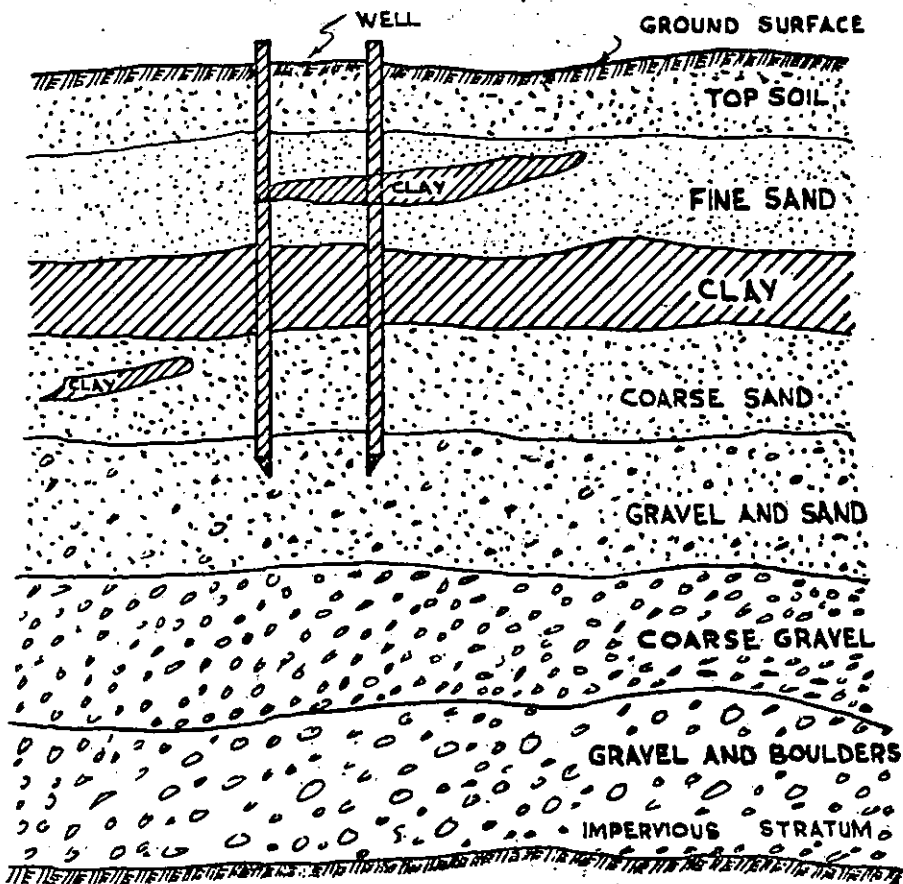


FIG. 3

Depending on the conditions stated above, groundwater occurs in different quantities, at varying depths below the ground surface and in complicated formations of an endless variety. A few typical formations are described below:

(1) *Alluvial formation* (Fig. 3)

Fig. 3 shows an ordinary ground water formation usually met with in the alluvial plains. The strata consist of a series of layers ranging from clay and fine sand to gravel, boulders, etc. Such alluvial formations usually extend to very great depths below the ground surface and provide good groundwater storage. As described later, the best water bearing aquifer in this formation will be provided by the layers of gravels, sands, etc.

(2) *Rock formation with eroded hollows* (Fig. 4)

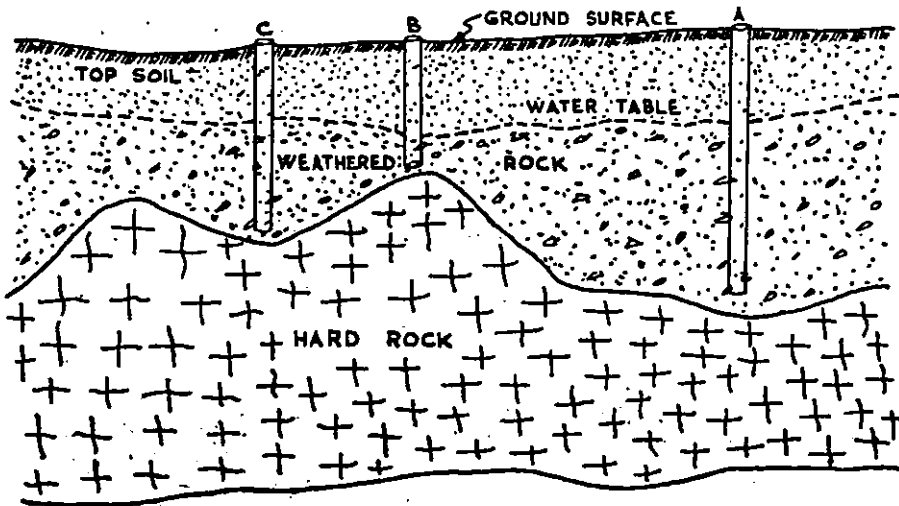


FIG. 4

A formation the type of which are met within various part of the country is shown in Fig. 4. The rain water that enters the rocks through various joints and cleavage planes is often charged with carbon dioxide and other organic acids. This water gradually breaks the rock into its constituent particles making it more and more permeable to water circulation and storage. This process goes on to such an extent as to form deep hollows and bays of weathered rocks extending sometimes as deep as 50 ft. and even more in the rocks. Such weathered zones form good receptacles for the storage of groundwater. In some formations, such valleys or hollows may have been eroded in some past geological age. Later these valleys may have been filled in with water bearing deposits of alluvial origin.

When wells are constructed in the region, conditions such as depicted at 'A', 'B' and 'C' in Fig. 4 may be found. At 'A' a good well is obtained because the water bearing medium extends to greater depth and also to

greater extent laterally. At 'B' the well may come out to be more or less dry. At 'C' a fairly good well may be obtained.

(3) *Rock formation with embedded aquiferous beds (Fig. 5)*

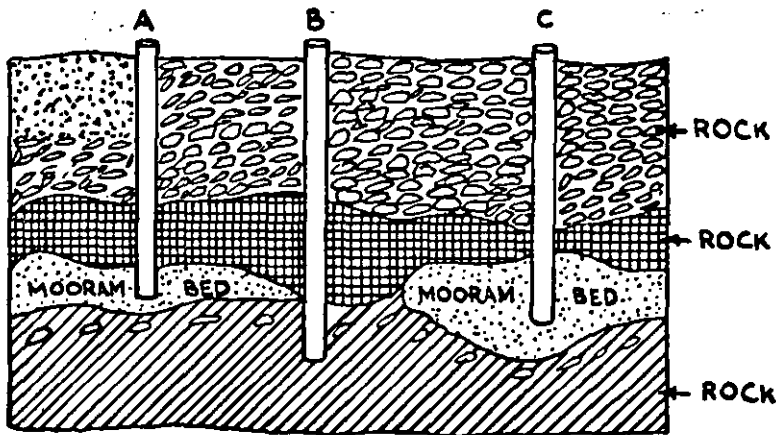


FIG. 5

The formation of the nature as shown in Fig. 5, is commonly met with in Deccan trap. The Deccan traps are composed of distinct horizontal layers. These layers are considered to have been formed by consolidation of the molten lavas at different periods of geological history, so that after each succeeding out-flow of molten lava, there intervened periods of quiescence. During such periods, fresh spread of lava had not only time to cool down thus developing joints and cracks, etc., but also gave occasion for the sub-aerial agencies to bring about weathering and disintegration of rock's surface. All of a sudden, then, occurred another out-pouring of hot liquid lava obliterating and burying everything beneath its onrush. It is in these regions, between the two trappean layers, subjected to weathering and disintegration in the earlier period, that are now found embedded aquiferous beds receiving water by percolation through the over-lying rocks.

Taking the case of bores 'A', 'B' and 'C' in Fig. 5, it is seen that 'A' passes through a mooram-like bed at its bottom, 'B' has entirely missed the bed and 'C' has again touched the same detached bed. The bores 'A' and 'C' are successful and among the two, the bore 'C' will yield more water. The bore 'B' may, however, prove dry.

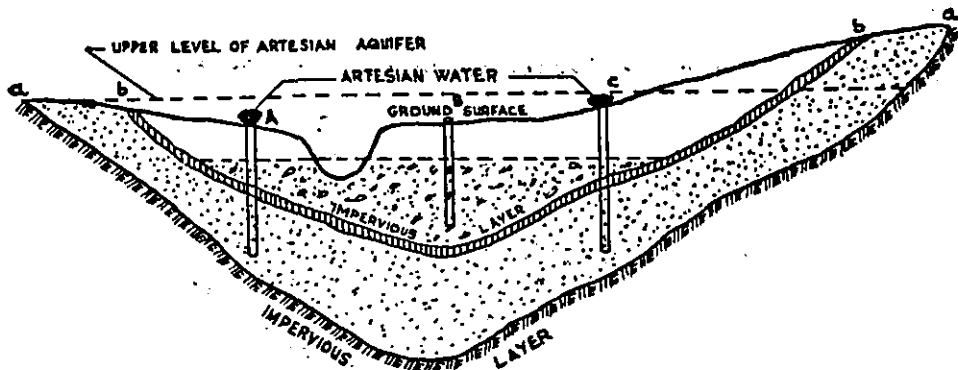
(4) *Formation with confined water* (Fig. 6)

FIG. 6

Fig. 6 shows a formation in which the water in the zone of saturation is confined between layers a, a and b, b of impervious material. The water in contact with the top layer of the impervious material is under pressure and consequently there is no free water table. When a zone of saturation of this type is tapped, water will rise above the level of the bottom of the confined layer. If the water rises above the ground surface, it is known as 'artesian water' and its source as 'artesian basin' or 'spring'. At some locations, the water may rise higher than the water table in the upper strata but not to the ground surface. This is referred to as *sub-artesian* formation.

Where such formations are met with, the extension of the well to the artesian basin may result in increased discharge, which may require no water lifting or only partial water lifting. For instance, if well 'B' in the formation depicted in Fig. 6 is extended to the artesian aquifer below, it will start discharging water automatically at the ground surface as wells 'A' and 'C'.

### 3—FLOW OF GROUNDWATER IN WELLS—CRITERIA OF GOOD WATER BEARING FORMATION

ALL water wells, although they vary considerably in size, depth and method/type of construction, consist essentially of pits, shafts or bores extending into the water bearing formation under the ground. When water is lifted from a well, a local depression/draw-down is created. This draw-down causes a difference of pressure and induces the water in the surrounding water bearing material to percolate towards the well. As the draw-down increases, the rate of flow in the well increases. In case of unconfined aquifer having unconsolidated water bearing material, a part of the flow entering the wells is drawn from unwatering of the surrounding soil material and the water table in the vicinity of the well is depressed in the shape of an inverted cone with the well at its apex (Fig. 7). The cone of depression continues to expand till the yield in the well is balanced by the normal groundwater flow in the stratum. If the aquifer is confined there is no actual unwatering of the surrounding soil material or depression of the water table. There is, however, lowering of pressure, around the well, which conforms to the shape of a cone, as shown in (Fig. 8). The cone is known as the cone of *pressure relief*.

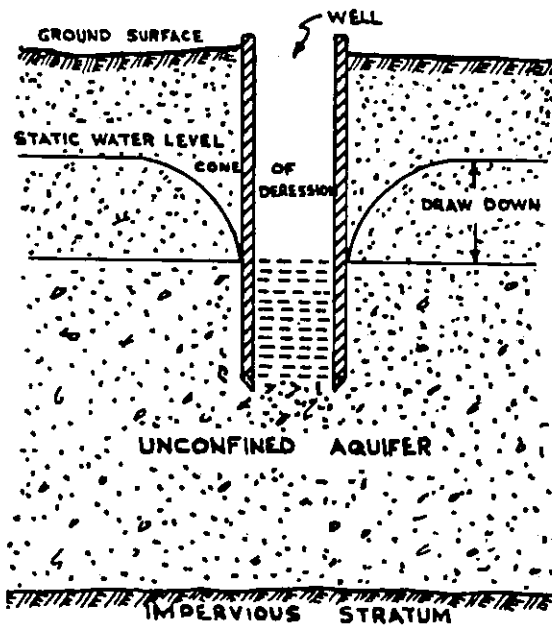


FIG. 7

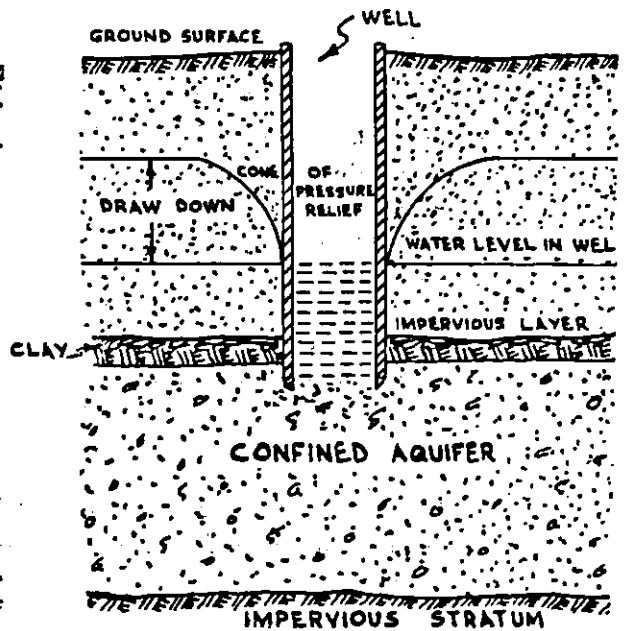


FIG. 8

The water output of a well depends not only on such factors as the size and the depth of the well and the type of its construction, *i.e.*, factors

pertaining to the design of the well; but also on the type and nature of the groundwater formation or strata tapped. The design or construction of a well can be altered or modified with a view to improving its discharge. The scope for such improvement, however, is determined largely by the groundwater availability in the formation. Similarly, the sustained water supply that may be drawn from a well or wells continually for a long period of time is governed entirely by the recharge and other conditions of the groundwater formation.

The main criteria of a good water bearing formation capable of yielding satisfactory and assured supplies in wells are: (a) *good storage*; (b) *good permeability* of the water bearing material; and (c) *good recharge*.

### Groundwater storage

Good storage of groundwater is essential for obtaining sustained supplies from a well or wells, without undue lowering of the water table, particularly during the dry season when the recharge dwindles down considerably. Storage is determined mainly by such factors as: (a) depth; (b) horizontal extension; and (c) effective *porosity* of the water bearing material.

The porosity of a rock or soil is defined as the ratio of the volume of the openings or pores in saturated material to its total volume and is usually expressed as a percentage. It, therefore, is a measure of the amount of water that can be contained in any given volume of rock or soil. The porosity of soils varies widely ranging from as low as 20% for graded sand to as high as 65% for very heavy clay. However, the total porosity does not give a clear picture of the water that may be available for extraction by wells. Some of the water contained in the pores is permanently retained in the aquifer by molecular forces and is referred to as *dead storage*. The amount of water, which is actually available for extraction by wells is determined by the factor known as *specific yield*. The specific yield is the quantity of water that a definite volume of water bearing material will yield as distinguished from that which it will retain. It is expressed as a percentage and is the ratio of the yield from a given volume of water bearing material to the volume of the material. The specific yield varies between 16 to 41%, is greatest for sand and gravel and least for clay and clay loam. Clays, thus, are good *stoppers* of water, but poor *yielders*.

### Permeability

The ability of a rock or soil to transmit water is called *permeability*. This is an important factor in groundwater studies as it determines the rate of inflow in the formation from the areas of recharge and also the flow or yield in the well.

Permeability is related not only to the number and size of openings in a rock or soil, but also to the degree of inter-connection of these openings. The relationship between permeability and rate of flow is expressed by Darcy's Law, which in somewhat modified form is  $Q=PIA$  ( $Q$ =quantity



of water discharged in a unit time;  $P$ —Coefficient of permeability usually expressed in the Meinzer Unit, which is the rate of flow of water in gallons a day, through a cross-sectional area of one square foot under a hydraulic gradient of 100%, *i.e.*, 1 to 1, at a temperature of 60° F;  $i$ —the hydraulic gradient; and  $A$ —cross sectional area through which the water percolates). The relationship shows that the greater the permeability of the medium the greater is the rate of flow of groundwater.

### Recharge.

The assured water supply that may be drawn from a well or wells on a permanent basis depends primarily on the recharge; that is the rate at which water is being added to the zone of saturation from all possible sources, such as inflow from other areas, percolation of moisture from rain or other surface applications of water and seepage from streams, rivers, lakes, tanks, etc. In an emergency, such as drought, water may be withdrawn at a faster rate than it is replenished by the recharge, but in the long run the rate of withdrawal cannot exceed the rate of recharge, or else the water table will continue to lower.

The average quantity of water per unit time, which can be extracted continuously from a groundwater reservoir over a prolonged period of time, by pumping or other artificial means without permanently depleting the supply of water in the reservoir is called *safe yield*. The determination of the safe yield is rather an involved problem as there are so many factors that have to be borne in mind when exploiting a groundwater source for irrigation. To some extent, safe yield can be increased by augmenting the recharge artificially, through such measures as contour bunding, gully-plugging, construction of percolation tanks etc. in the recharge area.

### Water bearing qualities of different materials.

Among all kinds of rocks or sub-soil, the best water bearers are deposits of *gravel*. Next to gravel come sand, sand stone, lime stone and basalt. The most completely unproductive of all material are the *true clays* and *fine silts*. *Shale* is a poor kind of formation to get water from, but it yields small quantities from the joints and along the bedding planes. Granite rocks yield large supply of water only when they are traversed by strong joints and fissures and sometimes faulted. *Quartzites*, unless heavily shattered, are disappointing for water supply. The *gneisses* and *schists* are usually discouraging, unless deeply weathered.

#### 4—OPEN WELLS—THEIR TYPES, USUAL PERFORMANCE AND LIMITATIONS

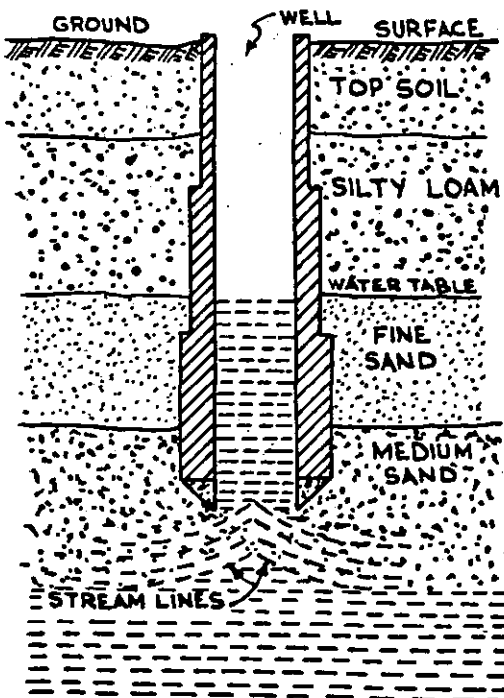
As distinct from tubewells, open wells are large sized holes in the ground. There are mainly four classes of open wells in irrigation use:

- (1) Masonry wells,
- (2) Wells with pervious lining,
- (3) *Kutch*a wells,
- (4) Wells in rocky sub-strata.

##### (1) *Masonry wells*.

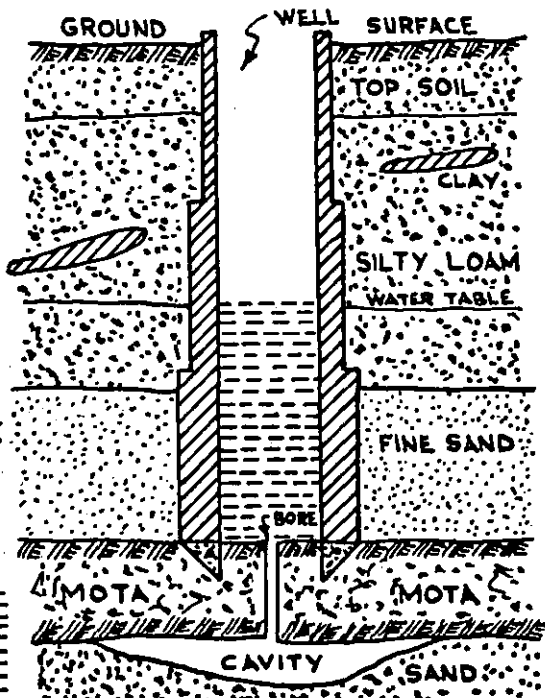
These wells have masonry steining wall usually sunk in sub-soil by applying static weight of sand bags and simultaneously scooping out of earth from inside. In locations, where it is not possible to sink masonry steining by ordinary methods due to presence of hard clays or boulders, etc., it is built up in a dug pit from the bottom upwards. Entire water supply on these wells is drawn from the bottom.

From the point of view of the type of the sub-stratum on which masonry steining of these wells is left and the manner in which they tap the groundwater, they may further be divided in two classes :



A  
SHALLOW WELL

FIG. 9



B  
DEEP WELL

FIG. 10

(i) Shallow wells—in which the steining wall is left in a sandy stratum. (Fig. 9).

(ii) Deep wells—in which the steining wall is left embedded in a thick impervious stratum called 'mota'. (Fig. 10).

Fig. 9 shows a well of the first type. These wells draw water from their pervious bottom. The arrangement is applicable for tapping only thin aquifers available near the water table. Streamlines entering the well have to deflect and converge upwards. Due to this pattern of flow, the loss of head in transmission is of higher order than that in other types of wells described later, or that in bored wells or tubewells.

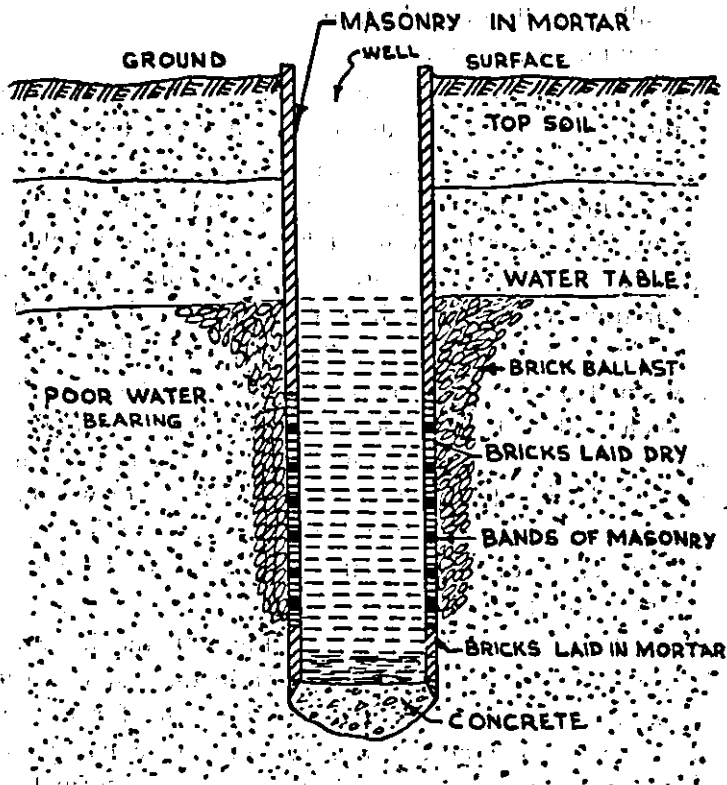
Only very small discharges usually under 500 gallons per hour may be drawn from such wells. If the velocity of flow in these wells exceeds the critical velocity—the velocity at which sand particles just begin to move—sand particles will be lifted up with the water and there will be danger for the steining wall to settle down, get damaged and even collapse. The draw-down and, therefore, the discharge of these wells has to be restricted in order to avoid any movement of sand.

In the second type of wells shown in Fig. 10, the impervious bed is bored in the centre in order to draw water from the water bearing medium below. As the water is raised, a cavity is gradually formed in the water bearing medium below the bore. The reason why a cavity is formed is that while the finer soil particles are lifted with water—a normal phenomenon in all wells—there is no subsidence of soil particles from above due to the roof action of the hard impervious layer. The cavity increases the percolation area and reduces excessive congestion of streamlines and resistance to flow at the entrance of the well. Such wells, therefore, often yield good discharges of the order of 2,000 gallons per hour and more, provided a good water bearing medium is available immediately below the impervious bed. If, however, the strata below the impervious layer consist of fine sand or silt, the discharge of such wells may be meagre.

The stability of these wells depends on the thickness, firmness and extensiveness of the impervious layer. Unless these conditions are met with, there is risk that under prolonged or excessive water lifting the cavity roof may subside, in which case the well would collapse.

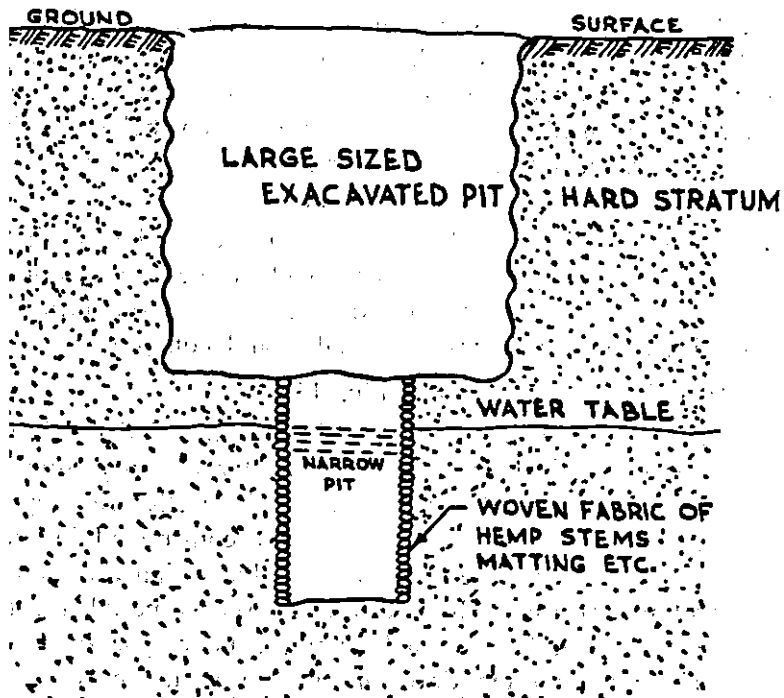
## (2) Wells with pervious lining (Fig. 11)

Some wells as shown in Fig. 11 are lined with cylinders of inter-twined brush wood or bricks laid dry. In between dry masonry, some bands of *pucca* masonry are provided for stability. The wells are plugged at the bottom by concrete. These wells are usually constructed in areas where no layer of good water bearing strata is available within a reasonable depth from the ground surface. Through their pervious periphery, they draw whatever discharge can be obtained from the poor type of strata that is available. These wells often draw in sand, from the pervious sides; the sand collects in the well and has to be removed periodically.



Wells with Pervious Lining

FIG. 11



Kutchha wells

FIG. 12

(3) *Kutchu Wells* (Fig. 12)

Wells for temporary use or those owned by small cultivators are frequently left unlined. Such wells (Fig. 12) are dug usually in the harder soils, which can stand vertically without lining. A relatively wider pit is dug upto just above the water table below which it is considerably narrowed down and usually lined with woven fabric of hemp stems or matting etc. through which the water oozes into the pit. As these wells usually extend only a few feet below the water table due to difficulties of underwater excavation, the draw-down to which they may be subjected in operation is limited. They can, therefore, yield only a small discharge which may be within the lifting capability of 'Dhenkli' or 'Picottah' (counterpoise lift).

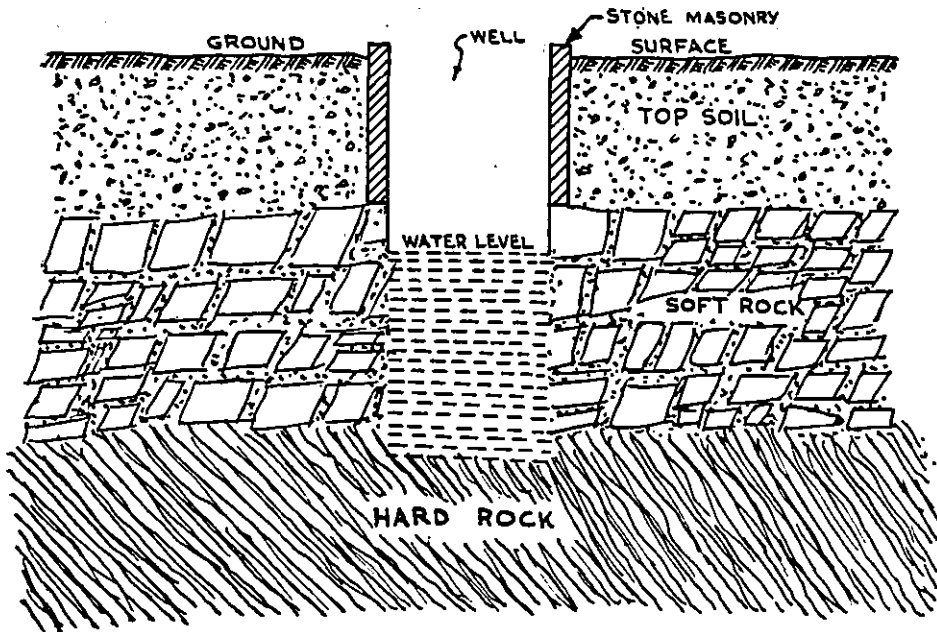
(4) *Wells in rocky sub-strata* (Fig. 13)

FIG. 13

In spite of rocky sub-stratum, well construction is undertaken in the Deccan Trap and in many other areas, as they provide the only convenient local source of irrigation. These wells (Fig. 13) are usually open excavated pits through top soil mantle and soft rock. For their water supply, these wells usually depend on joints, cracks, fissures, embedded layers of unconsolidated material, etc., which usually exist in rocks and serve as passages and receptacles of water. They are generally constructed in large sizes to provide storage and also in order to tap more joints and cracks or water bearing beds, if possible. The top portion above the rock is usually lined with masonry.

The discharge of these wells is usually a few hundred gallons per hour. A good storage inside the well is, therefore, necessary for their continued operation for some hours, during a day.

#### **Discharge limitations of open wells**

It would appear from what has been stated above that the average discharge of open wells is limited ranging usually between 100 to 1,000 gallons per hour. It is seldom that the discharge of an open well, unless it has been successfully bored, may exceed 1,000 gallons per hour. Because of meagre discharge, storage available inside the well also becomes an important factor specially if use of improved water lifting appliance is to be encouraged. For illustration, a persian wheel is usually capable of delivering about 2,000 gallons per hour at an average lift of about 25 to 30 ft. In order, therefore, that a well discharging about 500—1,000 gallons per hour under the average draw-down conditions, may be worked upon by a persian wheel continuously for a period of 8 hours or so per day (of 24 hours), the well should have an internal storage capacity of about 10,000 gallons. Taking another case, if a well yields about 100 to 200 gallons per hour and is operated by a 'Mhote' or 'Charas' discharging say about 1,500 gallons per hour and working for about 6 hrs. to 8 hrs. a day, continuously for a week or so in the period of keen irrigation demand, the well should have a storage capacity of 40,000 to 60,000 gallons. If these wells do not have such storage capacity, their operation for irrigation purposes may become very tedious.

## 5—BORING AND DEEPENING—THEIR SCOPE FOR IMPROVING WELL DISCHARGE

WITH the background given in the foregoing paragraph regarding the groundwater source, the factors affecting its flow in wells and discharge and other limitations of open wells, an attempt is now made in the following paragraphs to describe what the boring and deepening of wells comprise, what the conditions are under which these operations may be taken recourse to successfully and how these operations can be and should be carried out.

### Boring of Wells:

Boring of a well essential consists of drilling a small-sized bore through the bottom of the well and extending the bore up to layer or layers of good groundwater bearing medium lying further underneath the bottom of the well, with a view to tapping these underlying aquifers. The bores may be of two types, according to whether they tap the water bearing medium through a cavity formed below a hard impermeable strata or through strainer or screens provided opposite the vertical depths of the water bearing stratum/strata. A cavity bore is to be preferred only where there is available a hard, thick and extensive layer of impervious stratum immediately overlying a comparatively thin bed of good water bearing medium. A thick and extensive layer of impervious stratum is necessary in order that it may support its own weight and that of the overlying strata, by arch action. In case the water bearing strata available below the impervious layer is thick, a more suitable arrangement for tapping the aquifer fully may be to have a bore fitted with screens opposite almost the entire thickness of water bearing medium.

The suitable strata conditions under which one or the other types of these bores may be expected to improve discharge of open wells are described as under:

(1) *Good water bearing strata of small thickness underlying layer of clay of requisite thickness.* (Fig. 14).

When formation of this nature (Fig. 14) is available, there are good prospects for increasing the well discharge by boring. A bore without strainer ending in a cavity is to be preferred because hard impervious layer just overlying good water bearing stratum is available and secondly the vertical thickness of the sandy water bearing stratum is small. If the sandy stratum under the clay layer is substantially thick, a more appropriate arrangement for tapping the aquifer may be to have a bore with screen installation.

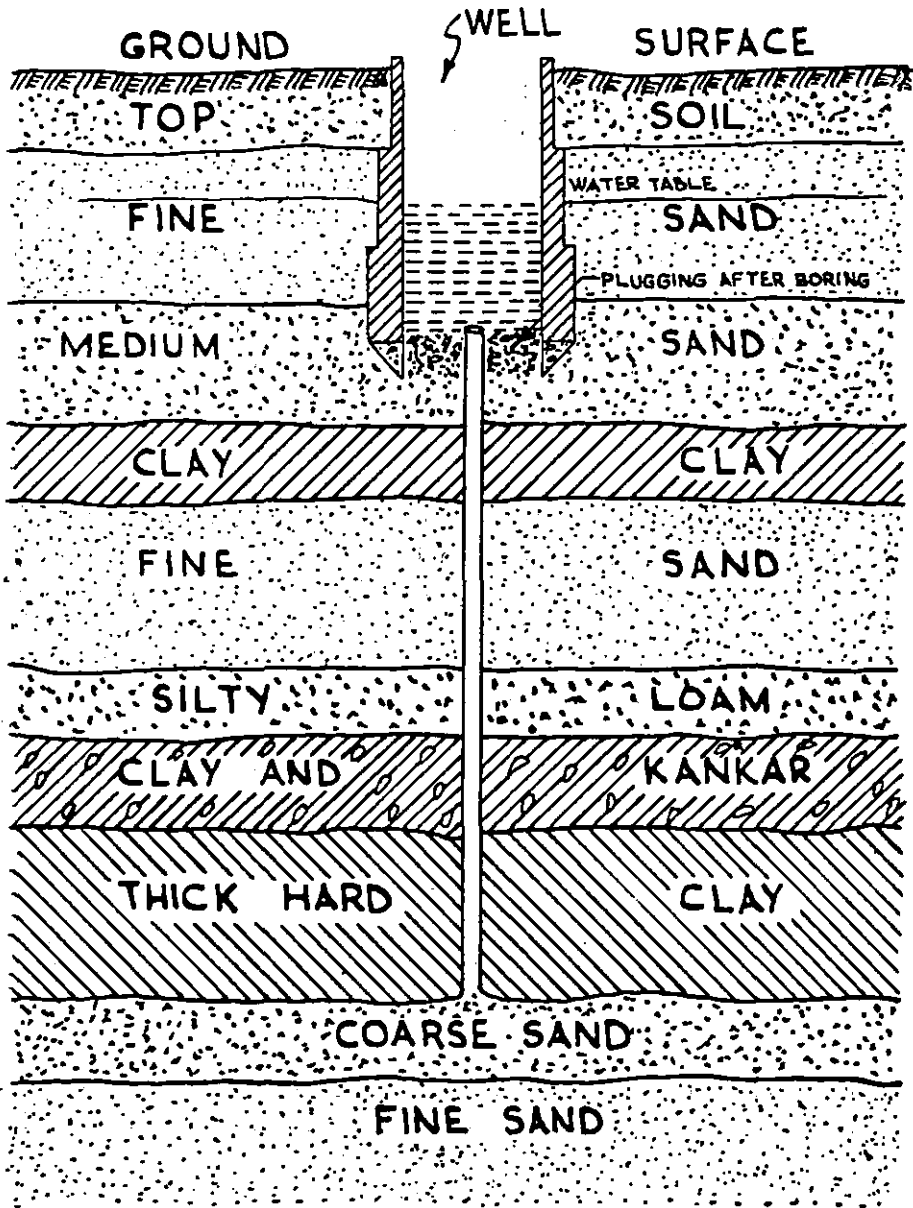


FIG. 14

(2) Good water bearing stratum available in substantial thickness below the bottom of the well. (Fig. 15).

In such formations (Fig. 15), strainer-bore should provide good prospects for improving the well discharge. The strainer has to be provided opposite the vertical thickness of the sandy water bearing strata. There is no chance



for a cavity-bore in such formations which do not have satisfactory clay-layers overlying the sandy strata.

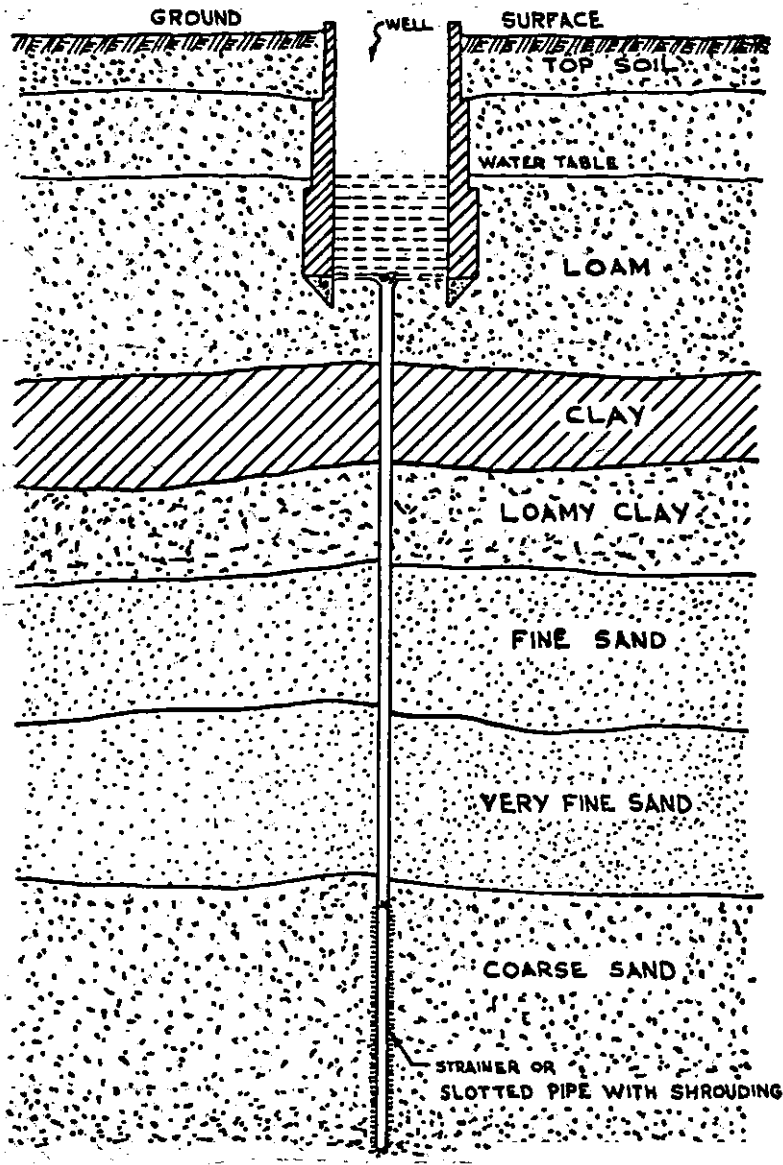


FIG. 15

(3) Two or more substantially thick layers of good water bearing medium available in the sub-strata below the bottom of the existing well. (Fig. 16).

In formation of this type, a high discharge if so required for irrigating the area that can be brought under the command of the well, can be had

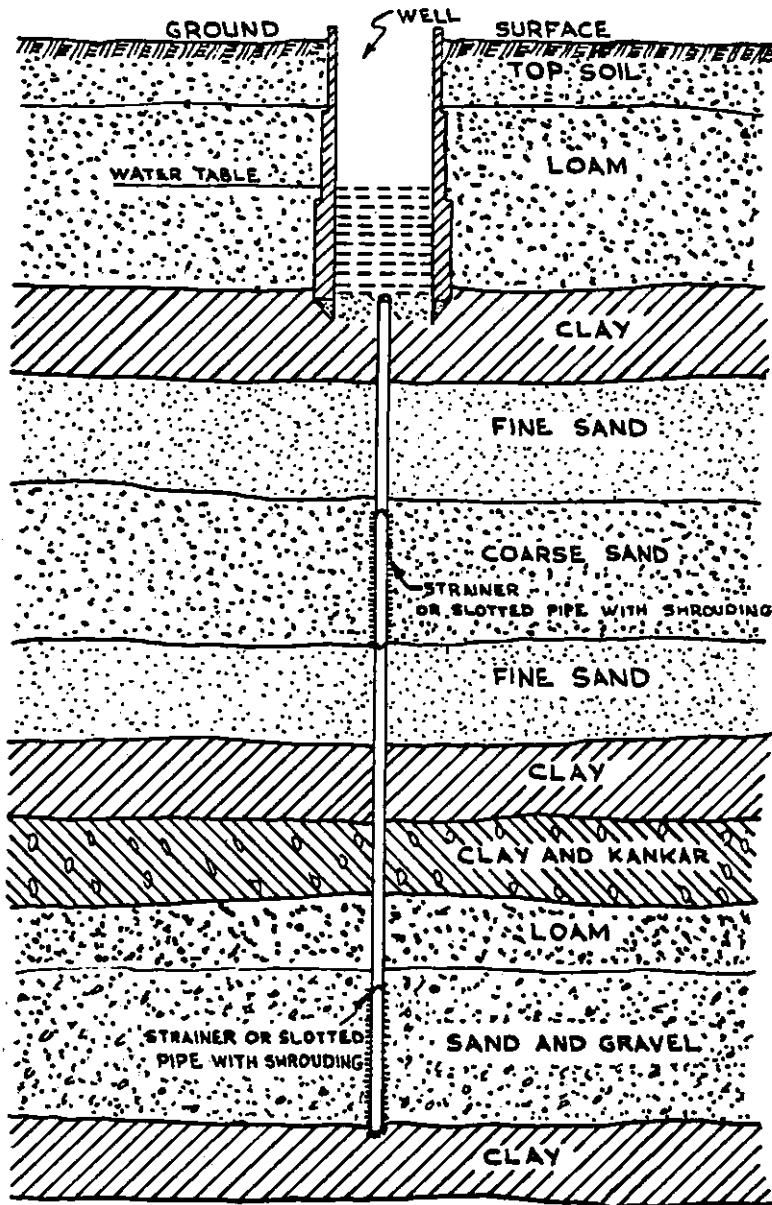


FIG. 16

by tapping the available aquifer as shown. (Fig. 16). The strainers may be provided along with thickness of the water bearing strata and they may be alternated with length of blind pipe provided along the poor water bearing strata. In this way, an appropriate length of the water bearing layers as available or as considered adequate for the required discharge may be tapped.

(4) *A good water bearing stratum available below an intervening hard rock. (Fig. 17).*

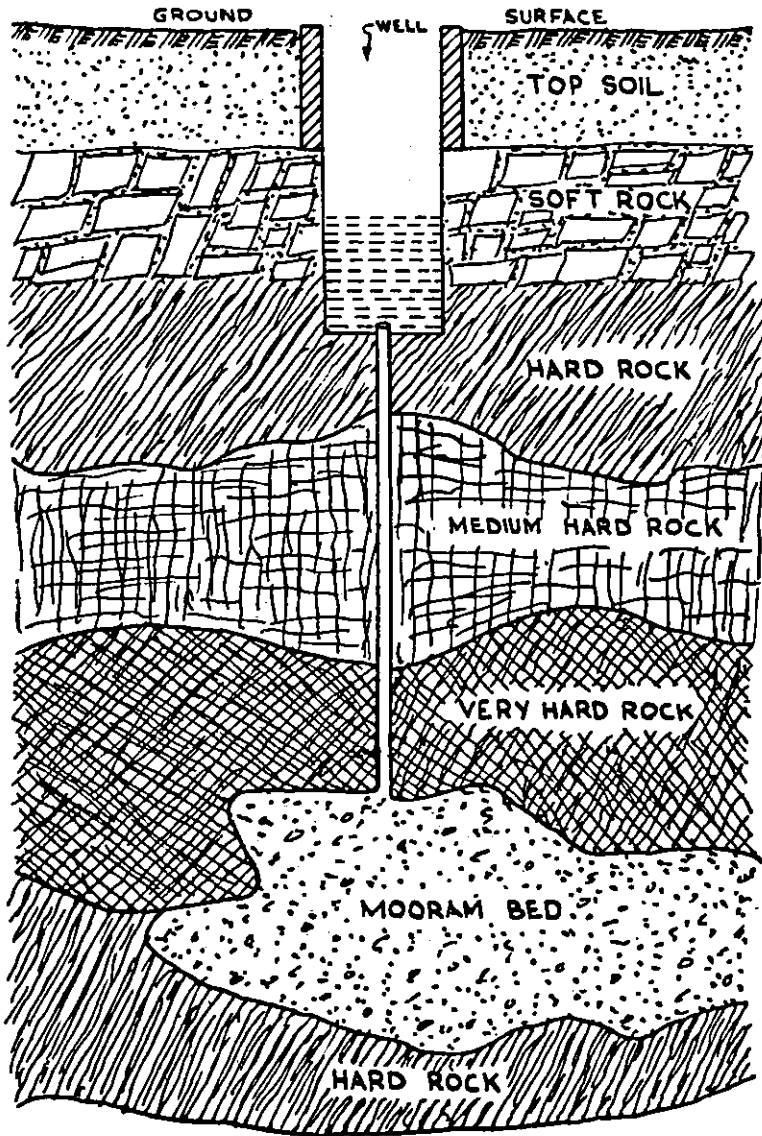


FIG. 17

There are good prospects of getting additional supplies if the hard rock is pierced through and the bore is extended up to the water bearing strata, which may be tapped through a strainer. If, however, the water bearing stratum is immediately below the hard rock and is comparatively thin, the simpler and better manner of tapping may be to finish the bore just at the bottom of the hard rock and get the water supply through the cavity formed below the bore. Such a bore through the hard rock may not be protected by any pipe as the bore in the rock is able to stand on its own. Before

attempting this, however, the stability of the rock to act as a roof over the cavity should be ascertained.

(5) *Artesian formation available below the bottom of the existing well.* (Fig. 18).

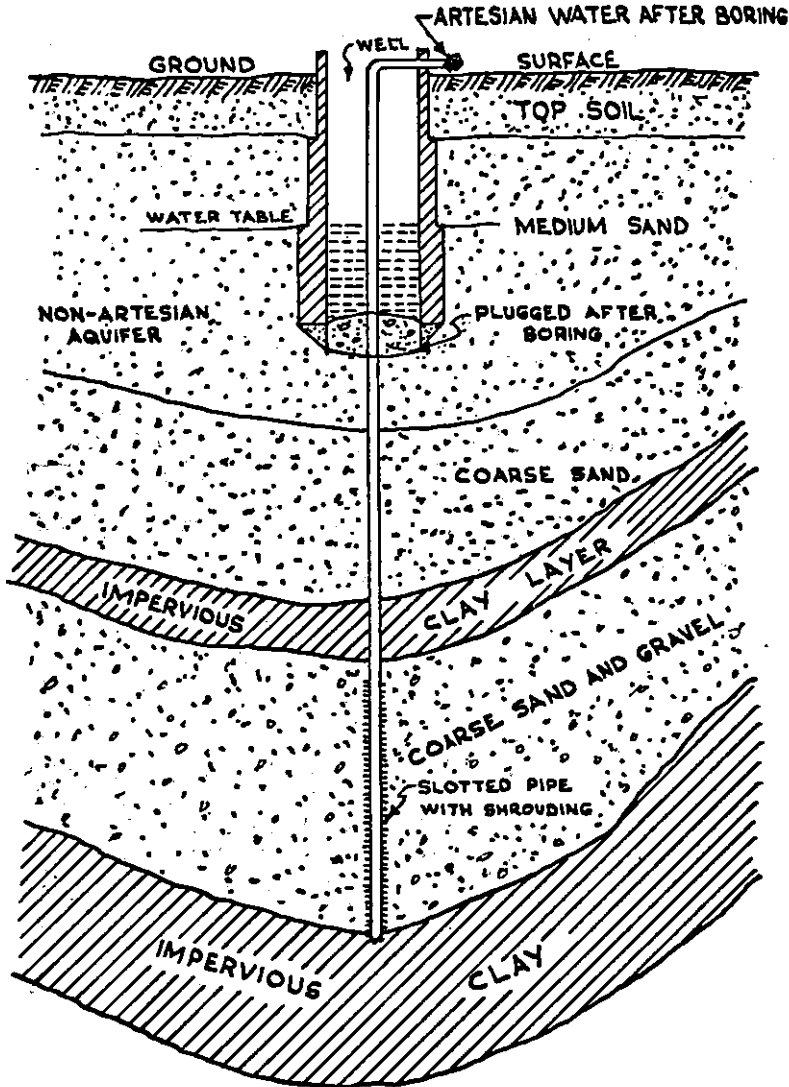


FIG. 18

In such a formation, there are not only chances that the boring would increase the water supply, but also that supplies may flow over the ground surface automatically or may considerably rise in the well. If the stratum of the artesian layer is thin and immediately below the intervening impervious stratum, it may be tapped without providing a strainer; otherwise the strainer may be necessary. In such a case a slotted pipe adequately shrouded may be better than a mesh-strainer as the latter may offer appreciable resistance.

## BORING IN DIFFERENT TYPES OF OPEN WELLS

### (1) *Masonry wells with pucca lining*

(a) *Shallow wells founded on sand:* After a successful bore has been completed on such wells, it is desirable that the bottom of the existing well may be plugged as shown in Fig. 19. This will eliminate chances of the well settling down and getting damaged due to uplifting of soil particles with the water.

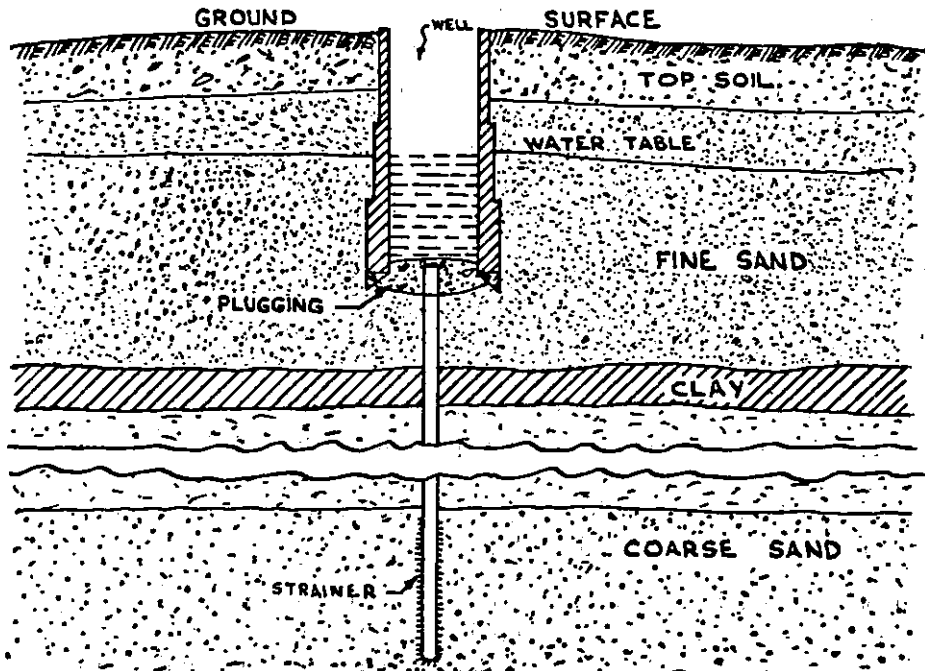


FIG. 19

(b) *Deep wells founded on 'Mota':* If the 'Mota' is sufficiently thick and extensive, it may not be necessary to plug the bottom of the well after its boring. In case, however, the 'Mota' is thin or only in the form of a small patch and is, therefore, likely to collapse under draw-down of higher order, it would be desirable to plug the bottom particularly when the discharge obtained through the bore is adequate and there is no need to draw-in any supplies from the sub-stratum just below the 'mota'.

### (2) *Wells with pervious lining*

The bottom of the pervious wells, even when not bored, is usually plugged with concrete in order to improve the stability of the pervious lining, which is prone to be structurally weak. If such wells are operated by power pumps after boring, it will be desirable that the suction pipe of the pump may be fitted directly in the bore. This will enable operation of only the bore with depressions of higher order, and stop the sand from entering the well through its porous sides.

### (3) *Kutch* Wells

*Kutch* wells are not permanent structures and boring in them should not normally be undertaken.

### (4) *Wells in rocky sub-stratum*

The object of boring of such wells is generally to tap an underlying water bearing aquifer. Occasionally boring on these wells is also carried out with a view to opening out additional water bearing fissures, cracks, joints, bedding planes etc., particularly when the rocks dip more towards the horizontal. The boring in such wells is likely to be mostly in rock and, therefore, costly. It is desirable that it should be resorted to only in such areas, where earlier investigations have proved their effectiveness for improving discharge of wells.

### **Deepening of Wells:**

Deepening of wells consists in blasting the bottom of the wells in rocky sub-stratum by dynamite, in stages, upto the desired depths. This is resorted to in cases where boring is not likely to help. If the rocks dip more towards the vertical, borings are least likely to help. The objective of deepening is two-fold; (a) to expose additional water bearing joints, cracks, crevices etc. and (b) to increase the storage capacity of the well. Some wells, however, require deepening in consequence of the lowering of water table due to unusual drought.

Rocks normally contain voids, interstices, cracks, joints, bedding planes etc., which serve as receptacles, holding the water in such formations. In most rocks, these are inter-connected so that a constant circulation of water is kept up under gravitation and hydraulic forces. In some rocks, however, these are generally isolated and there is little opportunity for water to permeate. In such type of rocks, where inter-connections are not sufficiently developed, percolation can be somewhat increased by deepening the existing wells.

The advantage of having good storage capacity on wells with meagre discharge has already been described earlier. It enables the daily working of such wells for a few hours, continuously for number of days during the period of keen irrigation demand.

## 6—BORING METHODS

THE earliest satisfactory method of boring a deep hole in the ground was evolved by the Chinese. This method, called the 'spring-pole' method utilised the springing action of a long wooden pole, suitably fulcrumed near the middle and weighted down and buried in the ground at its thicker end. (Fig. 20)

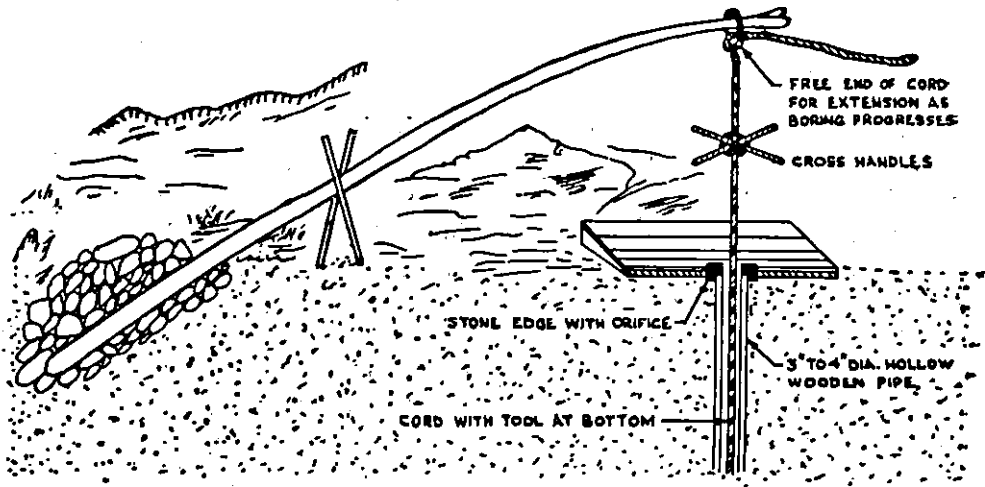


FIG. 20

The tapering end of the pole came vertically over the spot, where the well was to be drilled. A boring tool (Trepan) weighing 300 to 400 lbs. was attached to the tapering end by a cord and lowered into the hole. For drilling operation, the tool was raised and lowered manually, the lift being almost entirely accomplished by the spring in the pole. Two crossed handles attached to the cords were rotated at every stroke so that the cutting end of the tool did not strike at the same point, but at different points during the falls and, thus, made the hole uniform. The hole was kept wet. When it became clogged with drill cuttings, the drilling tool was replaced by a small bailer and the dislodged material removed to the ground surface. The hole was left unlined. The boring could thus be carried out in areas where the hole could stand without caving.

In India, there used to be a method of boring with ordinary crow-bars. The crow-bar was lowered with an ordinary rope and worked up and down the bore exactly in the same manner as boring tools are used in the modern system of boring with percussion tools, described later. A log of wood with a hole drilled in the centre throughout the length of the log was used as a guide pipe for the bore at the top. The remaining depth of the bore was kept unlined.

These early methods, though ingenuous in conception, were very slow in action and could drill only small diameter holes in relatively softer strata, which would stand without caving.

Since these early efforts, a number of mechanical improvements have been introduced gradually in the techniques of boring. Initial attempts at mechanisation consisted merely in using power units to replace the manual labour. The later technological developments, however, have resulted in evolving of highly mechanised and specialised equipment, which is compacted in mobile units and is very much faster and efficient in operation. The modern boring outfits have enabled drilling and successful completion of larger sized holes through deeper depths and stiffer strata in comparatively much less time.

It would appear that the process of boring essentially includes three types of operations: (a) pounding or abrading and loosening the sub-soil material within the hole; (b) removing the dislodged material from the hole to the ground-surface; and (c) lining the hole with suitable material to prevent caving of the walls in unconsolidated formations. The old methods—evolved in China and India—employed the percussion principle for drilling. The hole was made by percussion action of the boring tools oscillating up and down. The broken or crushed material in the bottom of the hole was removed by means of a bailer. These methods have led to the development of present day percussion rigs, which work essentially on the same principle, but much more powerfully and efficiently.

In addition to the percussion technique of drilling, another method called the rotary drilling has originated and developed highly in the oil fields. In this method, the hole is made by the quick rotation of a bit which also exerts a downward pressure against the soil material, during rotation. The drill cuttings are removed by constant circulation of a fluid under pressure.

There are also other methods which employ different variations or combinations of these two basic techniques of drilling.

The various methods of boring, which are currently used in India and other countries may be classified as under:

(1) *Percussion boring*

- (i) Hand boring by rope;
- (ii) Hand boring by rod;
- (iii) Mechanical boring with power rigs—standard cable tool method;
- (iv) Mechanical boring with power rigs—stove-pipe method.

(2) *Rotary drilling*

- (i) Direct circulation hydraulic rotary;
- (ii) Reverse rotary;
- (iii) Air rotary drilling.



(3) *Other methods*

- (a) Auger method;
- (b) Core drilling;
- (c) Water jetting method;
- (d) Hollow rod method.

The above methods are described in subsequent chapters.

## 7—PERCUSSION BORING

ALL methods of boring included under this category employ the same principle as the spring-pole method evolved by the Chinese hundreds of years ago. The hole is made by vertical oscillation of suitable tools and the dislodged soil material is removed by bailing. The hole is usually lined with casing pipe as drilling proceeds. The casing pipe serves the following purposes:

- (i) to prevent caving of the hole after completion;
- (ii) to permit the drilling of hole through inclined or creviced beds;
- (iii) to exclude highly mineralised water or water of inferior quality from upper formations;
- (iv) to prevent the loss of high-pressure water into low-pressure intermediate sands;
- (v) to prevent the entrance of shallow ground water, surface water, or waste that would contaminate the well-water supply.

Characteristic features of various percussion methods and the equipment and operations involved are described in the following paragraphs:

### (I) Hand Boring by Rope

This method is the simplest and is extensively used. A sand bucket equipped with a cutting shoe at its lower end acts, normally, as a drilling tool as well as a bailer, in this method. As drilling proceeds, a line of

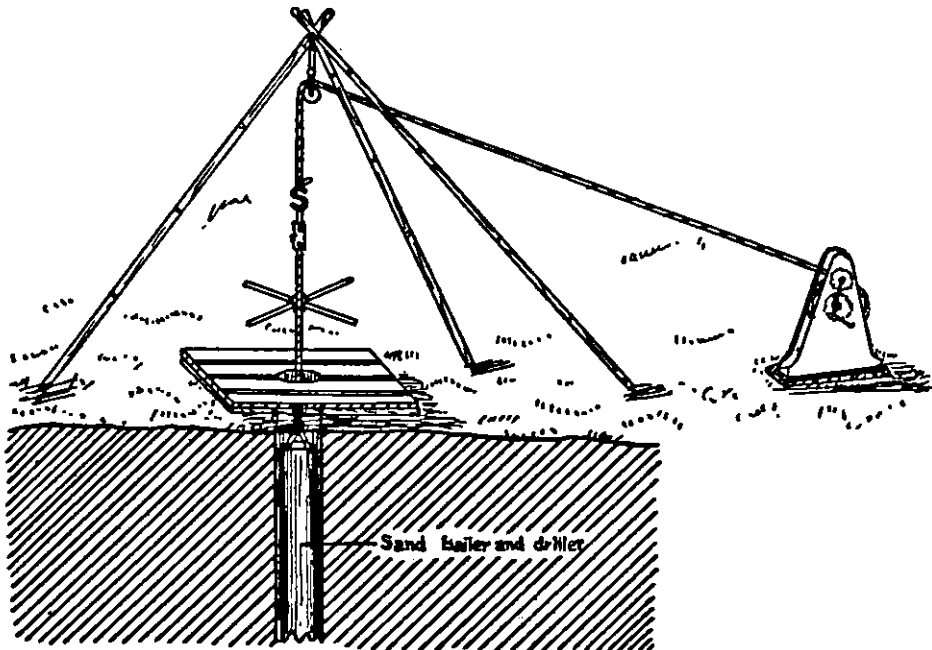


FIG. 21

casing pipe is gradually lowered into the hole to support the caving formations. For facilitating sinking, the casing pipe is weighted down by gunny bags or pressed down by means of screw or hydraulic jacks or anchor bolt method. The method is comparatively slow, but very satisfactory from the point of view of cost and simplicity of equipment involved.

The equipment, Fig. 21, comprises a tripod, a crab winch, a bailer or sand pump, a cutter shoe, an anchor bolt set, loading clamps, chain wrenches, pulley blocks, flexible steel wire rope and other such tools as spanners, level wrenches, etc. The pipe for casing the hole consists of lengths of wrought-steel tubes connected together with suitable joints. Three types of joints, as illustrated in Fig. 22 are used: (a) flush joints, (b) swelled and cressed joints; and (c) socketed joints.

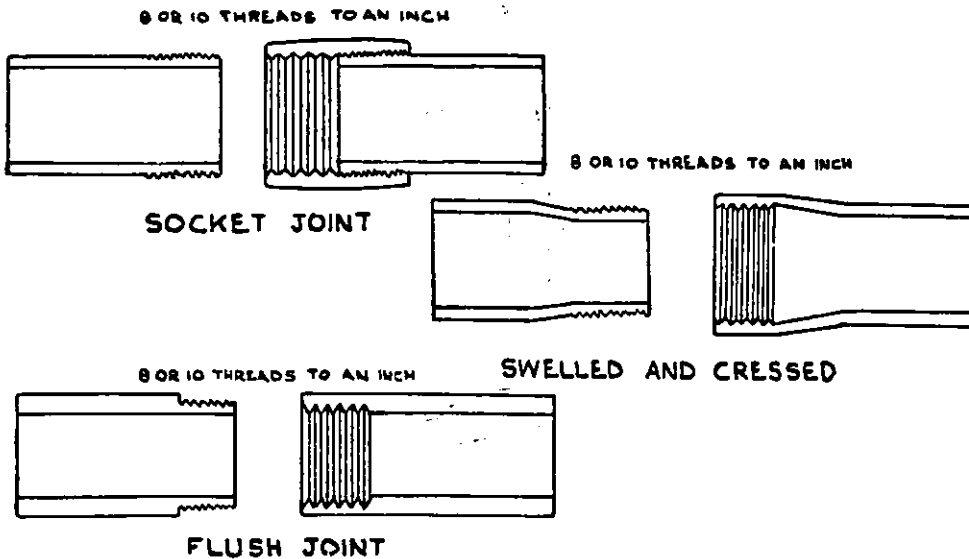


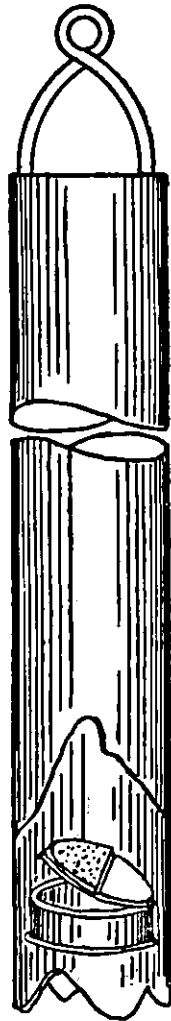
FIG. 22

The flush joint is the best for ease in lowering and withdrawal, but requires thicker pipes for the same strength. The usual practice is to have casing joints with either 8-threads to an inch or 10-threads to an inch. The threads in 8-thread pipe are cut deeper and, therefore, this pipe lacks, comparatively, in strength. On the contrary, it has been observed that 10-thread pipes have a tendency to slip at the joints during extraction. 8-thread pipes are better in this respect. Generally speaking, pipes of 10-threads to an inch are preferable where the thickness of pipes is less than  $\frac{1}{4}$ th of an inch, but with thickness between  $\frac{1}{4}$ th and  $\frac{1}{5}$ th of an inch, pipes with 8-threads to an inch are preferred.

The bottom length of the casing pipe is fitted with a cutter shoe at the bottom. The cutter shoe is either a 'slip shoe' or a 'screw shoe' and is slightly bigger in diameter than that of the casing pipe itself. This extra size of the shoe provides a clear passage for the casing pipe as it is sunk. The slip shoe is slid on to the casing pipe. It is left at the bottom of the bore when the casing pipe is withdrawn. The slip shoe is of a larger diameter

than the screw shoe for pipes of the same diameter. This shoe is useful in stiff clay, rocky soils, etc. and also for deep bores as it clears a slightly larger hole and thereby reduces the friction both in sinking and withdrawal of the pipe. The screw shoe is screwed to the pipe case and is, therefore, pulled out with the pipe when it is withdrawn. No clearance is thus, available during withdrawal.

To start with the boring operation, the first length of the casing pipe with the cutter shoe at its bottom is lowered at the centre of the well to be bored. The pipe is held in dead plumb position by means of wooden clamps fixed at convenient places inside the well and/or above the well. In the case of very deep borings or borings in clayey strata, the bore is started with a



BAILER

FIG. 23

larger diameter casing pipe and carried down till the friction on its outer surface makes it difficult to carry on the boring any further without damage to the pipes. A slightly smaller sized casing pipe is then lowered inside the larger sized pipe. If necessary, a still smaller size of the casing pipe is lowered inside the inner pipe when the friction of the latter also becomes excessive. Thus, the diameter of the bored hole is successively reduced as the conditions demand. This system of lowering pipes one inside the other is called '*Telescopic boring*'.

Actual boring is done with a tool known as 'bailer', 'sludger' or 'sand pump' (Fig. 23). This implement is a steel pipe of about  $\frac{1}{4}$ " in thickness, varying in length and diameter according to the size of the hole to be bored. It is about 2" less in diameter than that of the casing pipe and is about 8 to 12 feet long. A cutting shoe of hard steel or tungsten steel is riveted to the sludger at its lower end. A flap or ball valve is fitted inside the sludger pipe just above the cutter shoe. The sludger is suspended by a wire rope from a pulley on the tripod erected centrally over the well. The legs of the tripod are buried about 2 ft. underground to prevent their slipping or tilting. The sludger comes centrally over the casing pipe and is worked vertically up and down by manual labour. For operating the sludger, a group of work-men walk along the ground, alternately pulling and releasing the wire rope carrying the sludger. A modification of this may be to use a windlass or a crab winch so that men need not walk to operate the sludger, but they roll the rope on the axle and release it alternately. On the downward stroke of the sludger, the flap valve is forced open and the loose material pounded at the bottom of the bore hole enters into the sludger pipe. As the upstroke begins the flap valve closes, thus, retaining the loose material inside the sludger pipe. Owing to the vacuum created by the upward movement of the sludger, the loose material is also sucked upwards and gets thoroughly mixed with water. The loose material suspended in water enters the sludger pump on the downward stroke and at the same time the cutter shoe cuts some more of the material at the bottom of the bore. The process is repeated and more and more loose material collects in the sludger pipe. After about 30 to 40 strokes, the sludger is taken out and the loose material retained inside it, is emptied out. When a hard stratum is met with, the sludger is temporarily replaced by different tools, such as chisels, reamers, augers etc. to pierce through it and break it.

As a result of dislodging of the soil material by the bailer, the casing pipe sinks in the initial stages by its own weight. After a few feet of sinking, the casing pipe is weighted down by gunny bags full of sand or muck. The bags are placed over a platform made from a wooden sleeper clamps fixed around the casing pipes at a convenient point.

Another improved method is to sink down the pipes by means of screw or hydraulic jacks as shown in Fig. 24. The jacks are made to work against a wooden clamp 'A' fastened rigidly around the pipe and to react from another wooden clamp 'B' fitted loosely around the pipe and held rigidly

in position by means of two bolts, which are securely anchored a few feet below the ground level.

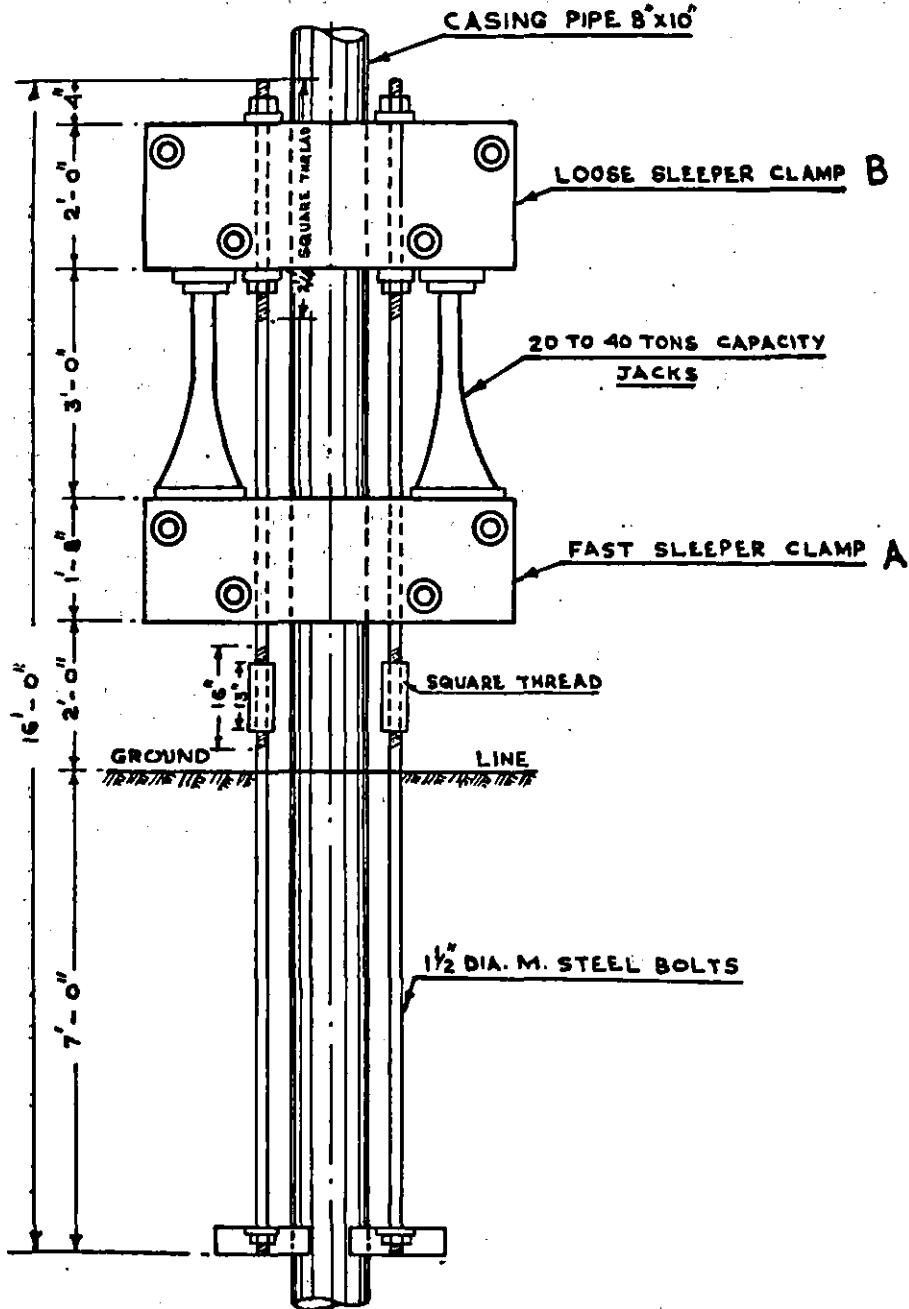


FIG. 24

The anchor bolts consist of two mild steel rods about  $1\frac{1}{2}$ " in diameter and about 16 ft. in length. The rods are suitably threaded at both ends. They are positioned on diametrically opposite sides of the pipe, keeping

about 4" away from the pipe as shown in Fig. 24. The rods pass freely through the rigid clamp 'A', but are bolted firmly with the loose clamp 'B' at their top. At the lower end, each rod is fastened, by means of nuts on either side with two pieces of steel joists about 6"×4" in section and about 4 ft. in length, to serve as anchors. The joists are placed in a cross form in a dug pit, which is subsequently filled up. The distance between the two clamps is adjusted according to the size of the jacks, which are held, one on either side of the pipe, between the clamps. As the jacks are operated, the clamp 'B' held rigidly by the anchor bolts, remains stationary while clamp 'A' moves down along with the pipe. After the pipe has sunk some distance, the clamp 'A' is moved up on the pipe and the jacks re-adjusted. The process is repeated, sinking down the pipe a few feet everytime.

This method is called the *anchor bolt system* and is more suitable for harder strata and for depths below 100 ft. from ground level. Use of this method, however, may not be convenient in the case of boring in open wells.

During drilling, a periodical check on the verticality of the casing pipe is essential so that any mistake in the initial stages of boring is not multiplied.

### (II) Hand Boring By Rod

Boring by rod is similar to rope boring except that rods extend from the ground-level to the boring tool instead of the rope. Use of rods enables slight rotation of the drilling tools during operation. Tools, such as augers can, therefore, be used and the hole is kept round. The disadvantage of this system is that much time is wasted in screwing and unscrewing the pieces of rod every time, the sand bucket is withdrawn, as the entire length of rod cannot be handled at one time. This system is used for relatively deeper borings or borings in very hard strata.

The rods that replace the rope are either of ash wood with metal male and female screws spliced on to their ends or of steel with screws. The rope carrying the rods and the boring tools and passing over the head-pulley-block in the tripod is pulled and released alternately just as in the case of boring by rope. The rod is now and then rotated slightly in order that the boring tools, such as the chisel or the auger, at the lower end of the rod may further break the stratum into fragments and puddle the same into muck for removal by bailer or some other device suitable for the purpose. Casing pipes are inserted and sunk gradually along with the drilling of the hole, as in the previous case, in order to prevent caving of sides.

### (III) Mechanical Boring With Power Rigs—Standard Cable Tool Method

With the use of power in percussion boring, the speed of drilling is very much increased, and deep and large sized borings in almost all types of strata become possible. The hole is made by the percussion and the cutting action of a drilling bit, which is alternately raised and dropped and also turned at every stroke so that the edge of the bit strikes on a different line

at each successive blow. The drill bit, a club-like chisel-edged tool breaks the formation into small fragments, which are turned into sludge, by addition of water, if necessary, and bailed out at intervals by a sand pump. In hard rock, the hole usually is drilled without a casing, but in soft cavy and unconsolidated materials, casing is used to keep the hole open. The casing is driven down if necessary, by fastening a drive clamp and hammering the casing. The casing pipe has to be strong enough to withstand the driving stresses and to resist the wear of the tools against the casing, while drilling is in progress.

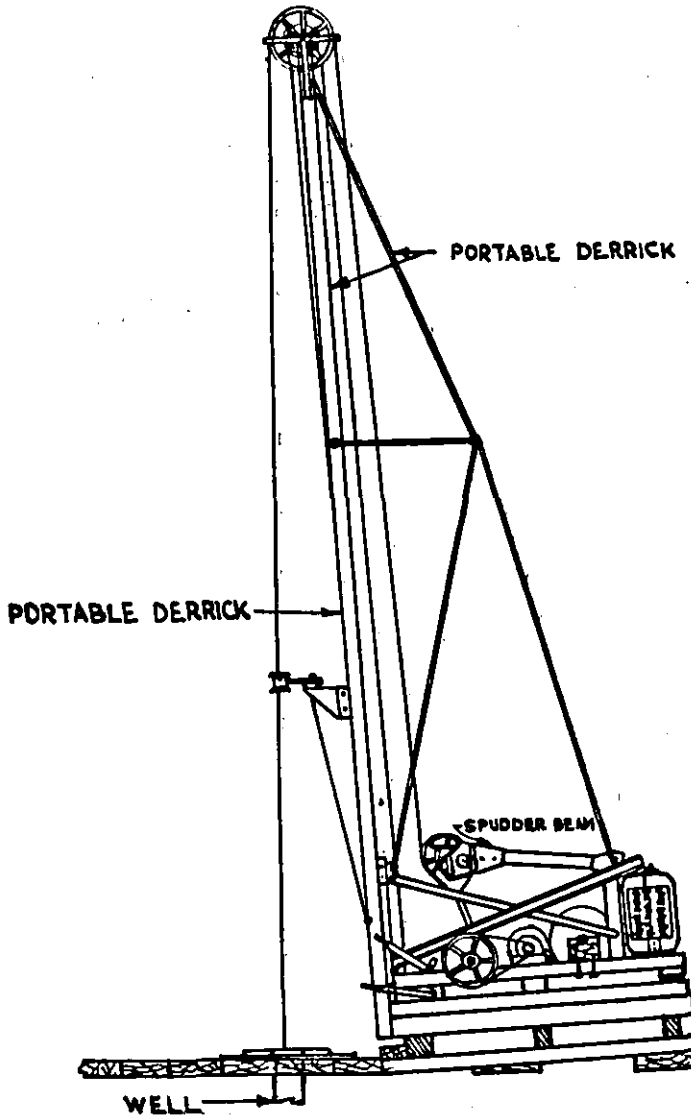


FIG. 25

The standard drilling equipment under this method consists of a portable rig mounted either on a truck chassis or on a trailer. The rig (Fig. 25)



consists essentially of a mast; a two-line hoist, one line for operating the drilling tools and the other for operating bailer or sand pump, a spudder for raising and dropping the tools; and a diesel engine for powering of these operations. The mast is made long enough to allow the longest string of tools or section of pipe to be hoisted out of the hole, the minimum height being about 30 ft. The mast is telescoped to its shortest length and folded down at the top of the machine during transit. The hoists consist of power-operated reels, large enough to hold sufficient cable for drilling the deepest holes of which the rig is capable. The reels are driven by friction pulleys or by positive drives such as gears or chains. When a positive drive is used a clutch has to be provided for each reel to throw the mechanism in and out of gear. The sand-line reel is smaller than the drilling-line reel and usually operates at a higher speed. The drilling-line reel has to have sufficient power to hoist tools and the cable out of the hole, and to operate fishing tools and other equipment. Long strings of casing also have to be raised or lowered by the drilling-line hoist. All the reels are equipped with powerful brakes capable of stopping or holding them at any time. In addition, the drilling reel is equipped with a hand operated slow motion drive for the purpose of raising or lowering the cable a small amount while drilling. The sheave for the drilling-line is usually mounted on springs or rubber to take up some of the shock when drilling is in progress.

The spudding mechanism consists of a heavy beam, which is hinged at one end. The free end together with the sheave that it carries, is moved up and down by a pitman, which is operated by a crank driven by the rig engine. The drilling-line carrying the string of tools is threaded over the sheave at the top of the mast and down under the sheave at the end of the spudding beam to the drill-line drum. Since the end of the line on the reel is held fixed by the brakes, the tools suspended at the other end of the line rise and fall, as the crank rotates and the spudding beam moves up and down. The length of the stroke depends on the radius of the crank arm, which may be varied by changing the setting of the crank pin.

Many commercial models of percussion rigs are available, the details of which vary from model to model. Complete information in regard to these machines can be obtained from the manufacturers. Various types of tools are used in drilling, but in case of drilling for water, it may not always be necessary to use the full equipment required for deep mineral drilling. When orders are placed for water drilling equipment it is desirable that this aspect is kept in mind and drilling tools which are actually required are selected.

An exhaustive account of the equipment, tools and the various operational details involved in actual drilling procedure is available in many books dealing exclusively with the subject of percussion drilling by power rigs. A brief description of main operations, tools involved, and other important aspects of drilling by this method is given below :

(1) *Erection of the power rig*

To start with, the drilling machinery, after being transported to the site of the well to be bored is placed in position properly by the side of the well.

The main frame is jacked up and blocked so as to be perfectly rigid. The mast is hoisted in vertical position and inclined slightly until exactly plumbed over the intended centre of the bore hole. The braces of the frame are fitted thereafter, and the guy-ropes for the mast set out to hold in place.

## (2) Drilling process

The drilling process in case of power rigs, includes three types of operations; viz., (i) making the hole; (ii) bailing out drill cuttings; and (iii) encasing the bore-hole. These three operations usually follow one another till the bore is completed.

(i) *Making the hole* : A complete string of standard tools (Fig. 26) for making the hole is made up of a drill bit, a stem, a set of jars, a sinking bar and a rope socket. It may weigh as much as 5,000 pounds. The tools are subjected to hard service and special steel is required in their manufacture. They are joined together by screw joints of the box-and-pin type. Special wrenches that fit the squared sections of the tools are used to tighten the joints.

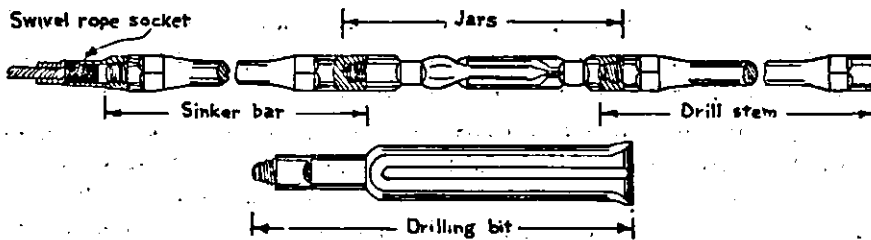


FIG. 26

The *bit* is the most important part of the string of tools. It does the actual drilling and consists of the cutting edge, the body, the wrench square, the shank and the pin. Bits of different forms and shapes are made for different purposes. The important types are shown in Fig. 27.

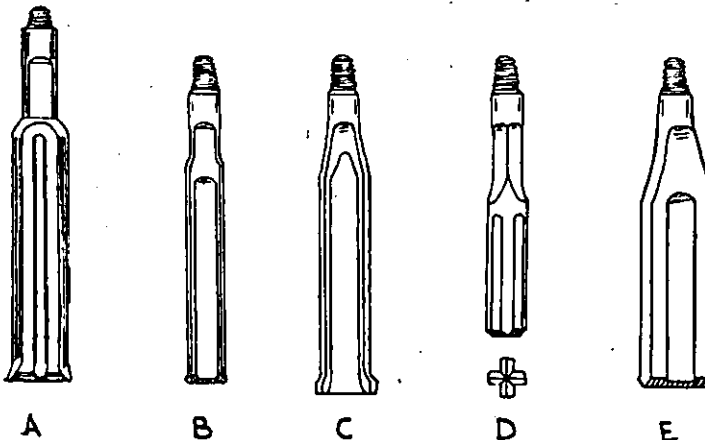


FIG. 27

The *regular pattern* drill bit (Fig. 27-A) also called the '*club drill*', having a 'figure-of-eight' section is the most common type and is used with reasonable success in almost any formation. The form of the cutting edge is varied to adopt it to the character of formation to be drilled. For hard rock, a fairly sharp chisel edge is used while for soft material, the bit used is almost flat on the bottom with only a blunt edge at the centre. The bit is made of a heavy bar of steel or iron from 4 to 11 ft. long and somewhat wider than it is thick. It is dressed to a blunt edge on end and terminates in a tapered tool joint at the other end. The shank of the bit is usually several inches smaller than the cutting edge, which permits the bit to work in the hole eccentrically, drilling a hole somewhat larger than the actual gauge of the drilling bit. A wide groove or "water course" is cut on each side of the bit to permit easy displacement of the fluid in the well as the tools rise and fall. This bit combines a relatively long and moderately full body with ample clearance for the sludge and permits a maximum amount of drilling between bailings. The *Mother Hubbard bit* (Fig. 27-B) is similar to the regular bit except that it has square instead of round shoulders. It is used because the sharp shoulders of the bit ream out the hole easily where the mud from drilling materials such as shale builds up on the sides of the hole. The *California pattern bit* (Fig. 27-C) has long sloping shoulders and is used in drilling large holes in hard formations and where the drilling is carried on ahead of the casing. The sloping shoulders do not catch on the bottom of the casing when the tools are being withdrawn. The *four wing* or *star pattern bit* (Fig. 27-D) has two cutting edges at right angles to each other. It is used for drilling in fissured or tilted rocks, because the additional cutting edges tend to keep the hole round and straight. The cutting end of this bit has four water channels. The diameter of the body section is only slightly smaller than the gauge size. The four cutting points and the small clearance between blade and hole make these bits particularly effective for reaming and straightening holes. This bit however is used sparingly, because it is slow cutting and difficult to dress in the field. *Spudding bit* (Fig. 27-E) is short and thin and is used in starting holes in soft formations. There are many other bits used for special purposes, such as reaming, undercutting or straightening a hole. Use of any particular bit is largely determined by the local formation and the experience of the driller. The drilling bit is actually required to perform four important functions, viz., penetrating, crushing, reaming, and mixing. The character of the formation to be drilled always determines, which of the four functions is most important. In hard lime stone, the most important function is penetration. Soft lime stone requires special attention to the crushing function and if the lime stone contains a noticeable amount of clay, some attention needs be given to mixing. Quartz and granite usually are hard and abrasive; therefore, the most important functions are to penetrate and ream and no attention need be given to crushing and mixing. Soft formation requires special attention to mixing and in many cases it is necessary to retard penetration in order to ensure maximum results. The bits are selected according to the prominent function they are required to perform.

The drilling bits lose gauge gradually as a result of wearing during drilling. For efficient performance, it is necessary that the drill bits *must be dressed properly* and maintained to gauge. Dressing of bits in the field, therefore, becomes an important item of the drilling operation. For this reason, drilling rig is always accompanied by a forge, the fan blower for which is fitted in the rig itself and is operated by the main engine. Much of the success and speed of drilling depends on the proper dressing of drill bits. Detailed instructions for dressing and hardening of drill bits are usually given in the handbooks on drilling. These instructions need be followed carefully for obtaining proficiency in the drilling operation. The frequency of dressing bits depends entirely on the nature of the formation being drilled. In softer materials, it may be the time to re-dress a bit when it has worn out of gauge by about 3/8th inch. Dressing at more frequent intervals may be needed in hard rocks, to prevent excessive sticking when a new bit is run in the bore-hole.

The *drill stem* consists of a round steel bar, which is connected to the drill bit by a box-and-pin joint. The purpose of the stem is to add weight and length to the drill so that it will cut rapidly and will make a straight hole. It is usually reckoned that 200 pounds of tool weight per inch of hole diameter is needed to penetrate a given formation.

The *sinker bar* is similar to the drill stem in shape, only shorter. It is occasionally used to give additional weight and length to the string of tools.

*Drill jars* consist of a pair of narrow steel links with a box joint on the lower end for attaching them to the drill stem and a pin joint on the upper end for attaching the rope socket or the sinker bar if one is used. The jars have no direct drilling function. Their purpose is to provide a means for jarring the tools loose by a sharp upward blow on the upstroke of the spudding beam.

The *rope sockets* are used for the purpose of fixing the rope or cable to the string of tools. When using a wire cable, it is the *swivel-type socket*, that is generally used. This socket allows the tool to spin or turn after each blow and, thus, it seldom allows the cutting edge of the bit to strike more than one blow in the same place. This eliminates some of the causes that are responsible for crooked or flat holes. The socket is bored out from the box-end to take a steel mandrel, into which the rope's end is babbited. To prevent the mandrel from getting jammed in the socket, a number of drainage holes are provided in the socket, to allow slurry and grit to drain away. A wire line attachment called the '*rope saver*' is slid over the neck of the drill line socket to prevent the line from kinking at this point when the tools are raised from any position other than the vertical.

The hole is made by raising and lowering the string of tools at the end of drilling cable, which is operated upon by the spudding mechanism of the rig. The tools make from 25 to 60 strokes per minute and by turning the cable back and forth, the bit rotates also and in so doing makes a round hole. For efficient performance, the stroke and the speed of this spudding beam

has to be varied according to the character of the formation and the depth of the hole. The spudding mechanism is provided with necessary adjustments for the purpose. Proper adjustment of the spudder assembly eliminates line whip, drill shock, and vibration, and increases the efficiency of the machine. Such adjustment requires the skill and care of an experienced driller. The driller holds his hand on the cable and notes the character of the jar, which indicates the manner in which the tools are operating. Each formation has its characteristic jar and satisfactory progress in drilling depends to a large extent upon the ability of the driller to interpret the vibrations which come to him through the drilling cable. As a rule, the full weight of the tools is not allowed to drop upon the bottom of the well, but is taken up in parts by stretching of the drill line. The stretch of the line is regulated so that the tools will strike the bottom and then jump back immediately. This action is called 'drilling on the stretch of the line'. This gives the tools less time to jam or to stick in the hole.

To start drilling in soft, unconsolidated formations, a hole to a depth of about 3 ft. is dug by means of a shovel, before starting drilling by cable tools. In the initial stages, the spudding motion is kept slow and the movement of tools is guided manually. In case of hard rocky formations, the hole is dug or chiselled out to a depth of about 6" and then a pipe installed in the hole to guide the drilling cable and tools.

A certain amount of *water is essential* to drilling operations in order that drill cuttings will be turned into sludge and removed. When sufficient water is found in the formation for this purpose, no additional water is needed. In drilling a dry hole, water must be added to replace that taken out in removing the drill cuttings. Some dry formations may take water in large volumes; in such cases mud or bran may be added to water to make it more like paste. Too much water in the hole, however, interferes with the progress of drilling because of the buoyant effect of the water on the string of tools and the friction of the cable in the water. Usually, from 1 to 5 gallons of water per foot of dry drilling is sufficient to make a good sludge for bailing.

(ii) *Bailing out drill cuttings* : The drill cuttings are bailed out from time to time, as drilling proceeds. The equipment used for removal of drill cuttings is either a bailer or a vacuum sand pump. A bailer consists of a section of pipe generally from 8 to 20 ft. long with a valve in the bottom and a bail at the top for attaching the drilling cable or the sand line, whichever is used. The diameter of the bailer is determined by the size of the hole being drilled, plenty of clearance being allowed so that the bailer will fall freely. Bailers are equipped with flap, dart or bayonet valves (Fig. 28).

The purpose of these valves is to allow the drillings to enter the bailer and to keep them from running out after they have been caught. The opening in the valve should be as large as possible in order to permit rocks and balls of clay to enter the bailer easily. The flap-valve bailer (Fig. 28-A) has a flapper valve which cannot be opened after the bailer is filled. This type has to be emptied from the top end by tipping the bailer. Bailer with

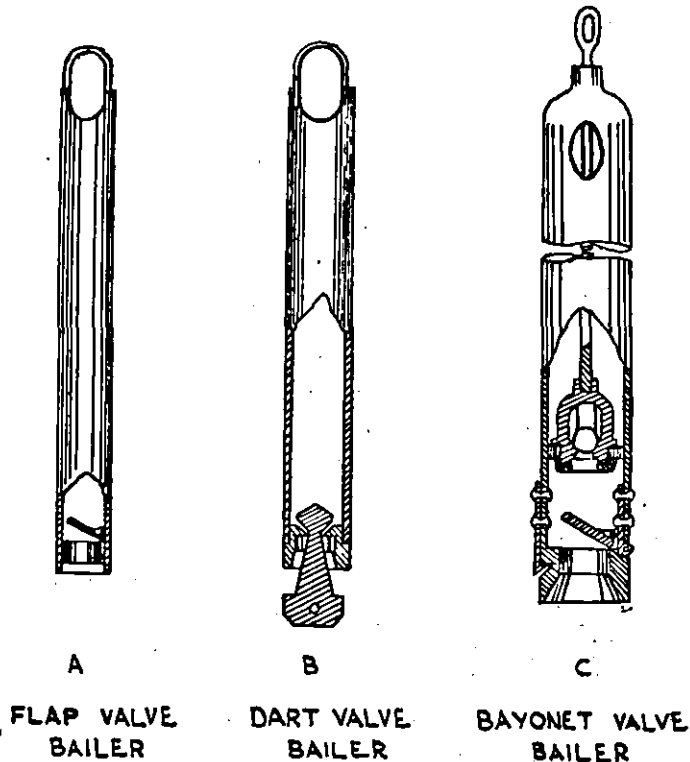


FIG. 28

dart valve (Fig. 28-B) is emptied by striking the dart attached to the valve on something solid which forces the valve open. Bailer with bayonet-valve (Fig. 28-C) has the valve mechanism in a hinged portion of the pipe, which is released by opening a latch.

The vacuum sand pump is similar to a bailer except that it is equipped with a hinged flap valve and a plunger that works inside the barrel. The sand line is attached to the top of the plunger rod. The sand pump is lowered to the bottom of the hole, the line slacked off, thus allowing the plunger to travel to the bottom of the sand pump. When the plunger is raised, the material is sucked into the bailer which holds on to the bottom of the hole by its own weight. The loaded sand pump is relieved of the drill cuttings at the ground-surface by tipping the barrel after the flap valve has been tripped. The sand pump is usually made in larger diameter than the ordinary bailer and, in experienced hands, is much more effective in removing material.

The drill cuttings are bailed out at regular intervals as the hole is drilled. The depth of the hole that can be made at each round of the tool would vary according to the strata tackled. Although, conditions differ greatly and no rule can be set, a 4 to 6 ft. of hole with each 'run' of the tools may be a fair average to aim at. After each 'run', the tools are

pulled from the hole and swung aside while the bailer is used. The bailer, after being lowered in the hole is raised and dropped, a few feet several times in order to force as much of the drilled material as possible through the valve.

(iii) *Encasing the bore-hole* : For reasons already explained earlier, the bore hole under the percussion method is lined with steel casings. An 'open hole' without casing may stand in rocky formations, but inserting of casing pipes in cavey formations is an essential feature of percussion drilling. Under drilling with percussion rigs, the casing pipe may be installed in the hole by any of these methods: (a) it may be made to sink by its own weight; (b) it may be loaded with extra weight to facilitate sinking; (c) downward pull may be applied by hydraulic or screw jacks; and (d) the pipe may be driven in by mechanical hammering.

The section of the casing pipes and its joints have to be sufficiently strong to withstand the stresses that may be created under sinking, driving or pulling of these pipes. These should be extra strong when hard driving is anticipated. Although, flush jointed or swelled and cressed jointed casings may normally be preferable due to comparative ease in sinking and extraction of pipes, but such joints may not be suitable for heavy driving. The most usual form of casing adopted for the purpose is the socket or coupled casing with non-butting taper screw joints having 10-threads to an inch.

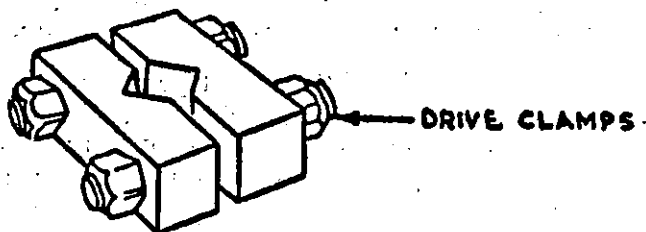
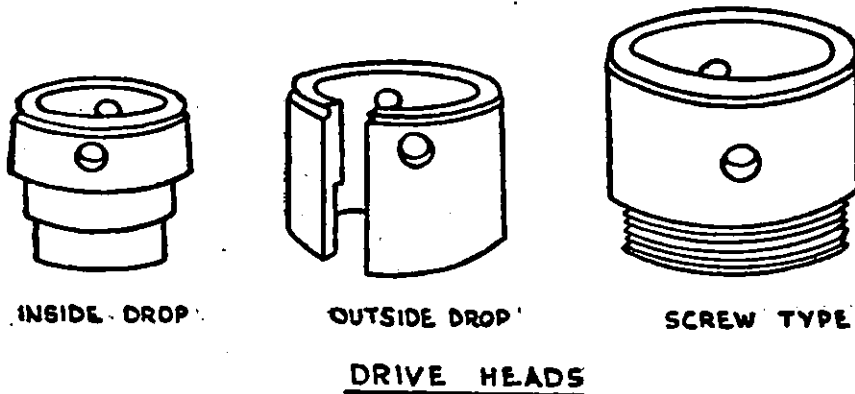


FIG. 29

Drive equipment consists of a *driving shoe* at the lower end of the casing pipe and a *drive head* fixed at the top. The string of tools is used as hammer. A *driving clamp* (Fig. 29) fixed on the wrench square of the drill stem by means of bolts and nuts strikes the drive head at the top of the casing pipe as the tools go up and down. The stem serves as a guide through the head and furnishes part of the weight required for driving. Drive head is used to protect the threads of the pipe from the drive blows of the clamp. Drive heads, are made in the following types: outside drop; inside drop and screw (Fig. 29). The outside drop type is convenient to use, gives good service, but tends to spring or pump off the end of the pipe under hard driving conditions. The screw type is more suitable for heavy driving.

For driving operation, the string of tools is lowered in the bore hole far enough for the clamp to hang about 5 inches above the drive head. This space between the clamp and drive head puts a high tension on the shock absorber springs with each stroke of the tools, and gives the tools a quick positive pick-up during spudding operation. The bit is carried on the drill stem at all times when the pipe is being driven in order to provide additional weight. The use of jars is undesirable while driving the pipe. It is important that the first 40 or 60 ft. of pipe go straight in the bore-hole. A plumb bob or a level used on two sides of the pipe will enable the driller to determine whether this is the case.

The bores usually are cased as drilling proceeds. When the casing pipe is hammered down in loose formations, the driving may either proceed ahead of drilling or it may slightly lag behind and follow drilling. In the first case, the casing is driven into the soft material as far as possible so that the material is forced up into the lower end of the casing forming 'plug' on the inside. When this 'plug' retards the progress of driving, it is drilled out and the material removed by bailing. This method is suitable for formations, which do not stand up to allow a hole to be made ahead of the pipe. The second method consists in drilling ahead of the casing and then driving. This is done by drilling below the casing as far as advisable, then bailing the material that has been loosened up. The usual practice is not to drill farther ahead of the drive shoe than is necessary to drive-in one joint of pipe at a time and never under any circumstances, to drill ahead far enough to place the rope socket below the shoe joint.

Driving of casing pipes has not been much in vogue in India because in this process, the water bearing layers get consolidated particularly when casing is driven ahead of drilling, and do not, later, yield water freely. Sinking of casing pipe in the bore hole is usually arranged by other methods.

The casing may be of the same type throughout its entire length. However, if in caving formations, casing difficulties or other problems prevent continuing the hole at the original size, the diameter may be reduced one or more times as required, strings of smaller casing being set in each section of smaller hole, as under 'telescopic boring' already described under 'Hand-boring by rope'.



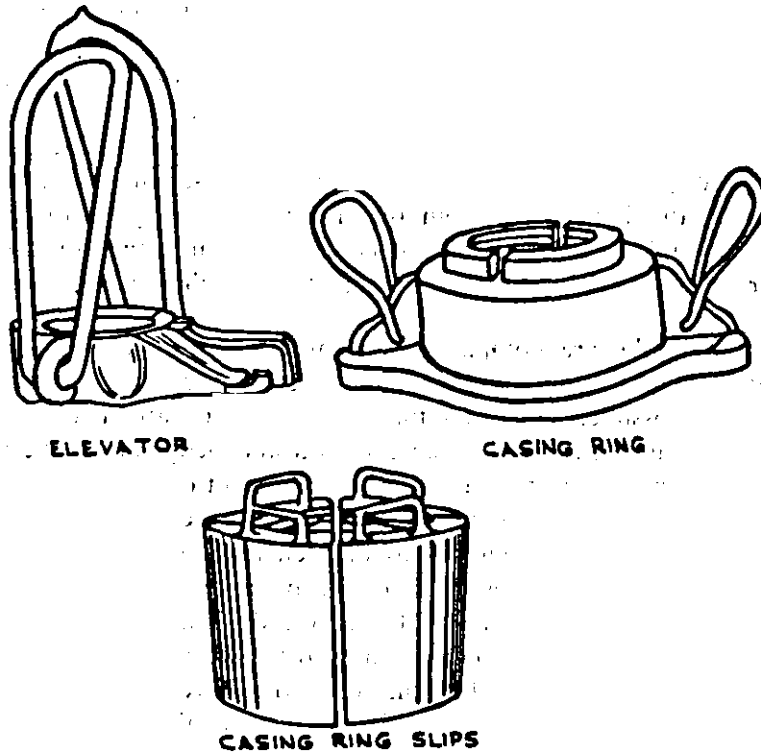


FIG. 30

*Casing elevators* or casing rings (jack rings) with slips are used for handling the casing pipes and placing them in proper position over the bore hole. The *elevator* (Fig. 30) is a heavy cast steel or forged body with two links hinged together, so that it can be fitted around the line of casing and is locked in position by a latch. For raising and lowering pipes, it is clamped directly under the coupling. However, when a firm grip is required over the pipe during handling, *casing ring* with *slips* is used. The *casing ring* (Fig. 30) is almost identical in form with the casing elevator, but is a solid ring casting, inner face being machined to taper to take casing slips with toothed jaws to grip the pipe.

Sand line may be used for lifting small strings. For handling long strings of casing pipe, drilling line has to be used.

### (3) Fishing tools

Sometimes, during drilling, the tools get lost or jammed up in the bore hole due to a number of causes such as: (a) snapping of wire rope; (b) loosening or unscrewing of tool joints; (c) breaking of pins or jars; (d) string of tools getting out of alignment in sloping formations; and (e) tools getting wedged by caving formations. A fishing job to recover tools so jammed or lost and referred to as 'fish' and remove obstruction, becomes necessary under these circumstances. A variety of special types of tools

called the fishing tools is used for the purpose. The fishing string is made up like the drilling string except for two items—the drilling jars and bit—which are removed. The stem is attached to the bottom of the sinker. At the bottom of the stem is attached the fishing jars, which have extra long strokes and on the bottom of these are attached the fishing tools. The fishing tools include: *rope spears, grabs* etc., for catching the loose wire rope; *rope knives* for swearing the loose rope from the 'fish'; different *types of sockets* for gripping and holding the 'fish'; *bumpers* for loosening the stuck tools; and *spuds* for bringing the tools in alignment of the fishing string.

All fishing jobs are comparatively simple until some mistake is made complicating them to a degree that makes the recovery of the lost tools difficult, if not impossible. In order that driller may go about a fishing job in an intelligent manner, he should have a good knowledge about the bore hole conditions and have a clear idea of the measurement of the tools to be fished. A driller should keep a log-book in which he records measurements of length and diameter and other details of each tool in order to facilitate the fishing operation. He should also keep a careful record of the progress of drilling and the depth of the hole drilled. Lost tools are more successfully fished for, when their position in the hole is definitely known. A tool may lean to the side of the hole, or into a caved area, in such a way that a fishing socket will not take hold. The top of the tools may be covered with cave materials. Such conditions can be determined by lowering in the bore hole an impression block, which carries soap or wax filling at its lower end. During fishing, following additional precautions may help to avoid complications and make the operation smooth:

- (a) Never run any fishing tools in the hole without the jars installed between the fishing tool and the sinker bar or drill stem. The weight of the sinker bar or drilling stem above the jars is the effective force in jarring loose tools stuck in the hole.
- (b) Examine the lines for broken and worn places.
- (c) Since the fishing tool may let go off the lost tools while they are being pulled up from a deep, dry hole, the danger of a damage to the tools can be minimised by filling the hole with water before pulling the tools. The water cushions their fall.
- (d) A short stroke on the crank arm gives best control of fishing tools. Use it until a longer stroke seems desirable.
- (e) Sockets having slips may be run, the first time without the slips, to see if the hole will let them pass through, whether the socket will go over the lost tool, and what hitch is required.

#### (4) *Crew required for drilling by percussion drill.*

The number of men required to operate a percussion rig efficiently depends upon the experience and ability of the drilling crew and to a certain extent upon the type and size of the equipment employed. For a drilling

rig when permanently truck-mounted, two experienced men usually are sufficient. For units, which must be unloaded and mounted on cribbing, at least four men are needed for unloading and installation. In either case, an additional man is required as truck driver for hauling water and supplies to the drill.

#### (5) *Speed of Percussion drilling*

The speed of percussion drilling in any given kind of formation often differs widely from place to place. Even in holes, that are close together, substantial differences in speed of penetration are often noted. Some of the chief limiting factors are listed below.:

- (i) Experience and ability of the operator and supervising officer.
- (ii) Conditions of the drill and equipment.
- (iii) Hydrostatic pressure at the bottom of the hole.
- (iv) Size of hole being drilled.
- (v) Depth of the hole.
- (vi) Hardness of the rock.
- (vii) Local conditions such as folds, crevices, caverns, caving formations, 'shells', and boulders.

With the above limiting factors in mind, it is usually not possible to give definite figures of footage that can be made in any certain operation. For a 6-inches diameter hole, about 350 ft. deep and reckoning an 8-hour working day, the following figures may be taken as a rough estimate of the footage of drilling that may be obtained per day:

Quicksand	...	...	...	30 ft.
Gravel	..	..	..	30 ft.
Shale, sticky	..	..	..	20 ft.
Shale, sandy	..	..	..	50 ft.
Clay, sticky	..	..	..	30 ft.
Clay, Sandy	..	..	..	70 ft.
Boulders	..	..	..	15 ft.
Sandstone, hard	..	..	..	20 ft.
Sandstone, soft	..	..	..	75 ft.
Conglomerate	..	..	..	20 ft.
Slate	..	..	..	80 ft.
Limestone	..	..	..	40 ft.
Dolomite	...	..	..	15 ft.
Granite	..	..	..	12 ft.
Metamorphic rocks	..	..	..	25 ft.
Lava	..	..	..	12 ft.

Although a certain amount of water is essential to drilling operations, drilling is usually faster in a dry hole than in a hole with excessive water. In a dry hole, a harder blow is struck by the bit, as the tools are not buoyed up, and the drilling cable also lasts a great deal longer, because it is liable to be abraded less by unsaturated sand.

**(IV) Mechanical Boring With Power Rigs—Stove-Pipe Method**

The stove-pipe method of drilling as developed in California primarily for boring in unconsolidated alluvial formations, involves the same principle as the cable tool method. The main differences are :

- (i) the use of the mud-scow bit, which acts as both bit and bailer; and
- (ii) the short joints of riveted casing.

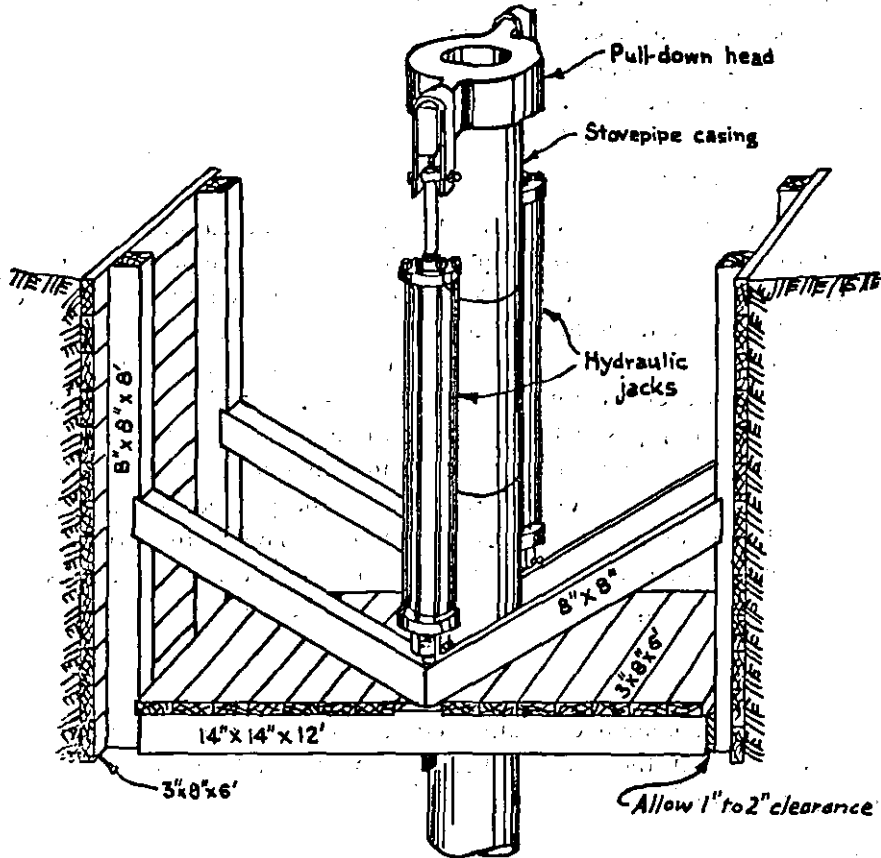


MUD SCOW BIT BAIL

FIG. 31

The *mud-scow bit* (Fig. 31) consists of a disc-valve bailer, with a sharp edged cutting shoe on the bottom, built a little larger than the outside diameter of the bailer tube to allow free passage of the tool. For drilling in clay, a special type of mud-scow is used, which has a cutting edge welded across the bottom of the shoe. This cuts the clay into small chunks so that it will not get caught in the valve at the bottom of the mud-scow. Each time the bit is dropped, part of the drillings are trapped in the bailer and when it is full, it is pulled to the surface and emptied. If tough or hard material is encountered, the mud-scow is sometimes replaced by a string of tools and drilling is continued by the cable tool method, until the hole is driven through the hard layer.

The type of casing used in this method is unique. The first bottom section of the casing called the '*starter*' usually consists of riveted-steel casing, 10 to 25 feet in length made of three or more thickness of sheet steel with a forged-steel shoe at the lower end. This re-inforcement prevents the bottom from collapsing, when pressed down under pressure. The length and thickness of the '*starter*' depends on the depth of the boring and the nature of the material in which the hole is to be drilled. Above the '*starter*' the casing consists of two thicknesses of sheet steel made into reveted lengths, each 2 to 3 ft. long. One set of sections is made just smaller enough than the other so that one length will telescope snugly inside of the other. Each outside section overlaps the inside section half its length so that a smooth surface results both outside and inside, when the casing is in place. Assembled in this way, the joints in the outside and inside sections of the casing never coincide. Denting of the casing with a pointed pick serves to lock the two casings, so that they will stay together when pulling strain is put on the casing string.



HYDRAULIC-JACK INSTALLATION FOR FORCING DOWN CALIFORNIA STOVEPIPE CASING. THE PIT SHOULD BE BACKFILLED WITH EARTH AFTER INSTALLATION OF THE JACKS.

FIG. 32

As drilling proceeds, the casing is forced down into the hole by means of the hydraulic jacks (Fig. 32). A heavy steel cap with two or four lugs on the sides for attaching the jacks is placed on top of the casing to protect it from crushing when the force is applied by the jacks. As the casing is forced down, more sections of the casings are added.

After the casing has been driven down to the required depth, it is perforated in place by a cutting knife lowered in the hole. Sometimes more satisfactory results are obtained by perforating the casing pipe before it is placed in the hole, if the locations of the water bearing strata are definitely known.

The California rig as first developed, differed from the ordinary portable cable tool rig in the manner of developing the drilling motion. The walking beam on the California rig was provided at the top of the mast instead of in the body of the rig. The drilling line was led through a sheave at the end

of the walking beam and the up and down motion of the beam was transmitted through the drill cable to the bit. However, this type of operation was less practical for many purposes than the use of a straight mast with a drilling sheave at the top and consequently has been discarded by many drillers. The use of short lengths of casings in well drilling, however, has proved very popular.

The method is suitable for drilling in unconsolidated and alluvial formations, in which the sinking of casing by jacks is particularly effective. The main advantages of this method are : (a) the elastic character of the casing permits it to adjust itself in direction and otherwise to dangerous stresses, obstacles, etc.; (b) the casing, being made of riveted sheet-steel, is cheap. The method, however, is not feasible in bore-hole drilling, where a second set of light weight pipes with suitable strainers or perforations is installed in the hole instead of perforating the casing, in place. The casing in such cases is pulled out for use elsewhere. This is the practice so far universally adopted in India for installation of bore holes. The method of perforating the casing, in place, (*i.e.*, after it has been put in the hole) requires special technique and trained hands and has not yet been attempted in India.

### Drilling Difficulties

Some of the common difficulties come across in percussion drilling and the ways in which these difficulties can be tackled are described in the following paragraphs.

#### (i) *Stuck-up pipes*

The casing pipes sometimes get stuck up due to sand or limestone cuttings settling around the pipe. A certain degree of relief may be obtained by lubricating the pipe with mud. Alternate pulling up and driving of the pipe may help in some circumstances. If the pipe becomes stuck and cannot be pulled within a short time, generally it is advisable to leave the hole and start a new one.

#### (ii) *Bad pipes*

A pipe remaining in a bore for sometime may go bad. This expression refers to a pipe that has become dented from a stone bruise and is in a state of partial collapse from outside sub-soil pressure. This type of defect is usually detected by the bailer or other drilling tools meeting with obstruction at the same place everytime during their movement. One of the remedies for a bad pipe is what is known as 'swaging'. The 'swage' is a heavy piece of steel, oval in shape, with its diameter a little less than the diameter of the pipe. The 'swage' is driven up and down through the place where the pipe has gone bad and the process repeated until the swage moves freely through the damaged pipe. If the pipe has split at the place of injury, care has to be taken to prevent the swage from getting wedged into the pipe.

(iii) *Sand blowing*

In some areas, a serious difficulty in drilling is caused by quick sand suddenly blowing up in the casing pipes. Beds of quick sand are usually inter-stratified with beds of coarse sand or clay. On some occasions quick sand, sandwiched between two layers, is under considerable pressure. When a sand bed of this type is struck during boring, there is a sudden release of pressure which causes the sand to blow up inside the casing pipe to considerable heights. If this sand is bailed out and the hole cleared up to the bottom, the equilibrium would once again be disturbed and the sand would blow up jamming up and even damaging the tools. To overcome this difficulty, the pipe should be allowed to sink under its own weight, while sand is cleared from inside the bore. The bore-hole should be kept full of water and the bailing operations carried out through the column of water. The head of water would counter-act the sand pressure and prevent or at least reduce its rushing up. If necessary, an additional piece of pipe may be added up at the top of the casing string and filled up with water to increase the effective head. This process should be continued till the difficult stratum has been crossed by the casing pipe.

In worst cases, some suitable soil cementing material may be used, which when added at the top may settle down, turn into a paste and plaster the quick sand layer.

## 8—ROTARY BORING

In rotary boring, the hole is made by rapid rotation of a bit on the bottom of a string of drill pipe. The bit cuts a hole slightly larger than the diameter of the pipe. Rotary motion is imparted to the bit by the drill pipe. A downward thrust is also applied on the bit through the drill pipe, so that the cutting points will penetrate the rock as the bit rotates. The rotating bit under pressure cuts, chips and abrades the formation into small particles and at the same time the drill pipe is lowered in the bore. The removal of material is accomplished by maintaining a constant circulation of a drilling fluid under pressure. In the *direct circulation hydraulic rotary method*, the fluid used is mud laden water, which is forced down under pressure through the drill pipe and made to ascend, with the drill cuttings, through the annular space between the drill pipe and the hole. In the *reverse circulation rotary method*, the drill fluid is pumped down through the annular space and is recovered through the drill pipe.

Because of the cohesive nature of the rotary mud plus the hydraulic pressure created, the sides of the hole stand up during drilling and usually no casing is involved in the drilling operation.

Of late, attempts are also being made to use air instead of mud laden water.

The rotary boring is one of the fastest method of drilling wells and is particularly adapted for larger sized holes. It was originally designed to drill wells through unconsolidated formations, but with the use of improved roller type bits can now be employed successfully to drill almost all types of formations. The method may not work very satisfactorily in highly jointed rocks or in formations with loose boulder or heavy gravel. The hydraulic rotary drilling usually requires large quantities of water, which may have to be brought from long distances, if not locally available. Because of adding large quantities of water and sand to the drill cuttings, the hydraulic rotary method is not suitable for obtaining accurate logs of the strata encountered.

Details of rotary methods are available in various handbooks dealing exclusively with the subject. Salient features of different rotary methods are described below.

### (1) *Direct circulation hydraulic rotary*

The two key operations in this method are;

- (a) operation of the bit; and
- (b) continuous circulation of the drilling mud.

The *bit* has to be rotated so that it will cut the hole and abrade the formations. Enough weight or pressure has to be applied on the bit to



make it penetrate effectively. The bit has to be moved up and down to ream portions of the hole; it has to be hoisted out of hole and changed.

The *drilling mud* has to carry the cuttings away from the bit and out of the hole in a constant stream. The hydrostatic pressure of the drilling fluid is depended upon to keep the hole open and prevent its collapsing, when drilling through unconsolidated formations. The drilling mud has also to puddle or plaster inside the hole with a coating of mud to prevent erosion of the walls. It has also to cool the drilling bit during operation.

The special feature of direct circulation hydraulic rotary method is that it enables phased form of drilling, that is, a smaller pilot hole drilled initially can be reamed later into a production hole by using bits and drill pipes of larger diameter.

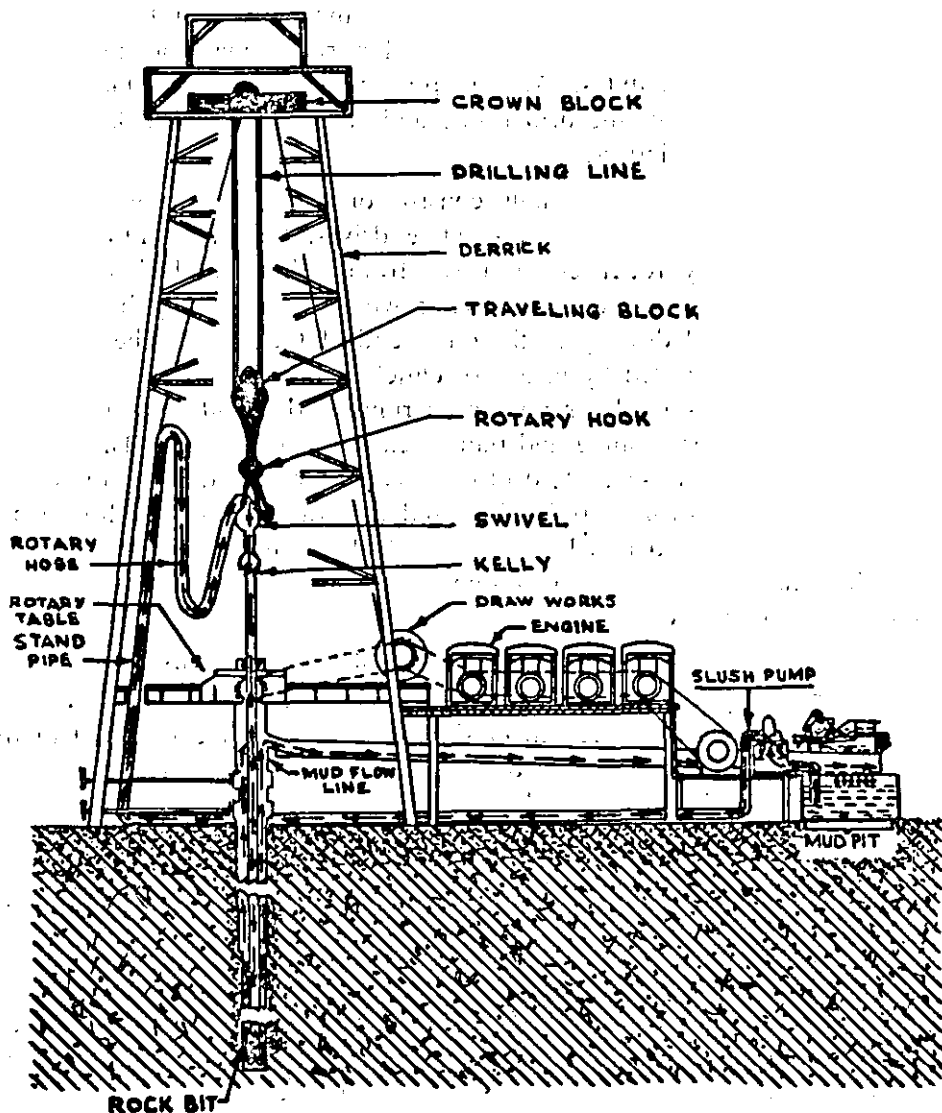


FIG. 33

**Equipment :** The rotary rig is designed to serve basic functions mentioned above. Rotary drilling rigs range from small, light and compact units to very big ones which are able to penetrate to depths of many thousand feet. Regardless of size, however, the same principles apply to all sizes.

A rotary rig (Fig. 33) essentially consists of a *derrick*; a *hoisting mechanism* for handling the tools and lowering the casing (if required); a *rotary table* for rotating the drill pipe and the bit; a *pull down mechanism* for applying a force or thrust load on the drill bit; *hydraulic system* for hoisting the mast and adjusting the position of drill head; pumps for handling the drilling mud; and a suitable source of *power* together with necessary shafts, gears, etc., required for operating the hoisting, rotating and pulling down mechanism and the pumps.

From old timber structures constructed permanently over the wells, the drill *derrick* has evolved into a folding and portable mast of steel, which can be erected within minutes. Modern portable rigs carry drill mast, which forms an integral part of the drill frame and can be raised and lowered by means of hydraulic cylinders.

The *hoisting mechanism* usually consists of a hoisting drum, a pick-up drum and a cathead with their respective drives, lines and fittings. The drums are driven by roller chain drives from a horizontal shaft running at right angles to the power in-put shaft which is turned by bevel gears. The cathead is keyed directly to the outer end of the shaft. The operation of the drums is controlled by means of clutches, brakes and engine throttle. The hoisting drum is used for pulling or running the drill pipe out of and into the hole, and for running and pulling casing, if necessary. The pick-up drum is used for lifting separate drill pipe sections when attaching or removing them from the string. It is also used to swab or bail the hole when necessary. The cathead lifts light loads and also is useful in jarring operations. The hoisting mechanism in some rigs may consist of only one hoist drum and one or two catheads.

The *rotary table* is the rotating device, which is set on tool steel rollers and is operated by a spiral bevel gearing mechanism. The table is provided with bushing, which is grooved to fit similar grooves on the top joint of the drill pipe called the kelly. This bushing, called the kelly drive bushing, is keyed to the kelly by means of driving pins, which fit in the grooves. The kelly, thus, can rotate and move vertically at the same time.

The *pull down mechanism* provided in most rotary drills, consists of a device on the drill stem for the express purpose of applying a portion of the drilling machine weight on the bit.

The *pumps* used are ordinary double action piston type force pumps capable of developing a pressure of 125 lbs. per sq. inch or more. As the pumps handle mud-laden fluid, they are provided with minimum number of valves. The pumps are connected to the drill pipe by means of a flexible hose.

The *power unit* in rotary rig is usually an internal combustion engine. The make of the engine varies from model to model and the power of the engine according to the size and capacity of the rig.

*Drilling string* : The drill string for rotary drilling consists of a *drill bit*, *drill stem* and a *swivel*.

The *bit* is the key piece of equipment. The proficiency in drilling rests largely on the bit. The bits may be divided into two broad classifications : (a) *the drag bit*; and (b) *the rolling cutter type bits*. (also called rock bits)

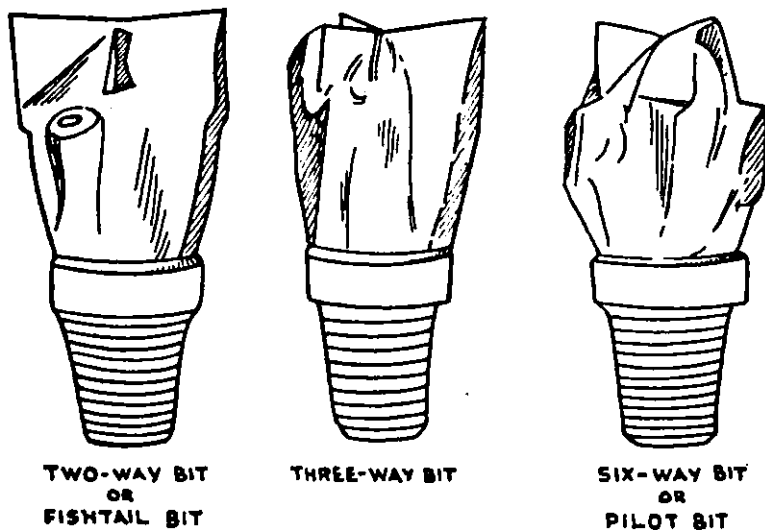


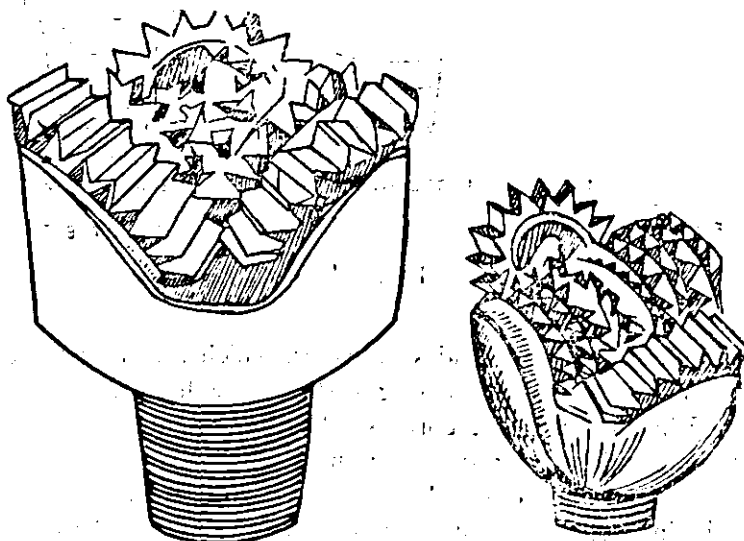
FIG. 34

The drag bits have short blades or wings, which are forged and dressed to form thin cutting edges. Wearing surfaces are hard-faced and dressed with hardened inserts set in the corners. The body of the bit is hollow with holes properly positioned for directing the drill mud in such a manner as to keep blades clean and cool and at the same time assist in penetration by means of a jetting action against the bottom of the hole. The drag bit may be a two-way bit—called the *fish tail bit* because of its resemblance with fish tail—a *three-way bit* or a *six-way bit*—called the *pilot bit*. (Fig. 34). The two-way bit having two blades is adopted specially to loose sands and clays. The three-way bit is much like the fish tail in design, but has three cutting blades instead of two. The three blades make its action much smoother in shattered or irregular formations. It also makes a better hole in semi-consolidated formations and has a less tendency to deflection. In soft formations, it cuts a little slower than the fish tail. The pilot bit is of the same general type as the fish tail and three-way bits. It has six-cutting edges each with a hole for circulating fluid. Three of these cutting blades cut a hole of about half the diameter of that cut by the other three. This bit is better for shattered formations and cemented sands than either the fish tail or the

three-way bits. It will cut somewhat harder formations, and with less irregular strain on the drill rods.

All the above bits have a shearing or scraping action and so are not adapted to hard rocks. When drilling large diameter holes, particularly, in hard or rough formations, they cause "still shock" to be induced and absorbed by the drill pipe causing fatigue. These bits, however, can be re-sharpened with welding equipment.

For rotary drilling in hard formations, *roller cutter bits* (rock bits) are more suitable. They depend upon crushing and chipping action, which makes it possible to cut hard formations effectively. The teeth of a rock bit are milled on the surface of cones or rollers, which revolve as the bit is turned. A jet of the circulating fluid is directed from the inside of the bit to the top of each cone or roller. Rock bits cannot be successfully redressed. Basically there are three major types of these bits; (a) the cone bit, (b) the cross roller bit; (c) the jet bit. The types (a) and (b) are shown in Fig. 35.



THREE-CONE DRILL BIT

CROSS ROLLER BIT

FIG. 35

Bits with cones or rollers having long teeth with wide spacing are best suited for soft rocks. Harder formations require a bit having shorter teeth, more closely spaced, and not so long.

A cone type bit has three-cones, a forged-steel body, and a cone axle or pin, which forms a part of the body. The cones have roller bearings fitted at the time of assembly. The cones are not removable. The three-cone construction provides smooth operation. Bits with different shapes of cutting surfaces and designs of teeth are available to suit different forma-

tions. Some have inter-fitted or self-cleaning teeth. All cutting surfaces are flushed by the circulating fluid.

Cross roller rock bits constitute a broad class of bits that have their main cutting elements disposed on a right angle cross. The cross roller bit usually consists of four cutters. The cutters are arranged so that all four cut the bottom of the hole, but only two of them cut the hole to gauge. As in the cone bits, the teeth of this type bit also vary with the formation to be cut.

The jet type roller cutter bit is the most recent development in the industry. It is designed so that flushing nozzles are arranged to let a high velocity jet stream of fluid be aimed directly at the bottom of the hole to add penetration by jet action. While this bit warrants mention, the over-all advantages of this type are still questionable specially in the hard formations. The investment for high volume and high pressure pumping equipment makes their use generally impractical for water well drilling.

The *drill stem* is a hollow rotating shaft, which operates the bit at the lower end. It forms link between the bit and the surface. It usually consists of 3 parts : (a) one or more drill collars just above the bit; (b) one or more lengths of drill pipe; and (c) the kelly.

Each *drill collar* is actually very heavy-walled joint of the drill pipe. One or more of these drill collars are added between the drill pipe and the bit, for the purpose of providing concentration of weight just above the bit. The extra weight keeps the drill pipe in tension which assures maximum resistance to fatigue and helps to stabilize the bit and keep the hole uniform and straight. The drill collars may not be necessary in case of a rotary rig which is equipped with pressure feed device for the express purpose of applying a portion of the drilling machine weight on the bit, unless the working conditions or the drilling efficiency requires extra stability of the drilling string.

The *drill pipe* is a seamless tubing, usually in pieces about 20 ft. long, with a tool-joint-pin on one end and tool-joint-box on the other. Sizes of drill pipes used for water well drilling usually range from 2 $\frac{3}{4}$  inches to 4 $\frac{1}{2}$  inches. The size indicates the outside diameter. In water well work, it is important to use drill pipe as large as possible because water well drilling demands relatively higher rate of circulation of the drilling fluid. Drill pipe with larger internal diameter keeps down friction losses in the pipe and reduces the power requirement of the pump. A good way to determine the correct size for drill pipe, particularly in case of deep drilling, is to use a tool joint with a diameter approximately two-thirds that of the hole. This practice makes conservative allowances for maximum torsional stresses required to turn the bit and allows adequate opening through the inside of the pipe and tool joints for the drilling mud to pass freely with less frictional losses or at low pressures. To illustrate, a 2 $\frac{7}{8}$  inches drill pipe can be equipped with tool joints having an outside diameter of 4 $\frac{1}{8}$  inches.

Therefore, it follows that  $2\frac{7}{8}$  inches drill pipe should be used in a  $6\frac{1}{4}$  inches hole, which is nearest standard bit size to the calculated diameter.

The *kelly*, sometimes called the '*grief stem*' is the upper-most section of the drill stem. It passes through and engages kelly drive bushing in the rotary table by means of driving pins. While rotating, the kelly slips down through the drive bushings as the hole is made. The kelly is usually square or hexagonal in outside section. It is usually made a few feet longer than one joint of the drill pipe. Being heavy-walled, its inside bore is smaller than the inside diameter of the drill pipe. The severe working conditions to which it is subjected demand that it be made of a high quality alloy steel.

The lower end of the kelly has a right-hand thread and is connected to the first joint of the drill pipe through a '*sub*'. The sub is a short tubular connection, which saves the threads on the kelly from wear due to frequent screwing and unscrewing. The sub is replaced when worn.

The upper end of the kelly connects to the *water swivel* with a left-hand threaded tool joint. The swivel is so built that the weight of the entire drill string is supported on freely-moving bearings. This permits the drill stem and the bit to rotate with the driving mechanism, during the drilling operation, while the upper part of the swivel remains stationary. The swivel also provides the mud hose connection. This permits free passage of drilling fluid while drilling proceeds. The drilling fluid passes through the swivel to the drill pipe and to the bit.

It would appear from above that the drill stem serves both the key items in rotary drilling—it operates the bit and also is the integral part of the mud circulation system.

The swivel together with the drill stem is suspended from the '*travelling block*' in the derrick.

*Operation of the bit* : When the drilling machinery is completely rigged up and ready to operate the drilling bit is fastened to the drill pipe, which in turn is screwed on to the end of the kelly. The gripping bushing is set around the kelly, the pump is started and the drill string positioned in the hole by means of the drilling hoist. The drilling fluid is circulated from the mud pit for a few minutes, rotary table and drill pipe are set in motion and the bit is slowly lowered. When bit touches the bottom, drilling begins. As the drill pipe is rotated adequate bit pressure against the material cut is maintained. The speed of rotation and bit pressure are regulated according to the type, form and size of the bit, the formation to be drilled and the strength of the drill pipe. These factors are adjusted for penetrating the formation at the highest rate consistent with protection of the cutting edge of the tool from undue wear, drilling a straight hole and the torsional and fatigue limits of the drill pipe. Adjustment in rotating speeds and bit pressures, depends more on the judgment of the driller and cannot be formulated in set rules. As a general guide, heavy weight on the bit improves

footage and penetration rate; however, for best bit bearing performance rotary speeds must be reduced as weight is increased. The speeds usually range between 30 to 150 RPM and the bit pressure from 6,000 to 1,000 pounds per inch diameter of the bit.

*Drilling mud circulation* : As the rotating bit rotates it cuts chips and abrades the formation into small particles. The removal of the drill-cutting is effected by mud-laden fluid kept under constant circulation by the mud pump. The drilling mud moves, under considerable pressure, from the mud pump to the drill pipe and to the bit. It streams out through the jetting nozzles of the bit at a high velocity and picks up the drill cuttings. Deflected upwards from the bottom of the hole, it travels through the annular space between the drill pipe and the walls of the drilled hole. At the ground surface, the drilling mud with the cuttings is led away from the drilled hole through a suitable ditch, to a settling pit. It over-flows from the settling pit to a suction pit where it is picked up in the suction hose of the mud pump to repeat its original course. Most of the cuttings settle down in the drain and the settling pit.

The drill fluid performs a number of functions in the drilling operation. The properties of the fluid, such as viscosity, gel strength and density have to be controlled and varied according to the conditions met with in drilling different formations and in working at different depths, in order that the fluid may perform its functions effectively. The important functions of the drilling fluid are as follows :

(i) *To remove cuttings from the hole* : For effective removal of the drill cuttings, the drill fluid must rise in the hole fast enough to carry the cuttings with it. The consistency of the fluid must permit the cuttings to be held in suspension in the hole, yet permit them to settle out in the surface pits. If local mud is not satisfactory for the purpose or it is impractical to attain the required fluid velocity, commercially prepared mud additives are used.

(ii) *To prevent caving and eroding of the hole walls*: The drilling mud supports the drill hole and prevents its caving by the fluid pressure, it exerts outwardly against the wall of the hole. The pressure developed at any given depth equals the weight of the column of drilling fluid from the static water level up to the ground surface plus the excess weight of the fluid over the weight of water in the column below the static water level. If the hole has a tendency to cave, more clay or bentonite is added to the fluid so that the extra weight may counteract the surplus formation pressure. Since use of extra thick mud in difficult cases may cause difficulty with the pump, special materials have to be used in the drilling fluid to increase its weight, without unduly increasing its viscosity.

As drilling progresses, the mud fluid, under surplus hydrostatic pressure, plasters the hole walls with what is commonly called the mud cake or the filter cake. Plastering action is assisted by the rotating drill pipe. The mud cake helps to hold loose particles or crumbling materials in place so

that they would not fall off into the hole, and to protect the wall from being washed or eroded by the upward flow of the drilling fluid.

(iii) *A substitute for casing* : In nearly all the cases the mud film formed on the wall of the hole substitutes for casing until drilling is finished.

(iv) *To prevent lost circulation* : Loss of circulation, that is, loss of fluid to porous or fissured formations is frequently encountered in drilling. These losses can be prevented by increase of colloidal content or adding other suitable materials commercially available, in the drilling fluid.

(v) *Lubrication* : All moving parts of the drilling equipment coming in contact with the mud are covered by an adhering gel that acts as an effective lubricant and corrosion resistant material.

(vi) *To cool the drill bit* : The circulating mud fluid cools the drill bit that becomes heated from the cutting action and friction of rotation in the hole.

(vii) *Jetting action* : Under high pump pressure, the mud fluid emerges from the bit openings at high velocity and impinges on the rock formations ahead of the cutting edges. The jetting action assists the drill bit in cutting rock.

The mud used in the circulating system also has undesirable properties. The lack of mud control may cause thick filter cake to form on the whole wall. This results in the undesirable effect of reducing the hole diameter and promotes the possibility of stuck drill pipe. Also, if this is allowed to occur, the passing of tools in and out of the hole may cause the mud film to be pulled away from the wall, eliminating the seal. An inefficient seal may produce caving conditions, or, what is more important from the water well drilling point of view, cause the invasion of filterates into the formations. This would be particularly undesirable should it occur near the water sand. In water-bearing sands mud invasion often continues until the pores of the formation are clogged. Once effective logging takes place, the wall cake forms in the hole. In coarse sand and gravel, however, hundreds of gallons of fluid may be lost to the formation before the wall cake is formed. The big disadvantage of this situation is that all the mud that is lost to the formation must be removed subsequently during development of the well, in order that the formation may yield good discharge. From this point of view, the drilling fluid evidently needs to be able to fill and seal the pores of sand and gravel formations with minimum of invasion. Very thick mud may accomplish this, but this may cause trouble with the pump. Use of a certain proportion of Aquagel or Bentonite clay in the fluid may help to develop 'gel-strength' within a short-radial distance and thus to minimise the extent of mud invasion. The advantage gained, however, may be partially off-set by greater difficulty that may be experienced in removing the mud, during development of the well, because of its high gel-strength.



The *return or annular velocity* at which the drilling fluid flows upward in the space between the wall of the hole and the drill stem is important in keeping the bit clean and the hole washed clear of cuttings. The ideal return velocity ranges between 120 and 180 ft. per minute. Should the pump be incapable of delivering sufficient volume of fluid with desirable return velocities, suitable adjustment in the quality and characteristics of the mud fluid may be necessary.

*Water supply* : A water supply is essential when drilling holes by the rotary method. There is no set rule as to the amount of water required to drill any one hole. In some cases, where the formations are compact, three to four gallons of water per foot of hole drilled are sufficient; but in other cases, where the formations are loose and extremely porous, a large supply is required. For ordinary purposes 750 to 1,000 gallons of water per 8-hour shift is needed.

*Casing* : Usually no casing is involved in drilling by rotary method. However, in areas, where the surface formations are soft or sandy, it is necessary to set surface casing to keep the walls of the hole from caving and to prevent the hole being enlarged by washing action of the circulating fluid. To set surface pipe, the hole is drilled or reamed so that it will accommodate the casing. Surface pipe is set through surface formations and seated in a firm formation. To run the casing, a sub is attached to the hoisting plug and screwed into the joint of casing. It then is run into the hole in the same manner as the drill pipe. If the hole has caved so the casing will not go down, the swivel is attached to the casing with a sub and the drilling fluid is circulated through the casing. A pipe clamp is fixed around the casing at the ground surface to prevent it from dropping into the hole if the formation is washed from beneath it.

*Fishing tools* : The most frequent fishing job in rotary drilling is occasioned by twisting off of the drill pipe. The break may consist of a simple shearing of the pipe, or may occur at a coupling. Sometimes the drill pipe is dropped accidentally into the hole. The first thing to remember when a break occurs is the exact depth of the break. This helps in locating the top of the tools and in engaging it with the fishing tool. A great variety of tools have been invented for use in fishing jobs. The important among these are : the *tapered tap*, the *die overshot* and the *circulating slip overshot*. Recovery of lost drill rods depends upon whether the driller can set the tool down on the top of the rods and then connect to them. The tapered tap and die overshot are simple tools usually effective only if run immediately after the failure occurs. In holes where the drill pipes have become 'frozen' from cuttings settling around them, circulation of drill fluid to the bottom of the hole is very helpful in loosening them. The circulating slip overshot which, after gripping the top of the pipe, enables circulation of drilling fluid through the pipe is the best tool for the purpose. In some cases use of a rotary jar immediately above the overshot becomes essential to exert jarring blows on the jammed fish.

*Crew required for drilling* : Normal operations require a three-man crew, consisting of the driller and two helpers. The driller is in charge of all operations and is responsible for the care and maintenance of the equipment. Experience of the driller is a vital element in successful drilling. The helpers keep the settling pit cleaned, maintain an adequate water supply, keep fuel and water in the engine and lubricate and service the equipment. When running the drill stem in or out of the hole, one helper works on the ground and helps the driller break the joints. He sets the slips, screws the hoisting plug in and out, and helps setting the drill pipes in place. The other helper works on the mast platform. He screws or unscrews the hoisting plug and helps in handling of the drill pipes.

*Drilling speeds* : The speed of drilling depends upon the character of the formation. The progress may vary from 5 ft. per hour in hard rock to 60 ft. per hour or so in unconsolidated formations.

### (2) *Reverse circulation hydraulic rotary*

In direct circulation hydraulic rotary drilling, heavy mud and a high ascending velocity in the annular space between the drill pipe and the well wall are necessary for raising large particles to the surface. Therefore, the method is not adapted for drilling into heavy gravel or cobbles, which must be grounded or broken up with great difficulty. With increasing diameter of hole, velocity drops to a point where large particles will not rise. It is in this category that the reverse-circulation method or reverse rotary, as it is frequently called, operates successfully.

In the reverse rotary method, the water stream, with its burden of material loosened by the drill bit is drawn up the drill pipe by a centrifugal pump. The method is superior to the standard rotary in drilling large-diameter holes (20 to 60 inches) in alluvial formations containing cobbles because of the high upward velocity attainable in the drill pipe.

In formations containing boulders and material that break out in chunks too large to enter the drill pipe or to pass through the circulation system, an orange-peel bucket, operated with the sand line, is employed to remove them, thus saving the time and other equipment it would take to break them into smaller pieces.

One of the most significant improvements in reverse-circulation equipment is the use of compressed air for circulating the drilling fluid. The use of compressed air has many advantages over the rotary displacement pump and other methods using vacuum. The use of air eliminates priming of the circulating system. The wells can be drilled much faster because a higher velocity of the drilling fluid can be maintained.

The reverse-circulation rotary drilling requires about five times the amount of water that is needed for direct rotary drilling. The method is, therefore, adapted for production drilling in areas where water availability is not a problem.

### (3) *Direct rotary air drilling* :

Lately attempts have been made to use air as a substitute for water drilling fluid in rotary drilling. The substitute was first used with rotary blast hole drilling for quarry work, in order to eliminate the problems of water hauling and winter freezing. Although, air drilling results in many advantages, such as : faster penetration; drilling mud being not required; longer bit life; faster return of cuttings; etc., it encounters serious difficulties with water-bearing formations and caving formations. In water-bearing formations, the cuttings mixed with water have a tendency to ball up, sticking to the drill pipe. Caving formations have a tendency to collapse in the absence of any mud coating. Experiments are being continued to overcome these difficulties.

### (4) *Drilling difficulties*

The common difficulties come across in rotary drilling and the ways in which these can be tackled are as under :

(i) *Lost circulation* : Formations with joints and fissures and those with sands and gravels absorb enough of the drilling mud to hinder drilling process seriously. Jointed and fissured shale on the other hand seldom drains off an excessive amount of the circulating fluid. However, the mud absorbed in this case causes the shale to swell and heave, filling up the drill hole.

These difficulties can usually be overcome and satisfactory drilling progress continued by suitably altering the character and properties of the circulating fluid.

(ii) *Crooked holes* : Crooked holes that would seriously damage the pump equipment may frequently be drilled without noticeable effect on the drilling machinery or equipment. To avoid crooked holes, the bits should be of a form and size that prevent undue eccentricity during rotation. They must be sharp, and dressed to proper gauge. The drill collar which holds the bit to the lower end of the drill pipe must be large enough in diameter to hold the pipe centrally in the hole and to prevent the bit from working off to one side. Excessive bit pressures may be avoided. The following considerations which help straight hole drilling may also be kept in view as far as feasible :

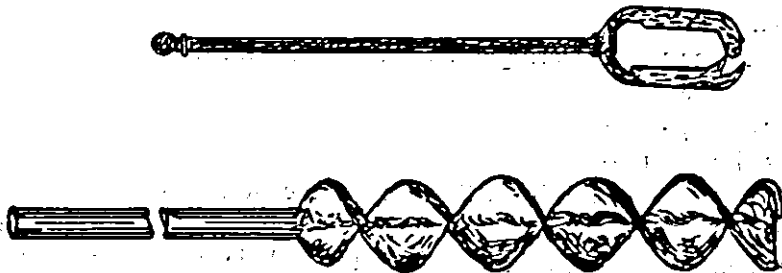
- (a) The diameter of the hole may not exceed twice the diameter of the drill pipe.
- (b) From 25 to 100 ft. of drill collars may be used in the drilling string.
- (c) Speed of bit rotation may be at least 150 RPM.
- (d) Mud circulation may be 50 gallons per minute per inch of the bit diameter.

(iii) *Balling up* : This is the accumulation of soft, sticky shale or clay around the bit and drill collar. Occasionally mud collars are formed which are forced up the hole by the pump action. This balling up, if allowed to continue, forms a coating around the drill collars which sticks the drill pipe securely when it is raised off bottom. The usual cause for balling up is a high rate of penetration combined with a speed of rotation insufficient to mix the drill cuttings thoroughly. When these conditions are encountered, the drill pipe is 'spudded' frequently by raising it off the bottom and dropping it 4 to 5 ft. at a time while the pipe is being rotated rapidly. If this is done and if the rate of penetration is held to a speed which gives the circulating fluid time to mix the drill cuttings thoroughly, this source of trouble can be held to a minimum.

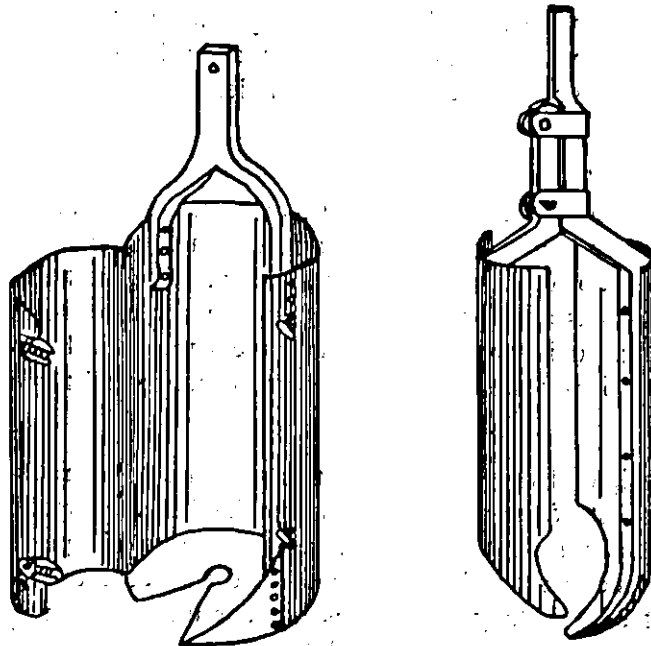
(iv) *Stuck up drill pipe due to lost-circulation* : Lost-circulation often causes the drill pipe to stick when a crevice or formation which drains away the drilling mud is penetrated. The sudden reversal of the circulation in the hole deposits the suspended drill cuttings around the drill pipe, sticking it tightly. This often happens so suddenly that there is little or no time to remove the pipe. When a drill pipe is so stuck, recovery may be effected by pulling the pipe with jacks.

## 9—OTHER METHODS

### (i) Auger method



ORDINARY AUGERS



AUGERS OF THE BUCKET TYPE

FIG. 36

In this method, augers are used to loosen and remove the soil material. The auger is turned into the hole until loaded, and is then pulled and cleaned. Augers of different shapes and sizes are made for the purpose (Fig. 36). Augers may be turned by hand, by animal power or mechanical power. The drilling rods used to suspend and rotate the auger, are usually of wood or hollow steel and may be of any length from 2 to 3 feet. If the hole is drilled by hand, a tripod and windlass is used to raise and lower the tools operated.

by drilling crew consisting of three men. Two men rotate the auger by pushing the handle around and around. The third man lifts the auger from time to time and removes the soil material contained in the auger.

The hole is bored open until caving formations are encountered. When caving occurs, blind casing pipe is used to retain the wells and enable soil penetration. Casing usually is required soon after the well reaches the water table. When the water-bearing gravel or sand is reached, the ordinary auger can no longer be used because it will not hold wet sand or gravel. *Augers of the bucket type* will be required for this purpose. Progress in saturated formations, however, becomes very slow as the sand and the gravel have a tendency to wash into the hole. Sometimes, the hole is so dry that the soil material will not remain in the auger while it is being pulled. This situation can be tackled by pouring a little water into the hole from time to time.

This method is suitable only for boring through shallow depths in unconsolidated formations, which can normally stand without casing. For deep boring, the method becomes cumbersome as it involves removing of rod every time the auger is taken out of the hole.

#### (ii) *Core drilling*

In this method, a core of the formation that is penetrated is obtained. The core is very helpful in determining the exact geological and other properties of the subsoil material and its location. The method is used in case of very hard rocks and for deep borings mostly for investigation purposes or for oil drilling. It is very expensive and the size of the bore is also limited to about 4 to 6 inches. Method is rather uneconomical for boring of water wells.

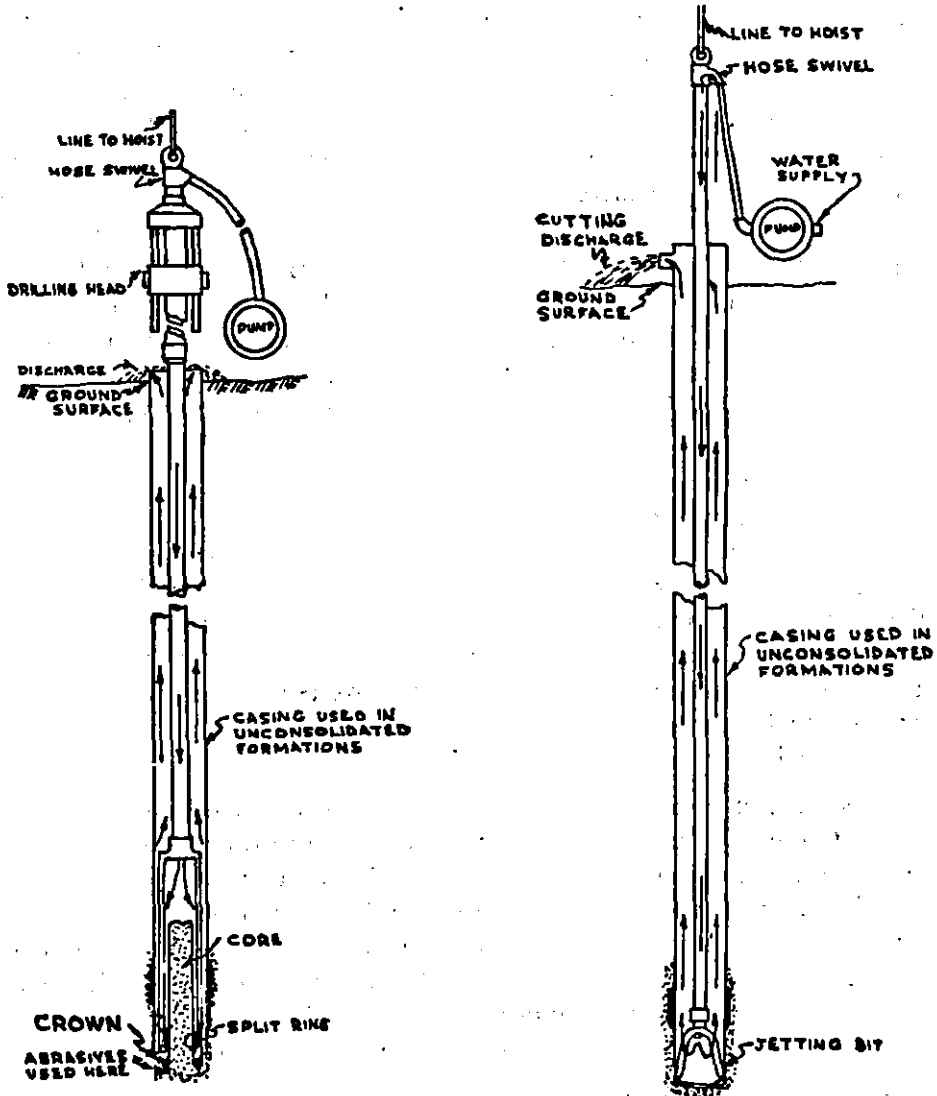
The principle of core drilling is similar to that of hydraulic rotary boring except that most of the material cut is obtained in the form of a core. Core drills very much resemble hydraulic rotary outfits in operation and many rotary hydraulic rigs can be easily converted into core drilling outfits. The operation of core drilling however is not continuous as in hydraulic rotary boring and other methods described later.

Core drills are also referred to as 'Diamond drills' as black diamonds are often set in the drill to facilitate cutting. The ordinary core drill (Fig. 37) consists of a tool called a 'Crown' which is a short piece of cast steel tube fitted with black diamond bits or chilled steel shot bits, circumferentially, at the lower end. The upper end of the 'Crown' is screwed to the steel pipes, which are rotated by the machinery at the ground surface. The rotating crown cuts through the strata causing a core to rise up the hollow tube into a core barrel. From time to time, the core is broken off, the barrel is raised, and the core extracted. Water is pumped down the drill pipe. As this water returns to the ground surface, through the annular

space between the drill pipe and the bore hole, it lubricates the drill and removes the loose debris.

(iii) *Water jetting method*

This method is convenient and suitable where water is found in loose unconsolidated formations at shallow depths. It is also convenient for boring through hard and tenacious soluble clays in which progress of boring with ordinary percussion outfits is usually very slow.



CORE DRILL METHOD

FIG. 37

JETTING METHOD

FIG. 38

Drilling in this method (Fig. 38) is done by means of jets of water carried to the jetting bit through the drill pipe. The rig with a force pump

and a spudding mechanism is desirable but for drilling shallow holes, hand-operated equipment may be used. The drill pipe is connected with the water swivel at the top and is turned slowly by hand. Water under pressure, pumped by means of a power pump is led into the drill pipe and forced down to the nozzles in the jetting bit against the bottom of the hole. The stream loosens the material, which is carried upward by the velocity of water under pressure. The water rises to the surface through the annular space between the drill pipe and the hole and discharges into a settling tank at the ground level. The cuttings settle down to the bottom of the tank and water is returned to the force pump and used over and over again. If the material in the hole tends to cave, it is cased with standard pipe. The casing pipe sinks by its own weight or extra weight added to it at the top. Slow rotating motion is also sometimes imparted to the casing pipe to expedite its sinking. The casing pipe may be driven down, if necessary, as the jetting proceeds. In fine textured soils, the loosened soft material itself may function as puddle to support the sides of the hole and casing pipe may not be necessary.

If a layer of hard material is encountered, the drill is attached to the spudding mechanism on the rig and special bit is attached at the bottom of the drill pipe. The drill pipe and the bit, thus, act as percussion drill, which on account of its weight is very effective in breaking up the hard formations.

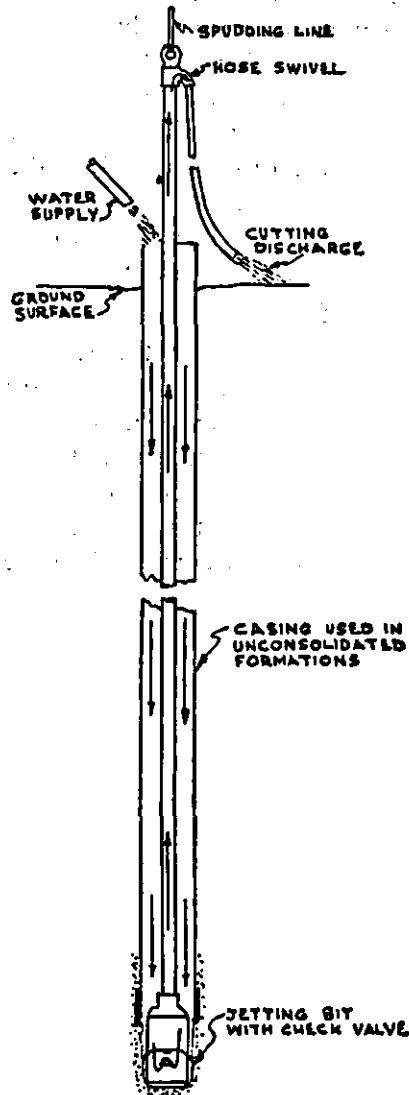
One of the important items in connection with the jetting outfit is the pump. Since the water is used over and over again, naturally the pump comes in contact with dirt and grit. An ordinary piston type of pump may soon break down under this condition. The pump used should be either of the displacement or the diaphragm type. Under ordinary drilling conditions, the displacement type is better but where the water is extensively gritty, the diaphragm pump is more suitable. As the maximum pressure of pumps has to be carried by the hose, it is necessary that a high grade of high pressure hose is used for efficient jetting.

This system of boring has the advantage that it is not necessary to withdraw the tool every time as in the case of cable tool drilling and, therefore, the operation is continuous, as in the case of hydraulic rotary drilling. It cannot, however, be widely used owing to the difficulty of obtaining sufficient water to ensure a constant supply of adequate pressure at the bottom of the bore. The method has similar disadvantages as the hydraulic rotary method, with regard to recording of water levels and also depths and samples of strata on account of abundance of water used during operations.

#### (iv) *Hollow Rod Method*

In this method of drilling (Fig. 39), a special drill bit with a valve is used with the drill pipe. A swivel hose connection and a means of raising and lowering the drill pipe are required. The spudding mechanism of standard portable rig is frequently used, but it has to be set to give a short stroke. For drilling by this method, the drill hole is filled with water.





HOLLOW ROD METHOD

FIG. 39

Instead of being under pressure, it is simply run in with the hose or poured in. No force pump is required. When the drill rig is started, the reciprocating motion of the drill forces the water and the drilling cuttings through the centre of the drill and up the drill pipe. The valve and the drill bit prevent the water from running back once it has entered the drill pipe. Auxiliary ball-valve in the drill pipe reduces the shock on the valve in the drill bit by supporting part of the water column. The drill cuttings are passed through the discharge hose at the ground-level, which shows at all times exactly what kind of formation is being drilled. Water and cuttings are discharged into a receptacle usually a tank or a barrel. The cuttings

settle to the bottom while the water is returned to the hole under the pressure of gravity. The drill pipe is turned slightly by hand in order to make the drill bit to strike in a different place each time it drops and thus, ensure a uniform straight hole. Drill holes are cased to prevent caving in loose material and also loss of drilling water. Casing may be driven, if necessary, by attaching drive clamps to the drill pipe. Both the drilling and driving operations put a severe strain on the drill pipe, and for this reason heavy pipe with special couplings is used. The strokes of the drill are carefully timed so that there will be more or less continuous upward movement of the water through the drill pipe.

This method is an improvement over the jetting method. It can be used for drilling in hard pans and soft rocks. Furthermore the water bearing strata can be definitely located and the samples obtained are more satisfactory because the material removed from the hole comes up to the drill pipe, where it cannot be contaminated. Holes as small as two inches in diameter can be drilled rapidly by this method. Since cable does not go into the hole, cable cost is less as compared to the ordinary percussion methods.

## 10—CHOICE OF BORING METHOD

BETWEEN the two basic techniques of drilling, the percussion and the rotary, by far a greater number of wells are bored by the cable tool percussion method. Each method has its advantages and disadvantages. Certain conditions limit the use of each.

Percussion drilling is a very satisfactory method of boring in almost all types of formations (with some exceptions), if speed is not a dominating factor and size and depth of the bore are not very large. Cost per foot of drilling is lower for relatively shallow holes in unconsolidated materials. In most cases, a percussion boring outfit is much lighter and can be easily transported in rough country side.

In certain types of formations, such as dune sand, quick sand and unconsolidated river gravels, cable tools are unsatisfactory and at times unusable, particularly for drilling deep, small diameter holes in such material. The pounding of the drill, the low fluid level, and the lack of mud sealing, contribute to slumping and caving in such formations.

For drilling larger sized holes, and particularly where speed is an important factor, rotary drilling is the method to be used. The method is also advantageous for drilling test holes in doubtful and unproven formations, so that if the prospects are found to be poor, the hole can be abandoned at a minimum expense without the trouble of pulling casing or leaving one or two strings of casing in the hole.

For drilling in low lands with clay and slit or sticky shale formations and saline or alkaline conditions, the rotary rig is the much faster method. Dunes, wind blown sand and quick sand are handled easily by the rotary machines.

Rotary machines however are unsatisfactory and at times unusable in cavernous or extremely permeable lost circulation zones. The circulating fluid is lost to a large extent in such formations and drilling becomes at times, almost impossible. Rotary method also may not drill successfully in alluvial formations with boulder beds and cobbles. The removal of big-sized cobbles with circulating mud fluid becomes problematic.

Metamorphic and igneous rocks can be handled at reasonable speeds by both machines. Chert nodules occasionally are encountered in sedimentary rocks. They are a hard, brittle silica glass and hence are particularly difficult for the rotary rig. The rock bit grinds and polishes the surface of the nodule and thereafter the teeth of the bit simply slide on the polished surface. The cable-tool spudder can handle this hard but brittle chert more easily.

Under certain conditions, the cost of drilling large diameter holes by rotary method does not go up in the same proportion as it does in cable

tool work. This means that where favourable conditions exist, the large diameter holes can be drilled more economically by rotary methods.

In the rotary method, the pressure of heavy mud fluid against the wall of the hole and against the water-bearing beds is generally higher than the hydrostatic pressure in the formation. Hence, the mud fluid tends to penetrate and seal the pore spaces. Aquifer water under low pressure, therefore, does not force itself into the hole and unless care is taken, such water-bearing zones may be *passed on as dry*. On the other hand, under percussion drilling the hole is devoid of mud-laden water under pressure. The water in the formation is allowed to seek its own hydrostatic level. Thus, the clogging of the wells is minimised, and low pressure water-bearing strata can be easily detected. It is also relatively easier to estimate the quantity of water available in the strata, by bailing.

The percussion method requires much less drilling water than the rotary method. The percussion method, therefore, is more suitable for boring in areas where sufficient water is not available within a reasonable distance.

Under the drilling technique adopted in the percussion method, a more accurate sample of the formation is obtained than under the rotary method (unless coring is used by the rotary process), although the accuracy of the log depends to a large extent upon the experience of the driller in each process. Under percussion drilling, it is possible to test quantity and quality of water in each stratum as drilling proceeds. The bad water can often be shut off by leaving blank casing through the contaminated stratum. Such information becomes difficult to obtain in case of the rotary method due to mixing of dislodged soil material and water with large quantities of surface water.

Among *other* methods of drilling, the auger method has a specific limited use for boring up to shallow depths in unconsolidated formations, which can normally stand without casing. Core drilling is a suitable method only where it is necessary that the soil sample should be extracted in the form of a core for investigation purposes. The method is very expensive for water well drilling. The other two methods, namely, the water jetting and the hollow rod, although they make certain improvements over the conventional percussion or rotary methods, have limited application. They are usually suitable for drilling smaller-sized holes through soft and unconsolidated formations. From the point of view of maintaining an accurate log of the strata encountered, they are more or less equally unsatisfactory as the hydraulic rotary method.

*Suitable method for boring in open wells* : Boring in open wells usually involves smaller-sized holes, which are also not very deep. However, the strata encountered in drilling may include all types of formations. For such conditions met with, in boring of open wells, percussion method has the widest application. Percussion drilling outfits are simple in operation and being comparatively lighter, can be moved easily from well to well. The

method is satisfactory from the point of view of cost and also enables obtaining fairly accurate logs, which are essential for proper setting of screens in the bore hole.

Among different types of percussion drilling equipment, power rigs give quicker results. However, the advantage of the hand-boring set is that the whole equipment is country made and can be operated and maintained and repaired with ease by local artisans.

## 11—OBSERVATIONS DURING BORING

To decide whether a bore hole, after completion, is to be worked as a cavity well or a strainer well and for proper installation of tubes and strainers in the bore hole to be worked as strainer well, it is essential that a proper and accurate record of strata samples in the form of a well log and other observations in regard to water level fluctuations and in-flow and out-flow of water in the bore hole should be maintained during boring. The well log is a written record of the geological formations met after the well is drilled. It records their depth, thickness and chief characteristics such as texture, colour, hardness and whether they appear to be as water-bearing. In recording the thickness of the formation, the depths of both top and bottom of the formation are shown.

### Formation recognition

An experienced driller recognizes changes in formations by the action, vibration or sound of his equipment; also by the behaviour of the circulation pump in the case of rotary drilling. To determine the exact kind of rock being drilled, however, it is necessary to take samples of drill cuttings at regular intervals of 5 ft.; even more often if necessary. The samples in the case of percussion drilling are taken by dumping the bailer load in a separate bucket. For taking samples in rotary drilling, the bit is hoisted about one foot off the bottom and rotated slightly, while the mud circulation is kept up to full volume. This is continued until the mud is comparatively free of drill cuttings. After this operation is completed, drilling is resumed for another 5 ft., after which the drill pipe is raised slightly and the mud circulated until it again is cleaned of drill cuttings. The mud is screened carefully as it flows over the top of well casing and the samples of the strata actually cut obtained.

### Recognition of water bearing formations

It is not difficult to detect water-bearing beds in percussion holes being drilled under ordinary conditions, because the comparatively clear water in the hole does not tend to clog the pores in the water-bearing formation. For this reason, a sudden rise or decline in the water level usually indicates that a permeable bed has been entered. Crevices or soft streaks met while drilling hard formations, often are water-bearing. Sand gravel, sand-stones and lime-stone produce the largest quantities of water. It is advisable therefore, to be especially watchful while drilling in these formations.

In rotary drilling, the following criteria, based upon changes in the character and circulation of the mud indicate some of the most important means of recognising water producing zones

(a) A loss of circulation fluid, much in excess of the normal or usual loss, indicates presence of water-bearing stratum.

(b) A noticeable increase in the volume of the returning circulation fluid invariably means that a water bearing formation has been met which has a higher hydro-static pressure than the mud column in the hole.

(c) Complete loss of circulation usually means that a large volume of water with a comparatively low hydro-static pressure has been met. This is especially true in lime-stones.

#### Testing water zones—bailer test

A record of water levels, maintained carefully at regular intervals particularly at the close of the day's drilling work, and the start of the work next day, helps a great deal in assessing the water yield of the different water bearing formations encountered in drilling. For more precise determination of water yield, it is desirable that a "bailer test" may be conducted as each individual water bearing stratum is encountered during boring. In carrying out this test, the bailer with its flap valve is used as bucket to bail out water rapidly. The rate at which the draw-down increases as a result of this dewatering, would give an approximate idea of the yield of the formation. If the level of water inside the bore remains steady even after bailing out water for say couple of hours (approximately 80 bails of 6" to 8" diameter and 8 ft. height in the case of 8" to 10" diameter borings), the stratum may be considered satisfactory for location of screens or for further development and gauging in the case of a cavity well.

If the hole is uncased and has been drilled in soft cavy formations, bailing the hole would result in slumping or caving of the walls. For estimating water yield in such cases, special type of equipment for formation-testing may have to be used.

## 12—SETTING SCREENS AFTER BORING

If the strata conditions as revealed by the boring log warrant a cavity bore, no screens will be necessary. In case of cavity wells, if the casing pipe used during drilling is an expensive one, a string of ordinary blank pipe of smaller diameter may be inserted inside the casing pipe, which may, thereafter, be pulled out. The annular space between the tube and the sides of the bore hole in the clay layer should be plugged with care so that no sand can enter the cavity from the upper layers. On the other hand, if the casing used consists of ordinary pipe, it may be left as such in the bore to tap the cavity. It is desirable that the cutting shoe at the lower end of the tubes in cavity bores should be left about two feet above the bottom of the clay layer. This enables formation of a bell-mouth at the entrance of the pipe thereby reducing friction and increasing discharge for the same draw-down.

Screens will be necessary when one or more layers of strata are decided to be tapped along the length of the pipe. The primary function of the screen is to admit water freely from the formation without clogging. Its function is not to prevent the entrance of all sand, but rather to permit the fine sand to enter so that it can be removed and to hold out large particles so they will build up a natural screen around the well. In this way the permeability of water bearing material around the bore is improved resulting in a greater yield from the strata.

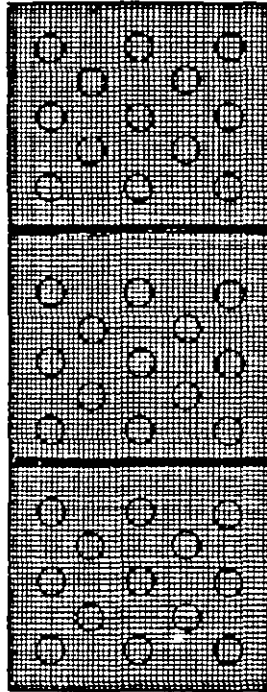
### Strainer

Screens usually consist of perforated or slotted pipes, which are wrapped with copper or brass mesh, so that the water with only fine particles of sand is allowed to enter the pipe. Such screens are called *strainers*. (Fig. 40)

For satisfactory working of the strainers, the straining material should not be in direct contact with the perforated pipe over which it is wrapped as the area of perforation is thereby reduced. This condition can be fulfilled by welding iron hoops and strips over the perforated pipe. The perforations are so arranged that these strips do not come over the perforated portion.

There are many commercial varieties of strainers available in the market. Size of slots in the pipe and the choice of the straining wire gauge should be made after carrying out an analysis of the grain size of the material in the strata. The main criteria for a good strainer are : (a) it should be sturdy and stand rough handling; (b) it should present maximum water way area per foot length of strainer consistent with strength and grading of the formation; (c) design, shape and type of openings should be conducive





STRAINER

FIG. 40

to development of the well without clogging or jamming; (d) it should be of one metal. In bi-metal construction, there is danger of electrolytic action if water has certain salts dissolved in it. This leads to deposition of salts and choking of strainer openings.

*Screens with gravel pack* : If the composition of water-bearing material includes fine-grained sand, it would normally require very fine openings in the screen to separate it from water. This will reduce the percentage area of openings and thereby the yield of water. The yield of well in such cases may be increased by arranging a gravel pack around the slotted pipe instead of the wire screen (Fig. 41).

The gravel pack, which essentially consists of a large percolating cylinder of coarse material may be arranged either by development of the natural gravel and coarse sand in the strata or by shrouding, that is, artificial gravel packing by adding material from outside. The primary purpose of gravel pack is to allow use of larger openings in the screen section and to increase effective diameter of the well. A secondary purpose is to control the entrance of fine sand from the formation into the well. The gravel pack serves as an auxiliary strainer, which taps a larger cylinder of percolation area, provides more openings and, therefore, yields more discharge.

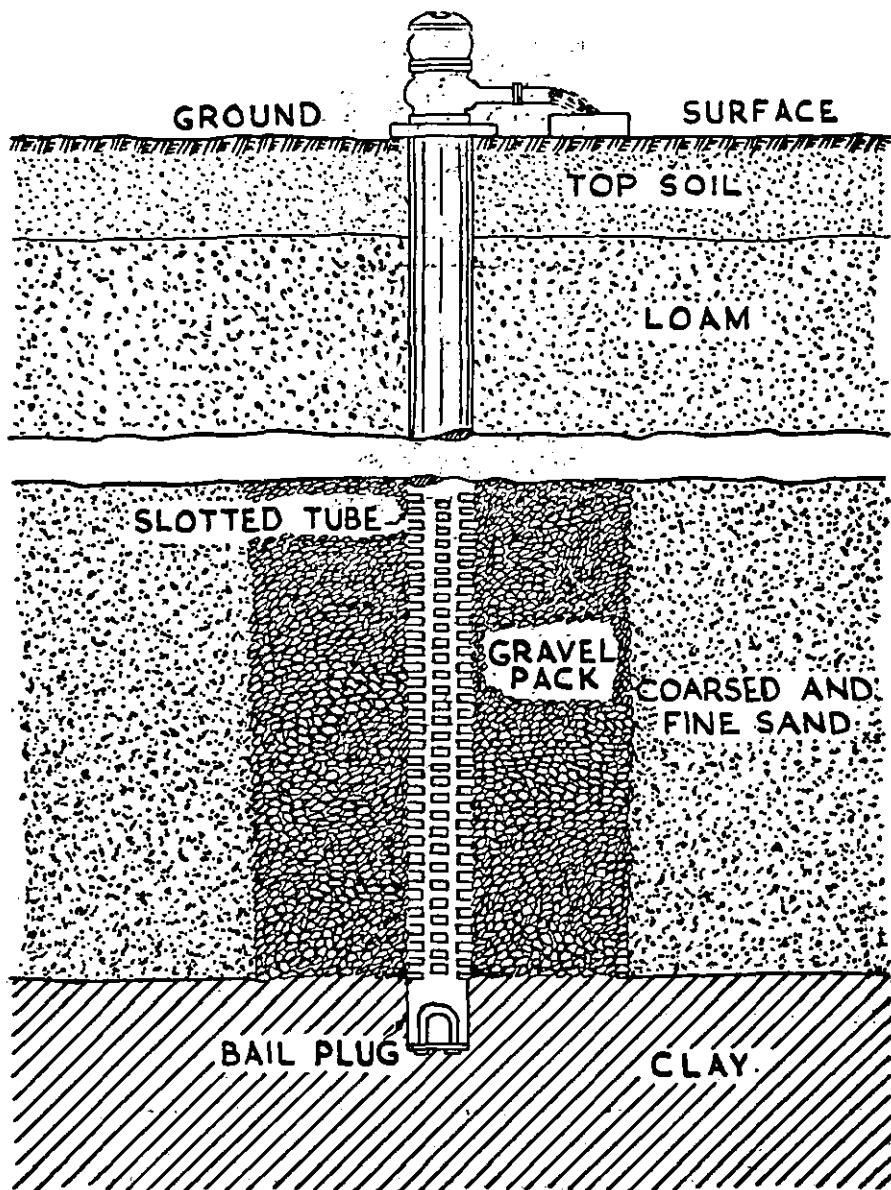


FIG. 41

The gravel used in shrouding should be properly screened to have a uniform grade. Mixture of gravels of various sizes are unsatisfactory because the smaller particles fill the space between the large ones and cut down the pore space, thus increasing resistance to the passage of water. It is also important that the size of the gravel should be correlated with the particle size of the surrounding sub-soil material. The size of the pore-spaces in a packed medium of soil varies from  $1/6$ th to  $1/3$ rd of the diameter of the particles comprising the medium. It, therefore, follows that if

the stratum consists of particles say of 1/3rd mm. diameter, the shrouding should be done with particles of sand of 1 mm. and not more. If shrouding is done with coarser material, there would be danger that soil particles in the medium would move in the shrouding and clog the pore spaces thereby reducing the percolation area and the yield.

The effectiveness of gravel pack to hold back fine sand is improved by increasing its thickness. The weight of the particles, which can be carried along by the water current varies as the sixth power of the velocity. The velocity decreases almost in proportion to the diameter as the distance from the strainer increases. It is, therefore, evident that velocity can be reduced by increasing the diameter of the sand screen sufficiently, to a point where it could no longer wash out particles of any given size. Very thick packs, however, are likely to interfere with proper development of the well and may not be desirable.

It is necessary that the size of the shrouding gravel is fixed for each water-bearing stratum tapped after taking into consideration the particle size of the medium. To put in one grade of shrouding material throughout the length of the bore irrespective of the strata encountered is not a desirable practice.

The slotted tube in the case of a gravel pack well should have the following essential features :

(a) The slot should be rectangular rather than round or square. Rectangular slots are less likely to be clogged or plugged by the soil particles. A sand grain cannot close a slot because it can make contact at two points only. On the other hand a sand grain can easily lodge in a round hole or square mesh and close it.

(b) The slot should be constructed with sharp outer lip and an abruptly widened inner opening. This will prevent any grains, which pass the outer lip, from wedging and clogging the opening.

(c) The slotted tube should provide the maximum area of opening, consistent with the grade of shrouding used. While the grading of gravel used in shrouding is a function of the effective size of the natural formation to be treated, the slot opening is governed by the grading of the gravel.

### Choice of well screen

The choice of screen in general may be governed by the following considerations :

(a) Ordinary coarse and medium sand with reasonable permeability is usually screened most effectively by using strainers without shrouding.

(b) A mixture of coarse, fine sand and gravel may be left unshrouded and the bore developed as a natural gravel pack well. The size of the slots for the screen should be determined by an analysis of the material of the strata.

(c) The artificial gravel pack is of greatest value where the water-bearing formation is composed of fine sand in which the individual grains are approximately of the same size.

#### Lowering and setting screens

The screens have to be located opposite the water bearing strata in order to draw water from the strata (Fig. 42). This is done by assembling

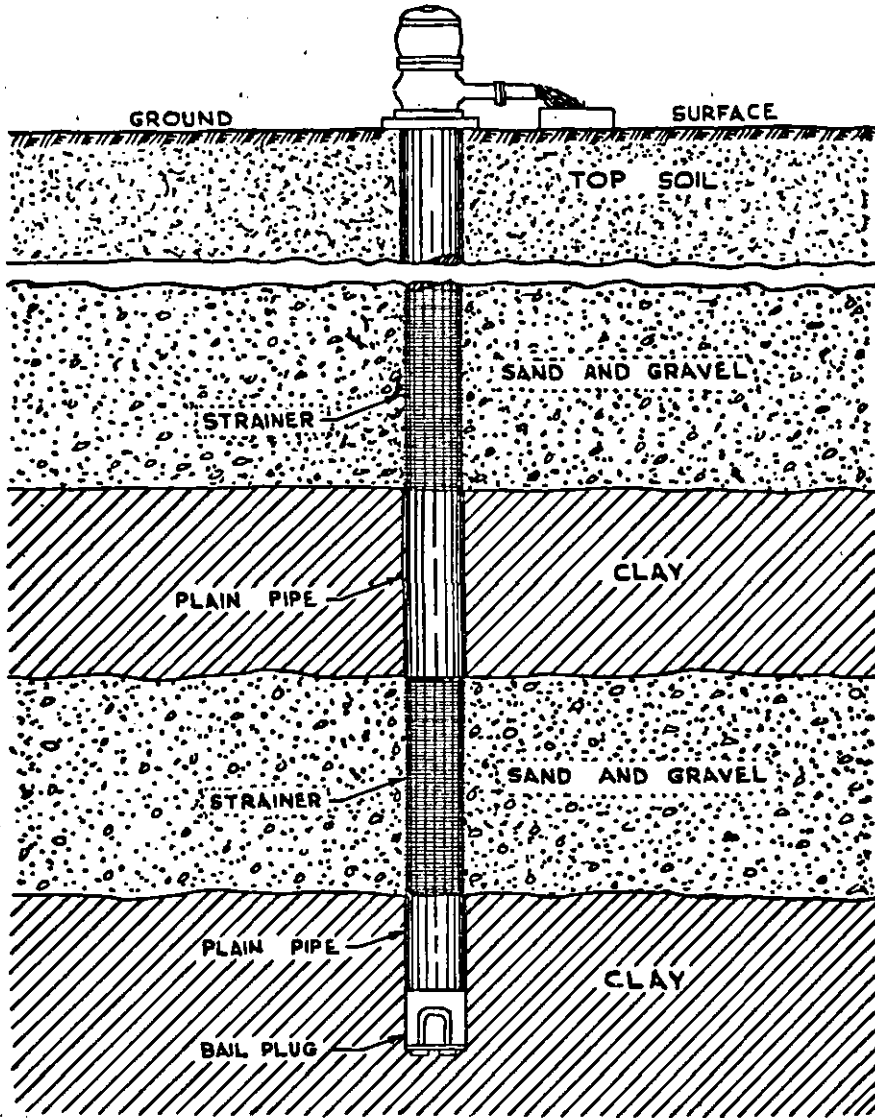


FIG. 42

together the whole length of the screens and the blank pipes in exactly the same order and lengths in which they are to be lowered in the bore. Every pipe, socket and strainer is numbered serially. The bottom end of

the assembly is fitted with about 4 ft. length of blind pipe with a cap to close the bottom end. The cap is known as "*bail plug*" and has an 'eye' fixed inside, which can be conveniently connected with a hook whenever it is necessary to pull out the string of screens. The piece of the blank pipe at the bottom serves to collect the sand particles that enter the bore-hole during development of the well and, thus, to prevent choking of the bottom portion of the screens.

The strainers and the plain pipes are lowered inside the boring tube, one by one as required, starting from the bottom end and in the same order in which they have been assembled at the ground level. To start with, the bottom pipe is fixed with a pair of clamps and is lowered in the bore hole till the pipe is supported by the clamp over the bore. The next piece is then screwed on top of the bottom piece and a second set of clamps is fixed at the top end of the upper piece. The pipe assembly is then lifted slightly by means of the drilling cable, and lower clamp removed. The drilling cable is gradually slackened, and the tubes lowered in the bore till the upper clamp rests on the top of the bore. The drilling cable is now disconnected and the next pipe is screwed on top of the upper pipe and the whole operation is repeated as before. Thus, one by one, the whole assembly is lowered inside the bore to fit in the correct position. The complete string is kept suspended from the top and the outer casing pipe is jacked up and extracted one by one. As the casing pipe is withdrawn, the surrounding material gets loosened and grips the strainers and tubes and holds them in position. Before starting the lowering of the pipes, the casing pipe is raised to such a level that its bottom end is only slightly lower than the proposed bottom of the finished bore hole. The bore hole is filled to this level with sand or gravel so that the bottom end of the tube rests on it, when lowered in position.

### Compound wells

When it is desired to operate the bored well by means of a bore-hole turbine pump, it becomes necessary that the upper section of the tube up to a certain length should have a diameter sufficiently large to accommodate the pump. This is achieved by having a compound well in which the diameter of the top pipe is larger than that of the lower section of the string carrying the screens. In such wells the annular space between the two sets of pipes is suitably plugged. When the inner tube carrying the strainers has been lowered in position, the upper section of this tube opposite the outer pipe of larger diameter is retrieved by unscrewing from the joint, which is specially provided with reverse threads for the purpose.

### Setting right eccentric bores

The eccentricity in the bore is an undesirable feature particularly when bore-hole pump installation is contemplated. If the eccentricity exceeds the

limit of clearance, the bore hole pump revolving with a speed ranging from 1,500 to 3,000 R.P.M. may seriously damage its own parts and the motor.

The eccentricity in the bore can be measured by use of a reel-like instrument, which can easily be made by joining together two circular discs of the same diameter (about 1/8th of an inch smaller than that of the bore) by means of a central hollow tube. The tube has threaded ends, so that discs of different sizes according to the sizes of bores come across may be fitted. The discs have holes punctured into them and are sufficiently heavy so that they can be lowered in water without any obstruction or difficulty. The instrument is suspended by a wire passing over a pulley adjusted centrally over the bore. The pulley is rigidly fixed to a tripod. As this instrument is lowered in the bore, the eccentricity is measured by the displacement of the wire in the horizontal plane at the top of the bore.

When eccentricity is detected and it exceeds the clearance provided between the outside diameter of the pump bowls and the inside diameter of the casing pipe, the casing pipe has to be brought into plumb before installation of the tubes. This can be done by loosening the earth on the side to which the casing pipe is inclined and then forcing the casing pipe back by applying jacks on the other side. Another method of setting right eccentric casing pipe is sinking of a new bore say about 2/3rd the diameter of the casing pipe close to the pipe on the side towards which it is inclined. This bore is carried down to about 10 ft. above the bottom end of the casing pipe. The casing pipe can, thereafter, be pushed by means of powerful jacks till its position is absolutely vertical. The hollow space between the new and the old position is filled with earth and gravel to ensure that the casing pipe does not resume its eccentric position.

#### **Extraction of well screens and pipes in case of unsuccessful bores**

If on testing a bore it is found to be unsatisfactory and it becomes necessary to extract the screen-tube, it can be done by lowering a wire rope with a hook inside the tube so as to catch 'eye' on the bail plug and then pulling up the string of pipes and screens. This operation can easily be carried out in case the screens and pipes are not jammed. If these are jammed, another device made up of a tapering conical piece of wood like a frustum of a cone is adopted. This conical piece should be loosely fitting inside the tube to be pulled. This is lowered inside the string of pipe, with its wider edge at its lower end, to some point opposite a plain pipe, so that it does not damage a strainer length when pulling out. Gravel or stone chips are then poured inside the pipe. These form a wedge between the wood and the pipe. The wooden piece is now pulled up by means of rods and because of the wedging effect, the wooden piece pulls up also the pipe alongwith it. A clamp is tightly fastened to the rod just above the top of the tube over which it rests. Another clamp is fastened on the screen-tube itself on the outside, and jacks are operated below this clamp to lift it up. A pull is transmitted from the

jacks through the clamps to the screen tube and the tube transmits it to the clamp on the steel rod resting on top of the tube. The rods convey the pull to the conical piece inside. The screen tube in this way is pulled up by the jacks directly from outside and by the wooden piece and the wedge of the gravel from inside and is gradually extracted out. The advantage of this method over the hook method is that instead of the tensile force being applied to the hook on the bail plug only, which may get bent or sheared, it is applied to a large surface of the tubewell pipe itself and is, therefore, more effective.

A special collapsible steel tube is also obtainable, which can be lowered inside the screen-tube instead of the conical piece of wood. This tool can be expanded out after being lowered inside the tube thus forming a sort of wedge to grip the pipe.

It is desirable that the pressure from the jacks should be applied gradually and not rapidly. A reasonable pressure may be applied and then allowed to set for a short time to give the tension 'stretch' of the pulling pipe, a chance to exert steady pull on the screen. The pressures may be increased gradually, from time to time, until the screen begins to move after which it may be pulled steadily without difficulty. In this way, there is much less chance of injuring the screen or breaking the pulling pipe than if the pressure is applied rapidly. If the heavy pressure is applied quickly, the screen may bulge out or the pulling pipe may break.

#### Gravel packing

In some wells, gravel envelope is put in at the same time the well is being drilled. However, the method generally adopted is the one in which the gravel pack is placed around the screens after the hole is completed (Fig. 43). After completion of the bore, the outer casing pipe is raised

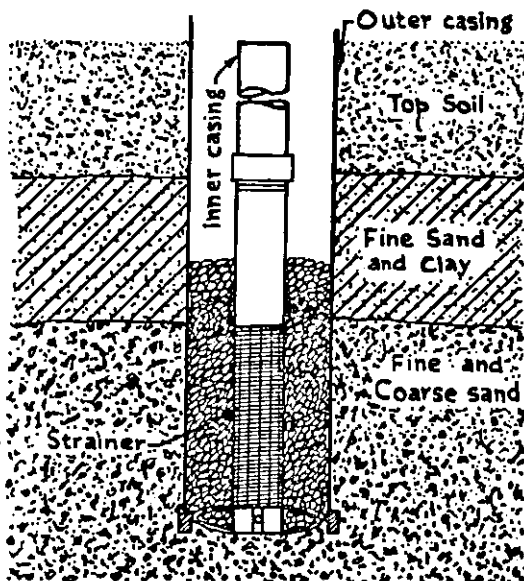


FIG. 43

to the level proposed for the bottom end of the screen casing and the latter is set in position as already described. The annular space between the two casings is filled with gravel poured from the ground level up to about 10 ft. above the top of the screens. The casing pipe is then raised to about 2 inches above the bottom of the screens and the development of the well is started. As development takes place, some of the displaced sand may be filled with the gravel-fed from the surface. The gravel pack is maintained at the same top level throughout the course of developing operations, by adding more gravel, if necessary. While the processes of development and gravel pouring continue, the casing pipe is gradually withdrawn by means of jacks. The extraction of the casing pipe should be done slowly and without jerks in order to ensure that the screen tube is not dragged up with the casing pipe.



### **13—DEVELOPMENT AND TESTING YIELD OF WELLS**

DEVELOPMENT of irrigation wells is very important for obtaining optimum supplies from the water bearing formations tapped. The purpose of developing wells is two-fold: (a) washing the fine sand, silt and clay in the area immediately surrounding the screen; and (b) to agitate water in the formation so that the tendency of 'bridging' of sand is prevented. When the water is pumped out of a well, the sand particles move in the direction of the well. As the finer material is pulled through the slots of the screen, all but the coarsest material next to the screen is removed. Then the finer material in the second zone moves to the first zone; that from the third zone moves to the second zone; that from the fourth zone to the third zone, and so on. As this is continued, the sand grains gradually arrange themselves with the largest and most uniform only, next to the screen; the largest and next smaller size, in the second zone; and the largest and next two smaller sizes, in the third zone, and so on. The mixture is more uniform and more permeable as the screen is approached, and with each zone graded in relation to the one beyond it so each acts as a stabilizer for the one outside it. This is the natural process of development of a well by pumping.

However, with a steady pull in the direction of the well, during pumping, the finer sand grains have a tendency to wedge against each other and form bridges, somewhat like arches, across the openings of voids between coarser grains. These particles refuse to move as long as the flow of water continues in one direction and naturally the yield in the well is adversely affected. For proper development of the well, it, therefore, becomes necessary that in addition to the pumping, the strata in the vicinity of the well should be back washed or agitated by surging, from time to time, during the development process.

#### **Development with surge plungers**

This is one of the most effective methods of developing wells in sand and gravel formations. The essential feature is the rapid up and down movement of a plunger in the well opposite the screens. Raising the plunger draws water and fine materials in the well and lowering it forces water out through the screen openings and into the material surrounding the screens. This reversal of flow overcomes the tendency of sand to bridge and brings in much more fine material than when the flow is always towards the well. The sand or gravel grains are removed from the well by any convenient means.

Surge plungers used may either be solid or valved. Both types may vary in details of design. For instance, some may have capped leather or rubber

facings; others flat leather or rubber discs. There are many different ways in which these may be made. Valve type surge plungers produce a great inrush than outrush of water. They are more suitable for developing formations that give small yields.

Simple surge plungers may be made by wrapping sacking, old rope, or some such material around the drill stem or bailer. The bailer of mud-scow type serves as a very satisfactory surge plunger. For developing formations requiring more thorough treatment, specially built surge plungers may be used.

Surge plungers may be operated by the spudding mechanism of boring outfits using long strokes. The tools are lowered into the casing until the plunger is about 15 ft. in water. Care is taken not to lower the tools so far that they batter the top of the screen. The surging is started slowly and the speed increased until it reaches the fastest limit at which the tools will drop and rise without too much slap of the cable. After the surging has been continued for a time when the driller feels the screen is filling up with sand, tools are hoisted and the bailer is run into the well to clean it thoroughly. Surging is again resumed after cleaning, and the procedure is repeated until the well is fully developed as evidenced by the fact that little or no more sand can be pulled into the screen.

Two or three days are usually required to develop a well by this method. Less time is ordinarily required to develop shallow wells than deep ones.

### Development with Pumps

Wells may be developed by means of pumps, either by over-pumping or by a process called 'rawhiding the well'. Over-pumping means pumping the well with excessive draw-down. This is not a very effective method of developing a well, particularly because the flow of water remains in one direction and, thus, encourages the phenomenon of bridging.

The other method consists in starting and stopping the pump intermittently to produce relatively rapid changes in the head of the well. While this may be done with any kind of pump, it is most effective with a turbine pump installed without a foot valve. There are three types of developing reactions, which may be obtained by operating the pump in different ways:

(a) The pump is operated at its fullest capacity until it has produced the greatest possible draw-down of the water-level. It is then stopped, the water receding rapidly out of the column of the pump, and the well being permitted to regain its full static water level. This procedure is repeated many times until the well shows no further improvement.

(b) The well is pumped to obtain maximum draw-down and the pump is then stopped and started alternately in short intervals. This has the effect of holding down the water level in the well and frequently agitating the formation by the back wash of the water in the pump column. The rapid

changes from start to stop, with resultant changes in pressure head, velocity head, and direction of flow at the bottom, produce a relatively forceful treatment of the water-bearing formation.

(c) The well is pumped until the water discharges at the surface. Pumping is then stopped and the water allowed to recede from the pump column. The process is repeated. No effort is made to draw the water level as low as possible or to hold it at a low point. The object of this method is simply, agitation of formation.

The time required to develop a well by these processes varies through wide limits. Sometimes very few hours are required, but usually at least a day is necessary. The method is inexpensive, speedy and fairly effective, but not vigorous enough for wells requiring heavy development.

### **Back washing**

Yet another method of developing a well or cleaning a clogged strainer by means of pumps is that of 'back washing'. Water under pressure is forced in the casing. The water eventually passes out into the formation, cleaning the strainer and carrying with it the clogging sand particles. Instead of using a force pump water under pressure from high storage tank may also be used. For treating partially clogged strainers, water jet may be carried down to a point directly opposite each part of the clogged strainer by using a small pipe, which can be lowered freely in the screen casing. The operation of back washing may be followed by bailing or pumping and the process repeated to develop the well fully.

### **Development with compressed air**

The use of compressed air in the development wells is, under favourable conditions a rapid and effective process. This method is suited to wells of relatively small diameter in which there is considerable depth of water in proportion to the total depth of the well. There are two general methods: the back washing method; and the open well or surging method. A combination of these methods may also be used for more effective development.

#### **(a) Back washing method**

The principle of this method is to force the water back out of the well through the screen and into the water bearing formations by means of compressed air introduced into the well through the top of the casing after it has been closed. The method cannot be used unless water in the well stands at a considerable height above the screen section of the casing. It is best used after the well has been cleared as completely as possible with the bailer.

When this method is used, the top of the casing is sealed with an air tight cap through which the air-line extends. The air-line is equipped with a three-way valve so that the pressure in the well can be released at any time.

When air is turned into the air-line, the water in the well is forced out through the screen. As soon as the air begins to escape through the openings in the screen, the air is then shut off and the pressure in the well is released by opening the three-way valve. This is done to prevent the danger of air-logging in the water bearing formation.

A pressure gauge on the air-line is very desirable in order to know definitely when the pressure has built up high enough to force air through the openings in the screen. As soon as the air starts to escape the pressure on the gauge would no longer rise. When the pressure is released, the water will flow back into the well through the screen and bring fine sand from the area surrounding the well. This process is repeated until no sand is brought in. The cap is, then, removed and the accumulated sand bailed out.

A large volume of air is lost each time the pressure is released; this loss can be partially eliminated by putting an air tight plug in the well at the water-surface rather than by capping the casing at the ground-surface.

(b) *The open well or surging method*

The use of this method is limited to wells in which the depth of water exceeds  $2/3$ rd of the total depth of the well. The principle upon which development is accomplished under this method is a combination of surging and pumping. The sudden release of large volumes of air produces a strong surge by virtue of friction and inertia. Pumping is done as with an ordinary air lift.

A typical arrangement of equipment used is shown in Fig. 44. It includes mainly, an air compressor, a drop pipe (education pipe), and air-line together with other necessary fittings and accessories. Sometimes, the drop pipe is dispensed with, the well casing being used to discharge the water. This practice is, however, not recommended because of the inefficient use of air under these circumstances. The drop pipe may be conveniently handled with a chain attached to the drill cable, and the air-line by connecting to the bailer line, if a cable tool rig is used. A tee at the top of the drop pipe is fitted with a short discharge pipe at the side of outlets and at the top a bushing is placed to clear the couplings of the air line. A sack is wrapped around the air line where it enters the drop pipe to prevent the water from spraying about the top of the well.

The discharge of the compressor is piped direct to the air tank without any valve in the line. The discharge pipe from the tank to the well is the full size of the air line in the well, or, if the air line is long, the next size larger. The air-line is fitted with a quick-opening valve near the tank. A heavy hose is used between the discharge pipe from the tank and the air line in the well. The hose is at least 15 ft. long to allow enough space for moving the drop-pipe and the air line up and down, when necessary.

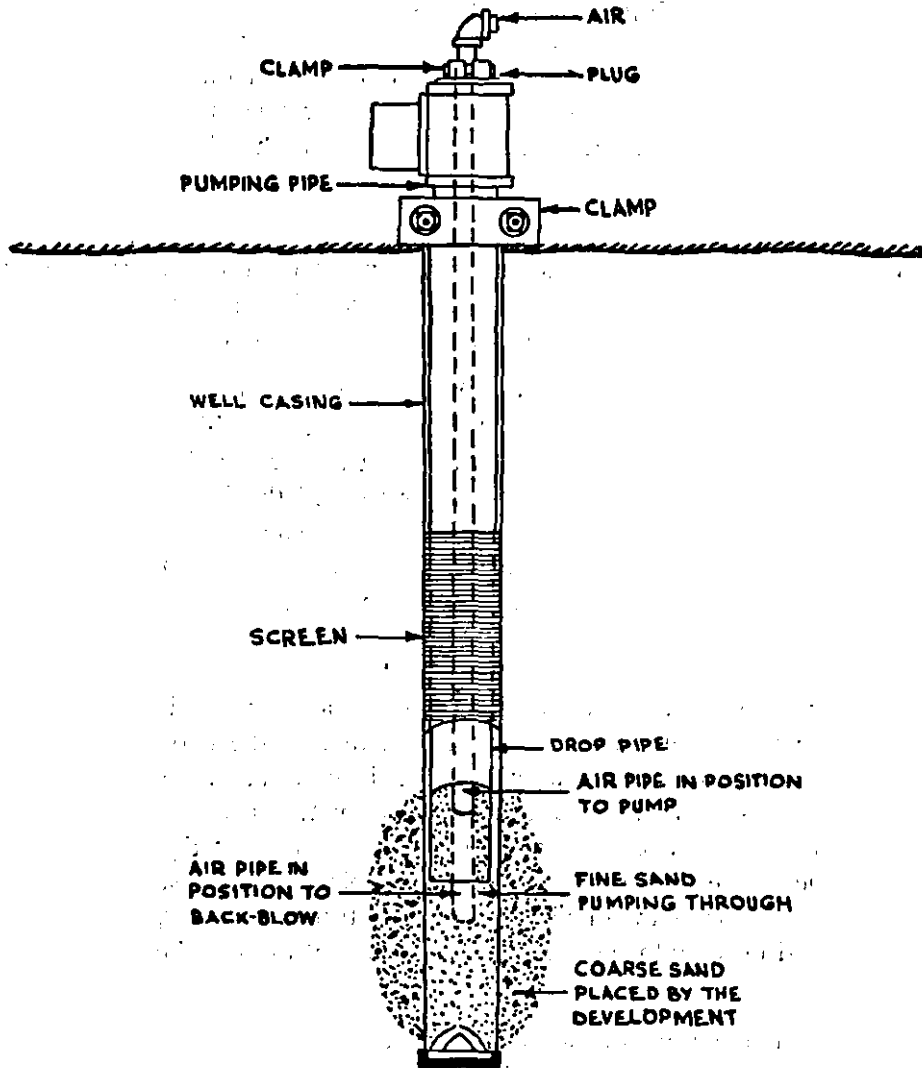


FIG. 44

To start with, the drop pipe is lowered within 2 ft. of the bottom of the screen. The air line is placed inside the drop pipe, so that its bottom is one foot or more above that of the drop pipe. If there is plenty of depth in the well, the air line needs to be lowered only far enough to get 65 to 70% submergence. The compressed air is turned into the air line and the well is pumped in the manner of a regular air lift until the water appears to be free from sand. The valve between the tank and the air line is then closed, allowing the tank to be pumped full of air up to a pressure of from 100 to 150 pounds. In the meantime, the air line is lowered until it is 1 ft. or so below the drop pipe. The valve is then opened quickly allowing the compressed air in the tanks to rush into the well under full pressure. There follows a brief but forceful surge of water. The water tends to rush

upward through the drop pipe and the space between the drop pipe and the casing. The inertia of the column of water causes it to resist the sudden movement and as a result water is forced out through the openings of the screen in the water bearing formation. If the air line is pulled back into the drop pipe as soon as the first heavy load of air has been released into the well, there is a strong reversal of flow up the drop pipe; and this effectively agitates the water-bearing formation.

The well is, then, allowed to pump as an air lift for a short time and then another 'head of air' is released. This procedure is repeated until the absence of further sand shows that the development is complete at this level.

The drop pipe is then lifted to a position two or three feet higher and the same procedure is followed at this new level. In this way the entire length of the screen is developed, a few feet at a time. It is then advisable to return the drop pipe to within 1 ft. or two of the bottom of the well and to release one or two heads on this point. The well is then pumped as an air lift with the air line pulled up in the drop pipe. This completes the work and thoroughly cleans out any loose sand.

#### **Combination of back washing and surging method**

A combination of the back washing and pumping method of developing well by means of air is more effective than either of the two methods used separately. When the combination method is used (Fig. 45), the top of the casing is closed, air tight, and a three-way valve is used as in the back washing method. The drop pipe is run through the air tight cap on the casing. The air line is inserted into the drop pipe as in the surging method and a separate line with an air cock is run through the cap. The drop pipe is carried down into the well to a point a foot or two above the top of the screens.

To develop the well, the air cock is opened and air is turned into the air line in the drop pipe. This pumps water out of the well through the discharge pipe and washes some of the fine sand material. When the water becomes clear, the supply of air is cut off and the water in the well is allowed to regain its static level. The air cock is then closed and a three-way valve turned to direct the air supply down the other air line. This forces the water out of the casing and back through the screen, agitating the sand and breaking down the bridges of sand grains. When the water has lowered to the bottom of the drop pipe, the hydraulic connection is broken, thus, making it impossible to air-log the formation.

When the air is heard escaping out of the discharge pipe, and when the pressure stops increasing, the supply of air is cut off and the air cock is reopened to allow water to reach static level. Then the three-way valve is turned and the air supply again directed down the air line to pump the well. The process of alternately pumping and back-washing is continued until

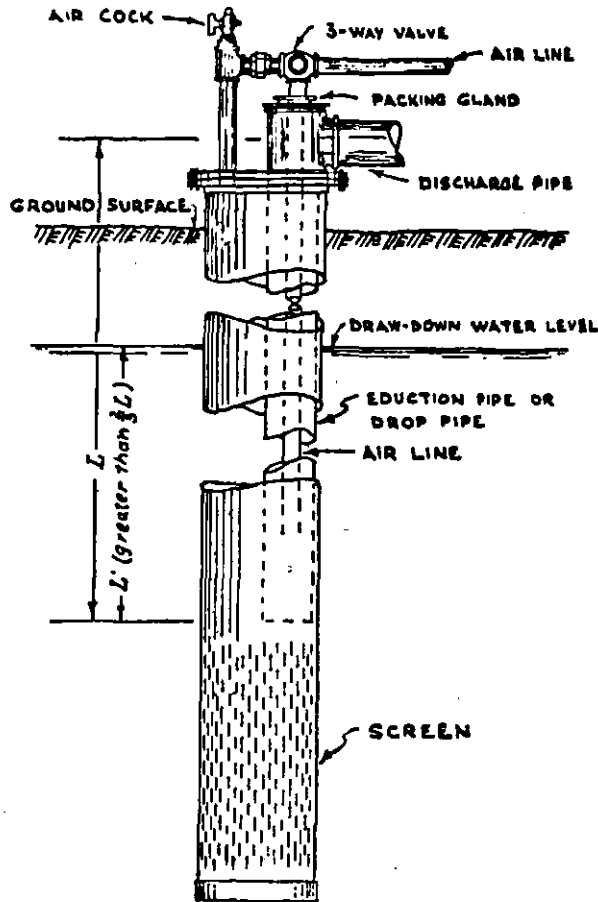


FIG. 45

no more sand comes into the well. Most of the sand that is washed into the well is lifted by the pump, but when the development is completed the well should be sounded, and, if any sand remains there, it should be pumped out by lowering the drop pipe to the top of the sand.

Development of wells by this process is a rapid and effective way to accomplish the desired results.

#### Size of compressor and pipe-lines

The compressor should be capable of developing a maximum pressure of not less than 100 pounds per square inch, and preferably 150 pounds. For capacities of displacement up to about 75 cubic feet per minute, a vertical one or two cylinder compressor usually is most economical and convenient. This size takes care of small wells nicely. Compressors are built in both belt-driven and direct connected types. For testing and developing wells, the direct connected type, with diesel engine drive, mounted on wheels, makes an ideal unit both for getting into place and connecting up.

In addition to having air capacity and a power unit of sufficient capacity, it is essential to have the drop pipe and air line of proper size with respect to each other and the well casing in order to prevent undue frictional losses and waste of air pressure. With wells of 4 in. diameter and smaller, sizes ordinarily used for capacities of less than 50 gallons per minute, it is customary to use the casing as the delivery pipe rather than to install a separate drop pipe. A  $\frac{3}{4}$  or 1 in. air line is used. Even in larger wells, this is sometimes done. The chief objections to doing so are less accurate control over the development, especially in wells with relatively long screens; somewhat lowered efficiency if the well is large in proportion to volume of air and pumping rate; and less accurate determination of draw-down and more difficulty in measuring the depth of water. Where drop pipe and air line are used, the table below shows the sizes, which may be used to the best advantage:

*Sizes of drop pipes and air lines for various capacities*

Pumping rate (gal. per min.)	Diameter of well casing (inches)	Diameter of drop pipe (inches)	Diameter of air line (inches)
30 to 60	3 $\frac{1}{2}$ or larger	2 $\frac{1}{2}$	$\frac{3}{4}$
60 to 75	4 $\frac{1}{2}$ or larger	3	1
75 to 100	5 or larger	3 $\frac{1}{2}$	1 $\frac{1}{4}$
100 to 150	6 or larger	4	1 $\frac{1}{2}$
150 to 250	8 or larger	5	1 $\frac{3}{4}$
250 to 400	8 or larger	6	2

In development work, some variation from these sizes is permissible; but a great variation produces poorer results, especially if much larger quantities of water are pumped.

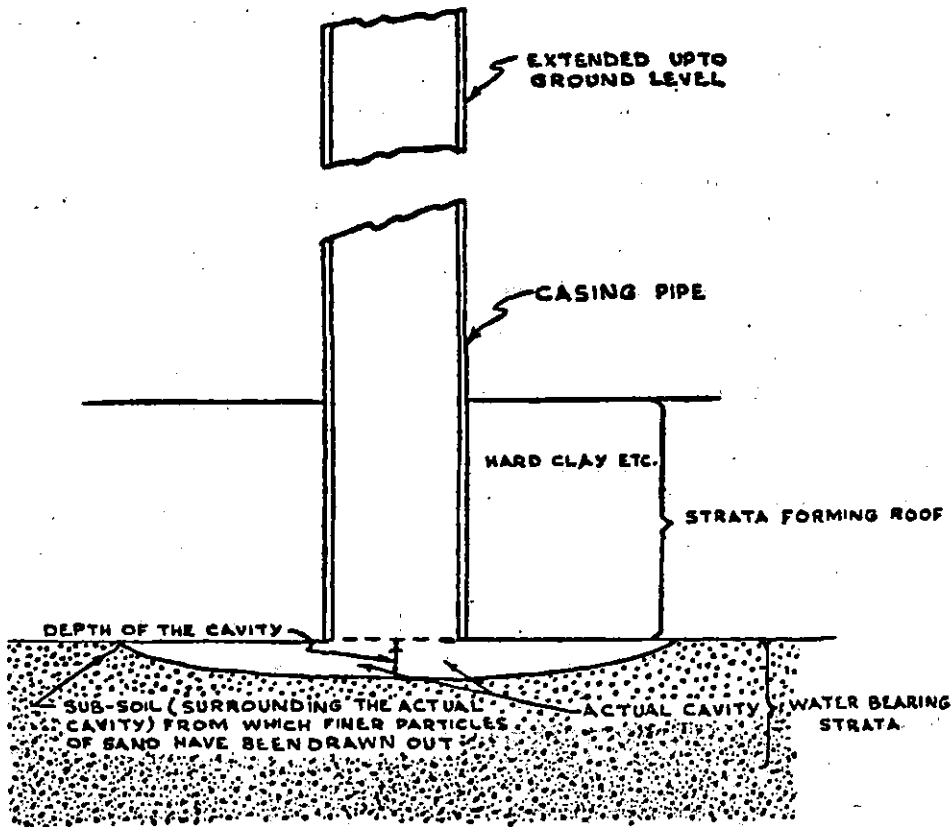
### Development of a Cavity Well

Development of a cavity well means the drawing out of sand from below the clay roof. As sand is drawn out, a cavity is formed in the water bearing stratum at the bottom of the clay roof. In shape, the cavity is plano-convex the plane face being the stratum forming the roof. (Fig. 46).

Generally the depth of the cavity is very small, only a few inches, but the circular area of the cavity is large; hence the strain on the roof. The area of the formation developed is even much larger than the area of the cavity, and it is on the development of this larger formation area that the yield of the cavity well depends.

Air compressors or pumps may not develop a cavity well satisfactorily unless a small cavity has previously been created by means of a sludger. Centrifugal pump is usually better suited for developing a cavity well than an air compressor. It is important that cavity should be developed slowly and with great care. If the cavity is not developed slowly, the sand is likely to rush into the casing and choke it. This may at times cause such





### CAVITY WELL

FIG. 46

a disturbance in the formation that the satisfactory development of a cavity may become impossible even after removing the initial mass of sand.

To begin with, the discharge should be kept low. When the discharging water has become clear, the depression may be increased slightly, which may result in further sand being drawn out. This process may be repeated till normal depression is reached and the discharge is clear. The pumping operation may then be stopped for an hour or so and then resumed. The discharge after restarting may again contain sand. The operation may be continued till the water is clear again. The procedure may be repeated till the well is fully developed, which is evidenced by the discharge being clear even on resumption of pumping after a closing interval.

#### Testing Yield of Wells

For proper selection of a water lifting appliance or the power pump to be installed on a well, it is necessary that the yield of the well should be tested carefully after it has been fully developed. The information to be obtained from a well test includes location of the static water level, the yield and the depth of water when the well is being pumped at different

rates. From these data, the draw-down, the yield and the specific capacity, that is the yield per foot of draw-down can be computed. In deep wells, tapping substantial thickness of the water bearing medium, the yield is almost directly proportional to the draw-down. This, however, is not true, in general, for shallow wells.

Before starting the test on a well, it is necessary to measure the depth to the static water level. After this the well is pumped at the maximum rate possible for a sufficient time for the draw-down and the discharge to become constant. When a condition of equilibrium is reached, the discharge of the pump is measured and the depth to water noted. The difference between this depth and the depth to the static water is the draw-down. The pumping rate is then reduced until the draw-down is about one/fifth less than it was before. Pumping is continued at this rate until the draw-down becomes constant when the discharge and draw-down are measured again. The discharge is then reduced until the draw-down is two/fifths less than the maximum. This process is repeated until the elevation of the surface of the water in the well returns to its original level.

From these data, a curve is plotted (Fig. 47) showing the relation between the draw-down and the discharge. The curve for a deep well is a straight line, whereas that for a shallow well bends upward.

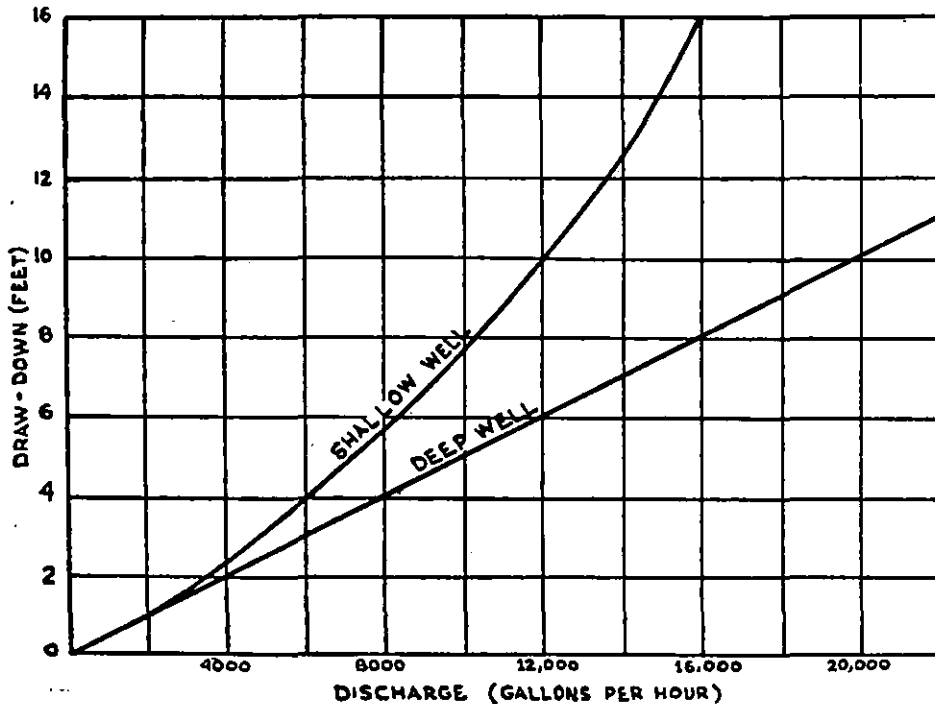


FIG. 47

### Measuring Yield

The discharge can be measured by means of orifices, weirs, tanks, etc. An accurate, simple and inexpensive way of measuring discharges is the

V-notch method. In this method, a sharp crested, right angled V-notch, of sufficient size to allow the full discharge to pass through it, is cut in a steel plate of about  $\frac{1}{4}$  in. thickness. The water is passed through a stilling chamber or tank with this V-notch plate fitted in front of it. When the flow through the notch is steady, the head on it is measured at a point sufficiently away upstream (about three times the depth of water over the crest) preferably on the wall or plate just opposite the notch. The discharge may then be calculated using Thomson's formula or the cone formula which are respectively as under:

$$Q = 0.305 H^{5/2} \text{ Cubic ft. per minute.}$$

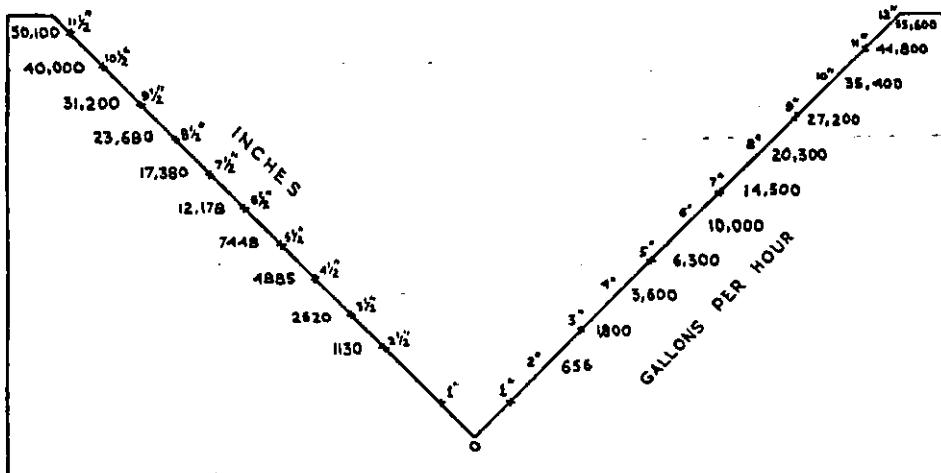
Where H is the head in inches.

$$Q = 2.49 H^{2.48} \text{ Cubic ft. per second}$$

where H is the head in feet.

Sketch of a V-notch, giving discharges at various heads is given *vide* Fig. 48.

### SKETCH OF V-NOTCH



In the case of horizontal centrifugal pumps directly connected with the well casing, the draw-down can be determined by measuring the suction head with a vacuum gauge screwed on the suction side of the pump. The reading on the gauge will indicate the suction head from the centre of gauge. The suction head will include the friction head due to friction in the suction pipe, which may be easily calculated or found out from tables. Making adjustments for the friction head and the distance between the static water level and the gauge, the draw-down can be determined.

In the case of bore-hole pumps, where the casing is not directly connected to the suction side of the pump, draw-down may be measured by means of 'air line' lowered into the annular space between the bore-hole pump column and the well casing and fitted at the upper end with a pressure gauge. (Fig. 49)

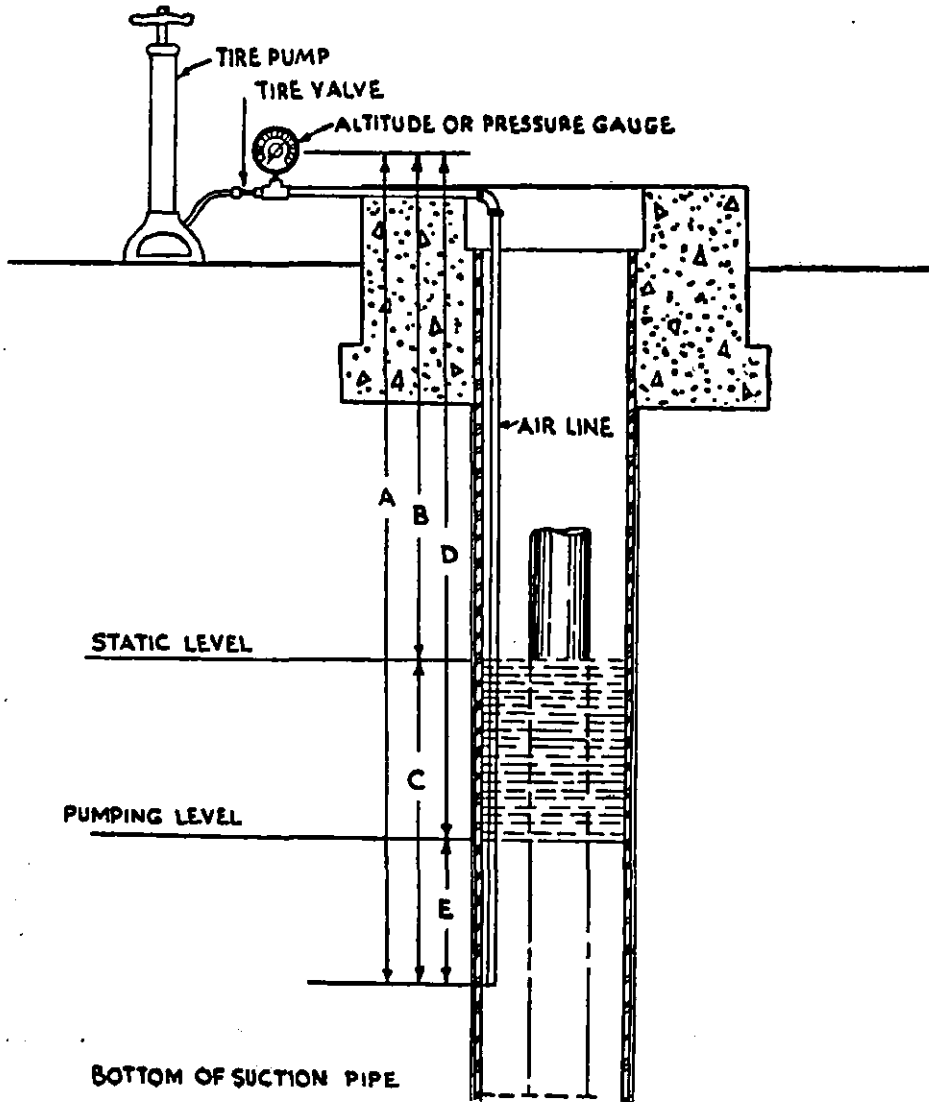


FIG. 49

The air-line should extend about 10 ft. below the limit of the draw-down, but it should not end within 5 ft. of the suction inlet of the pump because of the disturbed flow near this point. Air must be pumped into the line until the maximum possible pressure is reached. Normally the air-line is full of water up to the level of water in the well (static or pumping level). When air is forced into the line, it creates a pressure which forces the water out of the lower end until it is all expelled and the line is full of air. If more air is pumped in, air instead of water is expelled and it is not possible further to increase the pressure. The head of water 'C' or 'E' (Fig. 49), above the end of the line maintains this pressure, and gauge shows what the pressure or head above the end of the line actually is. If the gauge is graduated in feet of water (altitude gauge), it registers directly the amount of submergence of the end of the line. This reading subtracted from the length 'A' of the line gives the water level 'B' or 'D' (static or pumping level). If the gauge is graduated in pounds per square inch, the reading must be multiplied by 2.31 to give the submergence in feet. Then as above, the submergence is subtracted from the total length of the line to give the water level.

#### Test yield in wells with meagre discharge

Quite a number of open wells may yield only small discharges even after boring. The draw-down in such wells may not reach a steady state, but may continue to increase even when they are operated by smaller sized power pumps. Yield of such wells may be approximately computed by intermittent pumping as follows:

The depth of static water level is determined. The pump is operated for a short period and then stopped. Water levels in the well are observed before starting of pumping and at the closing of pumping. The duration of pumping is noted. The total quantity of water pumped is computed by the V-notch readings taken at regular intervals. Time in which the water in the well regains its original level, (at which the pumping was started) is also noted.

Let  $H$  = depth of the static water level below the ground surface.

$H_1$  = depth of the water level when pumping was started.

$H_2$  = depth of the water level when pumping was stopped.

$T_1$  = duration of pumping.

$T_2$  = Time taken by the water to recuperate from the post-pumping level to the pre-pumping level.

$Q$  = Total quantity of water pumped during time  $T_1$ .

Then the approximate yield of the well in time  $(T_1 + T_2) = Q$

Approximate yield of the well per-unit time is =

$$\frac{Q}{T_1 + T_2} \times \frac{H_1 - H_2}{2} = H$$

The corresponding effective draw-down to which the yield pertains

## 14—INSTALLATION OF A SUITABLE LIFTING APPLIANCE

THE choice of a suitable appliance for lifting water from a well after boring will be governed by the yield obtained, the water requirements of the cultivator and the capital he can afford to invest. In case the water supplies have been augmented by a moderate amount the cultivator can meet his requirements by installing a persian wheel (*rahat*), a rope and bucket lift (*charas* or *mhote*) or any other suitable animal driven device. However, if the resultant water supplies are more copious (say the total yield in a day of 24 hours exceeds 30,000 gallons or so) and the farmer has comparatively larger holdings, it will be desirable to go in for a power pump.

Various commercial makes of pumps are available in the market. These are usually known by the principle of their working such as centrifugal, rotary or reciprocating. Centrifugal pumps are generally suitable for pumping water from wells. The Centrifugal pumps commonly used for water lifting on wells are of two kinds: volute pumps and turbine pumps. In common usage these two are often referred to as centrifugal pumps and turbine pumps respectively. Mixed flow pumps (which also come under the class of centrifugal pumps) however, are more suitable when comparatively a large discharge is required to be lifted against a rather low head of say about 10' or so.

For ordinary requirements, when the well is to be operated with limited draw-down, centrifugal pump (volute type) with horizontal spindle may be preferred because of its simplicity, cheapness and ease of installation. Suction lift on such pumps is limited to about 15 ft. for average conditions. It, therefore, becomes necessary that the pump is installed as near the water surface as possible. If there is large fluctuation in water level, the position of the pump may have to be adjusted from time to time. This is a disadvantage with these types of pumps. When the water level is low, centrifugal pumps with vertical spindles are sometimes used. These pumps may be operated by prime-movers (oil engines or electric motors) placed at the ground level.

In all modern large sized bores, involving high lifts and draw-downs, deep turbine pumps (also called bore hole pumps) are now commonly used. These pumps are installed in the casing, with turbine impellers placed low enough so that the draw-down does not exceed the suction level below the impellers. In practice they are usually placed below the lowest draw-down. The impellers are operated by a vertical shaft worked upon by a power unit (an electric motor usually, but also a diesel engine sometimes) located at the ground level. If the power unit is an electric motor, it is installed directly over the casing. The pumps can, thus, be

operated with the maximum draw-down without requiring any shifting. The pumps do not require any priming and can also stand wide fluctuation in the water level. If the size of casing is small, they require, for installation, a compound well which as explained earlier in this Handbook, is a bored well with casing pipe of larger diameter provided at the top for housing the turbine pump. This upper portion of the casing pipe is termed as the housing pipe and its length is decided by the maximum draw-down in each case.

Turbine pumps are comparatively costly. They, however, are now available in various sizes and should be preferred for installation on open wells, which have been suitably bored, and are required to be operated against draw-down of higher order.

In order that the cultivator may make optimum use of the supplies available in his well without over-capitalisation, it is necessary that he should be properly guided in the choice of a pump set of suitable type and size. Details about the performance of pumps, their capacities, characteristics and other allied information are supplied by the manufacturers. These should be taken into consideration carefully while advising the cultivators.

Power pumps may be operated by either diesel engines or electric motors as stated earlier. Diesel engines are more expensive in initial cost, operation and maintenance than electric motors. Electric motors on the other hand are dependent on the availability of electric power, and if the electric transmission lines are not available in the immediate vicinity, may also require expensive extension of power lines. The cost of these power lines may become exorbitant, if the wells to be installed with electric motor pumps are scattered far and wide and the demand for irrigation is not keen all the year round. In such cases, diesel engines may be preferred. However, wherever diesel engines are installed, it is necessary to arrange proper facilities for their maintenance and repairs.

## 15—DEEPENING WELLS BY BLASTING

THE object of deepening wells is twofold: increasing their yield and also storage capacity. While the yield in wells, located in alluvial soils, may be increased by boring, deepening of wells, often, be the only course open for increasing discharge in wells in rocky sub-strata. As mentioned earlier, rocks forming the surface of wells in such strata are not solid throughout. They normally contain voids, interstices, cracks, joints, bedding planes, etc., which serve as receptacles holding water. Deepening of wells results in tapping of additional water bearing receptacles particularly in rocks, where these receptacles are comparatively isolated and inter-connections between them have not sufficiently developed.

The wells dug in alluvial soils can be deepened manually. There, however, are tracts where soft rock appears after the first few feet of top soil have been removed. The farmer in such cases, normally tries to carry out further excavation with his own resources. He successfully carries out blasting up to a few feet of soft rock with the use of gun-powder and a fuse coil for igniting the gun-powder. The gun-powder is placed in holes which are drilled with crow bars, chisels and hammers. The efforts of the cultivator continue till some hard consolidated rock formation is reached or water has made its appearance. His method cannot succeed under either of these conditions. At this stage, it is desirable that the work may be entrusted to organised blasting units, who may undertake the works systematically using explosives that can be operated even under water. The systematic operation for deepening wells consists in drilling holes in the bottom of the well, by means of pneumatic tools operated by air compressors, filling these holes with suitable gelignite sticks and finally exploding the well bottom. After the well bottom has been cleared of debris, the process is again repeated and so on till the well has been deepened to the required depth.

### Equipment required

The following equipment is ordinarily required by each blasting unit for carrying out deepening of wells:

1. Air compressor
2. Power unit to run air compressor
3. Drilling machine (jack hammer)
4. Air hose
5. Drill rod and drill bits
6. Pneumatic grinder
7. Boxes containing explosives and detonators
8. Exploder
9. C.T.S. cable
10. Pneumatic sump-pump
11. Haulage truck.



There is a wide range of capacities for which air compressors are now available indigenously. The ones commonly used for blasting operations have a capacity of free air supply from 105 to 120 cubic feet per minute at a pressure of 100 lbs. per sq. inch. The capacity should be 210 cft. in case sump-pump is also used in conjunction, for dewatering. The compressor is coupled to a suitable diesel engine of about 30 to 50 H.P. The air compressor along with the diesel engine is mounted on a truck (Fig. 50). It is built down rigidly to the floor of the truck's body by bolts, nuts, and welds. The compressor may also be portable trailer-mounted, provided most of the journeys are to be carried out on good roads.

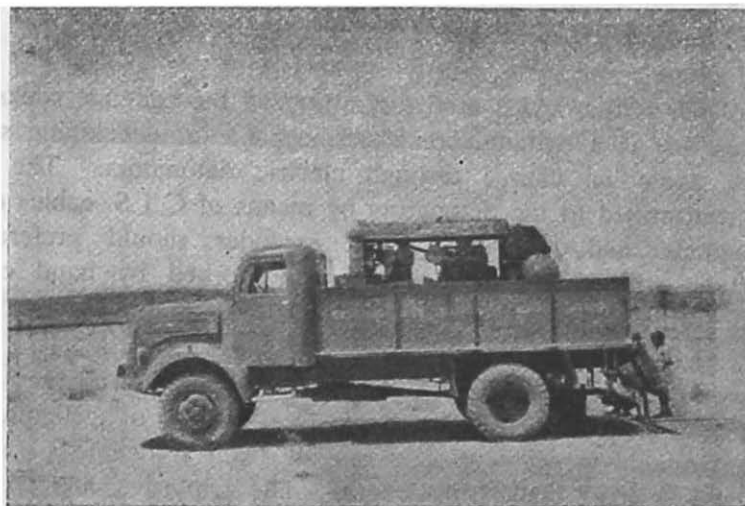


FIG. 50

The rock drill used for boring holes in the rocks is the jack hammer, which is operated by compressed air. The jack hammer is powered by the compressor through an airline rubber hose  $\frac{3}{4}$ " in diameter, available in 50 ft. long pieces and suitable for working under pressure of 200 P.S.I. The size of the jack hammer used varies generally from 30 to 50 lbs., weight, depending on the type of rock encountered. The optimum size selected should satisfy the following criteria: it should avoid wastage of manpower; be efficient and more economical in consumption of compressed air; and should be less strenuous on the operator.

The jack hammer is fitted with a drill rod on one end of which a drill bit is fixed. Drill rods are of different lengths varying from 6" to 5 ft., the choice of rod of a particular length being dependent on the depth of holes to be drilled. Usually rods about 2½ ft. in length, having  $\frac{3}{4}$ " hexagonal shank are used.

The drill bits used are of different diameters usually ranging from 1" to 2". Selection of the size of drill bits depends upon the thickness of

gelignite stick, which is used for blasting. The drill bits, which are of tungsten carbide steel, may either be inset in the drill rods or detachable. The latter ones have the advantage that they can be replaced when worn out, while the same drill rod can again be used. The bits lose their sharpness gradually, as they are used for drilling holes. They, however, can be sharpened again and again, in the field, by pneumatic grinding machine, which operates a grinding wheel 5 to 6 inches in diameter, with air supply at a rate of 60 cubic ft. per minute at 100 P.S.I. The process of repeated sharpening reduces the size of the bit and it cannot be used any more when it is reduced to a size smaller than that of the gelignite sticks. A drill bit normally gives a performance of approximately 1,000 running feet of drilling before it is rendered unserviceable.

An exploder is the device used for setting off the gelignite sticks placed in the holes. It is a dynamo condenser, capable of developing sufficient voltage for exploding charge through electric detonators. The electric current is transmitted to the detonators by means of C.T.S. cables connecting the exploder and detonators. The exploder should preferably be 250 volt/type with safety arrangement and worked by hand cranking. C.T.S. cable with  $3 \times 0.29$  twin core, insulated, is suitable for the purpose.

The explosives and the electric detonators for igniting charges are kept in separate wooden boxes. The explosives consist of gelignite sticks, which are available in different sizes ranging from 1 inch to  $1\frac{1}{2}$  inches in diameter and 4 to 8 inches in length. The explosive material of the sticks is made up of 80% nitro-glycerine and 20% absorbing powder. The electric detonators, which are meant to set off the explosives, consist of small copper or aluminium caps containing fulminate of mercury or azide of lead. The cap is connected with two fuse wires, each about 36 inches in length. The stock includes no-delay detonators, which set off the charges immediately after the current is passed, and also one-second or two-seconds delay detonators, which defer the charges by one or two seconds respectively.

The Fig. 51 shows important items of equipment, such as rock drill, air-line, rubber hose.

## Operations

Operations involved in deepening of wells by blasting are as under :

### (i) *Dewatering the well*

The Fig. 52 shows a well, prior to undertaking its deepening. The well contains water which must be removed for starting operations.

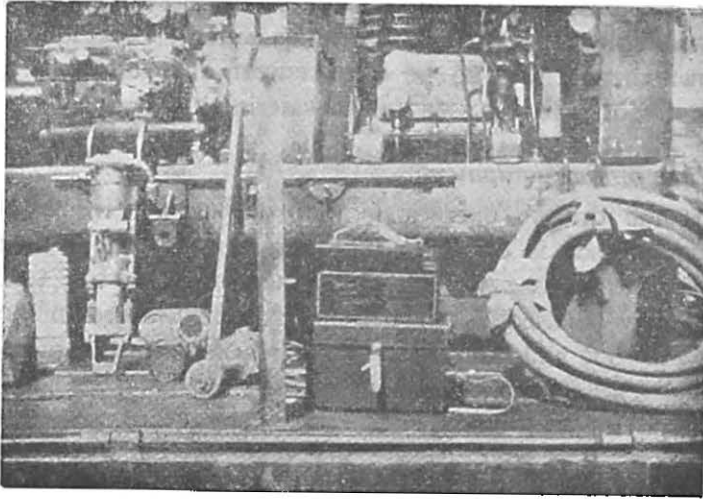


FIG. 51



FIG. 52

The holes can be drilled and loaded properly only when the well is empty or contains not more than a few inches of water. Dewatering of the well can be carried out by the cultivator himself, by means of a rope and bucket lift (*charas* or *mhote*) or some other suitable water lifting appliance which may be readily available with him. Members of the crew, along with the equipment and boxes containing sufficient stock of explosives, reach the well site in the haulage truck, after ensuring that the farmer has dewatered his well.

The air compressor, however, is also provided with a special type of pump known as the sump-pump for lifting water. In case the cultivator finds his own arrangement to be inconvenient, the sump-pump, provided with a compressor, can be used for dewatering the well.

*(ii) Lowering of the equipment*

To start the drilling operations after dewatering, the air connection from the compressor is established by lowering the air-line rubber hose inside the well. In case well depth is more than 50 ft., two pieces of rubber hose may be used. Jack hammer is next lowered in the well with the help of the rope and bucket lift or other water lifting appliance installed on the well. The same arrangement is used by the crew and the farmer to get down to the well-bottom.

*(iii) Drilling holes*

Drilling of holes is then started by the borer (Fig. 53). For drilling through the first 3 to 6 inches, the borer also takes help of the cleaner and the two together put their combined weight on the jack hammer, as during this stage of drilling, the jack hammer is subjected to excessive vibrations. After this initial stage of boring, the borer's own grip is sufficient to control the machine.



FIG. 53

The size of the holes to be drilled is governed by the size of the gelignite sticks used. The diameter of holes usually varies from 1 to 1½ inches. The depth of holes and the distance between them is generally governed by the nature of the rock formation. The holes are usually 2 to 2½ feet deep. In larger diameter wells, deeper holes may sometimes be drilled in order

to obtain a greater thickness of rock blast in each operation. In smaller diameter wells, this practice is not desirable as it may endanger the safety of the well walls.

Fig. 54 shows location of holes for blasting. Although there are no hard and fast rules, about 7 to 10 holes are usually drilled in a normal sized well and they are generally spaced two or three feet apart from one another. The main guide in spacing of holes is the type of rock and stones met with. The holes next to the edge of the well are usually removed at least 9 inches to 1 foot away from the edge of the well, towards the centre. Sometimes two or three holes are first drilled in the centre and are blasted so as to form a pit in the centre. This pit, later, facilitates blasting near the side walls. In bigger diameter wells, sometimes, half the area of wells is blasted in one operation, the other half being blasted in a subsequent operation.

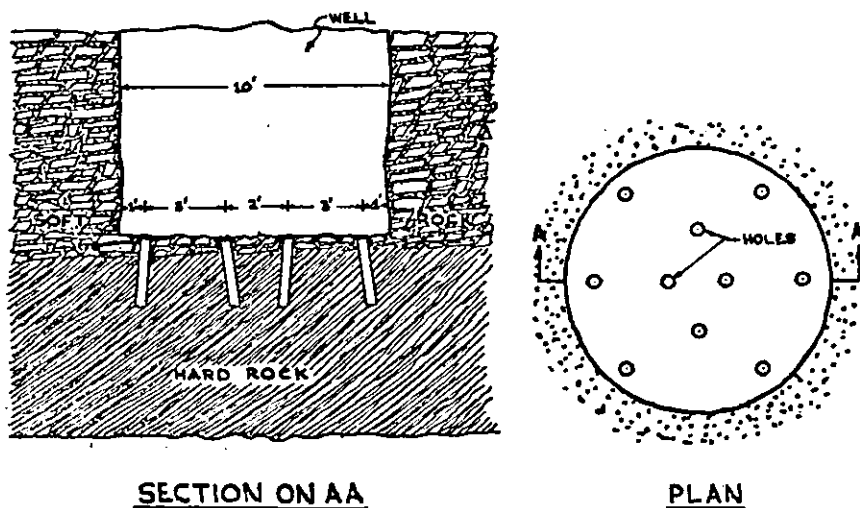


FIG. 54

The effect of the blast depends to a large extent on the position and inclination of the blast holes. The holes are usually drilled oblique with a view to minimising resistance to blast and thereby enabling the explosive force of the blast to be more effective in breaking the rock. Oblique holes also prevent the explosives from shooting out straight, as they sometimes do, if the holes are vertical and the charges not properly tamped. In soft rocks, the holes may be drilled straight, as comparatively less explosive force is required to break the rock.

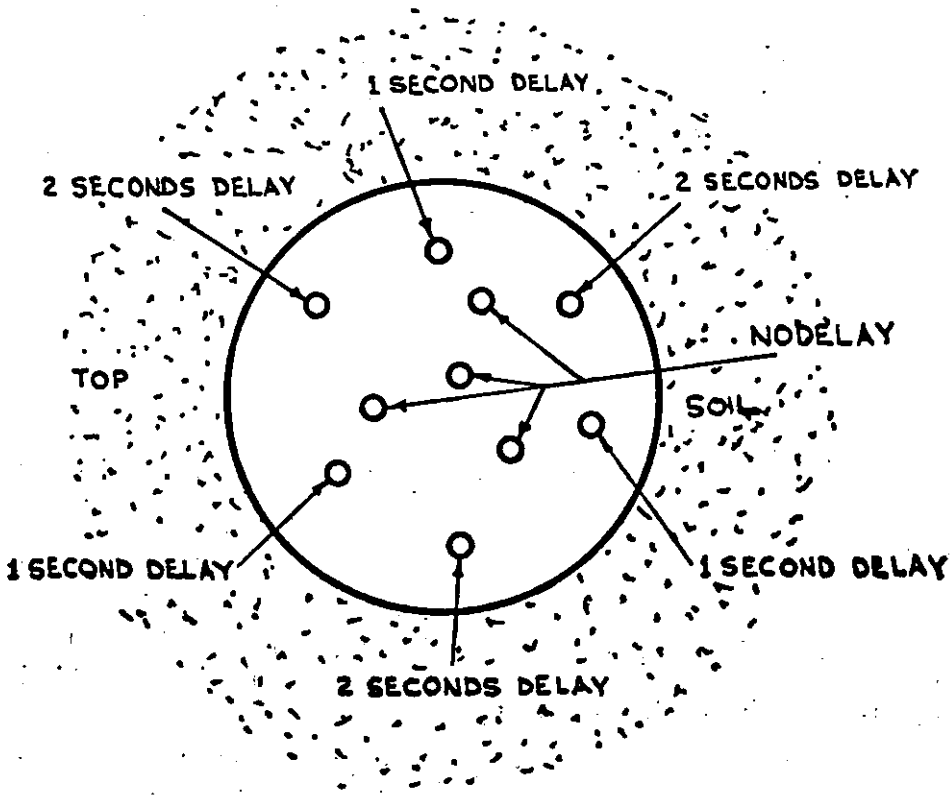
One of the guiding factors in successful blasting of the stratum met with is to follow the track of moisture in the stones or water oozing out of the crevices. The well owner himself usually guides the driller in this matter. Sometime even horizontal blasting may be resorted to in search of a source of water suspected to exist. The diameter of the well may undergo

slight changes as a result of such operations. It may become oval and irregular in dimensions.

In no case the holes are made through crevices from which water oozes out, as otherwise the heavy shock of the blast may disturb the flow condition and sometimes choke the existing passages, inducing a tendency for the sources of water to flow in the opposite direction.

(iv) *Placing Explosives*

While drilling of holes proceeds inside the well, the blaster, working outside, takes out gelignite sticks and detonators from their respective boxes. After a couple of holes have been drilled, the blaster alongwith his explosives and detonators enters the well and starts loading the holes with gelignite sticks. Usually two to two-and-a-half sticks are used per hole. The detonator cap is inserted at the lower end of the botom-most stick. Sometimes one or two-second's delay detonators are inserted in the outer holes (Fig. 55). This defers blasting of the portion near the well wall by a second or two as compared to the central portion and, thus, results in directing the force of the blast away from the well sides.



POSITION OF DETONATORS

The two wires on the lower end of the detonator are joined, one each to one wire from the adjacent hole on either side. These connections, in series, are continued till the last two wires, one each from the two adjacent holes are joined to 2 wires of the C.T.S. cable (Fig. 56). The other end of the cable extends to the exploder kept outside the well.

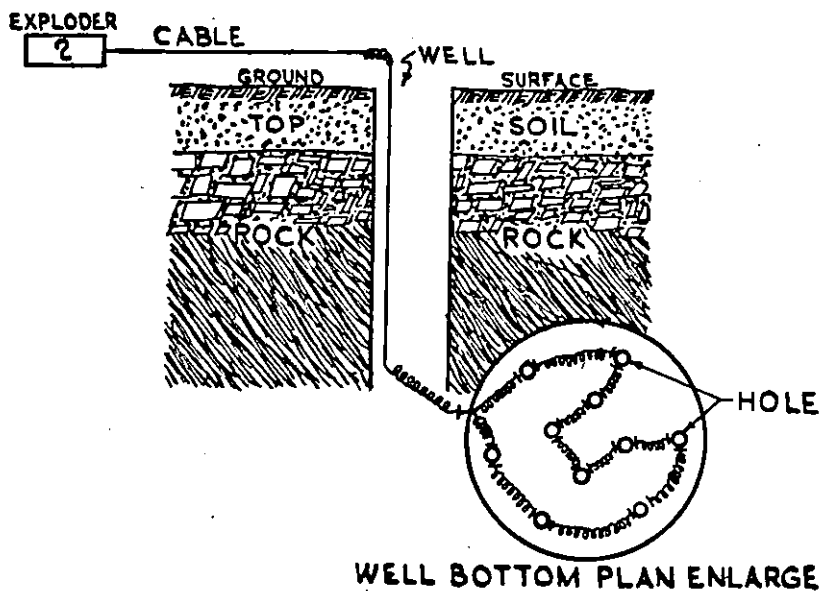


FIG. 56

### *Setting off the blast*

After the charges have been laid, a couple of pans containing sand are lowered inside the well. Sand is filled above the sticks in each hole and rammed by tamping with a wooden rod. In no case a metal rod is used for ramming the hole in which the gelignite sticks are already placed. When all the holes have been treated in this manner, the members of crew inside the well come out with the help of 'the rope and bucket' arrangement. The air hose, rock drill, empty sand pans, etc., are also taken out of the well. All those present at the site of the well and the crew retire to about 100 to 200 ft. from the well. The exploder and the haulage truck together with air compressor are also moved away. The length of the C.T.S. cable is kept sufficient for the purpose. After ensuring that everything has been removed and every person retired to a place of safety, the blaster starts winding the exploder by hand cranking. When the desired voltage has been generated and current stored, a light appears on this instrument. This is time for turning the switch marked with the word 'fire' on the instrument and the action results at once in setting off the blast.

### *Debris clearance*

After the blast has taken place, poisonous gases are produced in the well. It is not safe to enter the well and undertake clearing of debris for at least two to three hours after the blast has taken place. To accelerate the clearance of these gases, farmers sometimes fire big local bushes and throw them into the well. The shattered, broken and blasted material (Fig. 57) is usually cleared by the owner himself. For this purpose, he may have to employ about four bullocks and about 8 to 9 men for lifting the debris by means of the rope and the bucket lift. After clearing the debris, the owner and his men cut and smoothen all fissured stones and clear up cracks with chisels and hammers.

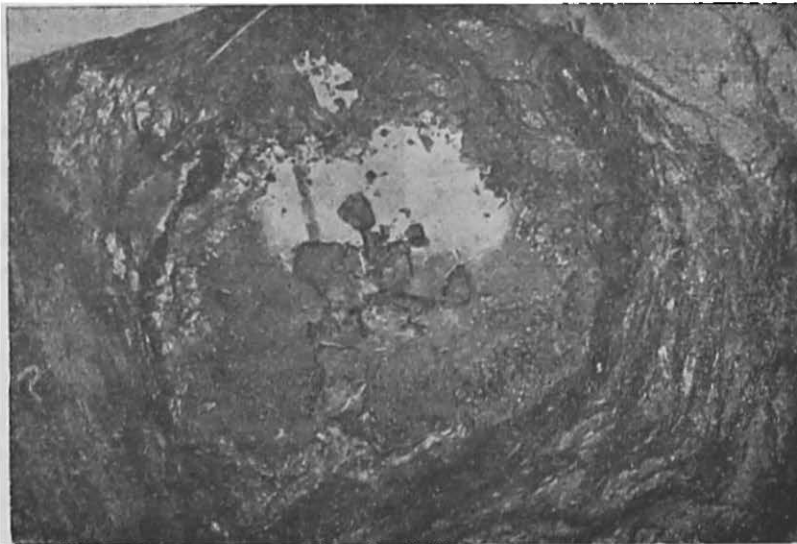


FIG. 57

### **Crew required for blasting operations**

The crew for each mobile unit usually consist of five members of which one is the truck-cum-compressor driver, one the borer for drilling holes, one the blaster for charging and blasting, and two cleaners or helpers for assisting in the driving and drilling operations. Alternatively, the crew may include separate drivers, one for each, the truck and the compressor, and there may be only one helper or cleaner, who is conversant with drilling operations.

### **Progress of deepening**

The clearance of debris, etc. takes considerable time after one blasting operation. For utilising this time and attaining maximum progress at comparatively economical cost, the blasting unit, after completing one blasting operation at one well, moves to the site of another well for undertaking similar work. After completing operation on the second well, the blasting



unit moves to the third well and so on. The unit returns in the same sequence for undertaking second and subsequent blasting operations on the original wells, after these wells have been cleared of debris from previous blasting operations. Working in a sequence in this manner, the blasting unit is able to fire about 40 to 50 charges (about 8 to 10 charges per blast) in a day covering about 5 wells. The well is normally deepened by about 1 ft. as a result of each blast. In the beginning when the top layers of rocks are tackled, or in rocks with hard stony surfaces, a blast may result in creating a cavity of 3 to 6 inches only. A better progress is obtained in the later stages when the rocks, initially more solid and compact, have been subjected to cracking and shattering influences of the previous blasts. The progress of even 3 ft. per blast is sometimes obtained in soft rocks.

#### **Common mechanical defects occurring in blasting operations**

The following mechanical defects commonly occur during the blasting operations, in the equipment used for the purpose. These may be prevented or tackled as indicated under :

(1) Jack hammers may fail due to wearing out of pawls and pawl springs, breakage of side rods, wearing out of drill steel holder, etc. It is necessary that jack hammers should be used with lubricator bottles so that the parts do not wear out quickly.

(2) Compressors may be over-heated due to improper working of unloader valves, loose belts, etc. This may result in reduction of cooling water circulation, thereby resulting in further over-heating and setting up of a vicious chain reaction. An eye should be kept on the temperature needle and the cause of over-heating removed as soon as the needle registers a temperature higher than the normal.

(3) The compressor may not develop proper pressure due to leakage of delivery or suction valves. These parts should be checked when the defect occurs.

(4) Oil may come in the air receiver due to wearing of rings or leakage of valves. The oil in air supply may cause undue wearage of air hose. Appearance of oil with air supply needs to be carefully watched.

(5) The drill bits gradually become blunt and inefficient as drilling proceeds. It is necessary, for efficient performance, that these should be sharpened periodically by means of pneumatic grinding machine.

## 16—ORGANISATION AND PROGRAMMING

PERUSAL of the foregoing chapters will show that the operations involved in boring and deepening of wells are fairly technical in nature and the cultivators left to themselves may not generally be able to do justice to these operations. In some isolated cases, they may be able to bore wells successfully, by using hand boring sets, while in some others, deepen the wells by their crude methods. By and large, however, it is desirable that, for sake of efficiency as well as economy, these operations should be handled by organised units on a systematic basis.

### Organisation

The technical organisation needed to undertake the work on statewise basis may be headed by a senior engineer, of the rank of Superintending Engineer or Executive Engineer, according to the size of the organisation required, with requisite number of Assistant Engineers under him. At the field level, the organisation should consist of mobile and compact units, separately for boring and deepening work. The crew required in each unit may conform more or less, to the following pattern :

#### *Boring Unit :*

- |                      |   |                      |
|----------------------|---|----------------------|
| 1. Truck driver      | 1 |                      |
| 2. Driller           | 1 |                      |
| 3. Assistant Driller | 1 |                      |
| 4. Helpers           | 2 | or more as necessary |

For units equipped with hand boring sets, additional 6 or 7 men may be required for operating the drill manually.

#### *Blasting Unit :*

- |                      |   |   |
|----------------------|---|---|
| 1. Truck driver      | 1 | } Ordinarily, only one truck-cum-com-<br>pressor driver may be sufficient |
| 2. Compressor driver | 1 |   |
| 3. Borer             | 1 |   |
| 4. Blaster           | 1 |   |
| 5. Helper            | 1 |   |

On an average about 2 to 3 such units can be placed under the charge of one Supervisor and 2 to 3 Supervisors together with the units under them, in turn, under one Assistant Engineer.

The over-all responsibility for speedy execution and good workmanship should rest with the Supervisor, who should stay at the site during operations, as far as possible, to expedite the progress of work and to see that the work is carried out properly. All the important decisions regarding the size, depth and type of the bore, location of strainers etc., spacing and size of holes for blasting would be taken by the Assistant Engineer. Assistant

Engineer will also be in the over-all charge of planning, as well as expeditions and successful implementation of the scheme in his jurisdiction.

For up-keep of instruments and undertaking timely repairs and replacements, it is essential that each boring or balsting unit should maintain a well-bound register in which details of equipment, accessories, tools, spare parts etc., with the unit, should be carefully entered. The record should include date and cost of purchasing equipment and also nature and dates of repairs and replacements carried out since the purchase of the equipment. A log-book giving the complete record of the work carried out and footage achieved by the equipment since its purchase should also be maintained.

### **Workshop and storage facilities**

For a successful operational programme, it is essential that the organisation should include adequate arrangements for supply, maintenance and repairs of the units. A well maintained central workshop and central stores, located at suitable places, should form an integral part of the organisation. In addition, there should be depot workshops and depot stores with each Assistant Engineer. This may further need to be supplemented by one or two good mobile workshops kept handy for attending to immediate field repairs.

Adequate arrangements are required to be made for storage and stocking of such parts of the equipment, as drill bits, drill rods, drill pipes, casing pipes, detonators, etc.; spare parts for equipment; oils and lubricants such as petrol, diesel oil, engine oils etc.; and other consumable stores. A continuous supply of these materials is very essential for sustaining a programme of operations un-interrupted by frequent and prolonged break-downs, or idle periods otherwise. To avoid break-downs, it is necessary to ensure that sufficient spares for the type of equipment used are stocked for about 2 years normal working of the equipment. These spares may be required in addition to the set of standard spares and tools supplied with the original equipment.

For storing and handling explosives, it is necessary that proper magazines should be constructed at convenient places. Portable magazines may be provided wherever necessary. In addition, it may also be essential to provide a couple of special vans for regular transport and supply of explosives.

### **Programming**

The units will be required to be constantly on the move in their respective jurisdictions for carrying out the boring and deepening programme from place to place. They may ordinarily cover a number of villages around the Central place, where they may, temporarily, be hauling. For quick and economical implementation of the programme, it is essential that infructuous journeys should be avoided and idle operation reduced to the minimum.

When in a region, the units should aim at tackling the largest possible number of wells in that area before proceeding to the next region. Handling of scattered wells is expensive and time consuming and must be avoided.

For efficient working of the blasting unit, it is particularly important that the unit should have enough work-load at a time (about 4 to 5 wells), so that the unit does not remain idle and minimum time is spent in covering distances from one well to another.

Systematic execution of work in this manner can be ensured by chalking out, in advance, a programme of work to be carried out in each area. The advantages of boring and deepening should be carefully explained and demonstrated to the cultivators, so that they may be persuaded to go in for these in large numbers. The assistance of the local Community Development and other staff should be taken and the programme announced in the Development Blocks well in advance so that the farmers may adjust their other operations accordingly. There should be proper co-ordination at the District level so that collection of applications, sanction of financial assistance and other procedural formalities are completed well ahead of the schedule of actual operations to be undertaken on the wells of cultivators.

When the organisation has boring units having more than one type of boring equipment, allocation of areas to the units should be made after taking into consideration the comparative suitability of the equipment for conditions to be met with in those areas.

## 17—ECONOMICS

THE Department-owned boring and blasting units should be able to levy a fixed charge per foot depth of boring or deepening, based on the experience gained and records kept of actual expenditure involved on such operations. The rate should preferably be fixed on no-profit-no-loss basis. The rate per foot would actually vary widely from place to place, depending upon the strata conditions met with, even from well to well in the same region. An approximate indication of these rates and how they may be analysed is given in the following paragraphs.

### Boring

The actual rates will depend, besides strata conditions and various unforeseen difficulties met with during actual operations, on the size of bores and type of boring, that is, whether it is completed as a cavity well, strainer well or a gravel pack well. Under ordinary conditions, the over-all rate may have itemwise break-up in the ranges as indicated under :

- (1) Drilling including cost of operation, depreciation and transport. Rs. 5 to Rs. 15 per running ft.
- (2) *Cost of pipe :*
  - (i) Cost of plain pipe, slotted pipe and wire mesh in case of strainer walls, or gravel packing in case of shrouded wells—average rate Rs. 15 to Rs. 30 per running ft.
  - (ii) Cost of plain pipe in cavity wells Rs. 7 to Rs. 15 per running,ft.
- (3) Extraction of casing pipe Re. 1 to Rs. 2 per running ft.
- (4) Development charges Re. 1 to Rs. 3 per running ft.

It will be apparent from above that in case of bores not requiring any casing pipe, the cost per foot of boring may be as low as Rs. 5. In case of cavity-bores, where the original casing pipe used is of cheap variety and is not replaced by another set of casing pipe and strata conditions are favourable to boring, the cost may work out as low as Rs. 12 per running foot. In strainer-bores or gravel-pack-bores, provided properly with screens or gravel packing, etc., and developed fully, the cost of boring may vary from Rs. 22 to Rs. 50 per running foot.

### Blasting

For a well of 8 to 10 ft. diameter, the rate per foot depth of blasting may vary from Rs. 40 to Rs. 50. Break-up of expenditure per day on the

operation and running of the blasting unit may be somewhat on the following pattern :

<b>(1) Cost of operation</b>		
<b>(a) Operating staff :</b>		
(i) Pay and allowances of truck-cum-compressor driver		Rs. 130.00 per month
(ii) Pay and allowances of Blaster		Rs. 150.00 " "
(iii) " " " " Borer		Rs. 130.00 " "
(iv) " " " of 2 Cleaners		Rs. 160.00 " "
		<hr/>
		Rs. 570.00 " "
Travelling and other field allowances, say		Rs. 180.00 " "
		<hr/>
		Rs. 750.00 " "
		<hr/>
	<i>i.e.</i>	Rs. 25.00 per day
		<hr/>
<b>(b) Oil and lubricants :</b>		
(i) 10 gallons of diesel oil		Rs. 29.00 " "
(ii) $\frac{1}{2}$ gallon of mobil oil		Rs. 5.00 " "
(iii) Grease, cotton waste, etc.		Rs. 1.00 " "
		<hr/>
	<b>TOTAL</b>	Rs. 35.00 " "
		<hr/>
<b>(c) Bits and explosives :</b>		
(i) 15 lbs. of gelnite		Rs. 40.00 per day
(ii) Electric detonators		Rs. 20.00 " "
(iii) Drill bit (depreciation)		Rs. 10.00 " "
		<hr/>
	<b>TOTAL</b>	Rs. 70.00 " "
		<hr/>
<b>(d) Total daily expenses on operation</b>		Rs. 130.00
		<hr/>
<b>(2) Cost of maintenance (average per day)</b>		Rs. 15.00
		<hr/>
<b>(3) Depreciation charges—these will depend upon capital cost, life of the machinery and the number of days of operation in a year—</b>		
on an average per day		Rs. 40.00
<b>(4) Over-heads on account of storage charges at 10% of the cost of items (b) and (c) under (1) above—</b>		
on an average per day		Rs. 10.00
<b>(5) Supervision charges, office establishment and other miscellaneous expenditure—</b>		
on an average per day		Rs. 5.00
		<hr/>
	<b>Total Daily Expenses</b>	Rs. 200.00
		<hr/>

Total depth blasted in a day at about one foot on an average in 4 to 5 wells will work out to 4 to 5 feet. Therefore, cost of blasting per foot depth will vary between Rs. 40 to Rs. 50 on 'no-profit-no-loss basis'.

## 18—SOME DO'S AND DONT'S FOR BORING AND DEEPENING OPERATIONS

### BORING

#### Do's

(1) Before starting boring, maximum possible data should be collected from borings, if any, carried out on adjoining or nearby wells. This data should be carefully examined for making a preliminary decision as to the size and the type of bores to be carried out.

(2) The casing pipe used for drilling a bore to be installed with strainer, should be at least 2 inches wider than the size of the strainer.

(3) The record of strata encountered during drilling should be maintained carefully in a register by the driller at site. The record should also include information on the morning and evening water levels.

(4) Samples of clay should be kept for every 5 ft. and those of sand for every 10 ft. of the strata encountered. Samples should be sufficient in quantity and should be kept in Polythene bags inside a wooden box.

(5) In the case of wells in which vertical turbine pumps are proposed to be installed, verticality test should be carried out before the casing pipe is lowered in the housing pipe for telescopic boring or before the boring is carried out to a depth below 80 ft. or so in case of direct boring.

(6) The lengths, location and type of strainers or slotted pipes to be installed in the well casing should be decided by the Assistant Engineer incharge of the boring operations after carefully examining the strata samples and strata chart.

(7) Utmost care should be taken in preparing the screen assembly according to the sketch approved by the Assistant Engineer. The separate lengths in the assembly should be numbered from the bottom of the tube upwards.

(8) The strainer should be despatched to the site, duly packed with dry grass or dried rice leaves in special boxes.

(9) The plain pipes and strainers should be lowered in the well in numerical order. The joints between pipes or the strainers should be fully tightened before lowering.

(10) The unlined portion of bore, if any, below the bail plug should be filled with coarse sand and well-rammed, before the assembly is lowered.

(11) The gravel used for shrouding slotted pipe with 1/8" slots should consist of hard well-rounded particles reasonably uniform in diameter and should be 1/8" to 5/16" size. Central guides should be fitted one at the top, second in the middle and third in the bottom to keep the assembly centrally in position while feeding the gravel.

(12) The development should be carried out by air compressor followed by over-pumping till :

- (a) The well ceases to absorb further gravel and the gravel pack is completely established; (in case of gravel pack wells)
- (b) Depression ceases to improve ;
- (c) Discharge ceases to improve ; and
- (d) The water is sand-free with a tolerance of say 10 parts per million by volume.

(13) The cavity well should be tried only after the suitability of clay and the quality of sand below the clay layer has been approved by the Assistant Engineer.

(14) The cutting shoe at the lower end of the pipe in cavity bores should be left about 2 ft. above the bottom of the clay layer.

(15) Cavity well should be developed by means of an over-sized capacity pump set.

(16) The screen assembly must invariably be provided with a tightly closing blind cap at the top after the assembly has been lowered and till the erection of the pumping set is completed.

### **Dont's**

(1) Do not use an expensive method of boring such as core drilling, etc., when the same work can be done by more economical methods.

(2) Do not go in for a deep or large diameter boring, if shallow and a small diameter bore is enough to meet the irrigation requirement of the cultivator.

(3) Do not go in for a strainer boring with or without gravel pack, if cavity wells are considered feasible under the strata conditions met with.

(4) Do not develop a cavity well by air compressor.

(5) Do not, normally, drive the casing pipe ahead of drilling in case of percussion method as this practice has a tendency to compact the water bearing stratum and reduce its permeability.

(6) Do not use such mud-fluid, in rotary boring, that may have a tendency to choke the water bearing formation.

(7) Do not take hasty steps to recover a jammed or lost tool from the hole. Hasty steps, without adequate appraisal of the situation, may only result in making the recovery of the 'fish' more difficult.

(8) Do not insist on a pump-set installation, if the water available in the well even after boring can be conveniently lifted by an animal operated water lift appliance or if the requirement of the cultivator is of low order.

### **BLASTING**

#### **Do's**

(1) Holes should be planned and drilled to suit the nature of rock formation met with.



(2) Tamping of charged holes should be proper as otherwise the charge may result in a misfire.

(3) In case a charge misfires, fresh holes should be connected with the old hole by detonator wires, so that it would blow off earlier charge also when fired.

(4) Partial or delayed blasting should be resorted to suit strata conditions.

(5) All possible care should be taken in proper handling, storage and transport of explosives. These should not be exposed to direct heat of the sun or other inflammable sources. Proper magazines apart from dwellings and other important buildings should be specially provided if a large stock or storing over a longer period is contemplated. The detonators should be kept in a separate box entirely apart from the gelignite sticks.

#### **Dont's**

(1) Do not enter the well for at least 2 hours after blasting to avoid exposure to poisonous gases.

(2) Do not drill holes through crevices from which water sprouts as otherwise the source may get choked and water may develop a tendency to flow in the opposite direction.

(3) In no case should tamping of holes, charged with explosives, be done by a metallic rod.

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