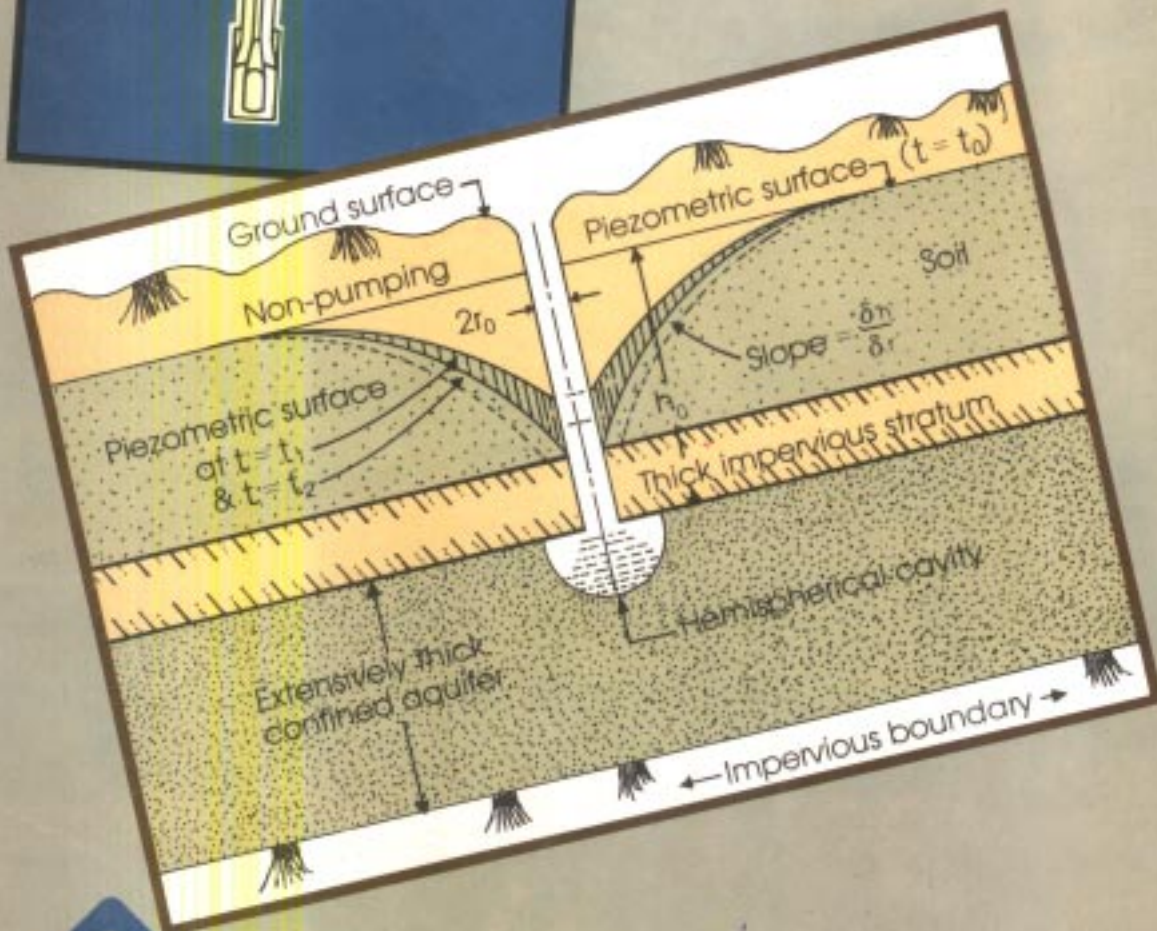
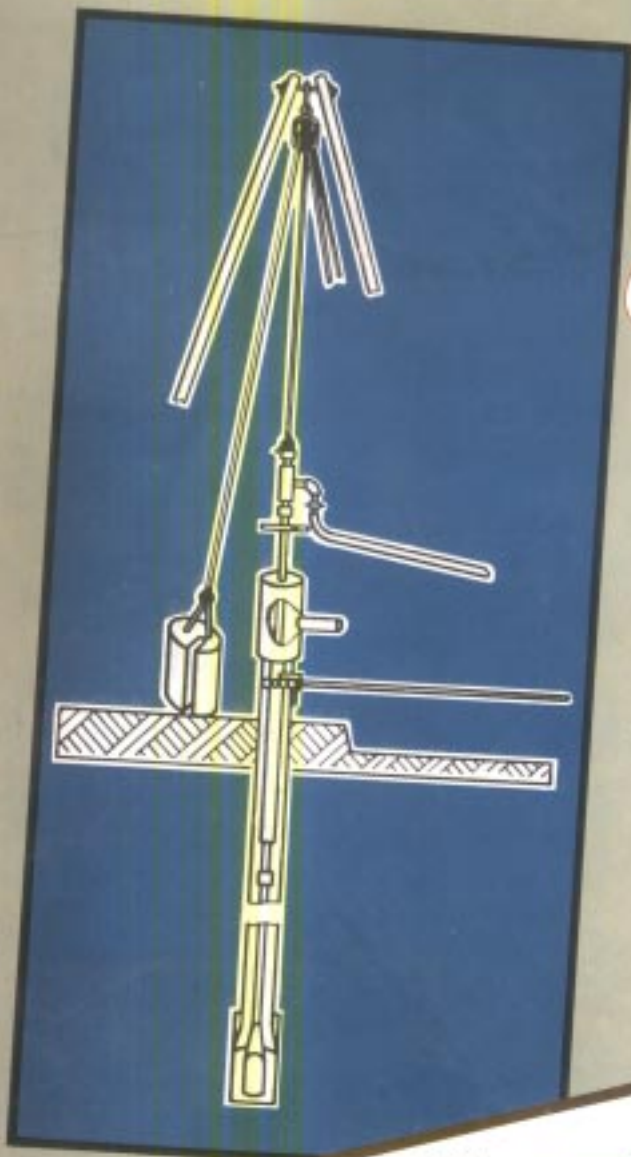


# LOCATION, OPERATION AND MAINTENANCE OF TUBE/ BORE WELLS — GUIDELINES



**LOCATION, OPERATION AND  
MAINTENANCE OF TUBE/BORE WELLS  
—GUIDELINES**

**BUREAU OF INDIAN STANDARDS  
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG  
NEW DELHI 110002**

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FOREWORD

As a signatory of the Alma Ata Declaration 1977, Government of India decided to provide potable water for all by 1991, during the International Drinking Water Supply and Sanitation Decade (1981-91).

Considerable work has been done in India towards this laudable objective. Cost effective technologies have been identified and pushed through. The work gained momentum after the launching of the National Drinking Water Mission (now named after Rajiv Gandhi) in 1986.

In the present programme for supplying water to the rural population, nearly 1,25,000 handpumps are installed every year. The deep well handpump India Mark-II and its improved version India Mark-III and the shallow well TARA pumps have brought in significant improvement in the rural water supply sector in the country. All but 750 identified problem villages have been covered with atleast one safe source by the end of March, 1993. These 750 villages are also expected to be covered during 1993-94.

At the request of the Rajiv Gandhi National Drinking Water Mission, the Bureau of Indian Standards has compiled a handbook, containing extensive information on the location, operation and maintenance aspects of tube/bore wells. The compendium contains a comprehensive and analytical study of all the technical aspects of ground water exploration, water quality, well drilling and design parameters, and maintenance and rehabilitation of tubewells. The chapters on well casings and screens, gravel packing, well development techniques and well completion have been discussed in depth. The Annexures to the handbook also contain a summary of the latest techniques for ground water exploration like satellite imagery, a glossary of the technical expressions and a list of all the relevant Indian standards issued by the Bureau of Indian Standards.

This book, which elaborates the Guidelines and Standards in the field of ground water development, would be very useful for the field Engineers and the officers who are engaged in ground water projects.

October 4, 1993

  
(Nirmala Buch)

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भारतीय मानक ब्यूरो

मानक भवन, 9 बहादुरशाह जफर मार्ग, नई दिल्ली 110002

**BUREAU OF INDIAN STANDARDS**

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002

P R E F A C E

The Bureau has been actively associated with the Rajiv Gandhi National Drinking Water Mission. It has significantly contributed to the Mission by way of Quality Assurance services through a cell namely Quality Assurance for Water Supply Mission (QAWSM).

Bureau's contribution primarily focusses on quality in the materials/products, construction/installation, operation and maintenance of works by way of formulation of standards in order to ensure uniformity, save time and resources at least in repetitive items. As further contribution to Water Mission, Bureau conducts training programmes on

- i) Statistical quality control for BIS licensed manufacturers
- ii) Sampling and testing of products/materials for organised purchasers.

It also conducts awareness programmes for water supply engineers for effective interaction and feed back, BIS also provides third party certification for products which helps users in choosing products conforming to Indian Standards thereby avoiding further inspection and testing.

A strong has been felt during the interactions for concise Handbook based on Indian Standards on some subjects of water supply to cover it fully.

This Handbook on Tubewells and Borewells is based on materials from more than 95 Indian Standards and inputs provided by various organizations in this field and gives a comprehensive idea of the subject.

Other handbook in the series, on Pipes and Pipe Fittings is already issued and Book on Pumps will be issued shortly.

Use of this Handbook will go a long way in enhancing the life of the water supply project in the form of assured quality and quantity of drinking water in the rural environment and in meeting the objectives of Water Mission.

N.S. Choudhary

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## INTRODUCTION

As society demands larger and larger quantities of fresh, potable water, the utilization of groundwater, which constitutes major part of the world's total fresh water supply and is largely uncontaminated, is becoming vitally important. This marked trend towards development of groundwater sources either integrated with or in preference to surface water sources offers a major advantage in the rural environment. Thus if a well is located judiciously in relation to existing or future sources of contamination, it assures supply of reasonably safe water.

A full groundwater management strategy involves surveys to locate the water-bearing strata, methods of defining the aquifer geometry and determining its capacity and water quality, design of suitable methods of groundwater withdrawal, and measures to regulate its exploitation and ensure its protection from contamination.

The amount of information about groundwater needed to ensure reliable designs for rural water supply schemes varies considerably from region to region. The effectiveness and reliability of the programme can be significantly influenced by proper consideration of the local groundwater conditions. Problems typically arise when designers fail to recognize seasonal movements in the water table or competing demands from irrigation pumps, or when low yielding aquifers are developed without allowing for drawdown which will arise during pumping, or when the chemical quality of the water makes it unpalatable or corrosive. Any large scale water supply programme should, therefore, include preparatory groundwater studies, geophysical surveys and continuous monitoring and record keeping.

Proper well design, its construction and development considerably improves the long term performance of the tubewell and reduces the chances of clogging of screen, sand content in water, contamination of water and other failures.

This guide aims to consolidate the available technical information on design, construction, operation and maintenance, chiefly from the wealth of practical, proven ideas contained in various Indian Standards and other publications from specialised agencies on the subject.

List of relevant and referred Indian Standards is given as Annex A and for the purpose of these guidelines the definitions, used are given in Annex B.

These guidelines have been compiled at the behest of the Rajiv Gandhi National Drinking Water Mission. BIS wishes to place on record its acknowledgement for the support and guidance received from the Mission from time to time.

Acknowledgements are also due to the following who have provided inputs in compilation of these guidelines in the form of informations and critical comments:

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# CHAPTER 1

## GROUNDWATER EXPLORATION

### 1 GENERAL

There is some water under the earth's surface almost everywhere. Locating groundwater, however, means determining where the water occurs under conditions that permit its sustained withdrawal through a well fast enough and over long periods to be useful and economical. The application of scientific methods and appropriate techniques for locating sites and drilling wells help accomplish this objective.

Groundwater may serve as a reliable source of water for various purposes. However, if withdrawal of groundwater exceeds its replenishment, it may cause several hazards like excessive decline in groundwater level, land subsidence, seawater intrusion into coastal aquifers, undesired reduction or cessation of spring flow and accumulation of contaminants.

Groundwater occurrence in an area is controlled by a number of factors like meteorological features such as precipitation, evapotranspiration, temperature and humidity, hydrogeological set-up, geomorphology, soil type and drainage. The spatio-temporal diversity in these conditions gives rise to wide variations in groundwater potential in different regions. A multidisciplinary approach is, therefore, imperative for the identification of water-bearing formations and the location of suitable sites for wells.

### 2 FEATURES TO BE INVESTIGATED

**2.0** The following features of an area have a significant bearing on the groundwater potential and should therefore be investigated under a scientific programme of groundwater exploration.

#### a) Physiography

The physiography and drainage of the area have a vital role in the groundwater regimen. Since the ground and surface waters are interrelated, the study of the basin as a whole comprising a) the recharge zone, b) groundwater flow regime and c) discharge zone is necessary to obtain a reliable estimate of groundwater potential.

#### b) Climatology

The study of climatological factors is imperative to assess the ground water potential of the area since meteoric precipitation is the source for groundwater. Other factors like evapo-transpiration, sunshine, wind velocity etc. govern the water losses to the atmosphere and determine the balance amount which can infiltrate into the aquifers after runoff losses.

#### c) Geology

The geology of the area as revealed by a geological map is an indicator of ground water potential of the area as rock types, structures etc. control the movement and storage of water in sub-terranean formations. An area underlain by rocks usually has less potential than the semiconsolidated and unconsolidated formations.

#### d) Water Table

The water table fluctuates with recharge and discharge of ground water regimen of an area at a given time and is an important parameter describing the state of the aquifer.

#### e) Water Quality

The chemical characteristics of water control its use for various purposes, therefore, an assessment of quality of water based on its anticipated use is necessary.

#### f) Land and Water Use

The land and water use of an area gives the status of surface and ground water utilization indicating the possibility of further development.

### 2.1 Information to be Collected

Keeping the above in view, appropriate investigations should be carried out to collect the following information to evaluate the groundwater potential of the area and plan optimal development of groundwater resources. The time variant data should be collected for as long as possible.

**2.1.1 Physiography**

- a) Location of the area,
- b) The basin/sub-basin to which it belongs,
- c) Topographic features, and
- d) Drainage : number of rivers, streams, etc.; their flow characteristics; catchments, runoff, width and thickness of stream and river beds, the physical characteristics of the material of beds; nature of incoming and effluent streams.

**2.1.2 Climatology**

- a) Rainfall : Annual, monthly, rainy days, storm precipitation and their duration, average rainfall,
- b) Temperature : Daily (Max., Min.), Monthly (Max., Min., Average),
- c) Wind : Speed and direction (monthwise/seasonwise),
- d) Humidity : Daily (Max., Min.), Monthly (Max., Min., Average),
- e) Atmospheric pressure : Daily (Max., Min.), Monthly (Max., Min., Average), and
- f) Solar radiation.

NOTE — The average estimates for climatological factors shall be based on a minimum of 30 years of record in view of their wide variations.

**2.1.3 Hydrogeology**

**a) Geology**

- 1) Nature of rocks: Igneous, metamorphic or sedimentary, Physical characteristics—extent, structure, Sub-surface geological information from the well and borehole logs;
- 2) Lithological and water-bearing characteristics of the formations: Hydrologic characteristics viz., permeability, transmissivity and storage coefficient/specific yield;
- 3) Water level data (reduced to mean sea level) in different aquifer zones viz. unconfined, semi-confined and confined

(as may exist); spatial density and frequency of measurements to be decided depending upon hydrogeological conditions. (This data should be collected on a continuing basis);

- 4) Delineation of recharge and discharge areas
- 5) Delineation of surface and groundwater divides;
- 6) Delineation of spring lines, if existing;
- 7) Delineation of surface flow losses;
- 8) Delineation of swampy and high water table area, if any; and
- 9) Geomorphology of the area.

**b) Hydrochemical Characteristics**

- 1) Chemical quality of surface waters;
- 2) Chemical quality of groundwater;
- 3) Any noticeable health hazard due to quality of water;
- 4) Suspected cause of deterioration of quality due to increase in mineral constituents;
- 5) Possibility of pollution due to sewage, industrial waste, oil well etc; and
- 6) Salinity problem including sea water intrusion.

**c) Land and Water Use**

- 1) Soil characteristics (physical & chemical), in-situ or transported soil;
- 2) Domestic supply (present and projected);
- 3) Irrigated area (present and projected);
- 4) Area under different types of crops, crop pattern and cropwise water requirement;
- 5) Sources of water for irrigation;
- 6) Method of irrigation; number, time and amount of watering;
- 7) Type and number of groundwater extraction structures (open wells, tube/bore

- wells, dug-cum borewells etc.); their depth, diameter, spacing and yield characteristics, number of pumps (electric/diesel) and pumping period;
- 8) Total draft (present and projected);
  - 9) Status of electrification and further plans;
  - 10) Surface water reservoirs; data on reservoir levels, water release etc (for a period 10 years);
  - 11) Water sources for industrial supply (present and projected); and
  - 12) Status and possibility of conjunctive use of surface and groundwater.
- d) Springs and swamps — Temperature, discharge, quality of water from springs and swamps.

**2.1.4** The location of ground water extraction structures, surface water reservoirs, climatological observation stations, stream gauging stations and sampling points should be indicated on the maps to appropriate scales.

**2.2** After processing the data collected, hydrogeological maps, water table/piezometric contour maps, water depth maps, water quality maps, groundwater potential maps etc. should be prepared.

### 3 PRELIMINARY INVESTIGATION

The investigations described below will help identify the most promising areas for economic development of groundwater:

#### 3.1 Preparatory Study

- a) The following information, if available, is useful in giving an idea of water-bearing areas and their potential, and deciding the location of the drilling sites:
  - i) Topographical maps (scale 1:50,000)
  - ii) Geological maps (scale 1:50,000)
  - iii) Hydrogeological maps (scale 1:50,000)
  - iv) Aerial photographs (scale 1:50,000)
  - v) Satellite imageries (scale 1:250,000)

- b) Making an inventory of the existing wells, if any. The main sources of information would be well logs pertaining to the drilling and construction of wells.
- c) Making a water-table map in the form of contours joining points of equal elevation of water table and showing the shape of the water table in the same way that topographic map shows the shape of the land surface, gives a clue not only to the depth below which groundwater is stored but also, from the slope of the water table, to the direction in which water is flowing.
- d) Besides, in groundwater investigation involving field work, consideration should be given to the accessibility to the study area by personnel and equipment. Such aspects of the area as location, extent, topography, transportation facilities, land ownership patterns and climate should be determined prior to planning field work.

#### 3.2 Remote Sensing

Remote sensing is a means of initial reconnaissance which allows areas to be evaluated for further detailed investigation and represents a vast saving in time and effort where new water supplies are needed in large, relatively undeveloped areas. The remotely sensed data permits inference of subsurface hydrological conditions through surficial expression of the aquifers.

##### 3.2.1 Satellite Imagery

Remote sensing through satellite imagery provides a fast means for reconnaissance of large areas and delineation of regions where detailed investigations are to be carried out. Satellite imagery and the multispectrum data derived from them provide useful information on lithology, landforms, land use, soil type and geomorphology for broad delineation of zones having good groundwater potential. Information on lineaments (faults, fractures, fissures etc.) is very important for groundwater exploration particularly in hard rock areas. The intensity of fracturing, jointing or folding can also be derived from satellite imagery. Landforms such as alluvial fans, buried channels, valley fills, etc. which have a significant bearing on the occurrence of groundwater may also be identified. Annex C

and Annex D list the features which may be seen on satellite imagery and help detect potential areas of groundwater occurrence. The data leads to the preparation of regional groundwater potential maps on a scale of 1:100,000 to 1:250,000 with a resolution of 10-30 m. These may be enlarged by intergrating and superimposing on a geological map or a topographical survey sheet in the scale of 1:50,000 which becomes a vitally important base map for further detailed investigations. The accuracy of interpretation shall be checked by carrying out field traverses before preparing the final hydrogeomorphological map. Annex E gives the sequence of investigation by the use of satellite imagery.

### 3.2.2 Aerial Photographs

Aerial photographs also provide a rapid means of identifying groundwater potential.

These photographs provide greater details than satellite imagery and greatly facilitate the preparation of hydrogeomorphological maps. The delineation of the most and least promising areas for groundwater studies can be indicated on such maps. These maps aid in selecting test-drilling sites and reducing costs of groundwater investigations.

The use of aerial photographs in groundwater investigation is based on the fact that the occurrence of groundwater is closely related to the characteristics of the terrain. Vegetation, tone, texture, land form and use, drainage pattern, erosion, colour and special ground features are apparent on aerial photographs and are direct indicators of subsurface conditions. The surficial features identifiable in aerial photographs that aid in groundwater evaluation are given in Annex F. In some areas, aerial photographs may serve as a substitute for topographic maps. If the photographs have been taken with sufficient overlap, they may be used with a stereoscope to obtain a three dimensional view of the terrain.

It is possible under certain conditions to determine from aerial photographs the chemical quality of water. A general familiarity with the terrain and the local plant types may be necessary in order to interpret aerial photographs with maximum effectiveness. Indications of ground water depend upon the correlations between water salinity and plant

species. The hydrobotanic inferences will need subsequent field investigation.

Aerial photographs may be prepared from black and white, infra red monochrome, true colour or false colour films.

## 4 FIELD INVESTIGATION

The purpose of the field investigation is to establish by surface and subsurface methods, the actual hydrogeology of the the area and to study the occurrence, distribution and quality of ground water.

### 4.1 Hydrogeological Survey

As a first step, a reconnaissance should be carried out with a minimum of time and equipment. The region is criss-crossed in a widely spaced grid pattern and all possible geological and hydrogeological observations made covering the structure of the land, estimate of the permeable areas, number of springs, state of vegetation, estimates of degree of aridity etc. The important surficial features noted on the topographic maps and aerial photographs are examined in greater detail for evidence of groundwater. The information may be used as a guide to determine the specific geophysical investigation to follow.

It is essential to study groundwater occurrence in terms of the lateral and vertical extent of the aquifer recharge and discharge areas and the hydraulic characteristics of the aquifer. Careful geologic inspection of an area will often indicate the extent and regularity of water bearing formations, the type of rock to be expected and the regularity of important aquifers. The availability of sources of natural recharge from streams and discharge to springs can also be delineated from such reconnaissance.

#### 4.1.1 Instruments Required

The main instruments for hydrogeological exploration include the following:

- a) Water level measuring tapes,
- b) Continuous water level recorders without moving parts (floats etc.), and
- c) Electrical conductivity meters, pH meters and thermometers.

## 4.2 Geophysical Surveys

Essentially, geophysical methods comprise measurement and interpretation of signals from natural or induced physical phenomena generated as a result of spatial changes in one or more physical properties of a sub-terranean formation. These signals measured repetitively at several points of space and time are appropriately interpreted, considering the available geological information, in terms of such sub-surface structures/features as may themselves have good groundwater potential or are indicative of good aquifers. In favourable situations, these methods may even yield useful information, albeit indirectly, on some characteristic parameters which might, in turn, help quantify the groundwater potential in the surveyed area.

**4.2.1** Geophysical methods make use of various physical characteristics such as density, elasticity, magnetic susceptibility, electrical resistivity and radioactivity. Depending upon the scale of operations, geophysical surveys can help delineate regional hydrogeologic features or pin-point locations for drilling of boreholes. Geophysical surveys, though costlier than hydrogeological investigations, can appreciably reduce much more costly infructuous drilling, specially in hard rock areas.

**4.2.2** A reliable interpretation, of geophysical survey data requires a good knowledge of geology and subsurface controls in the area. Therefore a geophysical survey should preferably be started near an outcrop or a bore hole where subsurface conditions may be better known.

**4.2.3** The four basic methods of geophysical surveying available are : Gravimetric, magnetic, electrical resistivity and seismic. The first two methods depend on the measurement of the variations in the intensity and direction of natural forces of gravity and magnetism. The latter two depend on the electrical or mechanical excitations respectively of shallow regions of the earth's crust and measurement of the spatially variant response of subsurface materials to these excitations. The gravimetric and magnetic methods, however, have very limited applicability in groundwater investigation since these methods do not directly indicate occurrence. In recent years, methods based on radioactivity measurements such as helium detectors have also come into use, particularly for detection of fractures in hard rocks.

### *4.2.4 Electrical Resistivity Method*

This method is the most commonly used geophysical method and has a direct relevance to the occurrence of groundwater and its quality in the subsurface formations.

**4.2.4.1** The method is based on the principle that the magnitude of electrical current that can flow through a formation to which an electrical potential is applied depends on its electrical resistivity. The latter, in turn, is dependent on material as well as porosity and water content of the formation. It has been observed that the electrical resistivity of a dry formation is much more than that of the same formation when it is saturated with water. Broad values of resistivity for various materials are given in Table 1.

Table 1 Resistivity Ranges of Various Materials

Material	Resistivity Ranges (Ohm.m)	
	Almost Dry	Aquifer zones <sup>1)</sup>
Clay	30-10 <sup>2</sup>	3 - 15
Fine sand	—	10 - 30
Medium sand	150 - 2×10 <sup>3</sup>	20 - 60
Coarse sand	—	50 - 100
Basalt	4×10 <sup>4</sup> - 1.3 ×10 <sup>8</sup>	10 - 50
Sandstone	9.6×10 <sup>3</sup> - 6.4×10 <sup>9</sup>	10 - 500
Granite	10 <sup>3</sup> - 10 <sup>6</sup>	50 - 300
Quartzite	4.4×10 <sup>3</sup> -2×10 <sup>8</sup>	50 - 500
Gneiss	6.8×10 <sup>4</sup> - 3× 10 <sup>6</sup>	50 - 350
Dolomite	350 - 5×10 <sup>6</sup>	50 - 1000
Limestone	600 - 10 <sup>7</sup>	50 - 1000
Gravel	—	80 - 150

<sup>1)</sup> In case of a hard rock, an aquifer zone implies that formation has a secondary porosity due to weathering, fracturing, etc., and is saturated with water.

**4.2.4.2** The electrical resistivity surveys may comprise profiling and/or sounding. While the latter is used to determine the resistivity variations with depth, the former is used for determining lateral variations of electrical resistivity of subsurface formations.

**4.2.4.3** In the electrical sounding method, the electrodes are moved farther and farther apart which enables current to penetrate progressively deeper and measurement of the resistivity of a constantly increasing volume of earth. The electrodes are normally arranged along a straight line, the potential electrodes being placed inside the current electrodes and symmetric with respect to the centre of the electrode configuration. The commonly used configurations are Wenner's configuration and Schlumberger's configuration. The apparent resistivity,  $\rho_a$  is calculated as follows:

$$\rho_a = 2 \pi a R \text{ (Wenner's), in ohm-m}$$

$$\rho_a = \frac{\pi (L^2 - l^2)}{2l} \times R \text{ (Schlumberger's), in ohm-m}$$

$a$ ,  $L$  and  $l$  are as shown in Figure 1, in  $m$  and  $R$  is the resistance measured in ohm.

In Wenner's configuration, the distances between all four electrodes are equal; in Schlumberger's configuration, the separation of electrodes is less than or equal to one fifth separation of the current electrodes.

**4.2.4.4** The apparent resistivity is plotted against the electrode separation. This resistivity curve is then interpreted in terms of horizontally stratified earth thereby obtaining the number of layers, their thicknesses and resistivities with the help of available standard curves. The interpretation can be further refined through forward modelling using a small computer. Standard interactive computer programmes are available for this purpose.



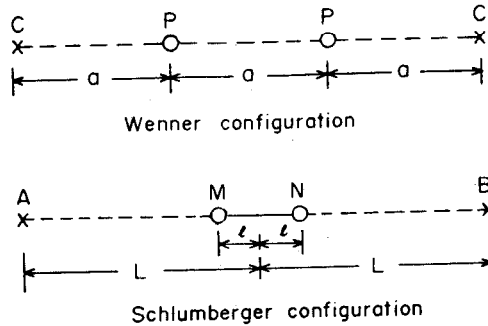


FIG. 1 WENNER AND SCHLUMBERGER ELECTRODE CONFIGURATION FOR ELECTRICAL RESISTIVITY SURVEYS

**4.2.4.5** While the electrical method is very useful for groundwater exploration, it has the following limitations :

- Any nearby high-tension power lines or electrical sub-stations etc. give rise to disturbances and the signals from the subterranean structures may get greatly masked/distorted unless special filters are used with the equipment;
- The strength of the signal progressively reduces with the increase in the depth of exploration. The method does not provide satisfactory quantitative results if the potential aquifers are very thin compared to their depth of occurrence. Also, if the potential aquifer does not have sufficient resistivity contrast with the overlying and underlying formations, the signal may not be discernible, and
- In hilly terrains or other areas of undulating topography the data interpretation is very difficult.

#### 4.2.5 Seismic Method

It is based on the principle that seismic waves follow the same laws of propagation as light rays and are reflected or refracted at any interface where a seismic velocity change occurs. The waves are induced by a mechanical shock at the earth's surface or at a certain depth below it either by the impact of a heavy contrivance like sledge hammer or by exploding a small dynamite charge. The time required by the the resulting shock wave to travel known distances is measured by picking it up by

means of vibration detectors (geophones) arranged in a pre-designed configuration.

**4.2.5.1** The velocity of the wave depends on the media through which it travels; it is the least in the unconsolidated formations, increases with the degree of consolidation and is the greatest in solid igneous rocks. The seismic wave velocities in different materials are given in Table 2.

Table 2 Velocity of Seismic Waves in Different Materials

(Clause 4.2.5.1)

Material	Velocity m/s
Weathered soil horizon	100 - 500
Sand	300 - 800
Alluvium	500 - 2500
Clay	1200 - 2500
Sandstone	1500 - 4000
Shale	2700 - 4800
Limestone	2500 - 6500
Granite	4000 - 7000

**4.2.5.2** The seismic method using explosives as a source of energy is particularly suited for use in large areas, but the introduction of energy mechanically by means of a hammer may be preferable for environmental reasons more so for exploration of shallow depths.

**4.2.5.3** This method requires special equipment and trained staff. The field procedure for seismic investigations has been simplified in recent years with the aid of compact and efficient instruments. The shock waves are detected by geophones and the signal is converted into electrical impulses which are amplified and recorded on an oscillograph in an analog fashion or more recently in digital form on magnetic media. Interpretations to a depth of a few hundred metres are possible with this type of equipment.

#### 4.2.6 Instruments

Various field instruments required for geophysical surveys and hydrogeological investigations need to be very carefully selected. Main instruments deployed for groundwater prospecting include the following :

- d.c. electric instruments;
- Electromagnetic unit useful in areas where surface resistance is high; and
- Magnetic instruments to locate hidden dykes etc.

Salient features and specifications of some of the electrical resistivity equipment which may help to select an appropriate instrument for a given cost of operation are given in Annex G.

## 5 EXPLORATORY DRILLING

**5.1** In order to avoid infructuous expenditure, it is desirable to drill an exploratory test borehole, particularly in a virgin area, to define the geometry of aquifer and its groundwater potential. The well log, consisting of a plot of depth versus the type of material obtained while drilling, provides valuable basic data and enables clear delineation of aquifer zones. The location for test hole should be chosen in such a way that if it yields prospects of a good aquifer, it can be converted for operational use by redrilling or reaming to a larger diameter to form a pumping well. The test holes often serve as observation wells for measuring water levels or for conducting pumping tests. At the same time, water samples collected during drilling reveal water quality information. Any of several types of well logs may be produced. The common well log is the driller's description of the geologic character of each stratum, the depth at which changes in character were observed, the thickness of the strata, and the depth of water. The following procedure is recommended for producing a driller's log:

- a) The test borehole should be at least 190 mm in diameter,
- b) A complete and accurate log of the borehole, when it is being drilled, should be kept. Samples of soil should be collected at a maximum interval of 2 m or whenever there is a change in strata,
- c) The total depth drilled should be sufficient to determine the depth and other characteristics of the lowest aquifer as anticipated from other local considerations, and
- d) In case of Percussion drilling, static water level in the borehole should be measured daily in the morning before commencement of drilling operations and in the evening at the end. A study of this data gives an indication of the behaviour of the aquifers met with during drilling operations.

After the drilling has reached sufficient depth, all the samples of strata collected should be carefully examined and analysed. The samples should be dried, stored and preserved carefully. A valuable supplement to the driller's log is the drilling-time log consisting of a record of time taken to drill every two meters of depth or where there is change of strata. The rate of penetration of a stratum can be correlated with the formation encountered. The interpretation of the log regarding the nature of the formations (hard, soft, unconsolidated etc.) gives an indication of their water yielding capacity.

**5.2** Besides the drilling logs, the following logs may also be prepared:

**a) Geophysical Logs** — These logs are obtained by lowering an instrument, connected to a surface-mounted recording device, down the borehole to obtain the subsurface record which can be interpreted in terms of the formation characteristics and then extrapolated laterally. Whereas properly made geophysical logs are unbiased and thus, may be utilized over wide geographic areas and for long periods of time, the conventional driller's logs are not of consistent value.

With the recent advancement in electronics, compact and relatively inexpensive logging units, which can be operated by one man, are now widely available. Many of the logging instruments provide necessary procedures for interpretation.

The basic deterrent in the widespread use of geophysical logs is that many engineers working on water well drilling projects do not have necessary knowledge and experience for detailed interpretation of the logs. Therefore, interpretations are usually provided along with logging units by the suppliers.

**b) Electric Logging** — This is the most common borehole geophysical operation and serves to verify and supplement the descriptive driller's log. An electric log consists of a record of the apparent resistivities of the subsurface formations and spontaneous potentials generated in the borehole both plotted in terms of depth below the ground surface. These two properties are related indirectly to the characteristics of subsurface formations and the quality of water contained within. The electrical logs may be single or multiple electrode types. The single electrode yields one spon-

tanous potential (SP) and one resistance curve; the multiple electrode yields one SP curve identical to that of single electrode and two or more resistance curves. The single point electrode is popular in groundwater investigation since the equipment required is much less complex and curves obtained can usually be readily interpreted to delineate aquifer boundaries.

Electric logs cannot be run in encased holes. Although a fluid-filled hole is more desirable, they can be run on dry holes using special types of probes.

c) **Temperature Logging** — Temperature logs are obtained by measuring the groundwater temperature using resistance thermometers. The temperature would, ordinarily, increase at approximately the rate of the geothermal gradient. Any departure from this normal gradient would suggest variations which may be interpreted in terms of groundwater conditions. Temperature logs are frequently made at the same time as electrical logs and contribute to the reliability of interpretation of multiple electrode electric logs. They also provide a valuable tool in investigating inter-aquifer migration of water, adequacy of grouting, quality of water, corrosion and other similar studies.

d) **Caliper Logging** — Caliper logs measure the diameter of uncased drill hole as a function of depth and are made by running a self-actoned caliper through the borehole. They are valuable in determining unconsolidated formations, identifying caving zones and estimating quantities of cement required for grouting and gravel required for packing. They are also useful in interpreting electric logs where apparent resistivity is influenced by borehole diameter variations.

e) **Radiation Logging** — Radiation logs are of two general types: those which measure the natural radiation of materials (gamma ray logs), and those which measure radiation transmitted through, from, or induced in the formation by a neutron emitting source (neutron log). Gamma ray log is a curve relating depth to intensity of natural radiation and is especially valuable in detecting clays and other materials of high radiation.

These logs are not affected by casing in a borehole and may be used to identify formation boundaries in a cased borehole. These can also be obtained for dry boreholes whether cased or uncased.

The logging techniques recommended for various purposes are summarised in Table 3.

**Table 3 Suggested Logging Techniques for Groundwater Investigations**

(Clause 5.2)

Information Needed on Properties of Rocks, Fluids, Wells or Groundwater System (1)	Logs Which Might be Utilized (2)
Formation water quality, determination of aquifer boundaries and surface geological correlation.	Spintaneous potential, Resistivity, Gamma log
Stratigraphic correlation	Gamma log
Determining aquifer boundaries (such as contact between weathered, fractured fresh granites; contact between massive and vesicular basalt)	Point resistance

Information Needed on Properties of Rocks, Fluids, Wells or Groundwater System (1)	Logs Which Might be Utilized (2)
Lithology of the formation	Spontaneous potential
Delineation of contacts between basaltic layers and intertrappean, infra trappean beds	Natural gamma log
Marker horizon for regional correlation	Natural gamma log
Laterite/basalt contact	Natural gamma log
Saturated water mantle	Natural gamma log
Aquifer demarcation in basalt (Vesicular zone)	Natural gamma log
Change in the composition porosity and moisture content in rock that is delimiting lithological contacts and hydrological characters	Differential temperature log Gradient temperature log
Caving Zones such as red bole zone, fractured or fissured zone, etc.	Caliper zone
'Swell' zone on account of hydration, such as, impervious strata that swell due to hydration	Caliper log
To define the position of the aquifer precisely	Flow log
To demarcate the lava flows in the Deccan trap even when borehole is dry or caved	Neutron log
To see fracture and vasecular zones in the surface (as in Deccan trap) of borehole by vewing video signals on TV screen	Telespec

## 6. SOURCES OF DATA

6.1 The data information required may be obtained from the following sources:

<i>Data</i>	<i>Source</i>
a) Landsat - TM Imagery	National Remote Sensing Agency, Hyderabad
b) Topographical Maps	Survey of India
c) Geological Maps	Geological Survey of India/State Departments of Geology & Mining or Groundwater
d) Hydrogeological Maps	Central Ground Water board/State Groundwater Departments
e) Geophysical Surveys	National Geophysical Research Institute, Hyderabad

## CHAPTER 2

### ESTIMATION OF AQUIFER CAPACITY

#### 1 GENERAL

The growing demand for groundwater makes it imperative that reliable quantitative estimates of the resources are made for their optimum utilisation. The development of groundwater resources without adequate pumping test data would be a speculative operation with the accompanying risk of high failure rate.

The hydrogeological characteristics of the aquifer are quantitatively defined by two parameters - permeability and storage. The most accurate, reliable and commonly used method of determining aquifer characteristics is by controlled aquifer pumping test. It is designed to impose a hydraulic stress on the aquifer in such a way that measurements of the responses to the stress will fit in a theoretical model of aquifer responses.

#### 2 TEST SET-UP

**2.1** The test set-up consists of a test well in which the aquifer is subjected to stress and two or more observation wells in which the response is measured. The set-up must permit the following controls and measurements :

- a) Constant pumping rate, even though the pumping level may vary during the pumping period;
- b) Accurate measurement of drawdown in the pumped well and in two or more observation wells some distance away;
- c) Accurate record of time at which each measurement is taken as pumping proceeds;
- d) Accurate measurement of water level recovery in each well with time after stopping the pump; and
- e) Constant rate of pumping of nearby wells if such wells can not be idle during the period of test.

**2.1.1** The aim is to get field data that permit study of the time-drawdown and the distance-drawdown relationships during the periods of

pumping and recovery after pumping is stopped. The observed data is analysed to obtain aquifer constants which make it possible to predict the maximum yield of water from the aquifer and subsequent effects of such yield.

#### 2.2 Preparations For Pumping Test

**2.2.1** As a first step towards determination of aquifer constants in a selected area, full hydrogeological information pertaining to the aquifer and confining layers should be collected, dealing with their nature, thickness and shade, boundary condition of the flow regime and the available estimates, if any, of aquifer constants. Such data may include dip and strike of aquifers, their configuration with respect to sources of recharge and discharge, slope of the water table and piezometric surface etc. In areas where the available hydrogeological data is inadequate, it may be desirable to carry out a field survey to augment the data. From the collected data, if possible, interpretation should be made as to whether the aquifers are confined, unconfined or leaky and whether they are extensive or bounded.

**2.2.2** An inventory of existing wells and analysis, if available, of existing borehole data and associated surface water levels and flows should be obtained as a prerequisite to pumping test.

**2.2.3** The period of the aquifer test should be selected in which no rainfall or recharge is likely. Infiltration and deep percolation of precipitation may adversely affect the test. If recharge occurs, it should be suitably accounted for.

**2.2.4** In areas of severe winter climate, where the frostline may extend to depths of several metres, pumping test should be avoided during the winter. Under some circumstances, the frozen soil acts as confining bed, combined with leaky aquifer and delayed storage characteristics, that may make the results of the test unreliable.

#### 3 DESIGNING THE AQUIFER TEST

##### 3.1 Selection of Site

The location of site selected should be such that it is representative of as wide an area as possible. It

should be away from railway line and roads where heavy traffic might produce fluctuations in the piezometric surface of a confined aquifer, and from existing wells, unlined distributaries and canals and other sources of recharge and discharge. In any case, distances to all such sources should be measured and their operational schedules recorded. While selecting the site, consideration should be given to the method and place of disposal of discharge from the well. The pumped water should be safely discharged sufficiently far off, through pipes or lined channels, so that no percolation of discharged water occurs in the zone overlying the cone of depression created in the unconfined aquifers.

### 3.2 Construction of Test Well

The test well should be properly constructed to ensure that the stress in the aquifer immediately outside the casing is reflected in the water level changes in the well.

3.2.1 The diameter of the test well should be as small as practicable so that the water in storage in the well is negligible in comparison to the water produced from the aquifer during the test. The diameter selected should, however, accommodate the test pump, provide sufficient clearance for measurement of the pumping level readily and pump water at the desired rate.

3.2.2 The screen opening and gravel packing should be adequate to allow desired pumping rate without much entrance and other losses. The length of the screen, as compared to the thickness of the aquifer, is an important factor. In relatively thin strata, the screen length should be three-fourths of the aquifer thickness or more. In thicker aquifers the wells screen should be as long as practicable and should be set in the most permeable portion of the sand or gravel formation.

3.2.3 As far as possible test wells should be constructed separately for confined and unconfined aquifers. Alternatively, a combined well tapping both the aquifers can be constructed with a cement seal in the confining clay outside the well. The wells should tap the full thickness of the aquifer.

### 3.3 Construction of Observation Wells

An aquifer test which employs one or more observation wells has a higher chance of successfully

predicting aquifer characteristics than one which relies entirely on the measurements in the test well even after well losses are estimated.

3.3.1 While any number of observation wells may be used, the recommended minimum number is four - three on a line passing through the centre of the test well and one on a normal line to other three but passing through the test well. The observation wells should be of small diameters to minimise the time lag in drawdown response due to storage in well but large enough to permit rapid and accurate measurement of water level. Observation wells of 50 mm, 100 mm and 150 mm diameters are adequate for shallow, medium and large depths. Larger diameter wells may be used if observations are to be made by automatic recorders.

3.3.2 The observation wells should generally tap the same or corresponding depth zone of the aquifer tapped by the test well. The observation wells may be screened at a depth corresponding to the centre of the screened portion in the test well. Longer screens are desirable but not absolutely necessary. Proper depth of observation wells is very important especially if short screen is used. At times, the observation wells may be terminated in the strata above or below that tapped by the test well to see if there is any hydraulic interconnection between the formation.

3.3.3 The distance of observation wells from the test well should be such as to yield good response curves. When observation wells are installed, they may be located at different distances so as to give greatest possible areal coverage. If the test well is fully penetrating, there is no restriction on distance of the observation wells; however, in case of partially penetrating test well, the nearest observation well may be placed at a distance at least 1.5 times the thickness of the aquifer.

3.3.4 The placement of the observation wells is governed by two factors: one, the aquifer is almost always stratified and not uniform from top to bottom, and, two, the length of the screen in the test well may be considerably less than the full saturated thickness of the aquifer. These factors distort the distribution of hydraulic head and drawdown in the vicinity of the test well during the aquifer test. This distorted pattern is ironed out at considerable

distances from the test well of about 3 to 5 times the aquifer thickness. Setting observation wells at distances of 30 to 100 m from the test well will work out best in most cases. Locating the wells too far away is not always convenient because the pumping test must be continued for a longer time in order to produce drawdowns of sufficient amount at the most distant points.

**3.4** Before conducting the aquifer test, the observation wells should be tested for response time by injecting a slug of about 10 l water. The water level should return to near static condition in two to ten minutes if the well has adequate response time.

#### **4 PRE-PUMPING PREPARATION**

**4.1** Before the aquifer test is undertaken it is necessary to establish the natural conditions of flow and determine any measurable trend in ground-water levels. The water levels in the test and observation wells should be periodically monitored at an interval of 1 to 2 h for 3 to 5 days prior to the actual test and a curve of change in depth versus time prepared to correct the observed drawdown during the test. If there is a pumping well in the neighbourhood, the effect of its pumping schedule on the test and observation wells should be recorded at specific discharge and taken into account in the aquifer test.

**4.2** In confined and unconfined aquifers, water level changes in response to fluctuations in the barometric pressure. These variations in water level and barometric pressure may be measured several times daily for at least 4 days prior to the actual test and a plot made. The slope of the straight line of fit through each set of measurement for each well will give the barometric efficiency of each well. If a relationship is recognized, barometric readings should be made at the same time as water level measurements during the test and required corrections made to the observed water levels.

**4.2.1** Similar observation of water levels should be recorded in response to tides where the test area is close to sea.

**4.3** A day or two before the test, the well should be tested for several hours for yield and drawdown, operation of the discharge measuring equipment, general operating conditions and approximate best

rates of discharge for the test. At the same time, water levels should be measured in observation wells to assure response.

**4.4** The measuring points in the test well and the observation wells should be selected, marked clearly with paint and elevations determined by levelling, if required.

**4.5** The distance and bearing from the centre of the test well to the centre of all observation wells should be measured as also the distance and bearing to the closest point of any nearby boundary such as lake or stream or other discharging wells.

#### **5 RUNNING A PUMPING TEST**

**5.1** The water level in test and observation wells should be measured immediately before starting the pumping test to establish static water levels upon which all drawdowns will be based. All water level measurements subsequently should be related to a common datum like general land surface or mean sea level.

**5.1.1** For water level measurements, steel tapes graduated up to one mm interval and coated with chalk provide a reasonably accurate method of measurements. Continuous records of water level can also be obtained by using automatic water level recorders especially in wells where change in water level is small and slow. However, care is required to be taken to see that float is free of friction from the casing. Electrical sounding may also be used if frequency of measurement is high. Air pressure lines are also useful in wells where heavy drawdowns are expected but measurements are not accurate. Accuracy of field measuring gauge needs to be determined before using the same.

**5.2** The method to be adopted for the measurement of discharge should be decided upon based on the rate of discharge and arrangements made accordingly. The usual methods are volumetric, rectangular and V notch (*see IS 9108 : 1979*), manometer tube (*see IS 9118 : 1979*) circular orifice [*see IS 2952 (Part 1) : 1964*], weir (*see IS 6059 : 1971*) and jet (*see IS 9119 : 1979*) methods.

**5.2.1** The circular orifice method is the most commonly used for measurement of the rate of discharge. The orifice is a perfectly round hole in the centre of a circular steel plate that is fastened

to the outer end of a level discharge pipe. A manometer tube is fitted in a 6.35 mm or 8.5 mm hole made in the discharge pipe exactly 61 cm from the orifice plate. The water level in the manometer tube represents the pressure in the discharge pipe when water is pumped through the orifice. Standard tables (Johnson, 1966) have been published which show the flow rate for various combinations of orifice and pipe diameter.

5.3 The watches of all observers should be synchronized correct to a second before starting the test. The instant of starting the pump should be recorded as the time of the test. The initial discharge may be somewhat in excess of the continuous discharge and it may be necessary to reduce it by partially closing the valve on the discharge pipe. The well discharge should be controlled to keep it as constant as possible after the initial excess

discharge has been stabilized.

5.4 The aquifer test consists of pumping out from a test well at constant discharge and shutting off the pump after an interval of time, and recording water levels in the test well and observation wells both during pumping and after stoppage of pump. Immediately after starting or stoppage of pump, the water level falls or rises very rapidly and therefore the water level measurement should be very rapid during this period in order to define the drawdown or recovery curves precisely. After about 100 minutes of pumping or stoppage, 25 measurements during each log cycle of time are adequate to define the drawdown curve with sufficient accuracy.

5.4.1 The recommended time intervals of measurements are given in Table 1.

Table 1 Recommended Time Interval

(Clause 5.4.1)

Time Since Pumping Started/Stopped		Time Interval for Water Level Measurements	No. of Recordings	Time Interval for Temperature and Conductivity Measurements (for Risk of Saline Water Encroachment)
From	To	(minute)	(4)	(hour)
(1)	(2)	(3)		(5)
0	10	1/2 or 1	10/20	2
10	20	2	5	2
20	60	5	8	2
60	100	10	4	2
100	300	20	10	2
300	1 000	50	14	4
1 000	3 000	100	20	8
3 000	Shutdown	200	—	12



**5.4.2** However, adherence to the time schedule should not be at the expense of accuracy in the drawdown measurements. If the water level fluctuates erratically or sudden changes in trend occur the schedule may be changed and frequent measurements taken to define the trend. The exact time of taking measurement should, however, be recorded.

**5.5** During the first 60 minutes, the timing of measurement should be accurate to nearest second. To achieve the desired accuracy, two observers should be posted at each well, during the early part of the test. Later, one observer can do the job. Stop watches should be used during early measurements but later synchronised watches can be used.

**5.6** In addition to water level measurements, temperature measurements of the discharged water should be made periodically. This will be required to effect correction to permeability value if it is to be corrected to a standard temperature. Similarly, water samples should be collected at appropriate intervals and the conductivity noted to observe changes in the quality specially if the aquifers are overlain or underlain by aquifers with different quality of ground water, or if there is lateral change in the quality. Selected samples may be subjected to complete chemical analysis.

**5.7** In general, the greater the pumping rate, the more responsive is the stress generated in the aquifer. While deciding the rate of pumping, the following points should be kept in mind :

- a) Pumping rate should be large enough to produce significant drawdown in the observation wells. The shorter the duration, the larger the pumping rate required to effect significant drawdown in the observation wells;
- b) The maximum rate of pumping should be considerably less than the capacity of the pump ;
- c) The resulting drawdown should be within the range of pump setting; and
- d) Entrance velocity through the well screens should not exceed 3 cm/s.

**5.7.1** Before deciding about the rate of pumping, trial runs with varying discharges (step drawdown

test) should be conducted and resultant response in the observation wells should be recorded. This will give a fairly good idea about the rate required for conducting the test. As the stress to the aquifer has to be applied at a constant rate, the discharge in the pumped well has to be maintained constant. It is worthwhile to mention here the common causes of fluctuation in discharge so that continuous monitoring of pumping rate is done to avoid such changes :

- a) Pumping rate will tend to decline as pumping lift increase with increased drawdown;
- b) Internal combustion engine will change its rate of operation in response to the change in temperature; and
- c) Electric motor will change the rate of rotation in response to fluctuation in voltage.

**5.7.2** If pumping rate changes by 10 percent or more during the test owing to accidental causes or negligence, the result of drawdown may contain sufficient error to vitiate the test. All changes in the discharge rate should be promptly recorded so that water level changes may be accounted for. In such cases it may be necessary to rely on recovery data. Under condition of erratic discharge rate, a reasonable estimate of average pumping rate should be made and only recovery data should be used for computation.

**5.8** If the test well used is a large diameter well, say a dug well, the diameters at various depths in the zone of water level fluctuation should be recorded to account for contribution of water from the storage in the well.

## 6 RECORDING AND PLOTTING OF DATA

**6.1** Data collected during aquifer test should be recorded in the type of Form 1. Erratic water level measurements may be due to errors of measurement or fluctuations in pumping rate. These need to be corrected by immediate remeasurement. For measurements taken in the test well, errors due to partial penetration, vertical flow and entrance losses need to be corrected. In all the wells involved in the testing, errors in water level due to regional water level trend and barometric effects should be nullified.

6.2 Plots of  $\log t$  versus  $s$  should be prepared as the test proceeds where  $t$  is pumping time in minutes and  $s$  is drawdown in  $m$  (see Fig.1). Such plots will give an indication whether it is a case of non-leaky artesian aquifer, or leaky confined aquifer. In unconfined aquifers, such plots will indicate if delayed yield phenomenon is occurring and how long pumping needs to be continued.

6.3 Distance drawdown plot should also be made and quantity of material dewatered in the cone of

depression for 1000, 2000, 3000 and 5000 minutes of pumping should be calculated and compared with the corresponding amount of water pumped. Recovery data may also be recorded and plots of residual drawdown,  $s'$  vs  $\log t/t'$  should be prepared where  $t$  is the pumping time in minutes,  $t'$  is the recovery time in minutes,  $r$  is the distance of observation well from test well in  $m$ ,  $s$  is the drawdown in  $m$ ,  $s'$  is the residual draw down in  $m$  and  $Q$ , is the discharge in  $l/min$ .

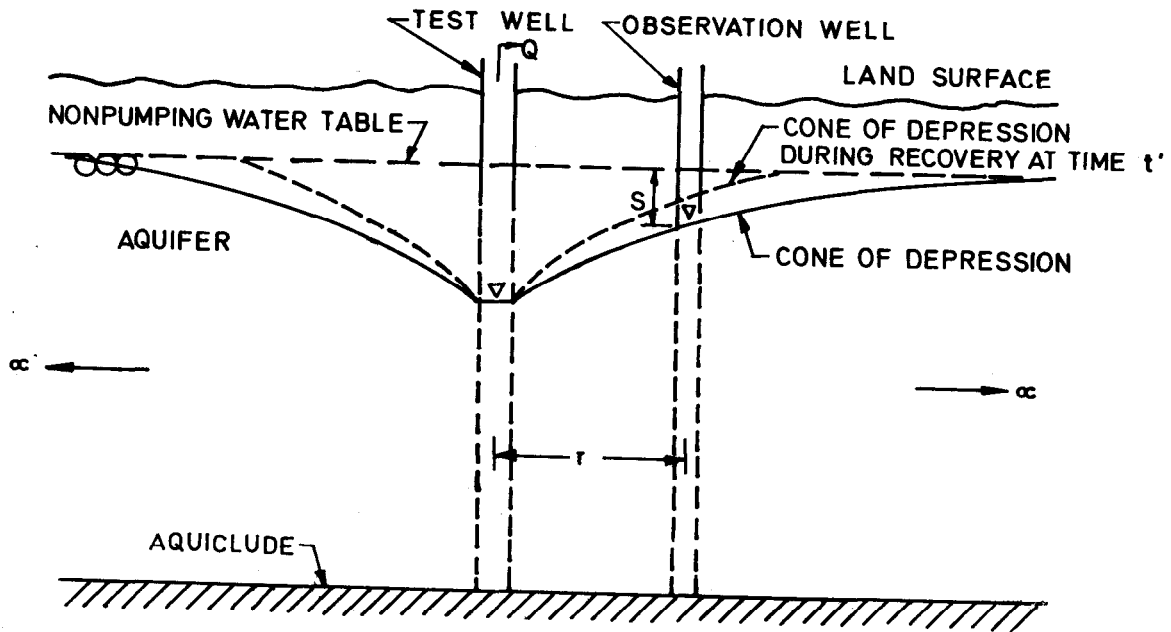


FIG. 1 PUMPING TEST.

**FORM - 1**  
(Clause 6.1)

Well No. ....

Code No. ....

**PUMPING TEST DATA**

- 1 NAME OF THE PROJECT. ....
- 2 LOCATION OF SITE : District.. .... Taluk/Tehsil ..... Village. ....  
Survey No. .... Coordinates. .... Toposheet No. ....
- 3 WELL DETAILS : Pumped well.. .... Observation wells.. ....  
Distance and bearing from pumped well to  
observation wells. ....
- 4 DATA OF PUMPED WELL/OBSERVATION WELL. ....  
(a) Measuring point ..... (m); Height ..... (m); Altitude.. ....  
(b) Method of discharge measurement .....  
(c) Water level measurement by tape .....

**NOTES**

- 1 Under remarks give temperature of water and indicate collection of water sample, turbidity, etc.
- 2 Recovery measurements should be continued till near prepumping level is reached.

Measured by	Date	Hour	Tape Reading at		Depth of Water below Measuring Point (m)	Q (l/min)	t (min)	t' (min)	t/t'	r <sup>2</sup> /t or t'/r <sup>2</sup>	s or s'	Remarks
			Measuring Point (m)	Water Level (m)								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)

## CHAPTER 3

### WATER QUALITY

#### 1 GENERAL

**1.1** Groundwater is a complex chemical solution in dynamic state the composition of which depends on the solution of materials in soils and rocks by percolating waters and chemical reactions between this water and the host medium. The chemical elements present are derived from precipitation, organic processes in soil and breakdown of minerals in the rock through which groundwater flows.

The major constituents in ground water normally available are salts of calcium, magnesium and sodium (in the form of bicarbonates, sulphates, chlorides, carbonates etc.) along with silica. The other constituents which may be present are iron, potassium, nitrates, fluorides, boron and strontium, etc.

The quality of groundwater tapped is important from the viewpoint of its potability as well as its corrosion effect and incrustation potential. The groundwater quality is determined on the basis of water quality standards for the anticipated possible uses of the groundwater.

Another water quality variable which may affect the movement, the chemical composition and the usability of groundwater is its temperature.

#### 2 QUALITY OF DRINKING WATER

**2.1** The quality of drinking water-physical, chemical, bacteriological, virological and biological-has been comprehensively laid down in IS 10500 : 1991 which has drawn information from the standards prescribed by the World Health Organization and the Indian Council of Medical Research.

**2.1.1** The Indian Standard categorises the characteristics of water as desirable and essential, prescribes the desirable requirements, the relaxation permitted in the absence of alternate source, and the adverse effects on health as well as water supply and distribution system if the prescribed desirable limits are exceeded (see Table 1). The methods of sampling and tests for microbiologi-

cal, physical and chemical properties are prescribed in IS 1622 : 1981 and IS 3025 : 1964.

**2.1.1.1** Ideally, water should be free from coliform organisms and fortunately groundwater, except perhaps from very shallow aquifers, is generally free from pathogenic bacteria and viruses. The objective in a drinking water scheme should be to ensure a coliform count of less than 10 per 100 ml but, more importantly to ensure the absence of faecal coliform organisms. The virus in water can be inactivated by mixing 0.5 mg/l of free chlorine for one hour. If free chlorine is present in water, active virus will generally be absent if coliform organisms are absent. If, however, free chlorine residual is not maintained, the absence of coliform organisms cannot be assumed to imply freedom from active virus. The drinking water should also be free from microscopic organisms such as algae, zooplanktons, flagillates, parasites and toxin-producing organisms. An illustrative list of microscopic organisms which may be present in water and their effect is provided in IS 10500 : 1991.

#### 3 CORROSION EFFECT

**3.1** The corrosivity of groundwater affects the casing life and pump breakdown rate which ultimately has a bearing on the operating efficiency, reliability and life of the well system. On a macro scale, corrosion may be due to the changes in chemical concentration of groundwater with depth, on a micro scale, it may be due to water lodged in small pores, cracks or hidden places like washers, couplings, gaskets etc., having dissolved oxygen. Besides, bacteria may cause metabolic corrosion.

**3.1.1** In general, corrosion is more severe if :

- a) groundwater is acidic or contains dissolved oxygen or salts especially chlorides, sulphides and calcium;
- b) groundwater temperature is high since all chemical reactions proceed faster at higher temperature; and

- c) entrance velocity of groundwater in the screen openings is high.

3.1.1.1 The following list of indicators of corrosive water can help the well designer recognize potentially corrosive conditions :

- a) Low pH — If the water is acidic (pH <7.0) corrosive conditions are indicated.
- b) Dissolved oxygen — If dissolved oxygen exceeds 2 ppm, corrosive water is indicated. Dissolved oxygen is likely to be found in shallow water-table wells. It is difficult to determine dissolved oxygen accurately.
- c) Hydrogen sulphide — Presence of hydrogen sulphide can be detected readily from its characteristic rotten egg odour. Less than 1 ppm can cause severe corrosion and this amount can be detected by odour or taste or lead acetate paper.
- d) Total dissolved solids — If total dissolved minerals exceed 1000 ppm, electrical conductivity of the water is great enough to cause serious electro-

lytic corrosion. To avoid this, well screens made of a single, corrosion-resistant metal are necessary.

- e) Carbon dioxide — If free carbon dioxide exceeds 50 ppm, corrosive water is indicated.
- f) Chlorides — If chlorides exceed 500 ppm, corrosion can be expected.

#### 4 INCRUSTATION POTENTIAL

4.1 Incrustation is caused by the precipitation of dissolved salts in the groundwater. The main precipitation products are carbonates of calcium and magnesium. The precipitation occurs with the increase in pH around the screens as the water enters the well. The pH increases due to decrease in dissolved carbon dioxide content of groundwater which in turn is caused by a decrease in pressure head as water moves from aquifer to well. The precipitation can also occur due to the decomposition of bicarbonates of calcium and magnesium at high temperature prevailing in the ground water.

#### 5 PROTECTION FROM CORROSION AND INCRUSTATION

5.1 The measures for minimizing corrosion and incrustation are covered in Chapter 4.

Table 1 Test Characteristics for Drinking Water

(Clause 2.1.1 )

Sl No.	Substance or Characteristic	Requirement ( Desirable Limit)	Undersirable Effect Outside the Desirable Limit	Permissible Limit in the Absence of Alternate Source	Methods of Test ( Ref to IS )	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Essential Characteristics</i>						
i)	Colour, Hazen units, <i>Max</i>	5	Above 5, consumer acceptance decreases	25	3025 ( Part 4 ) : 1983	Extended to 25 only if toxic substances are not suspected, in absence of alternate sources
ii)	Odour	Unobjectionable	—	—	3025 ( Part 5 ) : 1983	a) Test cold and when heated b) Test at several dilutions
iii)	Taste	Agreeable	—	—	3025 ( Parts 7 and 8 ) : 1984	Test to be conducted only after safety has been established
iv)	Turbidity, NTU, <i>Max</i>	5	Above 5, consumer acceptance decreases	10	3025 ( Part 10 ) : 1984	—
v)	pH value	6.5 to 8.5	Beyond this range the water will affect the mucous membrane and/or water supply system	No relaxation	3025 ( Part 11 ) : 1983	—
vi)	Total hardness (as CaCO <sub>3</sub> ) mg/l, <i>Max</i>	300	Incrustation in water supply structure and adverse effects on domestic use	600	3025 ( Part 21 ) : 1983	—
vii)	Iron ( as Fe ) mg/l, <i>Max</i>	0.3	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures, and promotes iron bacteria	1.0	32 of 3025 : 1964	—

Table 1 (Continued)

Sl No.	Substance or Characteristic	Requirement ( Desirable Limit)	Undersirable Effect Outside the Desirable Limit	Permissible Limit in the Absence of Alternate Source	Methods of Test ( Ref to IS )	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
viii)	Chlorides ( as Cl ) mg/l, <i>Max</i>	250	Beyond this limit, taste, corrosion and palatability are affected	1 000	3025 ( Part 32 ) : 1988	—
ix)	Residual, free chlorine, mg/l, <i>Min</i>	0.2	—	—	3025 ( Part 26 ) : 1986	To be applicable only when water is chlorinated. Tested at consumer end. When protection against viral infection is required, it should be <i>Min</i> 0.5 mg/l.
<i>Desirable Characteristics</i>						
x)	Dissolved solids mg/l, <i>Max</i>	500	Beyond this palatability decreases and may cause gastro-intestinal irritation	2 000	3025 ( Part 16 ) : 1984	—
xi)	Calcium (as Ca) mg/l, <i>Max</i>	75	Encrustation in water supply structure and adverse effects on domestic use	200	3025 ( Part 40 ) : 1991	—
xii)	Copper (as Cu) mg/l, <i>Max</i>	0.05	Astringent taste, discoloration and corrosion of pipes, fitting and utensils will be caused beyond this	1.5	36 of 3025 : 1964	—
xiii)	Manganese (as Mn) mg/l, <i>Max</i>	0.1	Beyond this limit taste/appearance are affected, has adverse effect on domestic uses and water supply structures	0.3	35 of 3025 : 1964	—

Table 1 (Continued)

SI No.	Substance or Characteristic	Requirement ( Desirable Limit)	Undersirable Effect Outside the Desirable Limit	Permissible Limit in the Absence of Alternate Source	Methods of Test ( Ref to IS )	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xiv)	Sulphate (as SO <sub>4</sub> ) mg/l, Max	200	Beyond this causes gastro intestinal irritation when magnesium or sodium are present	400 (see col 7)	3025 ( Part 24 ) : 1986	May be extended up to 400 provided (as Mg) does not exceed 30
xv)	Nitrate (as NO <sub>3</sub> ) mg/l, Max	45	Beyond this methaemoglobinemia takes place	100	3025 ( Part 34 ) : 1988	—
xvi)	Fluoride (as F) mg/l, Max	1.0	Fluoride may be kept as low as possible. High fluoride may cause fluorosis	1.5	23 of 3025 : 1964	—
xvii)	Phenolic compounds (as C <sub>6</sub> H <sub>5</sub> OH) mg/l, Max	0.001	Beyond this, it may cause objectionable taste and odour	0.002	54 of 3025 :1964	—
xviii)	Mercury (as Hg) mg/l, Max	0.001	Beyond this, the water becomes toxic	No relaxation	(see Note) Mercury ion analyser	To be tested when pollution is suspected
xix)	Cadmium (as Cd), mg/l, Max	0.01	Beyond this, the water becomes toxic	No relaxation	(see Note)	To be tested when pollution is suspected
xx)	Selenium (as Se) mg/l, Max	0.01	Beyond this, the water becomes toxic	No relaxation	28 of 3025 : 1964	To be tested when pollution is suspected
xxi)	Arsenic (as As), mg/l, Max	0.05	Beyond this, the water becomes toxic	No relaxation	3025 ( Part 37 ) : 1988	To be tested when pollution is suspected
xxii)	Cyanide (as CN), mg/l, Max	0.05	Beyond this limit, the water becomes toxic	No relaxation	3025 ( Part 27 ) : 1986	To be tested when pollution is suspected
xxiii)	Lead (as Pb), mg/l, Max	0.05	Beyond this limit, the water becomes toxic	No relaxation	(see Note)	To be tested when pollution/plumbosolvency is suspected



Table 1 (Continued)

Sl No.	Substance or Characteristic	Requirement ( Desirable Limit)	Undersirable Effect Outside the Desirable Limit	Permissible Limit in the Absence of Alternate Source	Methods of Test ( Ref to IS )	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xxiv)	Zinc (as Zn), mg/l, <i>Max</i>	5	Beyond this limit it can cause as-tringent taste and an opales- cence in water	15	39 of 3025 : 1964	To be tested when pollution is suspected
xxv)	Anionic deter- gents (as MBAS ) mg/l, <i>Max</i>	0.2	Beyond this limit it can cause a light froth in water	1.0	Methylene-blue extraction me- thod	To be tested when pollution is sus- pected
xxvi)	Chromium (as Cr <sup>6+</sup> ) mg/l, <i>Max</i>	0.05	May be carcino- genic above this limit	No relaxationn	38 of 3025 : 1964	To be tested when pollution is sus- pected
xxvii)	Polynuclear aro- matic hydro- carbons (as PAH) g/l, <i>Max</i>	—	May be carcino- genic	—	—	—
xxviii)	Mineral oil mg/l, <i>Max</i>	0.01	Beyond this limit undesirable taste and odour after chlorination takes place	0.03	Gas chromatogra- phic method	To be tested when pollution is sus- pected
xxix)	Pesticides mg/l, <i>Max</i>	Absent	Toxic	0.001	—	—
xxx)	Radiative materials:				58 of 3025 : 1964	
	a) Alpha emti- ters Bq/l, <i>Max</i>	—	—	0.1	—	—
	b) Beta emit- ters pci/l, <i>Max</i>	—	—	1	—	—
xxxi)	Alkalinity mg/l, <i>Max</i>	200	Beyond this limit taste becomes unpleasant	600	13 of 3025 : 1964	—

Table 1 (Concluded)

Sl No.	Substance or Characteristic	Requirement ( Desirable Limit)	Undesirable Effect Outside the Desirable Limit	Permissible Limit in the Absence of Alternate Source	Methods of Test ( Ref to IS )	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
xxxii)	Aluminium (as Al), mg/l, <i>Max</i>	0.03	Cumulative effect is reported to cause dementia	0.2	31 of 3025 : 1964	—
xxxiii)	Boron, mg/l. <i>Max</i>	1	—	5	29 of 3025 :1964	—

NOTE — Atomic absorption spectrophotometric method may be used.

## CHAPTER 4

## CORROSION AND INCRUSTATION

## 1 GENERAL

All natural waters, generally speaking, are either corrosive or incrusting or both. Management of corrosion and incrustation attacks on various well components, therefore, is a major concern in ensuring reasonable life of the well system.

## 2 CORROSION

**2.1** Corrosion is an electrochemical process which causes the destruction of metals. Corrosion of well screens, casing and pumping equipment installed in wells can, therefore, severely limit the life of the well installation.

**2.2** Corrosion may act in the following three ways in the well system :

- a) Enlargement of screen openings due to their dissolution in water followed by sand pumping failure;
- b) Strength reduction followed by collapse of well screen or casing; and
- c) Deposition of corroded products, followed by screen blockage.

**2.3** The corrosion in screen is more critical than that of the casing since a small enlargement of the screen opening is required for the entry of sand through the screen, while the full thickness of casing metal must be penetrated for the failure of a well.

**2.4** Forms of Corrosion — Over the years, certain well-defined forms of corrosive attack on metals have been observed. The commonly identified forms of corrosion are :

- a) General corrosion or uniform loss of metals such as attack on well screens, leaves the slots enlarged and the strength of the screen reduced to withstand the operating conditions;
- b) De-alloying or loss of one element of an alloy, leaving the structure in its original shape but in a spongy and weakened condition; it is deceptive

in appearance and failure occurs suddenly in brass screen and other pump components; graphitization of cast iron is frequently associated in the well;

- c) Galvanic corrosion in which a galvanic cell near the junction of two different metals immersed in water is set up for the corrosion to occur.
- d) Pitting corrosion in which highly localized attack and perforation with little loss of metal in water takes place;
- e) Stress corrosion in which cracking is induced at highly stressed areas.
- f) Crevice Corrosion which is corrosion in crevices, sockets, and under gaskets or washers; and
- g) Bacterial corrosion caused by both aerobic and anaerobic bacteria; the sulphate-reducing bacteria utilize sulphate ( $\text{SO}_4$ ) as the preliminary energy source; the sulphate-reducing bacteria require anaerobic environment for optimum metabolic activity and are inhibited by the presence of aerobic bacteria; iron bacteria may also cause corrosion; they grow best at low temperatures and in water with 0.3 to 9.0 ppm dissolved oxygen; they are commonly found in wells containing soluble iron salts.

**2.5** Assessment of Corrosion

An assessment of underground corrosion may be made in accordance with the procedure laid down in IS 7808 : 1975.

**2.6** Rate of Corrosion

The rate at which corrosion takes place depends on several environmental factors like acidity of groundwater, dissolved oxygen, carbon dioxide, hydrogen sulphide, total dissolved solids, velocity of

ground water over areas being corroded, electrolytic effect, formation of protective films, temperature of groundwater, etc.

## 2.7 Corrosion Control

In wells, where corrosion is a critical problem, standard effective counter measures are difficult to suggest. Many of the methods, although successful in above ground structures, may not be as effective for well structures such as screens, casing, pumping equipment, etc.

2.7.1 The preventive measures that are available are :

- a) The use of corrosion resistant alloys and materials like UPVC screens and casing pipes;
- b) The use of protective coating, non-metallic coating and/or lining materials;
- c) Grouting of the annular space around the casing. Although recommended for providing a sanitary seal, grouting may be done through the entire length of casing to protect the metal casing from corrosion attack;
- d) The injection of chemicals to condition the corrosive water and to treat the surface of metal - various alkaline substances for pH control, inhibitors and preferential wetting agents; and
- e) Cathodic protection, although not normally suitable for protection of internal surfaces, could be more widely used for the irradiation of external casing attack [ see IS 8062 (Part 1): 1976].

## 3 INCRUSTATION

3.1 Incrustation is defined as any clogging, cementation or stoppage of a well screen and water-bearing formation in the vicinity of the well resulting from accumulating of extraneous materials in the openings or voids of the well screen and water-bearing formation. This may occur regardless of

the material used in the screen or the type of well construction.

3.2 Water quality has much to do with the occurrence of incrustation. The kinds and amounts of dissolved minerals and gases in natural waters determine their tendency to deposit some of the mineral matters as incrustation. Deposition of even a minute fraction of the minerals present in water causes serious clogging. Chemical analysis of water ought to indicate the type of incrustation that might occur and the rate at which it might be expected to be deposited. The quality of water may change slowly as the well is used depending on geologic and hydrologic conditions of the area and, therefore, chemical analysis would be useful if done periodically.

3.3 Incrustation is often a hard, brittle, cement-like deposit but under different conditions it may be soft and pasty. The causes of incrustation in the order of frequency of occurrence are :

- a) precipitation of minerals carried to the screen in solution like carbonates of calcium and magnesium,
- b) presence of iron bacteria or other slime-forming organisms, and
- c) deposition of soil materials, such as clays, silts etc, carried to the screen in suspension.

Incrustation is usually of the first type and the chief incrustating agent is carbonate-principally of calcium. Other substances such as aluminium silicates and iron compounds may also be entrapped in the scale-like carbonates which cement the sand grains together around the screen. Water can dissolve appreciable amounts of calcium carbonate and other carbonate salts depending on the amount of dissolved carbon dioxide in the water. The capacity of water to hold carbon dioxide in solution varies with pressure, when water is pumped from a well, the hydrostatic pressure around the well decreases and carbon dioxide is released from water. The water is unable to carry its full load of carbonates, the excess being precipitated adjacent to the well screen.

3.3.1 Just as a change of pressure results in pre-

cipitation of carbonates, a change in pH may result in the formation of iron and manganese hydroxides. These hydroxides are jelly like. The hydrated ferrous oxide is a black sludge where as ferric oxide is reddish brown like common rust. The insoluble manganese oxide is also a black or dark brown substance.

**3.3.2** In case of depression surrounding a pumping well, air may enter the voids and initiate the corrosion of well structures. If pumping is started and stopped intermittently, a corrosion product mainly consisting of iron oxide builds up progressively reducing the space in this part of the formation.

**3.3.3** The production of slime is a result of the life cycle of the organisms and iron is changed to insoluble oxides by the iron bacteria in particular.

**3.3.4** The stoppage resulting from clay and silt is likely to happen where screen openings are too small, well has been improperly developed or finished, or where the aquifer contains an abnormal amount of these fine materials.

**3.4 Incrustation Control** – No means of entirely preventing the incrustation of well screens have been found. However, the process of incrustation may be delayed and the severity of incrustation may be reduced by adopting the following measures :

- a) The well must be developed thoroughly so as to permit water to enter the well with least possible resistance,
- b) The well screen should have the maximum possible inlet area to reduce the entrance velocity to a mini-

mum,

- c) The pumping period may be increased. This produces benefits since the drawdown is decreased and, in any case, the most economical operation of both pumps and wells is obtained when pumping is as continuous as practicable,
- d) The pumping load may be divided among a larger number of wells instead of pumping one or few large wells at excessive rates. A group of slightly smaller wells properly spaced can develop the full yield of the aquifer more efficiently. Velocities in the formation near each well are materially reduced and the drawdown in each well is decreased,
- e) Since excessive available oxygen is involved in incrustation, downhole packers or vacuum seals may be used to isolate the aquifer from atmospheric oxygen if the pumping level is considerably above the top of the well intake area. This would be applicable for water table wells in unconsolidated sediments, and
- f) A periodic maintenance or cleaning procedure should be practised whenever local experience shows high incrustation. A drilling rig may be used for cleaning a tubewell section by section using a scraping equipment such as steel wire brush attached to the drilling rod which revolves in the portion of slotted pipes or screens.

## CHAPTER 5

### WELL SITING AND CONSTRUCTION

#### 1 GENERAL

1.1 The geologic conditions dictate two general types of well construction. A well that taps an aquifer of consolidated rock consists basically of a cased portion, usually extending through the loose overburden material, and an open borehole in the below. A well that taps an aquifer of water-bearing sand must necessarily be provided with a casing through the overburden materials and a well screen in the aquifer proper.

It is convenient to think of well construction in terms of four or five distinct operations. These include drilling, installing the casing and screen, grouting to provide sanitary protection, and developing the well to ensure sand-free operation at maximum yield.

#### 2 TYPES OF TUBEWELLS

##### 2.1 Cavity Wells

Cavity wells are generally shallow tubewells drilled in alluvium formations (see Fig. 1A and 1B). These are wells with casings resting in a thick, hard, impervious clay layer above the aquifer. It is a prerequisite that the impervious clay layer, should be of adequate thickness to support the well and should not disintegrate when water is pumped out.

##### 2.2 Tubewells

These are wells constructed in unconsolidated formations to tap water bearing formations. These wells have a casing extending through the overburden and an intake section comprising screen pipe, with or without gravel packing in the water bearing formations (see Fig. 2).

##### 2.3 Borewells (in Hard Rock Formations)

The overburden in such a well is encased to eliminate the risk of caving in. Drilling is further carried out in rock formations and the bore is usually, left unsupported open to allow the water to flow from the crevices and fissures into the bore (see Fig. 3).

#### 3 SITING OF INDIVIDUAL WELLS

3.1 A well should be so located that it is accessible for pump repair, cleaning, treatment, testing and inspection. The top of the well should not be within the basement. When adjacent to a building, the well should at least be 60 cm outside any projection.

3.2 The well should be located on the highest ground practicable. It should certainly be on a ground higher than nearby sources of pollution; the ground surface at the well site should be built up when necessary so that the surface water will drain away from the well in all directions. Minimum distances from a well to possible sources of pollution should be large enough to prevent sub-surface flow or seepage of contaminated water from reaching the well. Recommended minimum distances from various types of pollution sources are listed below :

Cesspool receiving raw sewage	30m
Seepage pit or drain field	25m
Septic tank or tightly joined sewer	15m

3.2.1 These distances are meant to be guides to good practice and may be varied as soil and other conditions require. They should be applied only where the soil has a filtering capacity equal to, or better than that of sand.

#### 4 METHODS OF DRILLING

4.0 There are numerous methods of drilling wells and each method has advantages related to ease of construction, cost factors, character of formations to be penetrated, well diameter and depth, sanitary protection and intended use of the well itself. The basic principles of some of the methods are described here which give some ideas of the limits of practical use under various combinations of conditions.

##### 4.1 Percussion Drilling

The percussion method, often referred to as cable tool method, is one of the oldest, most versatile

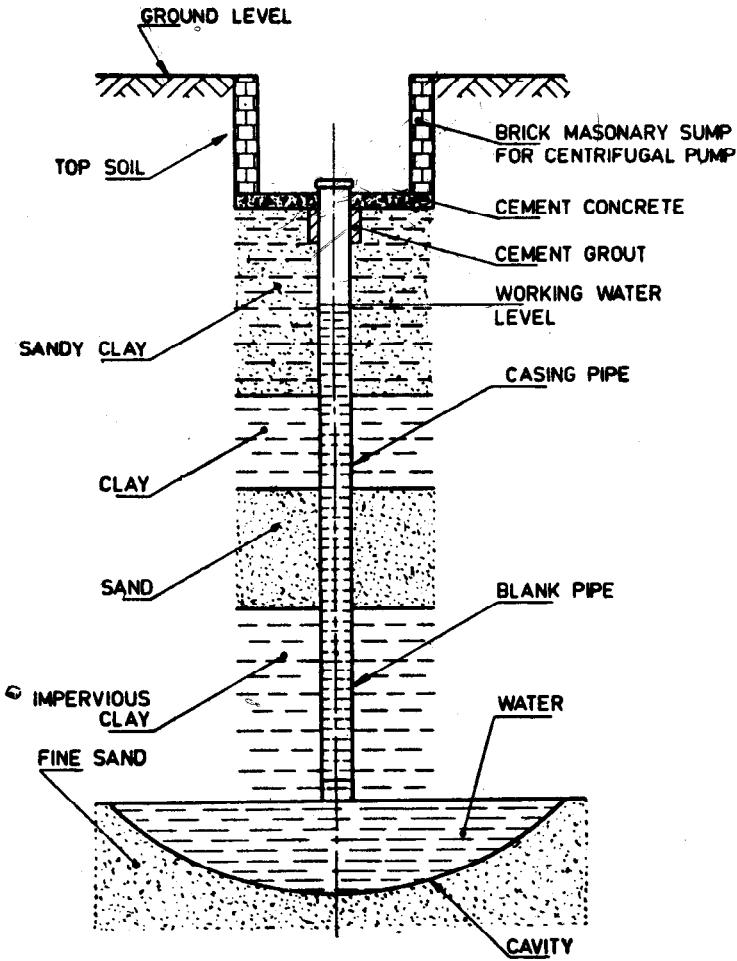


FIG. 1A CAVITY WELL ( FOR CENTRIFUGAL PUMP )

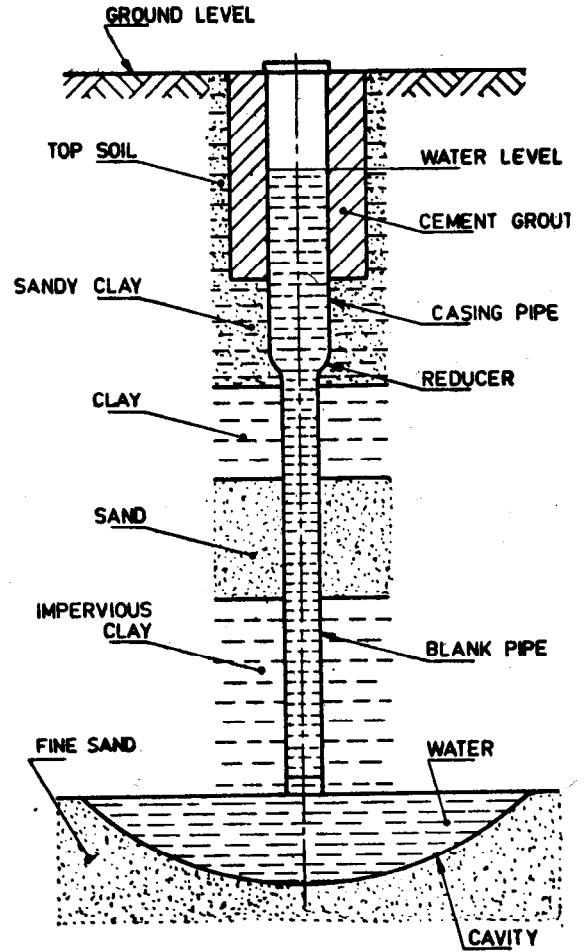


FIG. 1B CAVITY WELL ( FOR TURBINE SUBMERSIBLE PUMP )

FIG. 1 CAVITY WELL

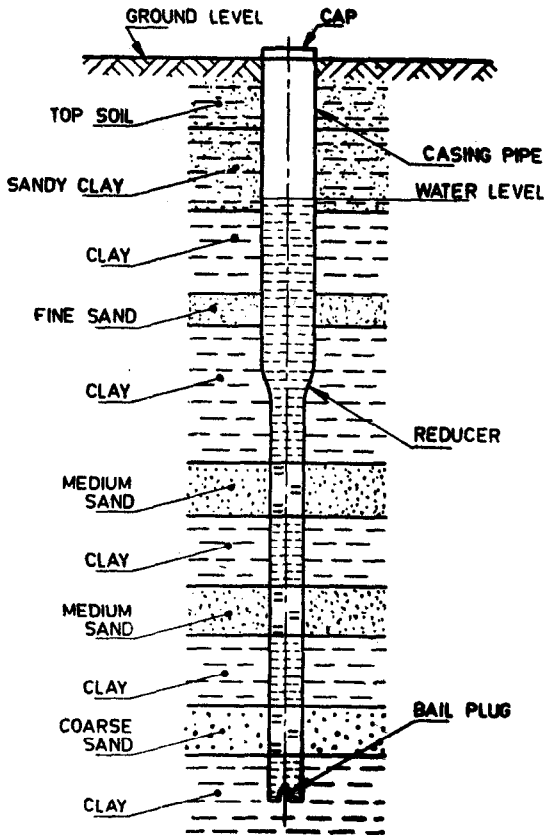


FIG. 2A TUBEWELL ( NATURAL GRAVEL PACK )

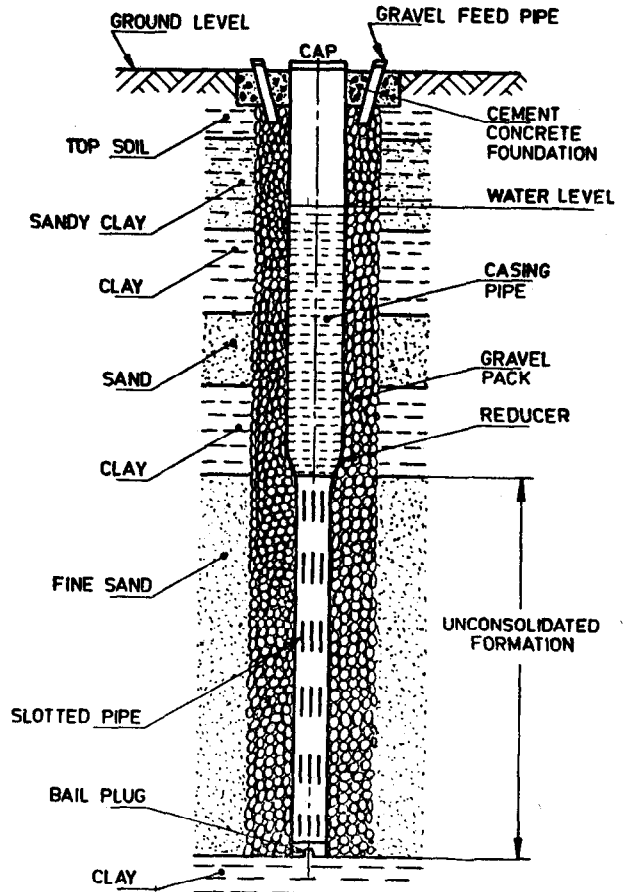


FIG. 2B TUBEWELL ( ARTIFICIAL GRAVEL PACK )

FIG 2. TUBE WELL



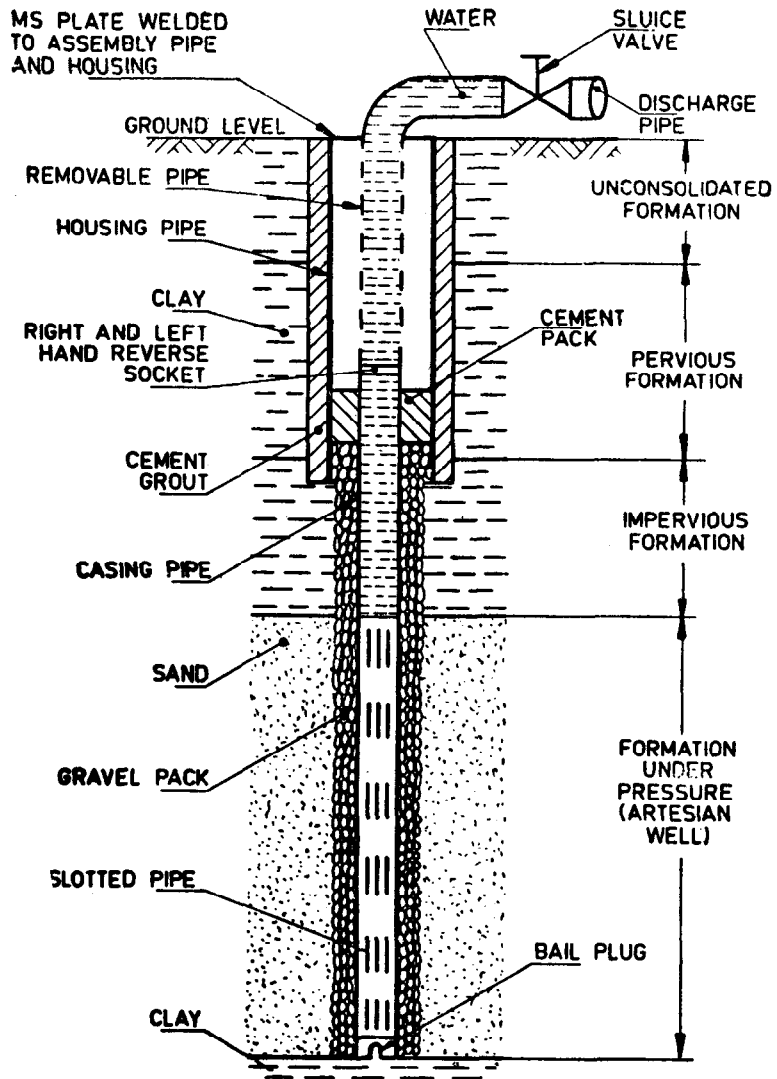


FIG. 2C TUBEWELL (ARTESIAN FLOWING)

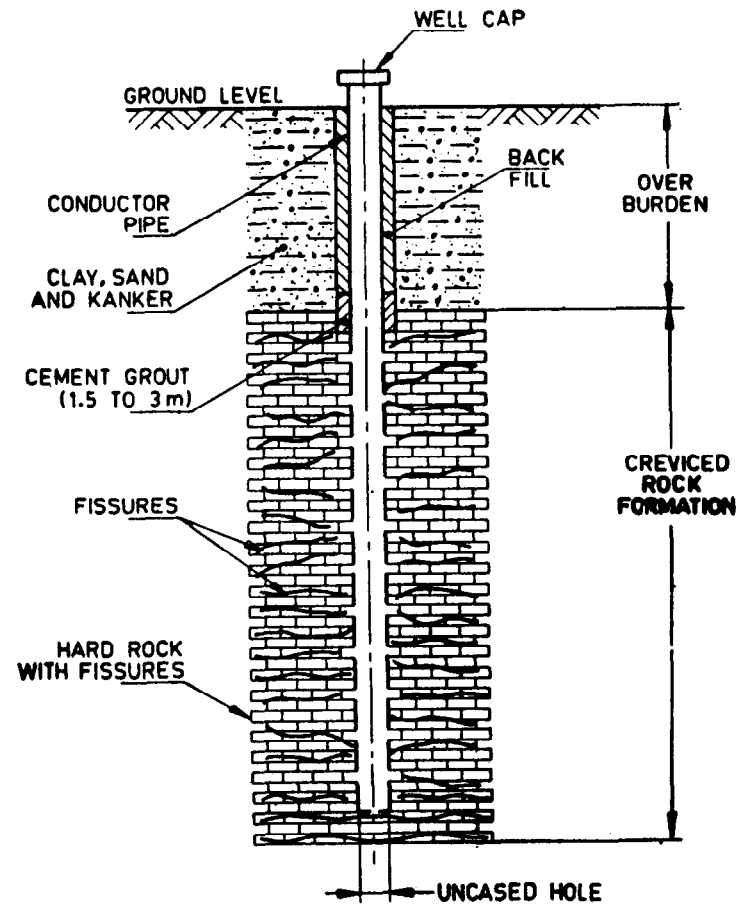


FIG. 3 BOREWELL IN HARD ROCK

and simplest drilling methods. A string of tools suspended on a cable is given up and down spudding motion either manually or by power. The string of tools, in ascending order, consists of a bit, a drill stem, drilling jars and a swivel socket which is attached to the cable. The bit strikes the bottom of the hole, crushing, breaking and mixing the cuttings. Above the water table or in otherwise dry formations, water is added to dissolve the cuttings which are lifted out by means of a bailer.

In consolidated rock, an open hole can be drilled, but in unconsolidated formations, steel casing pipe with drive shoes is driven down the hole as drilling progresses. The casing must closely follow the drill bit as the well is deepened in order to prevent caving and keep the borehole open.

**4.1.1** This method is most suitable for drilling in stratum where large boulders are encountered in abundance at different depths. The drilling is started with a large diameter casing and continued as long as it keeps driving smoothly. When the casing does not drive in freely, drilling is continued with the next smaller diameter casing.

**4.1.2** In unconsolidated formations, the vibrations, as the casing is driven in, cause the sides of the borehole to collapse against it and get compacted. Frictional forces increase until it is no longer possible to drive the casing. When this occurs, a smaller diameter casing is telescoped inside the casing already in place and drilling continued. In deep holes, as many as four or five reductions may be required.

**4.1.3** The drilling motion must be kept in step with the gravity fall of the tools for good operation. Variable factors interfere with the gravity fall and the motion and speed of the machine must be adjusted with the cycle of the tool travel. Care should be taken not to hammer the casing pipe, if used, unnecessarily giving rise to the possibility of getting stuck because extraction may be difficult and at times impossible. The casing should be turned frequently to prevent it from getting stuck.

**4.1.4.** The major drawback of this method is its slower rate of progress and depth limitations. The capacity of the drilling rig depends on the weight of tools which it can handle safely. Tool weight is determined largely by the diameter of the bit and

the diameter and length of drill stem. However, as the hole is deepened, the rig must support more and more cable weight also. The percussion drilling can economically drill maximum diameters of 60 to 75 cms and depths upto 600 m.

A further disadvantage of percussion drilling is that the necessity of driving casing coincident with drilling in unconsolidated formations precludes the use of electric logs. The obvious advantages of percussion drilling are its suitability in rugged terrains; the rigs are inexpensive, simple and compact requiring less accessory equipment and are more readily moved. They require less skilled operators and their ease of repair is advantageous in isolated areas.

Percussion drilling also permits acquisition of qualitative data on the water bearing characteristics and static heads of various formations as casing is being driven. Water quality data can be obtained by bailer samples as each formation in turn is opened to the bottom of the casing and upper formations are cased off.

## 4.2 Rotary Drilling

The rotary drilling method is becoming the most effective and widely practised of all drilling systems. The two key items in rotary drilling method are the bit and the drilling fluid. Both are indispensable in cutting and maintaining the borehole. All of the components that make up the rotary drilling machine are designed to serve simultaneously these two functions—operation of the bit and continuous circulation of the drilling fluid.

## 4.3 Direct Circulation Drilling

The rotary rig drills by mechanical rotation of a drill bit at the bottom of a string of drill pipe. The typical string consists of a bit which scrapes, grinds, fractures or otherwise breaks the formation drilled; a drill collar of heavy walled pipe to maintain a straight hole; and a drill pipe which extends to the surface and imparts rotation to the bit. As the bit is turned drilling fluid (usually bentonite mixed with other suitable material) is circulated under pressure which lubricates and cools the bit, carries the cuttings in suspension to the surface and plasters the wall of the hole to prevent caving in.

The rotary rig costs more than the percussion rig; larger and much more training and skill are needed. Maintenance and repair are more complex and more water is required for drilling when using drilling fluids. If the permeability of the aquifer is high, drilling fluid may invade it. Despite these disadvantages, the direct rotary rig offers relatively rapid drilling in most formations, greater depth capacities and an open hole which simplifies installation of casing, screen and grout and permits the use of most geophysical logging equipment.

It is best suited for drilling small diameter deep wells in soft to medium alluvial formations.

#### 4.4 Reverse circulation drilling

The reverse circulation rotary rig operates essentially in the same way as a direct rotary rig except that water is pumped up through the drill pipe rather than down through it. A string of drill pipes with a drill bit at the bottom is rotated by mechanical means. Plain water or a drilling fluid, depending on the strata conditions, is allowed to flow into the borehole; the drill cuttings along with water are sucked through the drill pipes by a centrifugal pump and thrown into a settling pit. As the diameter of the drill pipe is relatively small the velocity of the drilling fluid in it is high. It is therefore able to carry even large pieces of broken rock, stones etc. The strong upward flow in the drill pipe has another advantage. There is no need to use a heavy drilling fluid for bringing the cuttings to the surface and clear water can be used. The clogging of aquifer around the well is also avoided.

The reverse circulation drilling rig is probably the most rapid equipment available for unconsolidated formations. The strong suction at the end of the drill pipe is sufficient to loosen the material; a slow rotation of bit is all that is needed to achieve rapid progress. Because of the large hole diameters reverse circulation drilled holes are usually gravel packed. Large diameter wells can be drilled in alluvial formations by this method. The hole remains intact under the hydrostatic pressure of the drilling fluid. It has to be ensured that the head of the drilling fluid in the borehole is sufficiently larger than the head of water in the aquifer.

#### 4.5 Down-the-Hole (DTH) Hammer Drilling

It is accomplished by a tool called the down-the-hole hammer which is essentially a pneumatic hammer operated at the lower end of the drill pipe and combining the percussion and the rotary actions. The method utilizes compressed air for the rapid impacting action given by the hammer to the bit, thus crushing the formation into small chips which are flushed out through the annular space between the bore and the drill pipes by the up coming compressed air. The machine should, therefore, be fitted with a compressor capable of producing return velocity of 915 to 1 220 m/min.

The method is used for fast and economical drilling of small bore (200 mm max) in medium hard to hard rock formations.

#### 4.6 Water Jet Boring

A water jet is used for drilling the well which implies that a drill bit with nozzles is attached to the drill pipes at the bottom through which water is pumped at high pressure. The water on its return flows through the annular space between the bore and the drill pipe and brings out the cuttings along with it to the surface. Casing pipe is simultaneously used to avoid caving in. The nozzle can sometimes be used as a drilling bit in harder formations. The method is suitable for drilling shallow wells in loose sandy formations (see Fig. 4).

#### 4.7 Calyx Drilling

A bit made from steel tube with two inclined slots called 'shot bit' is connected below another tube (core barrel) which is further connected to the drill rods. These are rotated mechanically. Chilled shots are fed to the bottom of the bit through the drill string along with water. These are ground by the shot bit to form abrasive materials with sharp edges which cuts into the consolidated formation forming an annular ring to form a core inside the core barrel, which is then taken out from well by grouting the core with quartz chips, etc. This method is successful for shallow tubewells drilling in consolidated formations with large diameter holes.

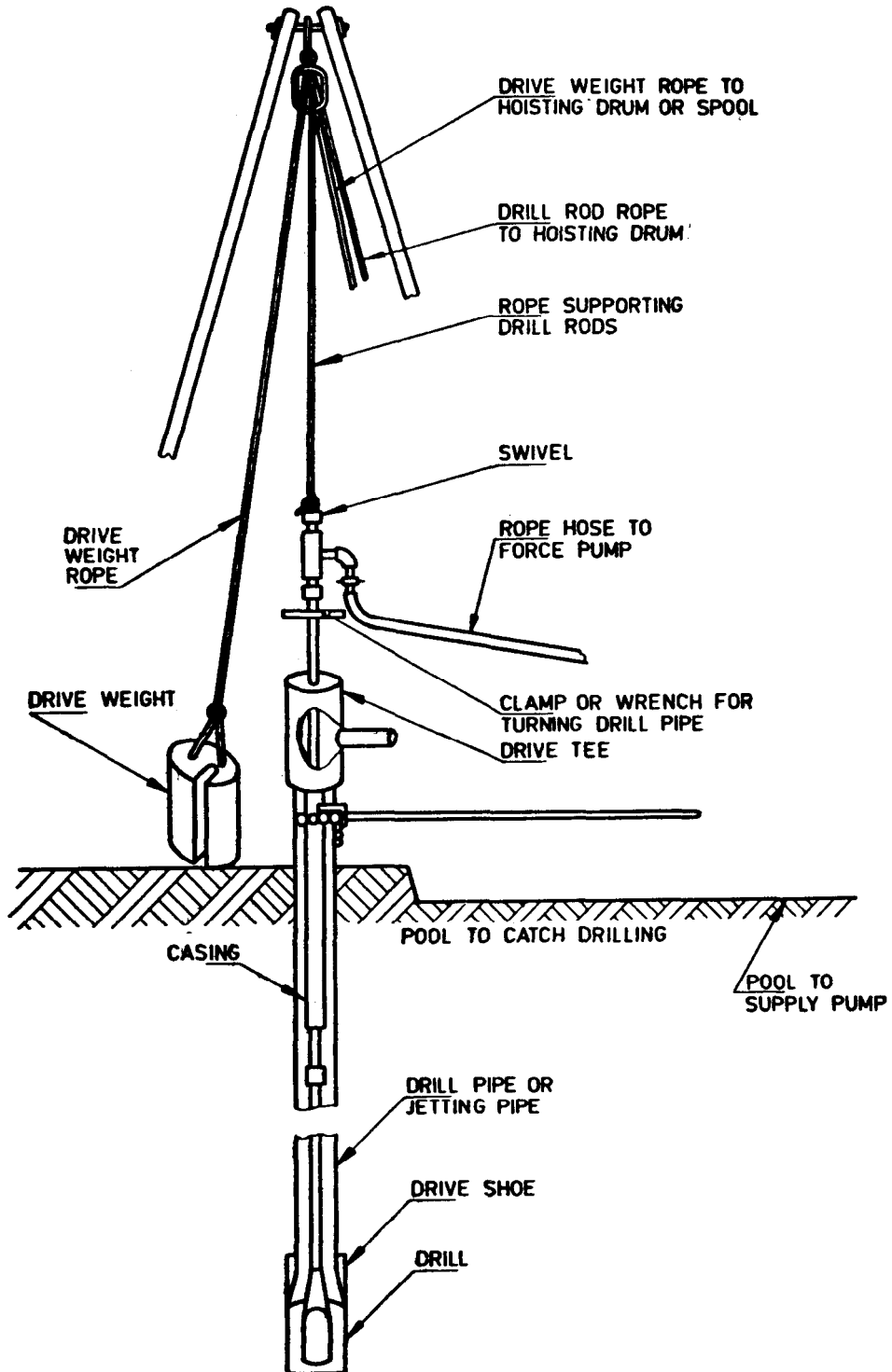


FIG. 4 SIMPLE JETTING RIG

**4.8 Auger Drilling**

The drilling is done with a spiral or worm auger connected to square rods turned manually with rod tillers. The cuttings produced as a result of drilling are removed with a sand shell. Steel casing pipes with drive shoes at the bottom are lowered as the drilling progresses. This method is employed where very shallow drilling in alluvium formation is involved (see Fig. 5A and 5B).

**5 SELECTION OF DRILLING RIGS**

**5.0** The recommendations for selection of drilling rigs include the suitability aspects of different types of drilling rigs for their proper selection for drilling water wells and bore holes in different geological formations.

**5.1 Classification**

Based on diameter of hole, depth of hole and the size of drill rod used, the drilling rigs shall be classified into light, medium and heavy duty as specified in Table 1.

The tool weight at the surface for percussion (cable tool) type of drilling rig of light, medium and heavy classes shall be 1135 kg, 1735 kg and 2 315 kg respectively.

**5.2 Selection**

Based on the formation to be encountered during drilling, the diameter and depth of the borehole/well, the recommended class of drilling equipment and the size of drill rod to be selected for drilling is given in Table 2.

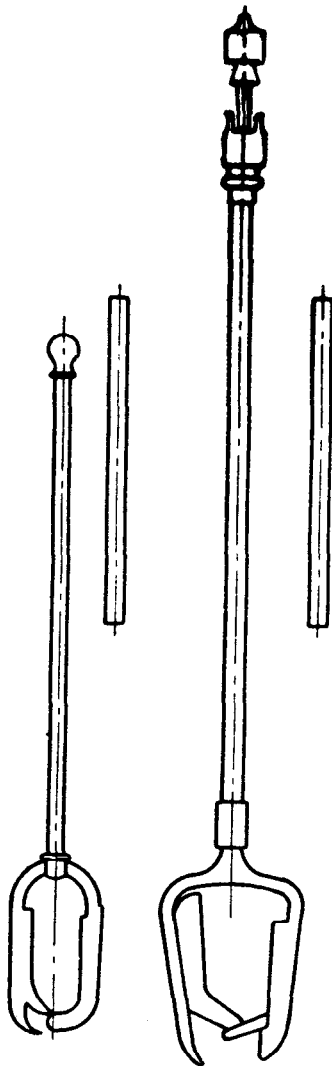


FIG. 5A HAND AUGER

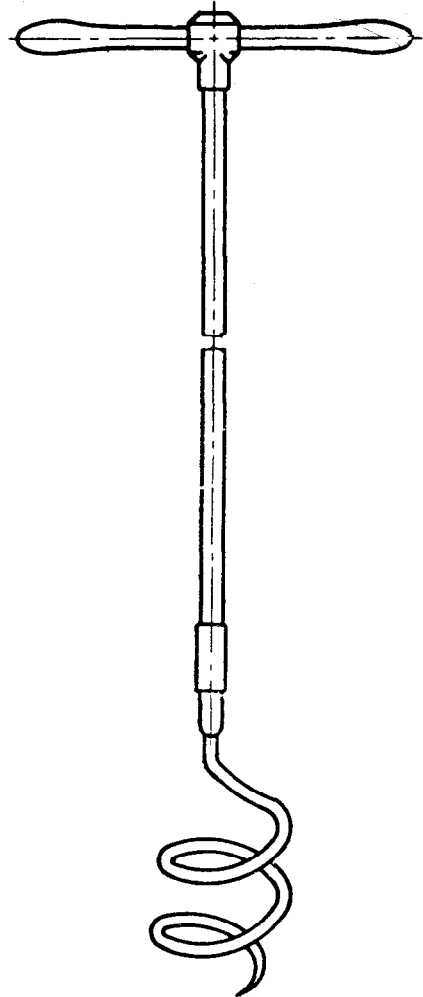


FIG. 5B SPIRAL AUGER OR RAM'S HORN

**Table 1: Classification of Drilling Rigs**  
(Clause 5.1)

Sl No.	Type of Drilling	Classification	Dia of Hole mm	Depth of Hole m	Size of Drill Rods mm
(1)	(2)	(3)	(4)	(5)	(6)
i)	Percussion (Cable Tool)	Light	200	up to 50	—
		Medium	200	up to 170	—
		Heavy	200	above 170	—
ii)	a) Rotary-Direct Circulation	Light	200	up to 250	73
		Medium	200	up to 450	89
		Heavy	200	above 450	89, 101, 114
	b) Rotary-Reverse Circulation	Medium	500	up to 170	150
		Heavy	675	above 170	150
iii)	Down-the-Hole (DTH) Hammer	Light	114	up to 50	76
		Medium	150	up to 170	114
		Heavy	150	above 170	114
		Heavy	200	above 170	114
iv)	Combination (Rotary-cum- Percussion)	Medium			
		Rotary	200	up to 450	89
		Percussion	300	up to 170	—
		Heavy			
		Rotary	200	above 450	89
v)	DTH-cum-Rotary	Percussion	300	above 170	—
		Medium			
		DTH	150	up to 170	114
		Rotary	250	up to 50	114
		Heavy			
DTH	150	above 170	114		
Rotary	250	up to 100	114		

**Table 2 Recommendations for Selection of Drilling Equipments**

(Clause 5.2 )

Sl No.	Formation	Size of Pilot Diameter mm	Borehole/well Depth m	Type	Class	Size of Drill Rods mm
(1)		(2)	(3)	(4)	(5)	(6)
i)	Consolidated formations like hard sandstone, limestone, Trap, Basalt, Quartzite, Granite, etc.	114	up to 50	DTH	Light	76
		150	up to 170	DTH	Medium	114
		150	above 170	DTH	Heavy	114
		200	above 170	DTH	Heavy	114
ii)	Semi-consolidated formations :					
a)	Sandstone, Clay, Shale	200	up to 250	Rotary-Direct Circulation	Light	73
		200	up to 450	Rotary-Direct Circulation	Medium	89
		200	up to 450	Rotary-Direct Circulation	Heavy	89,101,114
b)	Bouldery	200	up to 170	Percussion (Cable tool)	Medium	—
		200	above 170	Percussion (Cable tool)	Heavy	—
iii)	Semi-consolidated and Bouldery formation	150	up to 300	Rotary-cum-Percussion	Heavy	89
iv)	Unconsolidated formation	200	up to 250	Rotary-Direct-Circulation	Light	73
			up to 450	Rotary-Direct-Circulation	Medium	89
			above 450	Rotary-Direct-Circulation	Heavy	89
v)	Soft alluvial, clay, gravel small (upto 125 mm size) cobbles formation	500 675	up to 170	Rotary-Reverse-Circulation	Light	150
			above 170	Rotary-Reverse-Circulation	Medium	150

**6 INFORMATION TO BE FURNISHED BY THE OWNER OF THE TUBEWELL**

The owner shall furnish the following information to the drilling agency :

- a) Information regarding tubewells and dug wells, existing near his land. Their depth, formation encountered and discharge, etc. may be furnished as far as possible;
- b) Static water level;
- c) Expected yield;
- e) Purpose for which the water is needed, such as irrigation, industrial or domestic purpose, etc; and
- f) Any other information.

**7 INFORMATION TO BE FURNISHED BY DRILLING AGENCY**

7.1 When offering to sink a tubewell, the drilling agency shall furnish the owner with the following information :

- a) Suitability of the site proposed by the owner (if a more suitable site, other

than the one proposed by the owner is available, it should be suggested);

- b) Whether a test bore hole is proposed and if so, its diameter and depth, and also depth of production tubewell proposed;
- c) Likelihood of increase or decrease of the depth given at (b) above;
- d) Method of drilling with size of bore in different depths;
- e) Types of plain pipe with size, wall thickness and slotted/strainer pipes openings, may be mentioned;
- f) Guarantee with regard to the verticality of tubewell and sand content (ppm) in the discharge from the well at the time of handing over;
- g) Development methods to be adopted may be stated; and
- h) Any other information and conditions.

7.2 The drilling agency should furnish information to the owner on completion, as given in Form 1.



**Form 1**  
( Clause 7.2 )

**INFORMATION TO BE FURNISHED BY DRILLING AGENCY TO OWNER ON  
COMPLETION OF TUBEWELL**

1. Agency drilling the tubewell. ....
  2. Location of the tubewell .....
  3. Method of drilling adopted. ....
  4. Date of starting. ....
  5. Date of completion. ....
  6. Pilot hole or test hole ..... Bit size. .... Bit type. ....  
Hours ..... From ..... to. ....
  7. Coring done. .... Bit size ..... Bit type. .... Hours .....  
Recovery. .... From ..... to. ....
  8. Reaming. .... Bit size. .... Bit type ..... Hours .....  
From ..... to. ....
  9. Lithological data  

	From	To	
.....			Formations
.....			
  10. Assembly of production well ..... Size. .... Length. .... Type .....  
 Perforation per metre. ....  
 Housing pipe. ....  
 Blind pipe .....  
 Strainer. ....  
 Bail plug. ....
  11. Top of tubewell above/below ground level. ....  
 Size of gravel. .... Quantity used before development .....  
 Quantity used during development. ....
  13. Method used for development .....  
 Total hours of testing .....
  14. Further details appeneded :  
 a) Samples of strata, neatly packed in sample bags  
 b) Chart of pipe assembly lowered  
 c) Results of mechanical analysis of samples of unconsolidated strata.
  15. Remarks :
- Owner ..... Driller. ....

## CHAPTER 6

### WELL CASING

#### 1 GENERAL

Well casing in a pipe is used to prevent caving in of surrounding soil into the well or bore-hole. The upper portion of the casing, used for housing the pumping equipment, is called housing pipe. The casing may be temporary and removed on completion of the well (drive pipe) or it may be a permanent part of the structure. The length and diameter of the casing pipe is selected on the basis of static water level, drawdown, discharge expected from the pump and the size of pump to be installed.

#### 2 STEEL TUBES

2.1 Steel tubes most suitable for varied type of water well drilling operations — either casing or drive — are those made to IS 4270 : 1992. The tubes are seamless, automatic fusion welded or electric resistance welded or high frequency induction welded. They are designated Fe 410 or Fe 450 grades based on the minimum tensile strength.

##### 2.1.1 Dimensions

The dimensions and masses of various types of tubes are as given in Tables 1, 2, 3 and 4. Unless otherwise agreed to between the supplier and the

purchaser, the pipes shall be supplied in random lengths of 4 to 7 metres.

##### 2.1.1.1 Tolerances

- a) *Outside diameter* — Permissible tolerance on outside diameter of pipe and socket shall be  $\pm 1$  percent but not greater than 3 mm in the case of socket.
- b) *Thickness* — The permissible tolerances on tubes thickness shall be as follows :

Seamless tube	+ 20 percent
	- 12.5 percent

Welded tube	
Up to and including 406.4 mm outside diameter	+15 percent -12.5 percent
Over 406.4 mm outside diameter	+ 15 percent - 10 percent

- c) *Mass* — No single tube shall deviate from the mass specified in tables 1,2,3 and 4 with a tolerance of  $\begin{matrix} +10 \\ -8 \end{matrix}$  percent.

Table 1 Dimensions and Masses of Screwed and Socketed Casing Pipes

( Clause 2.1.1 )

Nominal Bore of Pipe (mm) (1)	Outside Diameter of Pipe (mm) (2)	Thickness of Pipe (mm) (3)	Mass of Plain Tube kg/m (4)	Socket Outside Diameter (mm) (5)	Overall Length of Socket, Min (mm) (6)
100	114.3	5.4	14.5	130.0	114.3
125	141.3	5.4	18.1	157.0	120.6
		7.1	23.5		
150	168.3	5.4	21.6	184.0	127.0
		7.1	28.2		
175	193.7	6.4	29.6	211.6	152.4
		8.0	36.6		
200	219.1	6.4	33.6	237.0	152.4
		8.0	41.6		
225	244.5	7.1	41.6	262.5	165.1
		9.0	52.3		
250	273.1	8.0	52.3	291.0	177.8
		10.0	64.9		
300	323.9	8.0	62.3	346.0	177.8
		10.0	77.4		

**Table 2 Dimensions and Masses of Plain End Casing Pipes**

( Clause 2.1.1 )

<b>Nominal Bore of Pipe</b>	<b>Outside Diameter of Pipe</b>	<b>Thickness of Pipe</b>	<b>Mass of Plain Tube</b>
(mm)	(mm)	(mm)	(kg/m)
(1)	(2)	(3)	(4)
100	114.3	5.0	13.48
125	141.3	5.0	16.80
150	168.3	5.0	20.13
175	193.7	5.4	25.10
200	219.1	5.4	28.46
225	244.5	6.0	35.29
250	273.0	7.1	46.57
300	323.9	7.1	55.47
350	355.6	8.0	68.57
350	355.6	10.0	85.22
400	406.4	8.0	78.60
400	406.4	10.0	97.75
450	457.2	10.0	110.28

**Table 3 Dimensions and Masses of Drive Pipes for Screwed Flush Butt Joints (Square Threads)**

( Clause 2.1.1 )

<b>Nominal Bore</b>	<b>Outside Diameter</b>	<b>Thickness</b>	<b>Mass of Plain Tube</b>
mm	mm	mm	kg/m
(1)	(2)	(3)	(4)
100	114.3	6.0	16.02
125	141.3	6.0	20.01
150	168.3	8.0	31.62
175	193.7	8.0	35.63
200	219.0	10.0	51.56
225	244.5	10.0	57.82
250	273.0	10.0	64.88
300	323.9	10.0	77.40
350	355.6	10.0	85.22
400	406.4	12.0	116.71
450	457.2	12.0	131.74
500	508.0	12.0	146.77

**Table 4 Dimensions and Masses of Plain End Drive Pipes**

( Clause 2.1.1 )

<b>Nominal Bore</b>	<b>Outside Diameter</b>	<b>Thickness</b>	<b>Mass Per Metre of Plain Tube</b>
mm	mm	mm	kg/m
(1)	(2)	(3)	(4)
300	323.9	10.0	77.5
350	355.6	10.0	85.2
400	406.4	10.0	97.8
450	457.2	10.0	110.3
500	508.0	10.0	122.8

d) *Thread* — The tolerance on V-form and square threads, shall be as follows :

Tolerances on 'V' type casing taper threads :

- |  |                          |
|--|--------------------------|
| 1) Taper per meter on diameter             | + 5.208 mm               |
|  | - 2.600 mm               |
| 2) Thread Height                           | + 0.05 mm                |
|  | - 0.15 mm                |
| 3) Angle                                   | $\pm 1\frac{1}{2}^\circ$ |
|  | -                        |
| 4) Total thread length                     | $\pm 1\frac{1}{2}$ pitch |
| 5) Chamfer on outside end of threaded pipe | + $5^\circ$              |
|  | - $0^\circ$              |

Tolerance on Square form parallel threads :

- |                                 |                          |
|---------------------------------|--------------------------|
| 1) Total thread length          | + 4.50 mm                |
|                                 | - 1.50 mm                |
| 2) Angle                        | $\pm 1\frac{1}{2}^\circ$ |
| 3) Outside end of threaded pipe | + $5^\circ$              |
|                                 | - $0^\circ$              |

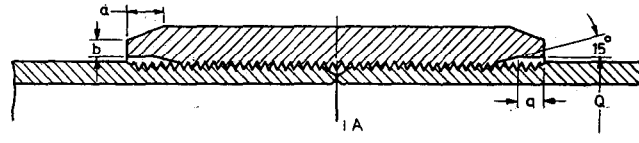
e) *Tolerance on length* — Unless otherwise agreed to tolerance on length for plain end pipe shall be  $\pm 25$  mm. For screwed end pipes, the tolerance on length shall be mutually agreed to between the supplier and the purchaser.

f) *Straightness tolerance* — Tubes shall not deviate from straightness by more than 1 in 600 of any length. Any special requirement shall be agreed to between the supplier and the purchaser.

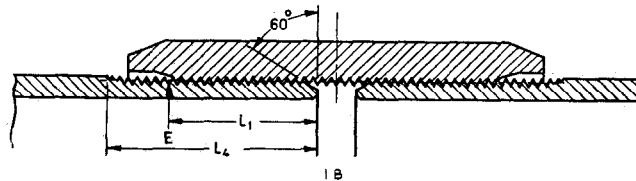
2.1.2 *Joints*

2.1.2.1 Screwed and socketed butt joints shall have right-handed V-form threads in accordance with the particulars given in Table 5 (see Fig. 1). There shall be not more than six incomplete external threads. The threads in the socket shall be continuous.

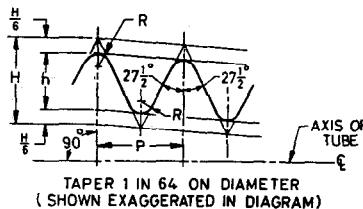
2.1.2.2 Screwed flush butt joints shall have right handed square form threads in accordance with the particulars given in Table 6 (see Fig. 2).



1A POWER MAKE UP (TUBE ENDS TO BUTT IN CENTRE OF SOCKET)

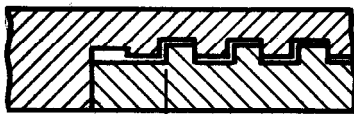
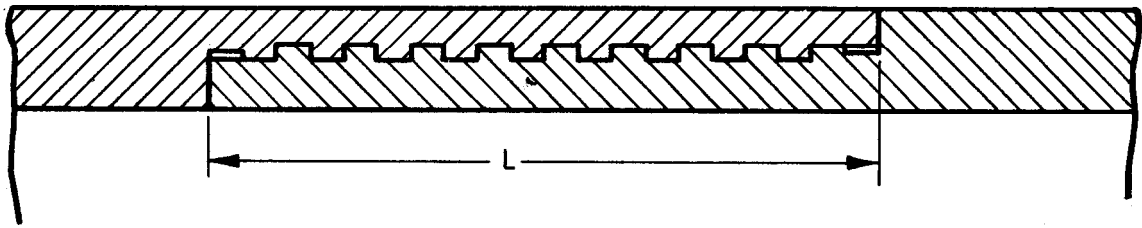


1B HAND TIGHT ASSEMBLY

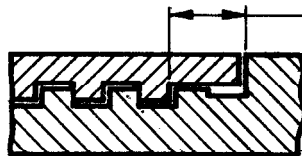


1C THREAD DETAIL

FIG. 1 SCREWED AND SOCKETED BUTT JOINTS WITH V-THREAD TAPER SCREWING



THE THREAD SHALL BE TURNED OFF THE MALE END FOR A DISTANCE OF APPROXIMATELY ONE PITCH AND THE FEATHER EDGE SHALL BE CUT BACK UNTIL THE WIDTH OF THE THREAD IS AT LEAST 1.6 mm



THE THREAD SHALL BE TURNED OFF THE FEMALE END FOR A DISTANCE OF APPROXIMATELY ONE PITCH AND THE FEATHER EDGE SHALL BE CUT BACK UNTIL THE WIDTH OF THE THREAD IS AT LEAST 1.6 mm

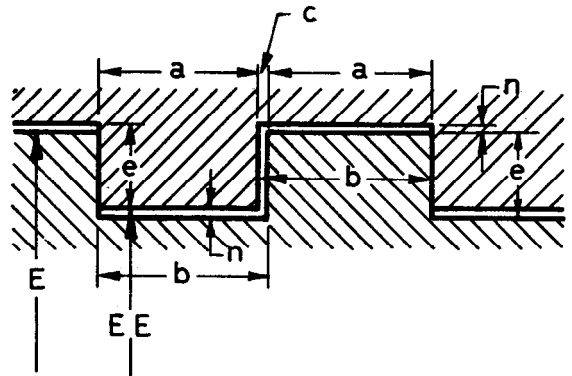


FIG. 2 SCREWED FLUSH BUTT JOINTS WITH SQUARE FORM THREAD PARALLEL SCREWING

**Table 5 Screwed and Socketed Butt Joints with V-Thread Taper Screwing**

( Clause 2.1.2.1 and Fig. 1 )

Nominal Size	Outside Diameter	Thickness	Pitch	Taper on Diameter	Total Length of Thread	End of Pipe to Hand Tight Plane	Diameter Over Threads	Diameter of Recess	Depth of Recess	Approx. Length of Chamfer	Approx. Width of Flat End of Socket
(mm)	(mm)	(mm)	(mm)		$L_t$	$L_i$	$E$	$Q$	$q$	$a$	$b$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
100	114.3	5.4	2.54	1 in 64	57.18	34.92	111.55	116.59	9.52	13	5
125	141.3	5.4	2.54	1 in 64	60.10	38.10	138.54	141.64	9.52	13	5
150	168.3	5.4	2.54	1 in 64	63.5	41.28	165.52	170.69	9.52	13	5
175	193.7	6.4	3.18	1 in 64	76.2	53.98	190.52	196.69	9.52	13	5
200	219.1	6.4	3.18	1 in 64	76.2	53.98	215.91	211.49	9.52	13	5
225	244.5	7.1	3.18	1 in 64	82.55	60.33	241.30	246.75	9.52	13	6
250	273.0	8.8	3.18	1 in 64	88.9	66.68	269.88	275.14	9.52	13	6
300	323.9	8.8	3.18	1 in 64	88.9	66.68	320.68	326.14	9.52	13	6

**Table 6 Screwed Flush Butt Joints Square Form Thread Parallel Screwing**

( Clause 2.1.2.2 and Fig. 2 )

All dimensions in millimetres.

Nominal Size	Outside Diameter	Thickness	Pitch	Width of Thread	Width of Groove	Flank Clearance Between Threads	Depth of Threads	Total Length of Threads	Diameter Over Male Threads	Inside Diameter of Female Threads	Radial Clearance Between Threads
(1)	(2)	(3)	(4)	$a$	$b$	$c$	$e$	$L$	$E$	$EE$	$n$
100	114.3	6	6.35	3.07	3.28	0.20	1.58	63.50	107.85	104.90	0.10
150	168.3	8	6.35	3.07	3.28	0.20	1.98	76.20	160.60	156.90	0.13
175	193.7	8	6.35	3.07	3.28	0.20	1.98	76.20	186.00	182.30	0.13
200	219.1	10	6.35	3.07	3.38	0.20	1.98	76.20	211.33	207.77	0.20
225	244.5	10	6.35	3.07	3.28	0.20	1.98	76.20	236.73	233.17	0.20
250	273.0	10	6.35	3.07	3.28	0.20	2.39	88.90	264.13	259.77	0.20
300	323.9	10	6.35	3.07	3.28	0.20	2.39	88.90	314.93	310.57	0.20
400	406.4	12	6.35	3.05	3.30	0.25	2.39	101.6	395.78	391.62	0.30
500	508.0	12	6.35	3.05	3.30	0.25	2.39	101.6	497.36	493.22	0.30



2.1.2.3 The plain-end pipes shall be supplied with both ends bevelled or both ends square cut or one end bevelled and one end square cut as required by the purchaser. If the pipe is bevelled at both ends, the angle of bevell shall be  $30^\circ \pm 5^\circ$  when measured from a line drawn perpendicular to the axis of the pipe and with root face of  $1.6 \pm 0.8$  mm (see Fig. 3) If one end is bevelled then the angle of bevel shall be  $45^\circ \pm 2.5^\circ$  with a root face of  $1.6 \pm 0.8$  mm.

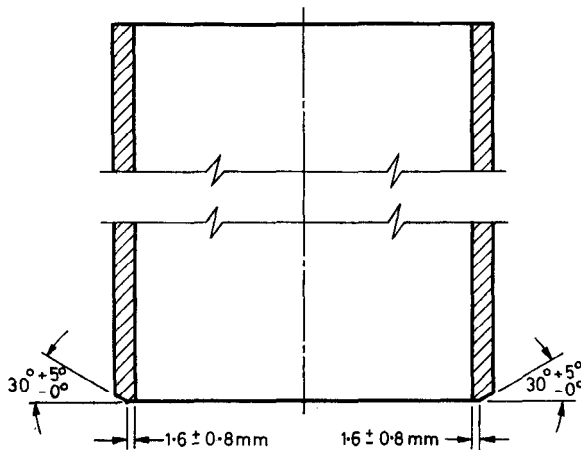


FIG. 3 TUBE END WITH 30° BEVELLING

2.1.3 All pipes shall be free from harmful defects, of good commercial finish and free from loose scale and rust. When required, the ends shall be cut square with the axis of the pipe (see 2.1.2.3). The repair by welding of minor defects shall be permitted but when pipes are being manufactured under inspection at the manufacturer's works such repairs shall be done only after the sanction of the purchaser or his representative has been first obtained. Such pipes shall be hydraulically tested after the repair by welding has been made.

2.1.4 Mechanical Properties

2.1.4.1 In case the purchaser does not require tests specifically related to his order, the manufacturer shall undertake the mechanical tests specified in this standard on a sufficient number of pipes to ensure that they comply with the requirements of the standard. For guidance, reference may be made to Appendix A of IS 4711:1974. When the purchaser requires tests specifically related to his order, sampling to his order, sampling and testing shall be carried out as per 2.1.13.

2.1.4.2 Tensile test - When tested in accordance with IS 1894 : 1972 tensile strength and elongation of tubes shall not be less than that specified in Table 7.

Table 7 Tensile Strength and Elongation

(Clause 2.1.4.2)

Type	Grade	Tensile	Yield	Elongation
		Strength Min (N/mm <sup>2</sup> )	Strength Min (N/mm <sup>2</sup> )	Min (Percent)
(1)	(2)	(3)	(4)	(5)
HFS,EFW	Fe 450	450	305	9500/TS <sup>9)</sup>
ERW and HFIW	Fe 410	410	240	9500/TS <sup>9)</sup>

<sup>9)</sup> TS = Tensile th in N/mm<sup>2</sup>

2.1.4.3 Flattening test — The test shall be carried out in accordance with IS 2328:1983. A ring not less than 40 mm long, cut from one end of each selected tube shall be flattened cold between parallel flat surfaces without showing either crack or flaw, until the distance between the plates under load conditions is not greater than the following :

Test	Distance Between Flat Surface as Percentage of Original Outside Diameter
a) On weld	66 percent
b) On material	33 percent

For welded tubes as specified, the welds shall be placed at 90° to the direction of the applied force.

For seamless tubes, the distance between the plates under load conditions shall not be greater than the value given by :

$$H = \frac{(1 + C) t}{C + t/d}$$

where

- H = distance between plates, mm;
- t = specified thickness, mm;
- d = specified outside diameter, mm; and
- C = constant, 0.07 for grade Fe 410 and 0.05 for grade Fe 450.

**2.1.4.4 Retests of Samples** — Should any one of the test pieces first selected fail to pass any of the tests specified, two further samples shall be selected for testing in respect of each failure from the same lot. Should the test pieces from both these additional samples pass, the material represented by the test samples, shall be deemed to comply with the requirement of the particular test. Should the test pieces from either of the additional samples fail the material represented by the test samples shall be rejected.

**2.1.5 Alignment**

**2.1.5.1** For this test any two tubes may be screwed together till they butt and their axes shall not then be out of line by more than 100 mm in each 6 metre length as indicated in Fig. 4.

NOTE - This test is not applicable to the plain end pipes.

There is a possibility of a cumulative effect of alignment error which may amount to 100 mm in each 6 m length and is the maximum error permitted. The actual error of alignment of any one joint will vary from zero to 20 mm, the former value being more probable than the latter. The direction of the alignment errors in a series of consecutive joints will be quite haphazardly distributed, with the result that it would be most unlikely that all the errors would be additive, in general some will tend to compensate others.

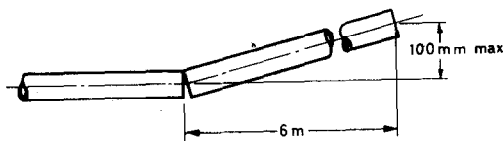


FIG. 4 ALIGNMENT TEST

**2.1.6 Hydraulic Pressure Test**

**2.1.6.1** Each tube shall be subjected to hydraulic pressure test at the manufacturer's works and, if required, in presence of the purchaser or his representative. Every pipe shall withstand the test pressure as calculated by the following formula:

Grade	Test Pressure N/mm <sup>2</sup>
Fe 410	280 t/d
Fe 450	350 t/d

where

$t$  = thickness of pipe in mm, and

$d$  = Outside diameter of pipe in mm.

Unless otherwise agreed to between the purchaser and the manufacturer the maximum pressure applied shall be 7 MPa.

**2.1.6.2** The pressure shall be steadily applied by approved means and maintained for a short period for proof and inspection. The pipe conveying the pressure shall be fitted with an accurate pressure gauge and be provided with means for attaching the purchaser's gauge. Welded tubes under test shall be hammered at the either ends of each length with a hammer weight approximately 1 kg.

**2.1.7 Condition of Pipes**

**2.1.7.1** All pipe shall be of good commercial finish and free from harmful defects, loose scale and rust. When required the ends shall be cut square with the axis of the pipe.

**2.1.7.2** The repair by welding of minor defects shall be permitted but when pipes are being manufactured under inspection at the manufacturer's works, such repairs shall be done only after the sanction of the purchaser or his representative has first been obtained. Such pipe shall be hydraulically tested after the repair by welding has been made.

**2.1.8 Coating of Tubes**

**2.1.8.1** Unless otherwise specified by the purchaser, the tubes shall be externally coated with a bituminous solution or any other protective anti-corrosion coating. The bitumenous solution shall

be of a quality such as to produce a coating which, when dry, shall be smooth, tough and tenacious and sufficiently hard not to flow on exposure to a temperature of 63°C and shall not be brittle at 0°C. It shall not be such as will impart a taste to the water.

**2.1.8.2** Where tubes are required to be galvanized the zinc coating on the tubes shall be in accordance with IS 4736 : 1986.

#### **2.1.9 Protection of Ends**

**2.1.9.1** All threads shall be coated with a petroleum jelly or other suitable rust preventing compound.

##### **2.1.9.2 V-form threads**

All tubes with V-form threads shall have the threads protected with plastic rings or sleeves, unless otherwise specified.

##### **2.1.9.3 Square form threads**

All tubes with square form threads shall have the exposed male threads protected with steel rings or sleeves and the female threads protected with steel nipples or bushes.

Except where otherwise agreed, this form of protection shall be applied to all orders.

##### **2.1.9.4 Tubes for butt welding**

No protection of the ends shall be provided unless specially called for by the purchaser.

#### **2.1.10 Manufacturer's Certificate**

**2.1.10.1** When required by the purchaser, manufacturer shall supply a certificate stating that the tube complies with the requirements of IS 4270:1992.

#### **2.1.11 Marking**

**2.1.11.1** Each pipe shall be marked with the following details:

- a) Nominal size,
- b) Length of tube, and
- c) Manufacturer's trade-mark.

#### **2.1.12 Information to be Supplied by the Purchaser**

**2.1.12.1** The purchaser shall state in his enquiry or order :

- a) The nominal size, thickness and the total effective length of the tubes required;
- b) the type and grade of tube required;
- c) the form of joint;
- d) the length in which individual tubes are to be supplied;
- e) whether he wishes to have tests made specially related to his order and, if so, whether or not he wishes himself or his representative to witness them;
- f) Whether he desires to receive test certificate;
- g) special requirements of surface coating if desired;
- h) any special welding technique desired;
- j) any special marking; and
- k) whether any protection of pipes for transit is required.

#### **2.1.13 Sampling and Criteria for Conformity**

##### **2.1.13.1 Visual dimensional, alignment and mass requirements**

The sampling and testing of steel tubes for these requirement shall be in accordance with IS 4711 : 1974.

##### **2.1.13.2 Mechanical requirement**

The number of tubes to be sampled and tested for mechanical properties are given below. The samples shall be taken at random by using random number tables.

<i>Nominal Size</i>	<i>Samples Size</i>
Up to 100 mm	One for every 400 pipes or part thereof
Above 100 mm and up to 300 mm	One for every 200 pipes or part thereof
Above 300 mm	One for every 100 pipes or part thereof
Minimum number of samples per lot	Two

**2.1.13.3 Retest of samples**

Should any one of the test pieces first selected fail to pass any of the test specified, two further samples shall be selected for testing in respect of each failure from the same lot, should the test pieces from the both these additional samples pass, the material represented by the test samples shall be deemed to comply with the requirement of that particular test. Should either of the additional samples fail, the material represented by the test samples shall be rejected.

**2.1.13.4 Hydraulic pressure test**

All the tubes shall be subjected to hydraulic pressure test as per 2.1.6. Those tubes failing in the test shall be rejected.

**2.1.13.5 Coating test**

One tube for every 1 000 tubes in the lot shall be subjected to coating test as per 2.1.8. The samples should pass if the lot is to be accepted under this clause.

**3 PVC PIPES**

**3.1** In order to overcome the problem of corrosion of casing pipes associated with metal casing pipes, UPVC casing pipes have been developed as an alternative material. UPVC casing pipes also have the advantage of having light weight compared to metal pipes. However they suffer from the disadvantage of having low tensile and impact strength. The requirements for UPVC casing pipes have been covered in IS 12818: 1992 which provides for two classes of UPVC casing pipes, namely, CS pipes & CM pipes, suitable for shallow and medium depth wells as follows:

CS Pipe: Casing pipe suitable for well with depth up to 80 m, and

CM Pipe: Casing pipe suitable for wells with depth above 80 m and up to 250 m.

**3.2 Composition of UPVC Casing Pipes**

**3.2.1** The pipe shall be produced from material consisting substantially polyvinyl chloride conforming to IS 10151: 1982 to which may be added only those additives as are needed to facilitate

manufacture of sound pipe with good surface finish, mechanical strength and opacity under the conditions of use. None of these additives shall be used separately or together in quantities sufficient to constitute a toxic hazard or materially to impair the fabrication, chemical and physical properties of the pipes.

**3.2.2** Up to 10 percent addition of the manufacturer's own rework material produced during the manufacture and testing of pipes complying to this standard is permissible.

**3.3 Colour**

The pipe shall be of regular blue colour throughout slight colour deviation is permissible.

**3.4 Designation**

Pipe shall be designated by its type (CS or CM) followed by its nominal diameter DN, and length of this pipe.

**3.5 Dimensions**

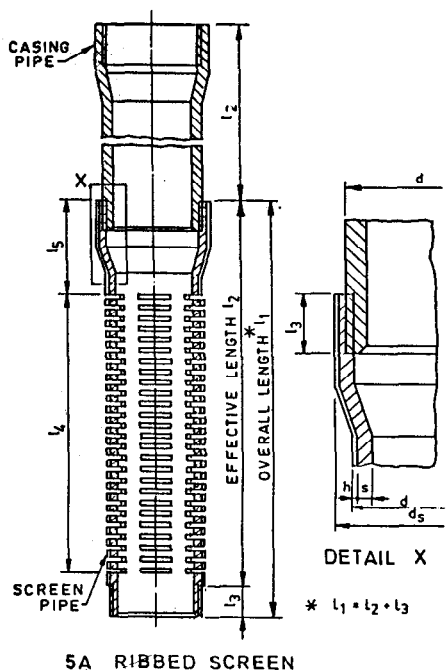
**3.5.1** The diameters and wall thickness for 'CM' casing pipes shall be as given in Table 8, read with Fig. 5.

**3.5.2** The diameters and wall thickness for 'CS' casing pipes for sizes DN 150 to DN 400 shall be as given in Table 9, read with Fig. 5.

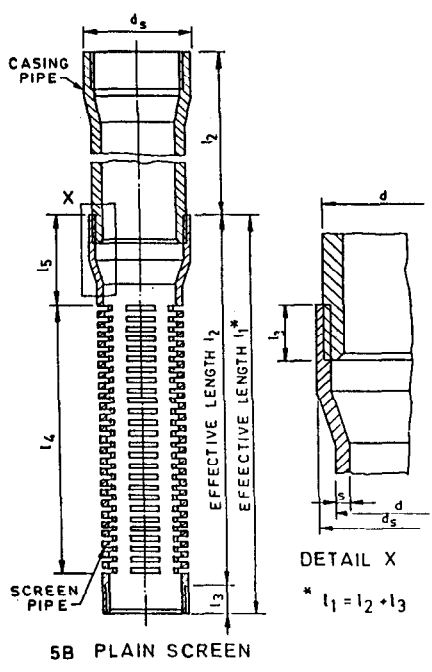
**3.5.3** Effective and segmental lengths of casing pipes shall be as given in Table 10, read with Fig. 5.

**3.5.4** Tolerances on overall length and segmental lengths of pipes shall be as follows:

- i) Overall length  $l_1$   $^{+20}_{-0}$  mm
- ii) Segmental length  $l_3$   
(Threaded portion)
  - a) for DN up to and including 200
    - Spigot end  $^{+0}_{-4}$  mm
    - Socket end  $^{+4}_{-0}$  mm
  - b) for DN above 200
    - Spigot end  $^{+0}_{-6}$  mm
    - Socket end  $^{+6}_{-0}$  mm



5A RIBBED SCREEN



5B PLAIN SCREEN

FIG. 5 SCREEN AND CASING PIPE

**Table 8 Dimensions of 'CM' Casing Pipes**

(Clause 3.5.1)

All dimensions in millimetres.

Nominal Diameter <i>DN</i>	Outer Diameter, <i>d</i> of Pipe		Outer Diameter, <i>ds</i> Over Connection	Wall Thickness, <i>s</i>	
	<i>Min</i>	<i>Max</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
(1)	(2)	(3)	(4)	(5)	(6)
40	48.0	48.2	52	3.5	4.0
50	60.0	60.2	64	4.0	4.6
80	88.0	88.3	94	4.0	4.6
100	113.0	113.3	120	5.0	5.7
125	140.0	140.4	150	6.5	7.3
150	165.0	165.4	177	7.5	8.5
175	200.0	200.5	215	8.8	9.8
200	225.0	225.5	243	10.0	11.2
250	280.0	280.5	298	12.5	14.0
300	330.0	330.6	351	14.5	16.2
350	400.0	400.7	428	17.5	19.5
400	450.0	450.8	478	19.5	21.7

**Table 9 Dimensions of 'CS' Casing Pipes**

(Clause 3.5.2)

All dimensions in millimetres.

Nominal Diameter <i>DN</i>	Outer Diameter, <i>d</i> of Pipe		Outer Diameter, <i>ds</i> Over Connection	Wall Thickness, <i>s</i>	
	<i>Min</i>	<i>Max</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
(1)	(2)	(3)	(4)	(5)	(6)
150	165.0	165.4	173	5.7	6.5
175	200.0	200.5	212	7.0	7.8
200	225.0	225.5	238	7.6	8.8
250	280.0	280.5	292	9.6	11.0
300	330.0	330.6	346	11.2	13.3
350	400.0	400.7	420	14.0	15.5
400	450.0	450.8	470	16.0	17.5

**Table 10 Effective and Segmental Lengths of Casing Pipes**

(Clause 3.5.3)

All dimensions in millimetres.

Nominal Diameter DN (1)	Effective Length (2)	Segmental Length (3)
40	2000	25
	3000	25
	4000	25
50	2000	30
	3000	30
	4000	30
80	2000	40
	3000	40
	4000	40
100	2000	45
	3000	45
	4000	45
125	2000	60
	3000	60
	4000	60
150	2000	60
	3000	60
	4000	60
175	2000	60
	3000	60
	4000	60
200	2000	70
	3000	70
	4000	70

250	2000	85
	3000	85
	4000	85
300	2000	85
	3000	85
	4000	85
350	2000	85
	3000	85
	4000	85
400	2000	95
	3000	95
	4000	95

**3.6 Threading**

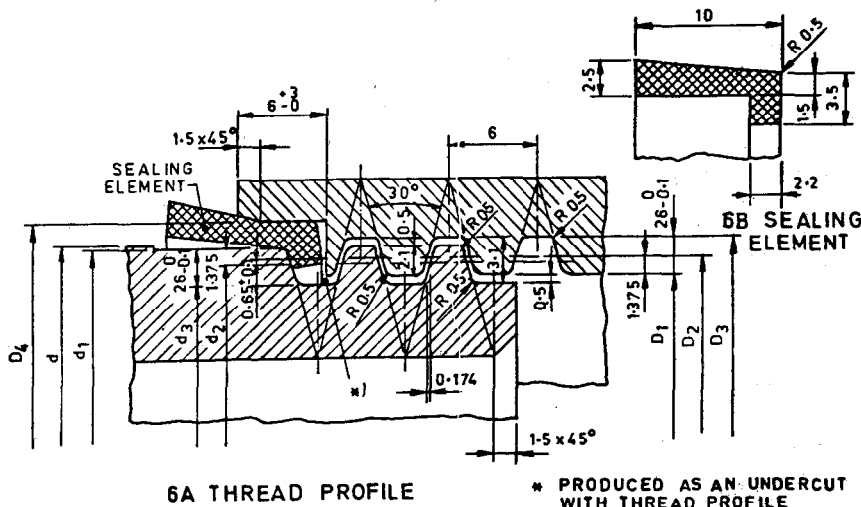
**3.6.1** The Casing pipes shall have male threads at spigot end and female threads at the socket end.

**3.6.2** Casing pipe of nominal diameter from 40 to 80 mm shall have threads in accordance with IS 554 : 1985.

**3.6.3** Casing pipes of nominal diameters of 100 to 400 mm shall have threads in accordance with basic profile for metric trapezoidal threads. Sealing rings to be used with the trapezoidal threads shall be of natural rubber conforming to IS 5382 : 1986, having hardness 65 ±5 sh.

**3.6.4** Pipes of nominal diameter 100 to 200 shall have the thread dimensions as given in Table 11, read with Fig. 6A. Dimensions of sealing element shall be as given in Fig. 6B.

**3.6.5** Pipes of nominal diameter 250 to 400 shall have the thread dimension as given in Table 12, read with Fig 7A Dimensions of sealing element shall be as given in Table 13, read with Fig. 7B.



**6A THREAD PROFILE**

\* PRODUCED AS AN UNDERCUT WITH THREAD PROFILE

**FIG. 6 METRIC TRAPEZOIDAL THREAD PROFILE (DN 100 TO 200)**

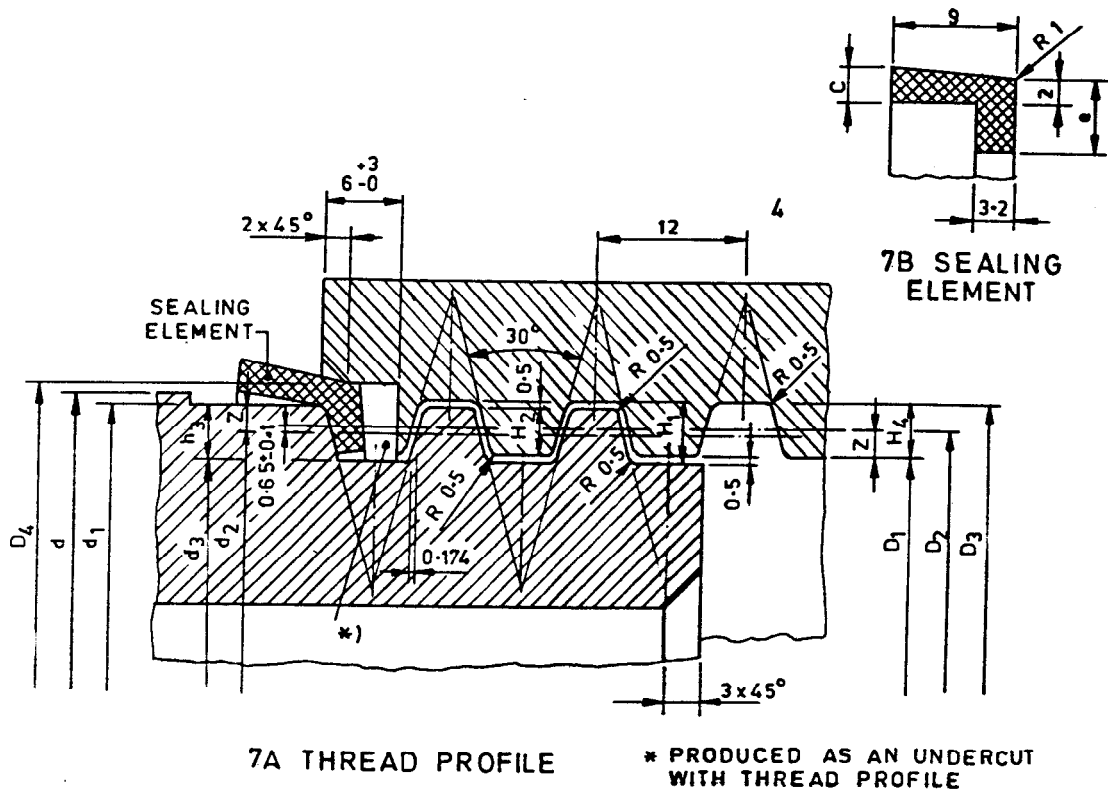


FIG. 7 METRIC TRAPEZOIDAL THREAD PROFILE (FOR DN 250 TO 400)

**Table 11 Trapezoidal Threads; DN 100 to 200**

(Clause 3.6.4)

All dimensions in millimetres

Nominal Size, DN	$d$	$d_1^{+0}_{-0.2}$	$d_2$	$d_3$	$D_1^{+0.2}_{-0}$	$D_2$	$D_3$	$D_4$
100	113	112.5	109.75	107.3	108.3	111.05	113.5	115.9
125	140	139.5	136.75	134.3	135.3	138.05	140.5	142.9
150	165	164.5	161.75	159.3	160.3	163.05	165.5	167.9
175	200	199.5	196.75	194.3	195.3	198.05	200.5	202.9
200	225	224.5	221.75	219.3	220.3	223.05	225.5	227.9



**Table 12 Trapezoidal Threads; DN 250 to 400**

(Clause 3.6.5)

All dimensions in millimetres.

Nominal Size, DN	$d$	$d_1$ <sup>+0</sup> <sub>-0.3</sub>	$d_2$	$d_3$	$d_1$ <sup>+0.3</sup> <sub>-0</sub>	$D_2$	$D_3$	$D_4$	$h_3$ <sup>+0</sup> <sub>-0.1</sub>	$H_1$	$H_2$	$H_4$ <sup>+0</sup> <sub>-0.1</sub>	$Z$
250	280	278	273.35	269	270	274.65	279	281.4	4.5	5.0	4.0	4.5	2.325
300	330	327	322.35	318	319	323.65	328	330.4	4.5	5.0	4.0	4.5	2.325
350	400	397	392.35	388	389	393.65	398	400.4	4.5	5.0	4.0	4.5	2.325
400	450	446	439.85	434	435	441.15	447	449.4	6.0	6.5	5.5	6.0	3.075

**Table 13 Dimensions of Sealing Element; DN 250 to 400**

(Clause 3.6.5)

All dimensions in millimetres.

Nominal Size, DN	$C$	$e$	$g$
250 to 350	2.7	6	10
400	2.84	7.5	12

**3.7 Tests**

**3.7.1 Visual Appearance**

The internal and external surfaces of each pipe shall be inspected for it being smooth, clean and free from any defects. The ends shall be clean and square with the axis of the pipe.

**3.7.2 Test for Internal Dia**

Test mandrel of diameter as given in Table 14, 100 mm in length shall pass smoothly through the pipe.

**Table 14 Mandrel Dia for Checking Internal Dia**

(Clause 3.7.2)

Nominal Pipe Dia, DN	Mandrel Dia
mm	mm
40	39
50	50
80	77
100	98
125	122
150	146
175	174
200	195
250	243
300	290
350	350
400	395

**3.7.3 Specific Gravity**

Specific gravity of the material of the pipe shall be within 1.40 g/cm<sup>3</sup> when determined in accordance with IS 8543 (Part 1/Sec 2): 1979.

**3.7.4 Impact Strength at 0°C**

When tested by the method described in IS 12235 (Part 9): 1986, read with A-1.7 of IS 4985: 1988 the pipe sample shall not fracture or crack through its complete wall thickness. The total mass of the striker and height of free fall shall correspond to the values given in Table 15.

**Table 15 Mass of Striker and Height of Free Fall**

(Clause 3.7.4)

Nominal Size, DN mm	Total Mass of Striker kg	Height of Free Fall mm
40	0.25	1000 ± 10
50	0.25	2000 ± 10
80 and 100	0.50	2000 ± 10
125 and above	1.00	2000 ± 10

NOTE — The test shall be carried out on the plain/ribbed portion taken at least 100mm away from the root of the socket.

**Table 16 Scale of Sampling and Criteria for Conformity**

(Clause 3.8.1)

Number of Pipes in the Lot	For Tests Under 3.5, 3.6, 3.7.1 and 3.7.2						For Tests Under 3.7.3 and 3.7.4				
	Sample		Cumulative Sample Size	Acceptance No.	Rejection No.	Sub-sample		Cumulative Size	Acceptance No.	Rejection No.	
	DN mm	No.				Size	No.				Size
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Up to 1000	Up to 100	First	13	13	0	2	First	3	3	0	2
	100	Second	13	26	1	2	Second	3	6	1	2
	Above 100	First	5	5	0	2	First	1	1	0	2
1001 to 3000	100	Second	5	10	1	2	Second	1	2	1	2
	Up to 100	First	20	20	0	2	First	5	5	0	2
		Second	20	40	1	2	Second	5	10	1	2
	Above 100	First	8	8	0	2	First	2	2	0	2
100	Second	8	16	1	2	Second	2	4	1	2	

**3.7.5 Elastic Modulus and Tensile Strength**

Elastic modulus and tensile strength at break shall be as given below when determined in accordance with the test procedure laid down in IS 8543 (Part 4/Sec 1) : 1984:

- i) Elastic modulus                    2800 ± 200 MPa
- ii) Tensile strength                    50 ± 5 MPa

NOTE - The specimen for the test shall be prepared from a section of the pipe heated to a temperature of 125 °C to 130°C and subsequently flattened and machined.

**3.7.6 Vicat Softening Temperature**

The vicat softening temperature shall not be less than 76°C when measured in accordance with the procedure given in IS 6307: 1985.

NOTE - The test may be done on specimen cut from the pipe, of dimensions as specified in IS 6307 : 1985 . The specimen shall be supported on a suitable concave surface of radius equal to that of the sample pipe ensuring support on all ends.

**3.7.7 Effect on Water**

The pipes shall not have any detrimental effect on the composition of water flowing through them. The pipes shall meet the requirements/tests specified in 6.3 of IS 4985 : 1988.

### 3.8 Sampling and Criteria for Conformity

#### 3.8.1 Routine Tests

The scale of sampling and criteria for conformity of a lot for routine tests specified under sub-clauses of 3.5, 3.6, 3.7.1 to 3.7.4 shall be as given in Table 16.

**3.8.1.1** All pipes, in a single consignment, of the same type (screen or casing ) same size and manufactured under essentially similar conditions shall constitute a lot.

**3.8.1.2** For ascertaining conformity of the lot to the requirements of specification, samples shall be tested from each lot separately.

**3.8.1.3** The pipes shall be selected at random from the lot and in order to ensure the randomness of selection, a random number table shall be used. For guidance and use of random number tables, IS 4905: 1968 may be referred to. In the absence of a random number table, the following procedure may be adopted:

Starting from any pipe in the lot, count them as 1, 2, 3, etc, up to  $r$  and so on, where  $r$  is the integral part of  $N/n$ ,  $N$  being the number of pipes in the lot and  $n$  the number of pipes in the sample. Every  $r$ th pipe so counted shall be withdrawn so as to constitute the required sample size.

**3.8.1.4** The number of pipes given for the first sample of col 4 of Table 16 shall be taken from the lot and examined for requirements given under 3.5, 3.6, 3.7.1 and 3.7.2. A pipe failing to satisfy any of these requirements shall be considered as defective. The lot shall be deemed to have satisfied these requirements, if the number of defectives found in the first sample is less than or equal to the corresponding acceptance number given in col 6 of Table 16. The lot shall be deemed not to have met these requirements, if the number of defectives found in the first sample is greater than or equal to the corresponding rejection number given in col 7. If, however, the number of defectives found in the first sample lies between the corresponding acceptance and rejection numbers given in col 6 and 7, a second sample of the size given in col 4 shall be taken and examined for these requirements. The lot shall be considered to have satisfied these requirements if the number of defective found in the cumulative sample is less than or equal to the corresponding acceptance number given in col 6 otherwise not.

**3.8.1.5** The lot having satisfied the requirements under 3.8.1.4 shall be tested for 3.7.3 and 3.7.4.

For this purpose a sub-sample from those tested under 3.8.1.4 shall be drawn as given in col 9 for the first/second sample size. The lot shall be deemed to have met the requirements given in the specification, if the number of defectives found in the first samples is less than or equal to the corresponding acceptance number given in col 11. The lot shall be deemed not to have met these requirements, if the number of defectives found in the first sample is greater than or equal to the corresponding rejection number given in col 12. If however, the number of defective found in the first sample lies between the corresponding acceptance and rejection numbers given in col 11 and 12, a second smple of size given in col 8 shall be taken and considered for the requirement. The lot shall be considered to have satisfied the requirements, if the number of defectives found in the cumulative sample is less than or equal to corresponding acceptance number given in col 11, otherwise not.

#### 3.8.2 Type Tests

Type tests are intended to prove the suitability and performance of pipes whenever there is a change in the composition, size and type of pipe as well as in the method/technique in the manufacturing process. Tests specified in 3.7.5 to 3.7.7 shall be taken as type tests.

**3.8.2.1** However, even if no change is envisaged, at least one sample from each size and type produced during the period shall be subjected to type test once in six months.

### 3.9 Marking

Each pipe shall be clearly and indelibly marked in red colour with the following information:

- a) Indication of source of manufacture,
- b) Letter CM or CS to denote medium well casing pipe or shallow well casing pipe as applicable,
- c) Nominal diameter in mm, and
- d) Overall length of pipe in mm.

**3.9.2** Pipe may also be marked with the Standard Mark.

## CHAPTER 7

### WELL SCREENS

#### 1 GENERAL

Well screens serve as intake section of a well that allows water to flow freely into the well, prevents sand from entering with water and acts as a structural retainer to support the borehole in unconsolidated material. To accomplish fully its intended purposes, the well screen must be of efficient design i.e. it should let ample quantity of sand-free water to flow into the well with minimum loss of head. The screens may range from pipes perforated in place to carefully fabricated cage-type wire-wound screens with accurately sized slot openings.

#### 2 TYPES

2.1 The following are the various types of well screens and slotted pipes :

- a) *Plain Slotted Pipes* — These are pipes with slots cut by milling.
- b) *Bridge Slotted Pipes* — The slots here are not cut but pressed out.
- c) *Mesh Wrapped Screens* — These are made by wrapping copper mesh over perforated steel pipe using spacers about 3 mm thick in between the copper mesh and the perforated pipe.
- d) *Cage Type Wire-wound Screens* — These are special type of screens wherein a continuous trapezoidal or circular wire is spirally wound around a fabricated cage. The screen consists of wedge profile wire of various dimensions, resistance welded to a cylindrical body made of various members and cross sections of longitudinally arranged metal rods, which are in turn welded into cylindrical ring couplings at either end.
- e) *Pre-Packed Resin Bonded Gravel Screens* — Gravel is pasted on the perforated pipe with the help of resin type adhesive material. The thickness of gravel bond varies between 10 to 15 mm depending upon the diameter of the base pipe used.

- f) *Brass Screens* — Brass screens are made from brass sheet in which slots of required sizes are cut before rolling.

#### 3 MATERIAL

3.1 The well screens and slotted pipes shall be made of either corrosion resistant material or steel pipes having sufficient thickness to guard against the effect of corrosion and to ensure reasonable life of tubewell. The following are the recommended materials for various type of well screens and slotted pipes :

- a) Low carbon steel or mild steel;
- b) Leaded brass sheet (see IS 5494 : 1969);
- c) Fibre glass reinforced thermosetting plastics;
- d) Unplasticised polyvinyl chloride (UPVC); and
- e) Copper Wire, galvanized steel wire and stainless steel wire.

#### 4 DESIGN FEATURES

##### 4.1 Length of Screen

The length of screen shall be governed by the thickness of aquifer and shall be sufficient to obtain the specified yield from tubewell. However, the minimum total length shall be such that the entrance velocity is less than the permissible entrance velocity of 0.03 m/s to ensure longer life of the well. The lengths of individual pipes shall be such as to afford easy handling for transport and lowering into wells, and removal in case of recovery, etc. The lengths of individual pipes shall be such that there is minimum wastage in using combinations of various lengths inside the wells, and to ensure that the combinations form the nearest requirement to obtain the estimated specific yield of the well. They may be in random length specified by the use in consultation with the manufacturer. To account for possibility of inaccuracy in logging, screen shall not be placed in at least 0.3 metre on both sides of the stratum.

##### 4.2 Diameter of the Screen

The criteria for determining the diameter of the

well screen shall depend on the design yield of the tubewell. It shall be ensured that the area of opening available in the screen for flow of water, after giving allowance for possible coverage of gravel, clogging, incrustation, etc, produces a screen entrance velocity of not more than 0.03 m/s. The screen diameter shall be so selected that the percentage of slot area to screen surface area is generally between 15 to 22 percent.

4.2.1 Screen diameters for various discharges to be pumped from the well, are given in Table 1 for general guidance.

**Table 1 Screen Diameter**

(Clause 4.2.1)

Discharge l/minute	Screen Dia (mm)	
	Minimum	Recommended
Up to 475	100	100
475 1125	150	150
1300 3000	200	250
3000 5250	250	300
5200 9500	300	350
9500 13300	350	400
13300 19000	400	450
19000 26500	450	500
26500 34000	500	550

**4.3 Slot Size**

The shape and size of the slots shall be such that the gravel or aquifer material is not allowed to block the open spaces. Based on the sieve analysis of the aquifer material, the size of the slot openings shall be determined in such a way that finer fractions remain outside the slots. the slots shall not be too wide to cause entry of the gravel and resulting in plugging. Sharp edges on the periphery of the pipe may offer resistance to flow and hence [it is] preferable to have smooth rounded edges.

4.3.1 The slot size for gravel pack shall be so selected as to retain at least 90 percent of the pack material. However, in case the well is not provided with gravel pack, slot size shall be such that it allows 40 to 60 percent of the aquifer material to pass through. The normal slot sizes shall be 1.0,

1.6 and 3.2 mm. For fibre reinforced plastic (FRP) pipes, the slot width shall not be less than 1.6 mm. For PVC pipes, these shall be as given in 5.1.3.3.

**4.3.2 Percentage Openings**

The percentage slot openings shall be such that the screen length provides sufficient inlet area to limit the entrance velocity to 0.03 m/s.

**4.3.3 Distribution of Slots**

The slots shall be cut in a pattern designed to get even distribution of flow all over the priphery of the pipe. The slots shall be distributed in rows as closely and evenly as possible, staggering the slots between each row.

4.3.3.1 The slot size, design and distribution should be such as to maintain sufficient collapse strength of the screen.

**5 SPECIFIC DESIGN FEATURES**

**5.1 Plain Slotted Pipes**

**5.1.1 Low Carbon or Mild Steel Slotted Pipes**

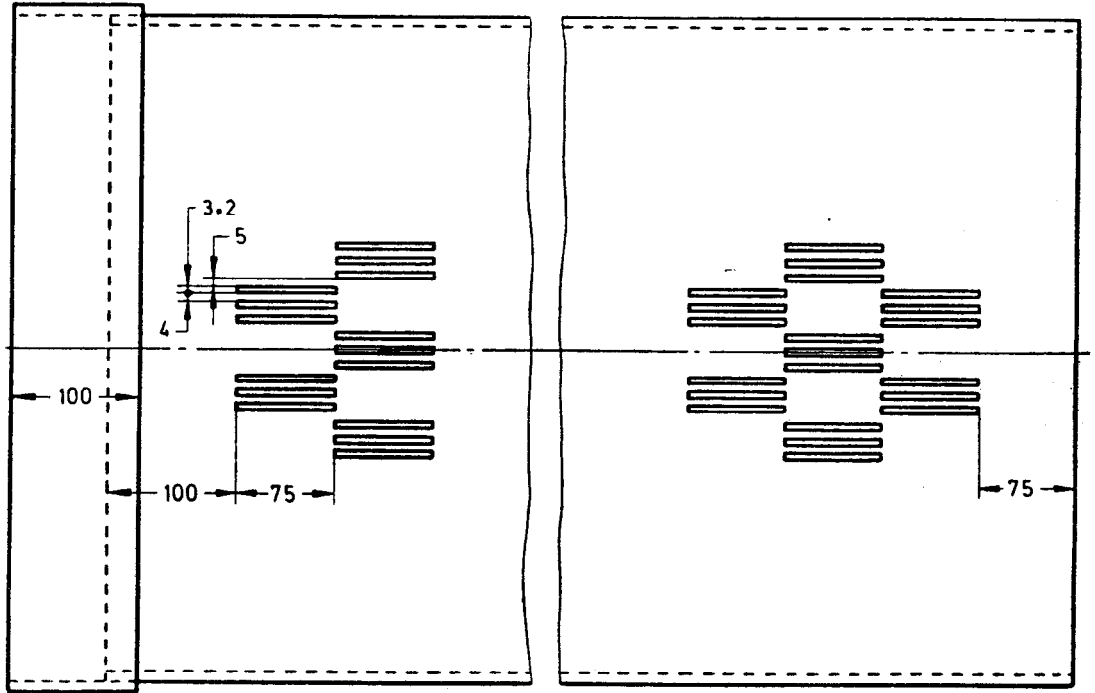
The slots shall be cut by milling or by slitting saw. The recommended thicknesses for different diameters for various depths of tubewell under normal conditions are given in Table 2.

**Table 2 Thickness of Pipes**

( Clause 5.1.1 )

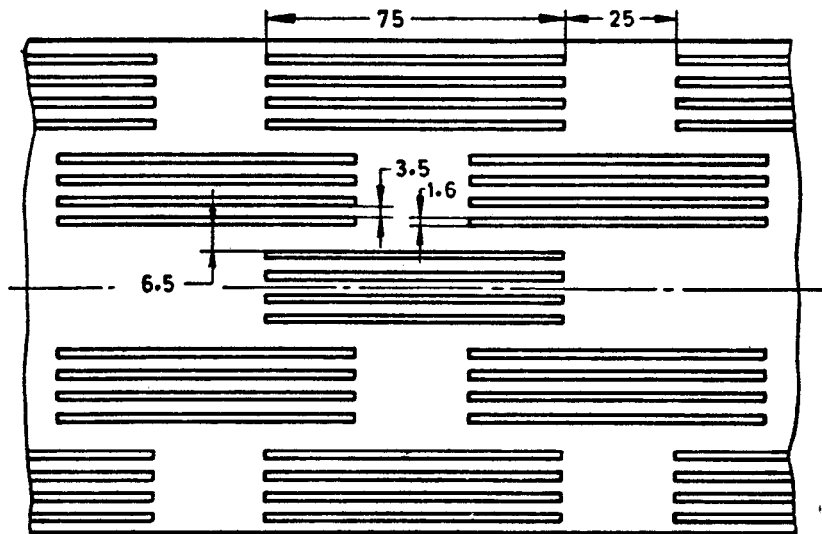
Depth of Well m	Thickness for Pipe Size (OD) in mm				
	166.6/ 168.3	219.1	273.00	323.80	355.00
50	4.85	7.04	7.09	8.38	9.52
100	5.4	7.04	7.09	8.38	9.52
125	5.4	7.04	7.8	8.38	9.52
150	5.4	7.04	7.8	8.38	9.52
175	5.4	7.04	7.8	8.38	9.52
200	5.4	7.04	7.8	8.38	9.52
250	7.11	8.18	9.27	9.52	9.52
275	7.11	8.18	9.27	9.52	9.52
300	7.11	8.18	9.27	9.52	9.52

Typical slot pattern of well screens is shown in Fig. 1 and 2.



All dimensions in millimetres.

FIG. 1 DEVELOPED VIEW OF A TYPICAL WELL SCREEN, PLAIN SLOTTED TYPE



All dimensions in millimetres.

FIG. 2 SLOTTING ARRANGEMENT

The slots shall not be cut within 12 mm on either side of the longitudinal welded joints of the pipes.

The plain space after thread cutting over the larger diameter pipes shall not be less than 150 mm so that wrenches could easily be used on plain space only.

### 5.1.2 FRP Pipes

The FRP slotted pipes shall be cut by milling. The slotting pattern shall be such as to ensure the minimum cutting of the glass fibre in the pipe and thereby maintaining maximum strength.

The recommended thicknesses of FRP pipes are given in Table 3.

**Table 3 Thickness of FRP Pipe**

(Clause 5.1.2)

Depth of Well m	Thickness of Pipe for Given Dia (mm)				
	150	200	250	300	350
150	5.00	6.00	6.50	8.25	8.50
300	6.00	6.75	8.00	9.00	9.50

The FRP based material shall fulfil the requirements as given below :

### Mechanical Strength

- 1) *Axial tension* — The pipe shall be able to withstand an axial load (at break) of not less than 102 kN or ten times the weight of a hypothetical well string comprising of 18 m of upper well casing, 4 m of screen and 6 m of lower well casing, whichever is greater.
- 2) *Axial compression* — The pipe shall be able to withstand an axial compressive load of not less than 102 kN.
- 3) *Internal hydrostatic pressure* — The pipe shall withstand a hydraulic pressure of 210 N/cm<sup>2</sup> continuously.
- 4) *External collapse pressure* — The slotted pipes shall withstand the external pressures given in Table 4.

**Table 4 External Collapse Pressure**

(Clause 5.1.2)

Well Depth m	Collapse Pressure (N/cm <sup>2</sup> )
Up to 100	28
100-150	49
150-225	70
225-300	84
300-400	98

- 5) *Water absorption and retention of strength* — water absorption in boiling water for 72 hours shall be less than one percent. Strength retention after boil test shall be at least 50 percent of original strength.

### NOTES

- 1 Axial tension and axial compression values given are based on required handling strength, chiefly from previous experience. Further the axial tensile value includes a safety factor, and the load required to withdraw the well string after gravel packing but before full development.
- 2 Internal hydrostatic pressure strength is based on the ability of slotted pipes to withstand cleaning by explosive of masked string of cordtex.
- 3 External collapse pressure is based on estimated maximum pressure likely to be experienced during development.

**5.1.3 PVC Screen Pipes** — PVC screen pipes have come to be recognized as suitable in tubewell construction owing to their desirable performance characteristics such as corrosion resistance. These are of two types, namely, Ribbed Screen Pipes and Plain Screen Pipes which are defined and designated as follows :

#### a) Ribbed Screen Pipe

Pipe with external longitudinal ribs and transverse (horizontal to pipe axis) slots. This shall be designated as 'RS' pipe.

#### b) Plain Screen Pipe

Plain surface pipe with transverse slots. This shall be designated as 'PS' pipe.

5.1.3.1 *Composition* — The composition of material of PVC screen pipes shall be same as given for PVC casing pipes (see 3.2 of Chapter 6).

5.1.3.2 *Dimensions*

a) The diameters and wall thickness of screen pipes with ribs shall be as given in Table 5, read with Fig. 5A of Chapter 6.

b) Screen pipes for DN above 200 mm may be plain (without ribs). The diameters and wall thickness of these pipes shall be as given in Table 6, read with Fig. 5B of Chapter 6.

**Table 5 Dimensions of Screen Pipes with Ribs**

[Clause 5.1.3.2 (a)]

All dimensions in millimetres.

Nominal Diameter	Outer Diameter, <i>d</i> of Pipe		Outer Diameter, <i>ds</i> Over Connection	Wall Thickness, <i>s</i> (Under Ribs)	
	<i>Min</i>	<i>Max</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
<i>DN</i>					
(1)	(2)	(3)	(4)	(5)	(6)
40	52.0	52.2	56	3.5	4.0
50	64.0	64.2	68	4.0	4.6
80	92.0	92.3	98	4.0	4.6
100	117.0	117.3	125	5.0	5.7
125	144.0	144.4	154	6.5	7.3
150	169.0	169.4	183	7.5	8.5
175	204.0	204.5	221	8.8	9.8
200	229.0	229.5	247	10.0	11.2
250	284.0	284.5	301	12.5	14.0
300	334.0	334.6	354	14.5	16.2
350	404.0	404.7	434	17.5	19.5
400	454.0	454.8	489	19.5	21.7

**Table 6 Dimensions of Plain Screen Pipes**

[Clause 5.1.3.2 (b)]

All dimensions in millimetres.

Nominal Diameter	Outer Diameter, <i>d</i> of Pipe		Outer Diameter, <i>ds</i> Over Connection	Wall Thickness, <i>s</i>	
	<i>Min</i>	<i>Max</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
<i>DN</i>					
(1)	(2)	(3)	(4)	(5)	(6)
250	280.0	280.5	297	12.5	14.0
300	330.0	330.6	350	14.5	16.2
350	400.0	400.7	430	17.5	19.5
400	450.0	450.8	485	19.5	21.7



**Table 7 Effective and Segmental Lengths of Screen Pipes**

[Clause 5.1.3.2(c)]

Nominal Diameter <i>DN</i> mm	Effective Length, mm $l_2$	Segmental Lengths, mm		
		$l_3$	$l_4$	$l_5$
(1)	(2)	(3)	(4)	(5)
40	1 000	25	880	60
	2 000	25	1 880	60
	3 000	25	2 880	60
50	1 000	30	870	70
	2 000	30	1 870	70
	3 000	30	2 870	70
80	1 000	40	860	80
	2 000	40	1 860	80
	3 000	40	2 860	80
100	1 000	45	850	90
	2 000	45	1 850	90
	3 000	45	2 850	90
125	2 000	60	1 800	160
	3 000	60	2 800	160
150	2 000	60	1 770	170
	3 000	60	2 770	170
175	2 000	60	1 770	170
	3 000	60	2 770	170
200	2 000	70	1 760	180
	3 000	70	2 760	180
250	2 000	85	1 720	220
	3 000	85	2 720	220
300	2 000	85	1 720	220
	3 000	85	2 720	220
350	2 000	85	1 700	240
	3 000	85	2 700	240
400	2 000	95	1 700	240
	3 000	95	2 700	240

c) Effective and segmental length of screen shall be as given in Table 7 read with Fig. 5 of Chapter 6.

d) Tolerances on overall length and segmental lengths of pipes shall be as follows :

i) Overall length,  $l_1$   $\begin{matrix} +20 \\ -0 \end{matrix}$  mm

ii) Segmental length,  $l_3$

(Threaded portion)

a) for *DN* up to and including 200

— spigot end  $\begin{matrix} +0 \\ -4 \end{matrix}$  mm

— socket end  $\begin{matrix} +4 \\ -0 \end{matrix}$  mm

b) for *DN* above 200

— spigot end  $\begin{matrix} +0 \\ -6 \end{matrix}$  mm

— socket end  $\begin{matrix} +6 \\ -0 \end{matrix}$  mm

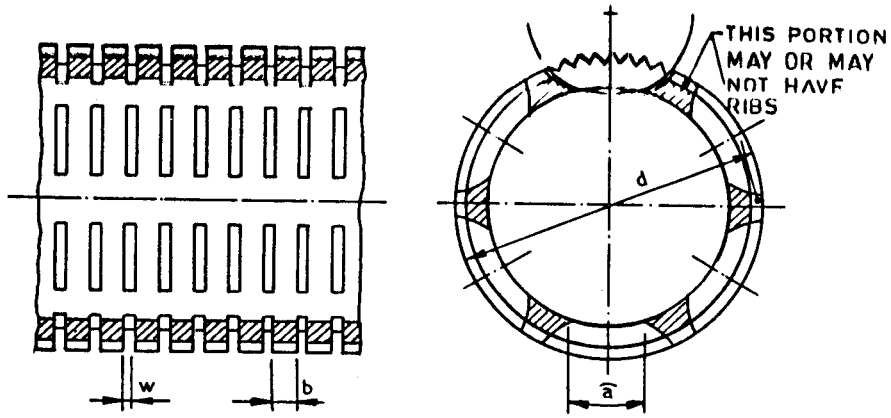
iii) Segmental length,  $l_4$   $\pm 25$  mm

(screen portion)

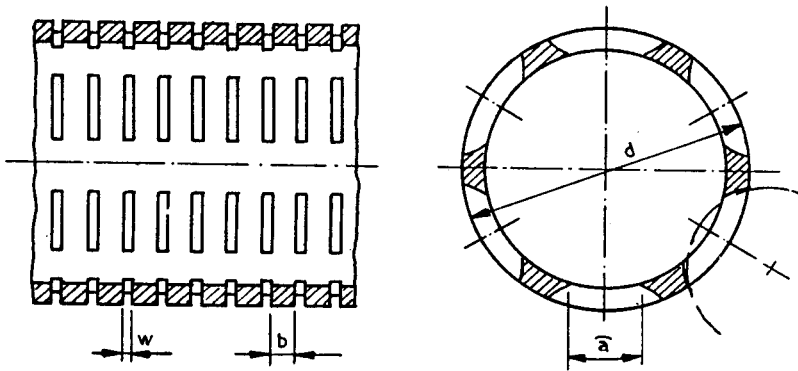
iv) Segmental length,  $l_5$   $\begin{matrix} +25 \\ -0 \end{matrix}$  mm

5.1.3.3 Slots

a) The dimensions and layout of the slots on screens shall be as indicated in Table 8, read with Fig. 3.



3A RIBBED SCREEN PIPE



3B PLAIN SCREEN PIPE

FIG. 3 EXAMPLE SHOWING 6 SLOTS AROUND CIRCUMFERENCE OF PIPE

Table 8 Dimensions and Layout of Slots on Screen Pipe

(Clause 5.1.3.3)

Nominal Diameter DN, mm	n	$\Sigma a \pm 5\%$ mm	Free Passage Area, in % (Mean Value) for Width of Slot (w), mm of								
			0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0	
40	3	85	3.5	5.0	6.0	8.5	9.0	9.5	12.0	—	
50	3	108	3.5	5.0	6.0	8.5	9.0	9.5	12.0	—	
80	3	168	3.5	5.0	6.0	8.5	9.0	9.5	12.0	—	
100	5	216	3.5	5.0	6.0	8.5	9.0	9.5	12.0	—	
125	5	240	—	4.5	5.5	7.5	8.0	8.5	11.0	—	
150	5	285	—	—	5.5	7.5	8.0	8.5	11.0	13.5	
175	5	335	—	—	5.5	7.5	8.0	8.5	11.0	13.5	
200	6	390	—	—	—	7.5	8.0	8.5	11.0	13.5	
250	6	450	—	—	—	7.0	7.5	8.0	10.0	12.5	
300	6	530	—	—	—	7.0	7.5	8.0	10.0	12.5	
350	8	640	—	—	—	—	7.5	8.0	10.0	12.5	
400	8	720	—	—	—	—	7.5	8.0	10.0	5	
Width of material between slots (b) $\pm 0.5$ (see Note 3)			4.0	4.0	5.5	5.5	6.5	9.5	9.5	—	

## NOTES

- 1  $\Sigma a$  is the summation of slot lengths over the internal circumference of the cross section.
- 2  $n$  is the minimum number of slots on the circumference of the cross section.
- 3 In each metre of screen 10 wider pieces between slits up to 2 mm in width are permitted.
- 4 Percentages of opening given in the table are based on internal surface area versus internal open area of pipe.

b) Tolerance on width of slot (w), given in Table 8 shall be as under:

Slot width in mm	0.2	0.3	0.5	0.75	1.0	1.5	2.0	3.0
<b>Tolerance,</b> <b>mm</b>	+ 0.06 - 0.0	+ 0.06 - 0.0	+0.10 - 0.0	+ 0.20 - 0.0	+ 0.20 - 0.0	+ 0.20 - 0.0	+ 0.20 - 0.0	+0.30 - 0.0

**5.1.3.4 Threading of screen pipes** — The requirements on threads shall be same as given under 3.6 of Chapter 6 for casing pipes.

**5.1.3.5 Tests** — All tests as given in 3.7 of Chapter 6 shall be applicable to PVC screen pipes also. For screen pipes, however, these test shall be carried out on pipes before cutting slots. Likewise criteria for conformity and method of sampling shall be same as given in 3.8 of Chapter 6.

## 5.2 Mesh Wrapped Screens

The pipes used in mesh wrapped screens shall be of mild steel or low carbon steel. The diameter of perforations shall not be less than 12 mm and the distance between the two adjacent holes shall be

between 25 to 40 mm depending upon the diameter and the thickness of the pipes used. The pipe thickness shall be the same as given in Table 2.

The spacers shall be of mild steel and shall be of thickness 3 mm minimum and shall be 6 mm wide. The distance between the two adjacent spacers shall be 75 mm minimum.

The copper mesh shall be made of copper wire according to IS 4412:1981 and shall not be less than 0.710 mm in thickness.

## 5.3 Cage Type Wire-Wound Screens

The wrapping wire having a wedge profile with

flat surface on the outside and producing expanding slots on the inside should be used. This shape facilitates setting and back washing operation and also avoids the screens being clogged by fine particles.

For obtaining a minimum of 15 percent open area, the screen aperture shall not be less than 0.375 mm. The number and cross-section of the vertical support rods and the profile of the wrapping wire shall be such as to give sufficient axial and collapse strength (see Fig. 4).

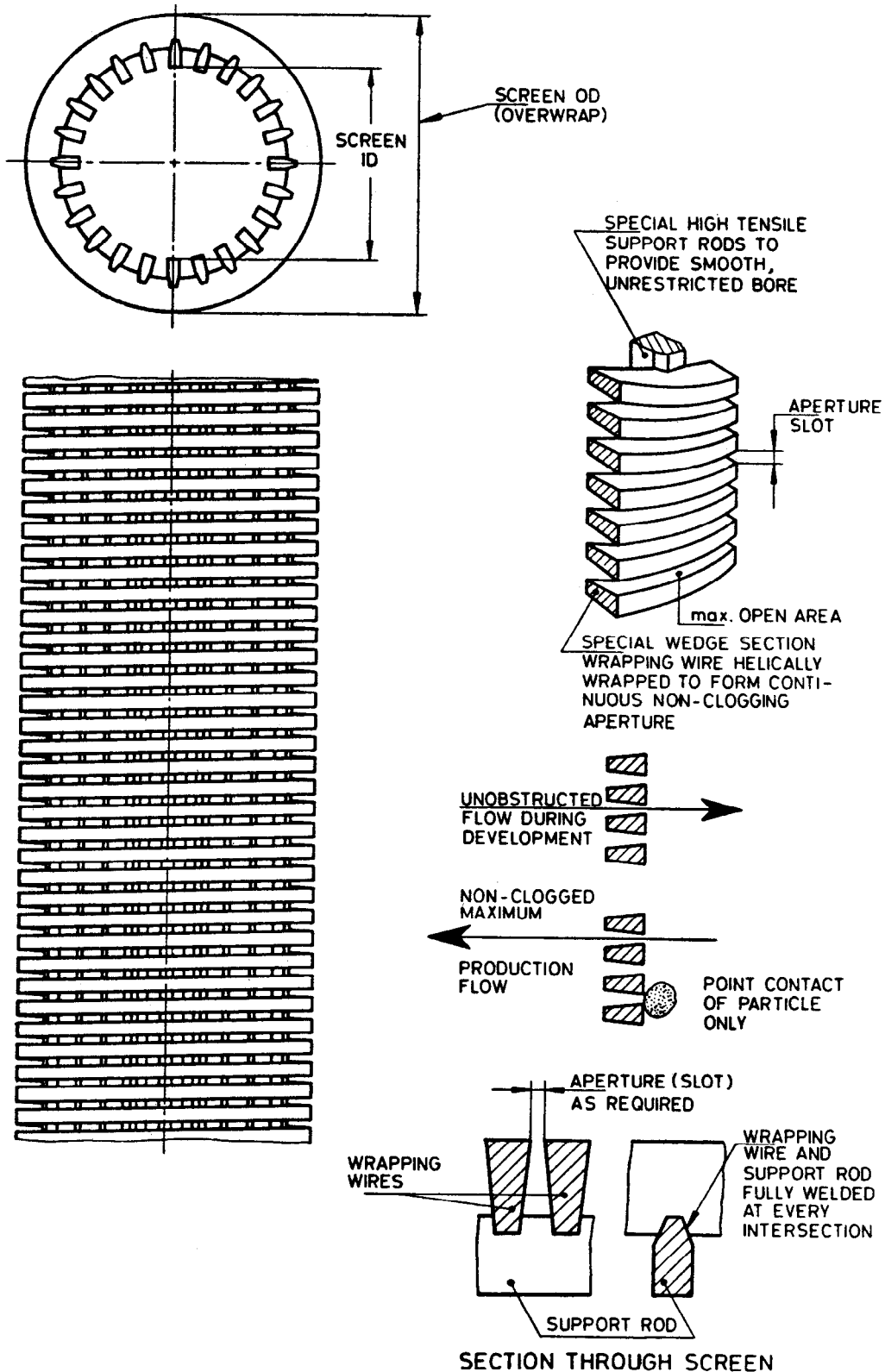


FIG. 4 CAGE TYPE WIRE-WOUND SCREENS

## 5.4 Brass Screens

The screens shall be manufactured from brass sheets conforming to IS 5494:1969 unless otherwise specified. The minimum thickness of the sheet shall be as given in Table 9.

**Table 9 Thickness of Screen**

(Clause 5.4)

Depth of tubewell (m)	Diameter of Screens (mm)			
	150	200	250	300
	Thickness (mm), <i>Min</i>			
Up to 100 m	3.2	4.5	5.4	5.4
Above 100 m	4.5	5.4	5.4	5.4

Distance between each slot shall not be less than 3.2 mm and each row shall not be less than 18 mm (see Fig. 5).

## 6 GENERAL REQUIREMENTS

6.1 The screens shall possess adequate resistance to corrosion and incrustation due to chemical content of soil and water. Where water is of highly incrustating nature, the screen shall be such as to permit the water to enter the well with minimum resistance. Also, wherever incrustation commonly occurs, it is desirable to choose such material for the screen that can withstand subsequent acid treatment for removing incrustation.

6.2 The screen shall be as far as possible of single metal construction to avoid galvanic corrosion.

6.3 Well screens shall be threaded and socketed, plain bevel ended, collared or male and female types so that convenient lengths could be added. The slotted pipe screens shall have adequate strength to withstand axial, collapse and hydrostatic loads to be experienced during development and use.

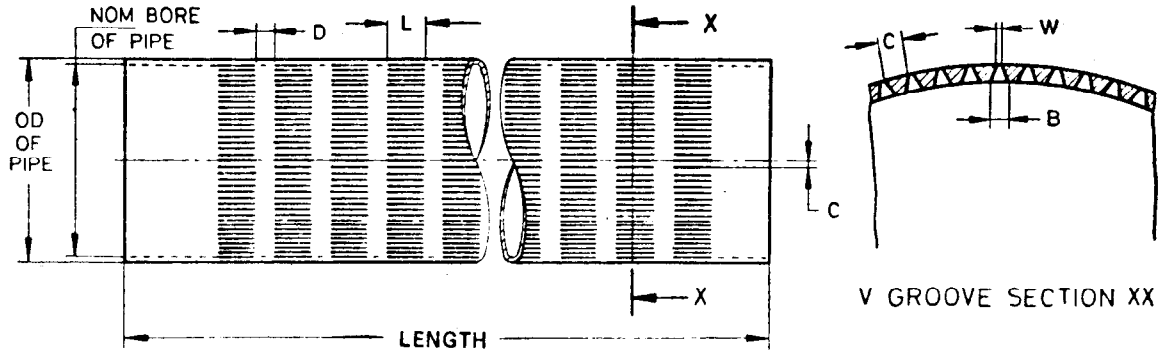
NOTE — PVC screen pipes shall have male threads at spigot end and female threads at the socket end in accordance with 5.1.3.4.

## 7 GUIDELINES FOR SELECTION OF SLOT SIZE

### 7.1 Determination of Slot Size

The size of slot openings suitable for different formations shall be based on sieve analysis of the aquifer material. Following procedure and design criterion is laid down for general guidance:

A weighed quantity of the thoroughly mixed sample is passed through a set of Indian Standard sieves from No. 75 onwards. The sieves are arranged such that the coarsest sieve is placed at the top and the finest at the bottom. After proper shaking, the sieve set is opened and material retained on each sieve is correctly weighed. The cumulative weight passing through each sieve is plotted on semilogarithmic graph paper having percentage weight as ordinate on arithmetic scale and size of the sieve opening as abscissa on logarithmic scale. A smooth graph is then drawn through the points based on which selection of slot size shall be done.

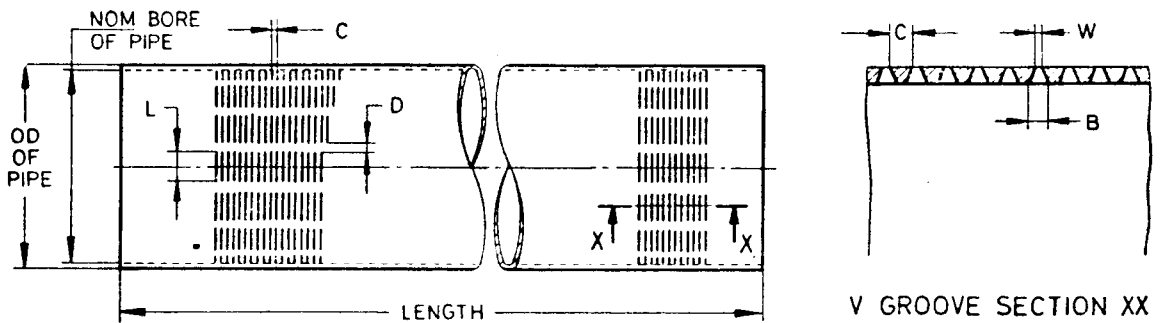


NB of Pipe	OD of Pipe	Sizes of Slots		No. of Rows per Metre	Total Slots per Metre	Area of Slots per Metre in mm <sup>2</sup>	Water Way Area, percent	B	Distance Between Slots C	Distance Between Rows D
		W	L							
152	162	0.793	40	16	2128	67500.160	13.25	2.778	3.627	19.050
152	162	1.587	40	16	1216	77191.680	15.18	4.762	6.350	19.050
204	213	0.793	40	16	2800	88816.000	13.28	2.778	3.627	19.060
204	213	1.587	40	16	1600	101568.00	15.17	4.762	6.350	19.050

Metal — Brass sheets according to IS : 5494-1969 'Leaded brass sheets and strips for use in the manufacture of tubewell strainers'.

All dimensions in millimetres.

FIG. 5A BRASS SCREENS WITH VERTICAL SLOTS



NB of Pipe	OD of Pipe	Sizes of Slots		No. of Rows in Dia	Total Slots per Metre	Area of Slots per Metre in mm <sup>2</sup>	Water Way Area, Percent	B	Distance Between Slots C	Distance Between Rows D
		W	L							
152	162	0.793	30	12	3300	78507.000	15.41	2.778	3.627	9.525
152	162	1.587	30	12	1884	89697.240	17.79	4.762	6.350	19.525
204	213	0.793	30	16	4400	104676.000	15.63	2.770	3.627	11.303
204	213	1.507	30	16	2512	119596.320	17.86	4.762	6.350	11.303

Metal — Brass sheets according to IS : 5494-1969 'Leaded brass sheets and strips for use in the manufacture of tubewell strainers'.

All dimensions in millimetres.

FIG. 5B BRASS SCREENS WITH HORIZONTAL SLOTS

## CHAPTER 8

### GRAVEL PACKING

#### 1 GENERAL

The wells, if need be, may be gravel-packed by providing an envelope of specially graded sand and gravel around the well screen in a predetermined thickness. This takes the place of the zone of permeable material which is produced around the well by the conventional development. Both types of wells, naturally packed or gravel packed, when properly constructed, are efficient and stable. The decision as to which to use must be based upon considerations of the conditions and economics of each situation.

#### 2 NEED FOR GRAVEL PACKING

2.1 The four common reasons for gravel packing are:

- a) to increase the specific capacity of the well,
- b) to minimize sand flow through the screen in fine formations,
- c) to aid in the construction of well, and
- d) to minimize the rate of incrustation by using a larger screen slot opening where the formation is relatively thin but very permeable and the chemical characteristics of the groundwater indicate potential for significant incrustation.

#### 3 CRITERION FOR GRAVEL PACKING

3.1 The desirability of gravel packing decreases as the water bearing formation becomes coarser. Generally, formation with an effective grain size,  $D_{10}$  that is that size, than which only 10 percent of the formation is finer, of more than 0.30 mm and a uniformity co-efficient of 5 or more can be safely developed without gravel packing.

3.2 In case gravel pack has to be provided in a well where more than one formation is to be tapped, the gravel pack designed for the finest formation should be provided for all the formations, provided the average grain size of the material in the coarsest aquifer is less than 4 times the 50 percent size of the materials in the finest aquifer.

#### 4 CHARACTERISTICS OF GRAVEL PACK

4.1 The Gravel for use as pack shall be free from impurities, such as shale, mica, feldspar, clay, sand, dirt, loam, haematite and organic materials.

4.2 The gravel selected for packing tubewells shall consist of hard quartz (about 96 percent  $\text{SiO}_2$  or other suitable material) with an average specific gravity of not less than 2.5. Not more than 10 per cent by weight of the material shall have a specific gravity of less than 2.25. The gravel shall contain not more than two percent by weight of thin, flat or elongated pieces. In case of such pieces, the larger dimensions shall not be more than 3 times the smallest dimensions. The quartz shall be of sub-rounded to rounded with minimum angular features.

#### 4.3 Porosity

The porosity of the gravel when laid as a pack shall not be less than 25 per cent.

#### 4.4 Gravel Sizes

The gravel sizes shall be as given in Table. 1.

**Table 1 Gravel Sizes**

(Clause 4.4)

Sl No.	Grade	Pack	Particle Size Range (mm)	IS Sieves [see IS 460 (Part 2) : 1985]
1.	A	Fine gravel	Over 2.0 to 3.35	2.0, 3.35
2.	B	Fine gravel	Over 3.35 to 4.75	3.35, 4.75
3.	C	Medium gravel	Over 4.75 to 6.3	4.75, 6.3
4.	D	Medium gravel	Over 6.3 to 8.0	6.3, 8.0
5.	E	Coarse gravel	Over 8.0 to 12.5	8.0, 12.5

To avoid trouble in placing and irrespective of gradation, packs should not contain particles greater than 13 mm.

For determination of the particle size the corresponding sieves, selected from IS 460 (Part 2) : 1985 shall be used.

#### 4.5 Particle Size Distribution

The particle size distribution of gravel shall be determined by screening through standard sieves in accordance with IS 460 (Part 2): 1985. The percentage distribution of the sizes shall be determined from a graph in which the percentage of material passing through each sieve is plotted against the standard aperture of that sieve. Any size, say  $D_{20}$  will thus indicate that the cumulative weight of all the grains smaller than this size is 20 percent of the total weight of the test sample.

4.5.1 The uniformity coefficient of the gravel, that is, the ratio of its  $D_{60}$  to  $D_{10}$  sizes shall not exceed 2. A material with uniformity coefficient less than 2 shall be classified as uniform and if greater than 2 it shall be taken as non-uniform.

4.5.2 The limiting sizes given in 4.4 are the maxima and minima, and the stacks containing smaller or bigger sizes as shown by sieve analysis shall be rejected.

#### 4.6 Hardness

The gravel shall have a hardness of not less than 5 in Moh's scale.

#### 4.7 Pack Aquifer Ratio

The pack aquifer ratio (P/A ratio) is defined as the ratio of 50 percent size  $D_{50}$  of the gravel pack to the 50 percent size of the aquifer. The size of gravel when used as pack in tubewells shall be decided in accordance with the size of the aquifer material proposed to be tapped. The gravel size, based on minimum head loss through gravel pack and minimum sand movement, shall be limited as below :

a) Uniform aquifer with uniform gravel pack:

Pack aquifer ratio shall be 9 to 12.5

b) Non-uniform aquifer with uniform gravel pack :

Pack aquifer ratio shall be 11 to 15.5

#### 4.8 Thickness

The thickness of gravel pack shall be limited to 13 to 18 cm.

## 5 INSTALLATION

5.1 In percussion method of drilling, gravel is fed into the annular space between the casing pipe and the assembly pipe up to 3 m above the bottom of the slotted pipe. The well is developed using compressed air or by bailers. As the water becomes clear, surging or backwashing is done to make the development more perfect. More gravel is fed, if necessary, and when the water becomes free from sand, the casing pipe is jacked up and the process repeated until all the aquifers are gravel packed. Care should be taken to ensure that the pack of gravel above the bottom of the casing pipe is never more than 3m in length as otherwise, casing pipe is likely to be locked up with the well assembly due to the friction of the gravel pack in between.

5.2 In rotary method, the pipe assembly is lowered into position and gravel packing done to a suitable depth below the bottom of the housing pipe in the first instance. Thereafter, the gravel packing upto the required depth is completed after keeping the housing pipe vertical within limits. To achieve uniform packing around the pipe assembly, inverted cones should be used.

## 6 SLOT SIZE

The size of the screen slot opening is governed, among other factors, by the size of the gravel or aquifer material which it has to retain. The slot size for gravel packed wells should be such that it retains about 90 percent of the gravel.

## 7 STERILIZATION OF GRAVEL PACK

7.1 When wells are constructed using a gravel pack, sterilization of the pack at the time it is installed is recommended. It may be achieved either by mixing calcium hypochlorite in gravel or by pouring one of the chlorine compound solutions down the tremie pipes with the gravel.

### 7.1.1 Gravel-Pack Design

In the naturally developed well, it has been shown that the width of the slot openings of the screen is chosen to retain about 40 percent of the natural formation and to permit 60 percent to pass through the openings during the development process. In the gravel-packed well, an artificially-graded gravel is chosen that will retain essentially all of the



formation material; a well screen opening is then selected of a size that will retain the gravel.

Some geologic conditions favour artificially gravel-packed wells and this design should be considered in those situations. Some of these are discussed in the following paragraphs.

- a) **Fine Uniform Sand:** In this type of formation, gravel packing should be considered because larger slot openings in the screen may be used. The open area of the screen is, accordingly, greater. Low percentage of open area is characteristic of screens with small slot opening. If the slot opening selected on the basis of a naturally developed well is smaller than 0.2 mm, the gravel pack alternate should be considered.
- b) **Artesian Aquifers:** In this type of aquifer where a long screen is required and where the pump is to be set above the screened section of the well, a smaller diameter screen can be centered in the borehole and the annular space filled with gravel. This is preferable to using a shorter screen of a diameter about the same as that of the borehole.
- c) **Loosely Cemented Sandstone:** Many excellent sandstone aquifers are poorly cemented. If a well is finished as an open hole in such aquifers, some sand particles slough from the walls of the hole and this results in a sand-pumping well.

Another reason for gravel packing of a sandstone aquifer is that the formation material usually provides little or no lateral support for the screen. The formation does not readily slump or cave against the screen during development as do unconsolidated sands. Some void spaces may remain between the screen and the wall of the hole. This leaves the possibility that a section of the sandstone could break off and fall against the screen and damage

it at any time. Loose granular material inserted between the screen and the wall of the hole accommodates itself to all the irregularities of the borehole. It supports the wall of the hole and at the same time gives lateral support to the screen.

- d) **Extensively Laminated Formations:** Some aquifers consist of thin alternating fine, medium, and coarse layers. It is often difficult to determine precisely the position and thickness of each individual stratum and to choose the proper length of each section of a multiple slot screen corresponding to the stratification. It is usually more desirable in such a case to reduce the chances of error by designing the well for artificial gravel packing.

The grading of the gravel pack should be based on the layer of fines material in the water-bearing section. A gravel pack selected in this manner does not restrict the flow from the layers of coarsest material because the permeability of the pack would still be several times that of the permeability of coarsest stratum.

**7.1.2 Gravel Pack Gradation**—The following are logical steps in designing an artificial gravel pack:

Plot sieve analysis curves for all strata comprising the aquifer. Determine the stratum composed of the finest sand and select the grading of the gravel pack on the basis of the sieve analysis of this material.

Gravel-pack material consisting mostly of siliceous rather than calcareous particles is preferred. Up to 5 percent calcareous material is a common allowable limit.

Under most conditions, the thickness of the gravel pack should not exceed about 20 mm. Too thick a gravel pack can make final development of the well more difficult.

## CHAPTER 9

### WELL COMPLETION

#### 1 WELL DEVELOPMENT

The development of a well is its treatment for the purpose of establishing the maximum rate of usable water by cleaning the produced water of turbidity, sand, sediment or other impurities introduced during drilling. All methods of drilling cause compaction of unconsolidated material around the bore hole. In addition, fines are driven into the formation and drilling mud may invade some of the area. Similar compaction and mud cake formation takes place in consolidated materials also. These factors reduce the permeability of the formation adjacent to the well and act to reduce the yield. Proper well development considerably improves the long term performance of the drilled well. Extensive sand pumping, before the well is brought into commission, boosts the water flow into the well, avoids clogging later by removing fines from around the screen and reduces the amount of sand which might otherwise be working its way towards the pumping elements. Development creates a stable zone around the screen and contributes to a more efficient well, longer well life and reduced operation and maintenance costs.

#### 2 METHODS OF DEVELOPMENT

**2.1** There are numerous methods of development and an important factor in all these is that the development work be started slowly and gently and increased in vigour as the well is developed.

The development should be started as far as possible from the bottom of the screen because with this compaction takes place as the work progresses upwards and the overlying material can move downwards. The known methods of development are described below.

##### 2.1.1 *Overpumping*

Overpumping means pumping the well at a higher rate than it will be pumped when it is put in service. It may be simpler to overpump in small wells or poor aquifers by employing the pumping equipment intended for regular use in the well. However, where large quantity of water has to be pumped, the required high capacity pumping equipment may not always be conveniently available.

There is an objection to overpumping with a permanent pump when considerable sand is to be pumped. The pump is subjected to excessive wear, its efficiency is reduced and under severe conditions, sand-locking of pump may occur which means the pump must be pulled, disassembled and cleaned before being put back into service. Overpumping may also leave some of the sand grains bridged in the formation and thus only partially stabilized:

- a) *Continuous overpumping* — The simplest and the most common method of removing fines is by pumping the well at generally 50% above the designed discharge. When water is pumped from the well, sand tends to move in the direction of the well. In addition, the finer sand particles wedge against each other and form bridges across openings or voids between coarser grains. This is prevented by resorting to backwashing. The pump is operated at maximum capacity until maximum draw-down is produced. It is then stopped and water allowed to recede rapidly and return to its normal static level. This procedure is repeated many times until the well is sand free.
- b) *Interrupted overpumping* — The pumping is done with a pump capable of pumping at rates upto twice the designed discharge. The pumping is carried out in at least five steps of 0.25, 0.5, 1.0, 1.5 and 2 times the designed discharge without using any check or foot valve. The pumping is conducted in five minute cycles for at least two hours or until acceptable development is achieved.

##### 2.1.2 *Compressed Air*

Another popular way of development is by using compressed air but it requires considerable equipment and skill on the part of the operator. The two methods generally used are :

- a) *Back washing (closed well method)* — It is based on the principle of alternately forcing water out of the well through the screen and into the aquifer by means of compressed air and pumping

from the well by airlift. A 3-way valve is turned to deliver air down the air-line which pumps water out of the well through the discharge pipe whose bottom is usually set 30 to 60 cm above the top of the screen. When the discharged water becomes clear, the supply of air is cut off and the water in the well allowed to return to the static level which can be checked by listening to the escape of air through the air cock as the water rises in the casing.

The air cock is then closed and the 3-way valve turned to direct air down the by pass into the well above the static water level. This forces water into the aquifer through the screen breaking down the bridges of sand grains. When the water level reaches the bottom of the drop pipe, air escapes from the discharge pipe and the pressure stops increasing. At this point, the supply of air is cut off and the air cock opened to allow the water to return to its static level.

This procedure is repeated until the well is thoroughly developed. The well, if necessary, should be bailed to remove any sand accumulated at the bottom before installing the pump.

The hook-up of the equipment for back-washing is shown in Fig. 1. The diameter of the drop pipe is usually kept about 5 cm less than that of the well pipe and that of air line usually varies from 2 to 6 cm.

b) *Surging open well method* — The development is achieved by a combination of surging and pumping. Surging within the well is produced by sudden release of large volume of air and pumping is accomplished as with an ordinary airlift pump. The best efficiency is achieved when 60% of the total length of the air-line is beneath the water surface during pumping. The efficiency reduces rapidly if submergence is less than 60%. If the airline is submerged too deeply in proportion to the net height of the lift, an uneconomically high pressure will be required to force the air out.

The drop pipe, in this method, is kept inside the screen and lowered to within about 60 cm of the bottom of the screen. The airline is placed inside the drop pipe about 30 cm from its bottom. The air is turned into the airline and the well is pumped until the water appears free of sand. The air tank is pumped to maximum pressure while the airline

is lowered about 30 cm below the bottom of the drop pipe. When the air tank is full the quick-opening valve is thrown open allowing the air to rush into the well and produce a brief but forceful surge of water. The airline is immediately pulled back to about 30 cm above the bottom of the drop pipe. Pumping by airlift is then resumed until the water is free of sand and the cycle is repeated until little or no sand is evident on pumping immediately after surging.

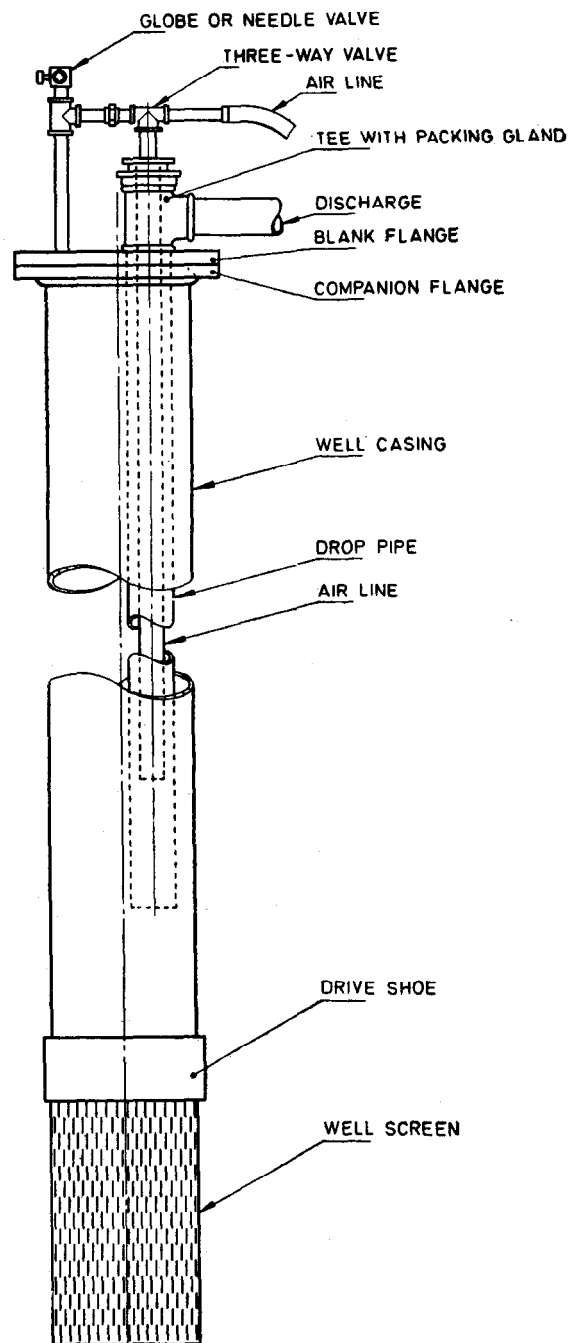


FIG. 1 CLOSED WELL DEVELOPMENT WITH AIR COMPRESSOR.

The drop pipe is then raised and the cycle of pumping and surging repeated at convenient points along the screen until the entire length of the screen has been developed. The sand which may have accumulated at the bottom of the screen may be pumped out by lowering the drop pipe and the airline to the bottom of the well.

The hook-up of the equipment for surging is shown in Fig. 2. The compressor should be capable of developing sufficient pressure to overcome initial head of water in the airline. The recommended sizes of pumping pipe and airline are given in Table 1.

**Table 1 Recommended Size of Pumping Pipe and Airline**

Pumping Rate l/min	Size of Pumping Pipe, mm	Size of Airline mm
450 - 700	100	30
700 - 900	125	40
1 125 - 1 800	150	50
1 800 - 3 200	200	65

The air-lift is operated slowly for some time before starting the development to ensure that the screen is sufficiently open and water flows freely into the well; otherwise the screen may get damaged. When surging and pumping with air, the discharge should be directed into a fairly large tank in which the sand discharged can be collected so that the degree of effectiveness and progress of development can be determined.

The method has its own limitations where the yield is weak, draw-down rapid or submergence low.

**2.1.3 High Velocity Jetting**

Jetting with water at high velocity is a recent and generally the most effective method of well development. It offers the following advantages:

- a) The energy is concentrated over a small area with correspondingly higher effectiveness,
- b) It is relatively simple to apply and is not likely to cause trouble from over-application, and
- c) Every part of the screen can be covered selectively and if well screen

openings are closely spaced and correctly shaped to direct the jet stream out into the surrounding formation material so that complete development is achieved.

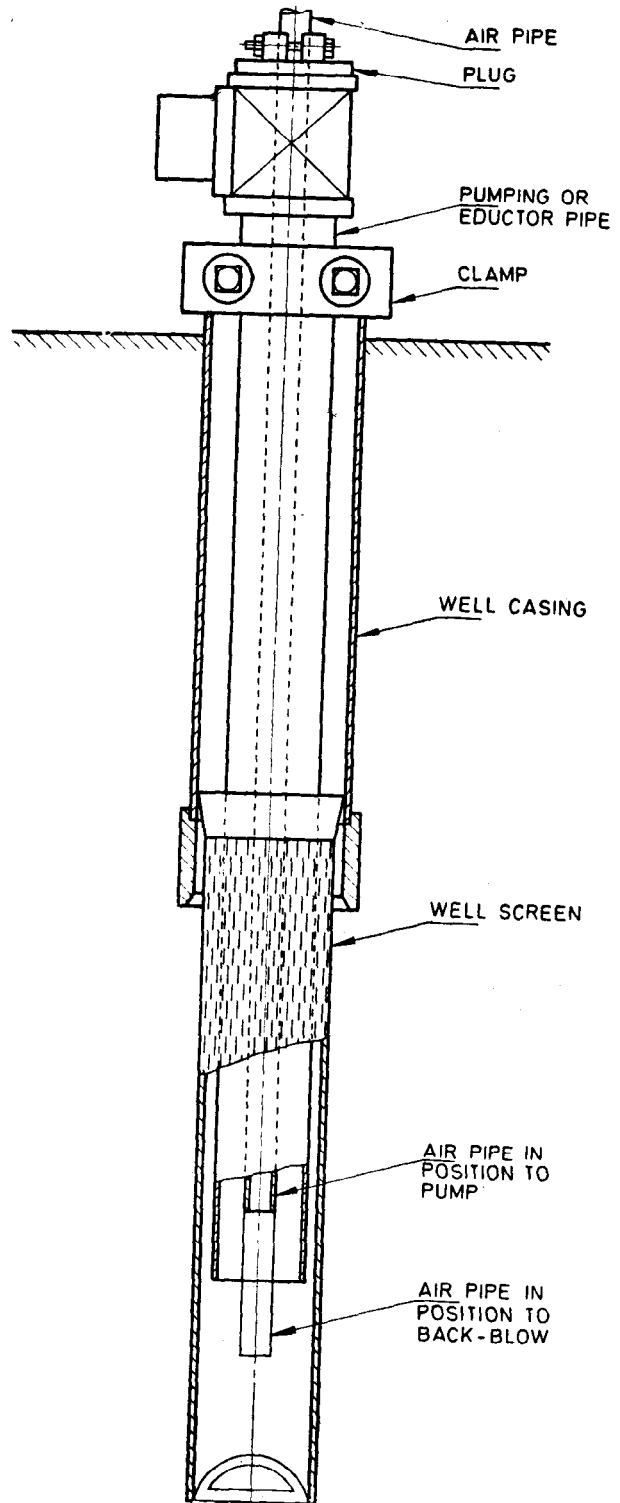


FIG. 2 OPEN WELL DEVELOPMENT WITH AIR COMPRESSOR

**2.1.3.1** In this method the high velocity jets, working through the screen openings, agitate and loosen the fine sand, silt and clay and wash them out of the water-bearing formation. These materials move into the well through the screen openings due to the turbulence created by the jets and are removed by pumping or bailing. For this method to be most effective, it is desirable to pump or air lift the turbid water from the well at a rate higher than at which water is being jetted into the formation. This causes a net movement of water through the screen and into the well, speeding the 'cleaning' process further. The simultaneous pumping makes it possible to continuously monitor the effect of jetting by inspecting the pumped water. The water so pumped can be reused for jet development after pumping it into a settling tank. The equipment required for this method is a jetting tool together with high-pressure pump and necessary hose and piping. The jetting tool consists of an attachment fitted with two or more evenly spaced horizontal nozzles having 6.2, 9.5 or 12.7 mm orifices. The diameter of the jetting tool shall be about 25 mm less than the inside diameter of the screen. The size of the pipe for feeding water to the nozzles should be large enough to keep friction losses to the minimum. It generally ranges from 4.0 to 7.5 cm depending on the length of the pipe and discharge it has to carry.

#### **2.1.4 Surge Blocks**

The fundamental intent of the development operation is to reverse the flow through screen openings which rearranges the formation particles and breaks down bridging of group of particles. This is effectively accomplished by surging, the outflow portion of the surge cycle breaking down the bridges and the inflow portion moving the fines towards the screen and into the well.

**2.1.4.1** An effective means of surging for developing the well is by rapid up and down motion of a plunger, called surge block or surge plunger, operated in the casing pipe and above the screen portion of the well.

Where the aquifer contains clay, the action of the plunger can cause it to plaster over the screen surface thereby reducing the yield. It may also produce high differential pressures which may cause collapse of the screen if it is partly or wholly plugged by clay or mud.

The surge plunger should be operated after the well has been bailed, sufficient free flow of water into the well established and any sand that may have settled in the screen removed.

**2.1.4.2** The total time for developing a well by surging may range from four hours for a small well to 3-4 days for a large well with longer screens.

#### **2.1.5 Explosives**

These are sometimes employed in wells drilled in rocks. The blasting enlarges the hole and removes the fine materials deposited on the well face during drilling. Charges of 14 to 230 kg are generally used, the size varying with the hardness of the rock to be broken and the depth at which the charge is to be denoted. Since the water pressure increases with depth, heavier charges must be used at greater depths to overcome the confining effect of the greater water pressure.

**2.2 Criteria for Proper Development of Tubewells** — Development work is an essential operation in the completion of drilling job. It consists of steps to remove the finer material and opening up the passage in the formation so that water can enter the well through the screen more freely. Proper development is said to have been satisfactorily done when :

- a) The stabilization of the sand formation has taken place, that is, there is no further sinking of gravel and the discharge is sand free; and
- b) Permeability of the formation is increased by removing fines utilising proper development method.

#### **2.3 Recommended Methods of Development**

Information pertaining to various methods of development of tubewells is given in Table 2.

#### **2.4 Well Stimulation**

Stimulation may be undertaken in addition to development, to increase the yield of the wells. It is the treatment of the well by mechanical, chemical or other means for the purpose of reducing or removing an underground resistance to flow and is distinct from development which is essentially an operation for clearing the water of impurities introduced during drilling.

**2.4.1** Stimulation may be accomplished by setting off explosives in borehole in consolidated stratum. This would enlarge well diameter, loosen deposits of fine particles on hole wall, shatter rock around it and achieve 10-20% yield gain.

**2.4.2** Acid treatment of formation, especially in carbonate rocks, dissolves particles blocking the flow and permits higher rate of flow into the well.

**2.4.3** The most advanced technique of stimulation, however, is hydraulic fracturing. It consists of injecting liquid in the well at high pressure so that the formation is actually fractured. The fracture occurs at 60% of overburden pressure and fractures are mostly vertical extending as radial planes from boreholes. The increase in yield of the well is due to increased vertical communication between various layers in aquifer which increases lateral flow in more permeable layers.

**2.4.4** The stimulation techniques have been devised for oil industry but are finding increasing application for improving ground water production both from technical performance as well as economic view point. Extensive research and application of water well stimulation techniques can potentially result in a greater and more efficient utilization of ground water resources.

### 3 WELL STERILIZATION/DISINFECTION

**3.1** Theoretically, any water introduced into the well as a drilling fluid or for well development should be of drinking water quality. The need for sterilization arises because disease-producing bacteria and virus enter the well through drilling equipment and fluids, soil and other material falling in during construction and surface water running into the hole. The well water needs to be freed not only of pathogenic bacteria but of corrosion and incrustation fastening organisms which may reduce the life of the well. All newly constructed wells or existing wells subjected to any repair work, etc, should be disinfected before being

placed into service. The well should be cleaned as thoroughly as possible of foreign substances such as soil, grease, oil etc, which may harbour bacteria.

**3.1.1** Chlorine solution is the simplest and most effective agent for disinfecting a well, pump, storage tank or piping system. A stock solution of chlorine may be prepared by dissolving fresh chlorinated lime. Calcium hypochlorite and sodium hypochlorite are other readily available disinfectants for field operation.

All the exterior parts of the pump coming in contact with water shall be thoroughly cleaned and dusted with powdered chlorine compound. Since any disinfecting agent can only destroy bacteria with which it comes in contact, the disinfectant should be thoroughly mixed in the well water. Effective disinfection depends on the time of contact, therefore, the disinfectant, after being agitated shall be left in the well for at least 4 hours, preferably longer. Apart from the dilution that takes place in the well, the well may also contain organic materials which may combine and neutralize the effectiveness of the chlorine. Therefore, to assure an adequate concentration of chlorine in the well the volume of water in the screen and casing should be estimated. A stock solution of chlorine may be prepared by dissolving free chlorinated lime in water, for obtaining an applied standard concentration of 50 ppm. One litre of stock solution should be used to treat 300 litres of water.

**3.1.2** The success of the chlorine treatment may be evaluated by determining the number of coliform bacteria in water after the well has been pumped for few hours. Sterilization of well, except possibly for some pathogens is seldom 100% effective. Organisms may remain lodged in crevices or covered by incrustation products and not readily penetrated by the sterilizing solution. These continue to multiply and sterilization at periodic intervals may be required to control them.

**Table 2 Summary of Recommendations for Developments of Various Types of Wells**  
(Clause 2.3)

SI No.	Method of Development	Tubewell Up to and Including 150 m in Alluvium		Tubewell Above 150 Up to and Including 300 m in Alluvium		Tubewell Above 300 Up to and Including 800 m in Alluvium		Boulders and Pebbles	Hard Rock (DTH)	Remarks
		Artificial Gravel Pack	Natural Pack	Artificial Gravel Pack	Natural Pack	Artificial Gravel Pack	Natural Pack			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
i)	Over pumping	effective	effective	Satisfactory	Satisfactory	—	—	Most effective	Most effective	In case of hard rock areas only pumping at normal discharge should be carried out
ii)	Compressed air	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Not every effective	Not every effective	Satisfactory	—	Over pumping should follow the development with air compressor wherever needed
iii)	high velocity jetting	Satisfactory	Satisfactory	Very effective	Very effective	Very effective	Very effective	Not effective	Not effective	Simultaneous pumping of silt and clay with air compressor is recommended
iv)	Surge block	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	—	—	This is not recommended where streaks of clay and fine sand formation are encountered
v)	Explosives	—	—	—	—	—	—	—	Effective	This usually increases the capacity of water veins and fractures

## CHAPTER 10

### TESTING OF TUBEWELLS

#### 1 GENERAL

Every well upon completion should be tested for and results recorded of sand content of the discharge, drawdown, plumbness and alignment, depth, and chemical and biological suitability of water. These data, together with diagram of the constructed well, formation log, mechanical analyses of aquifer and gravel pack, if used, and a copy of the pump and well specifications, constitute and basic data to which the results of the subsequent tests of entire installation will be compared so that pump and well performance may be evaluated and the need for rehabilitation or other maintenance determined.

#### 2 MEASUREMENT OF TUBEWELL DEPTH

##### 2.1 Measurement by Cables or Rods

This method is suitable for measurement of depth of tubewells for a consolidated formation. The bottom of tubewell shall first be cleaned and the depth measured by :

- a) twisted metallic cable strained by a plumb-bob, or
- b) rigid rods.

With any of the above methods, three distinct measurements shall be taken and effective one will be the average reading of the three.

**2.1.1** If the depth of tubewell does not exceed 100 m, the accuracy of measurement is  $\pm 0.5$  percent. If the depth exceeds 100 m, the accuracy of measurement shall be agreed to between the drilling agency and the owner.

##### 2.2 Measurement by Casing — This method

applies to unconsolidated formation and is used for any tubewell with casing. The depth of tubewell shall be deemed to be equal to the length of pipe lowered after the deduction of screwed ends. Each pipe should be measured to an accuracy of  $\pm 0.1$  percent. The accuracy of overall measurement is  $\pm 0.3$  percent.

#### 3 MEASUREMENT OF WATER LEVEL

##### 3.1 Direct Measurement

This is carried out by a steel tape or cable with a suitable sinker attached at the end. The steel tape or cable is wound round a rotating drum. Measurements shall be made by measuring the length of tape or cable. Depth of immersion of sinker shall be taken into account in the measurement. A set of three readings shall be taken and effective will be their average. Any measurement which deviates from the average by more than  $\pm 0.3$  percent shall be discarded and new measurements taken. Accuracy of measurement shall be as agreed between the drilling agency and owner.

##### 3.2 Electric Measurement (Double-Pole Contact)

For double-pole contact (*see* Fig. 1) a sufficiently rated battery, a reel with a length of twin electric cable and an electrical indicating instrument as a high resistance voltmeter or a milli-ammeter are required. The items should be adjusted as shown in Fig. 1. One end of the cable shall be permanently connected to voltmeter/ammeter and the other end connected through battery. As the cable is lowered into the tubewell, the circuit is completed as the two electrodes strike the water which is indicated by the instrument. The depth of water levels is obtained by measuring the twin-cable length from the electrodes to the top of tubewell.

Wherever electric power is more easily available, battery may be replaced with the power supply mains. In this case, single pole method may be used. For single-pole contact, the apparatus similar to that for two-pole contact with the difference that the contact casing is fitted with one electrode and a single cable. The circuit is completed through the rising main as soon as the electrode touches the water. Measurement is similar to two-pole contact method. This method shall be employed only when the casing extends from the top of the borehole to below the water surface to be measured.



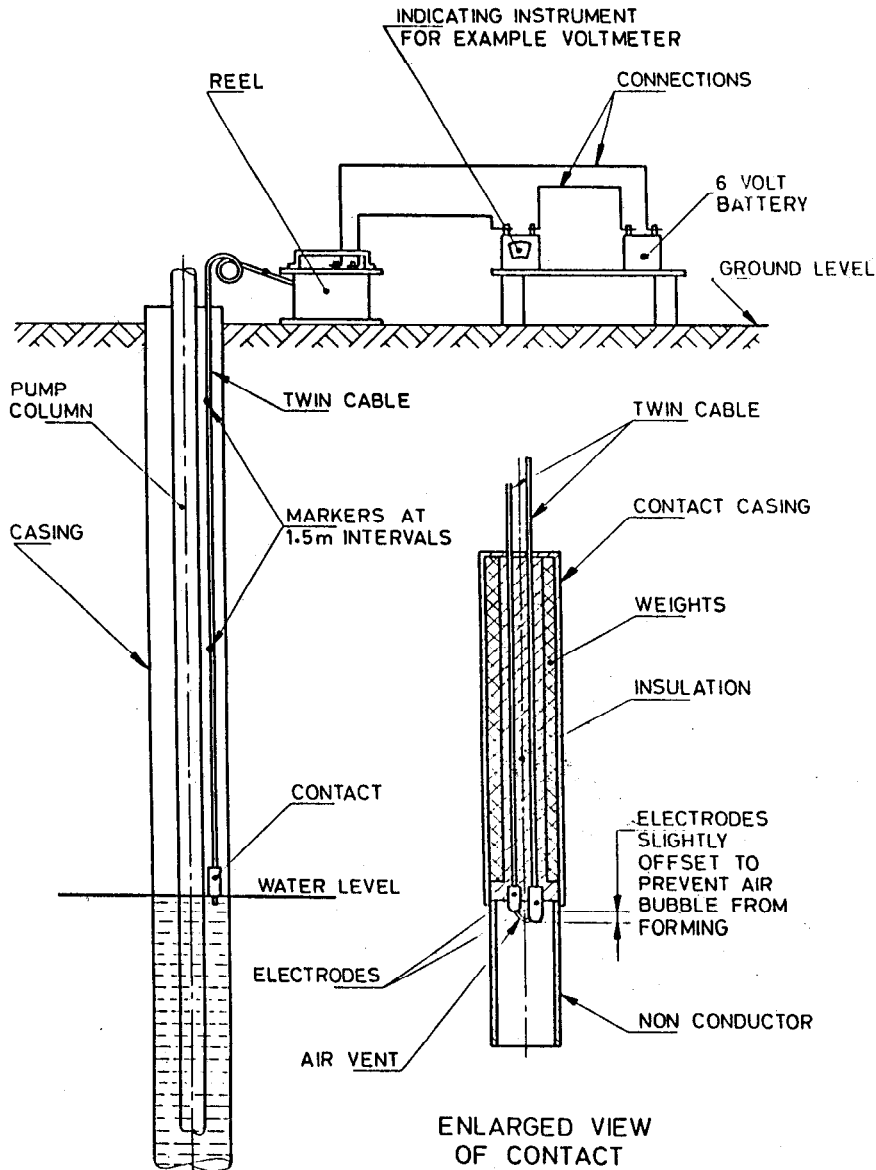


FIG. 1 ELECTRICAL APPARATUS WITH DOUBLE-POLE CONTACT FOR DETERMINING THE WATER LEVEL IN A TUBEWELL

**3.3 Air Pressure Line Method** — This consists of :

- a) a tube positioned between casing and the outlet pipe and extending to below the depth of water,
- b) a calibrated pressure gauge, and
- c) an air pump and non-return air valve.

All the above items should be adjusted as shown in Fig. 2. For example, if water level 'L' is to be determined, air is pumped into the air tube, until maximum reading is obtained on the pressure gauge.

The complete air tube will be filled with air and the pressure reading corresponds to 'A'. At the time of setting, distance 'B' should be noted. The required depth 'C' will be the difference of 'B' and 'A' readings.

#### 4 VERTICALITY AND ALIGNMENT

4.1 If a turbine well pump is to be installed in a well, the well should be true to line from its top to a point just below the maximum depth at which it is proposed to set the pump. A tubewell out of alignment and containing kinks and bends or corkscrews should be rejected because such deviations

cause severe wear on the pump shaft bearings and discharge casing and in a severe case, might make it impossible to get a pump in or out. If an air-lift or a suction pump is used for pumping, alignment is not so important and the same is applicable to the submersible type of pump.

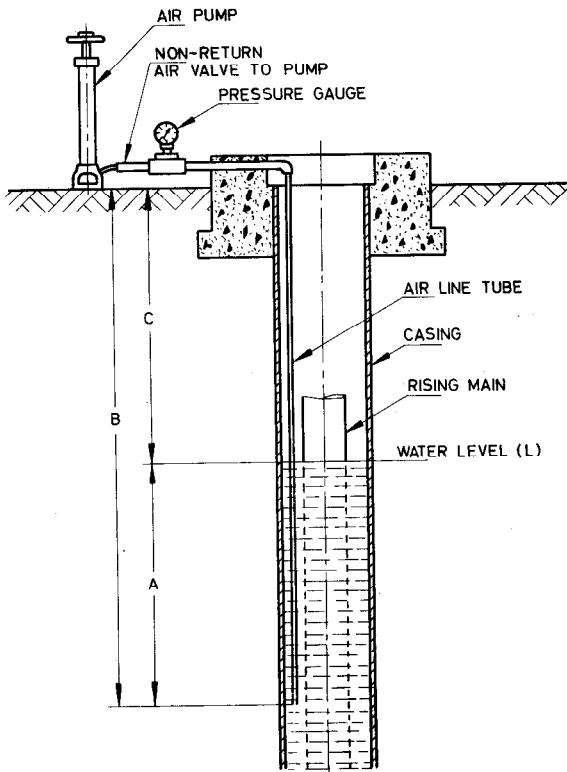


FIG. 2 AIR PRESSURE LINE APPARATUS FOR DETERMINING THE WATER LEVEL IN A TUBEWELL

4.1.1 The conditions that cause wells to be out of plumb are :

- a) the character of the sub-surface material penetrated during drilling,
- b) the trueness of the pipe used as well casing, and
- c) the pull-down force on the drill pipe during rotary drilling.

While drilling, gravity tends to make the drilling bit cut a vertical drill hole. Varying hardness of the materials being penetrated, however, deflects the bit from a truly vertical course.

4.1.2 The measurements made are of the plumbness and straightness of the cased hole. Thus, an oversized hole may be out of plumb but the casing

may fall within specified limits. The casing should not be permitted to excessively encroach on the annulus and hinder placement of grout or gravel pack.

4.1.3 In case of gravel-shrouded tubewells, if the pipe assembly is found inclined in a slant position before completing the gravel pack, the assembly should be pulled in a desired direction by suitable methods with a view to rectify slantness and bringing the pipe assembly within the permissible limits of verticality. The gravel pack should be completed immediately after the verticality has been tested and rectified.

4.1.4 The verticality of the tubewell shall be tested by using plumb or plunger E (see Fig. 3) 6 mm smaller in diameter within the inside diameter of the well casing. The plumb may be made from a piece of sheet steel or a short piece of pipe. Whichever is used, it shall be heavy enough to keep the plumb line taut. The hub of the ring shall not be solid as the water shall pass through it as it is lowered in the well. The hole F from which the plumb line A passes shall be in the exact centre of the ring. Knots or marks shall be made every 3 m on the plumb line to indicate the depth to which the ring has been lowered in the well. The plumb shall be suspended from the guide pulley where it shall be at least 3 m above the top of the well. The guide pulley is fixed on a tripod or frame B as shown in the figure. The vertical centre of the pulley shall be so located that the plumb line A comes off its outer edge exactly over the centre D of the well casing. The results shall be recorded in Form A.

4.1.5 For tubewells encased with pipes up to 350 mm diameter, the verticality of the tubewell shall be measured in terms of clear cylindrical space available within the housing pipe after the construction of the tubewell.

4.1.5.1 Verticality of the tubewell may have a deviation so as to provide clear cylindrical space not less than the clear cylindrical space available in a hypothetical tubewell of the same size but having deviation of 10 cm per 30 m in one direction and in one plane only.

4.1.5.2 The verticality of tubewell is to be tested as given in 4.1.4 After the necessary computation is made, cross sections of housing pipes at differ-

ent depths are drawn on a graph and clear cylindrical space is determined. The cylindrical space of the actually constructed tubewell shall be referred to as 'G' in the following paragraphs.

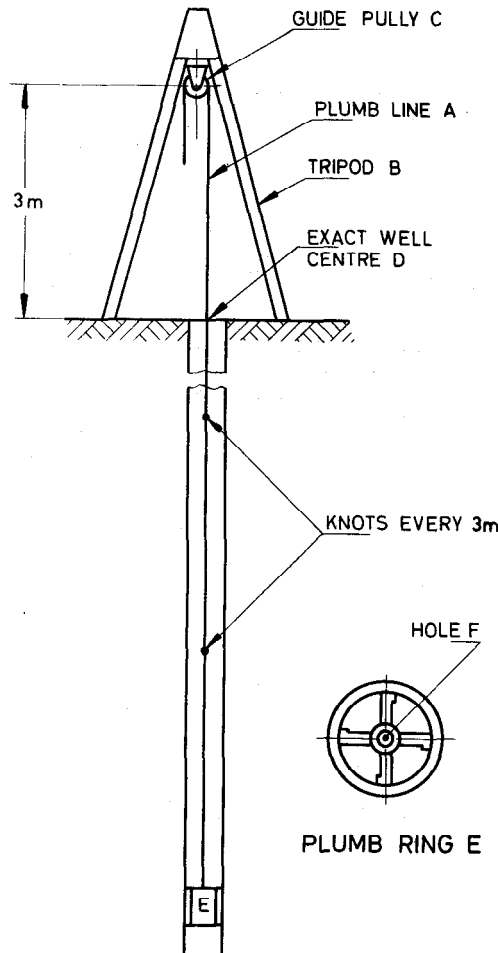


FIG. 3 METHOD OF PLUMBING A WELL

4.1.5.3 Cross sections of hypothetical tubewell identical in dimensions to the actual tubewell but having deviation of 10 cm per 30 m in one direction and in one plane are drawn on the graph sheet and the minimum allowable cylindrical space 'H' is determined.

4.1.5.4 If cylindrical space 'G' of the actually constructed tubewell is equal or more than the cylindrical space 'H' of the hypothetical tubewell (having deviation 10 cm in 30 m in one direction and one plane), the tubewell actually constructed shall be considered within the permissible limits of verticality.

4.1.5.5 As an example, cross sections of two tubewells G1 and G2 having 300 mm diameter of housing pipe have been drawn after computation of verticality results in Fig. 4 and Fig. 5 while Fig. 6 shows the cylindrical space H of hypothetical

tubewell having deviation of 10 cm per 30 m depth of the tubewell. It will be noticed that space G1 is more than space 'H', while space G2 is less than the space 'H'. Therefore, tubewell G1 shall be considered within the limits of verticality while G2 is not within the limits of verticality.

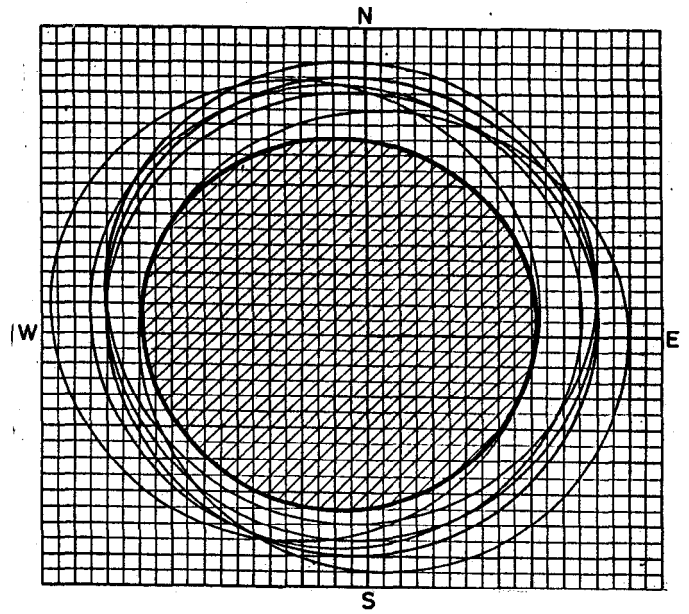


FIG. 4 G1

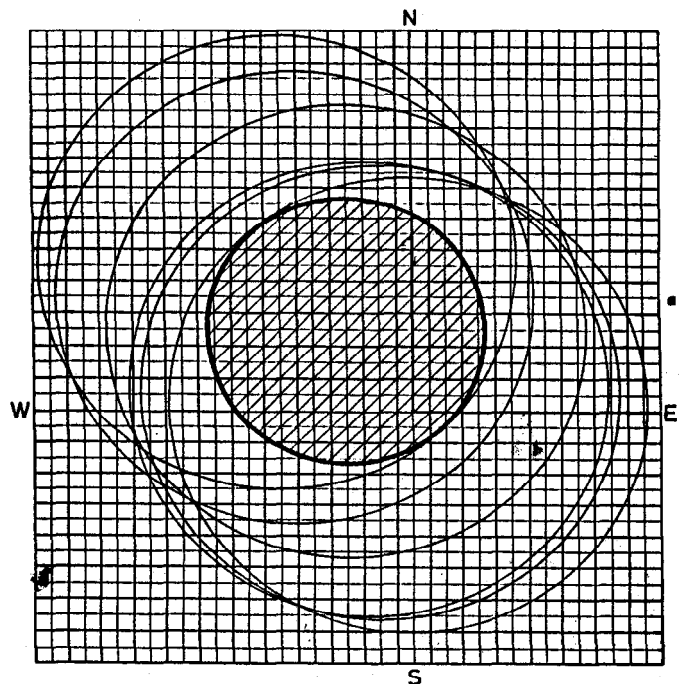


FIG. 5 G2

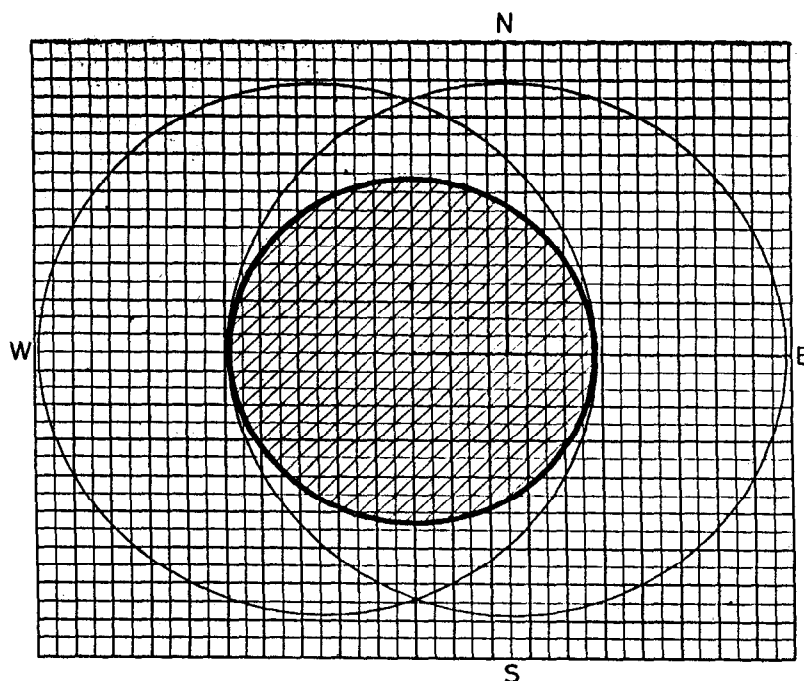


FIG. 6 H

## 5 TESTING FOR YIELD AND DRAWDOWN

**5.1** The drawing off of water through a tubewell results in lowering of water level. This drawdown creates a hydraulic gradient in the water-bearing material with the result that underground flow into the tubewell takes place. The rate of inflow depends upon the hydraulic gradient, permeability and saturated thickness of the water bearing material and tube well construction.

**5.2** After the well has been completely constructed and cleaned out and the depth of the well accurately measured, this test should be carried out.

**5.3** This test is conducted by installing a test pump in the tubewell temporarily and pumping out water. At each rate of discharge, pumping is carried out at least for 30 minutes. If the water level and dis-

charge are found to be fluctuating, development is carried out for some more hours, until the discharge becomes steady and sand content is within tolerable limits. The specific capacities of the well for various pumping rates is computed based on drawdown test data. Discharge may be measured by any method detailed in IS 5120 : 1977.

**5.4** Since the yield is influenced by a number of factors such as geological formation, rainfall, neighbouring tubewell, etc, the pumping rate shall, in general, not exceed 60 percent of the yield determined by test. It is recommended, however, that geological advice should be obtained on the percentage to be adopted for each location.

## 6 QUALITY OF WATER

**6.1** In the construction of the well, due precautions shall be taken by the drilling agency to maintain

the premises in a sanitary condition and to avoid as much as practical, the entrance of contaminated water into the water-bearing formations. Any water or materials, used shall be free of contamination and, if their nature permits, adequately disinfected with chlorine before use. A slush pit should be constructed so that no material enters the well, except mud reused when the construction is by rotary method. In such cases the slush pit and mud return channels should be protected against contamination from surface water or any other sources.

**6.2** Water shall be collected during aquifer performance test and analysed chemically as desired by the owner, for different constituents depending on the ultimate use to which water will be put.

## **7 HANDING OVER OF TUBEWELL**

**7.1** The following information should be furnished by the testing agency to the owner on completion of testing of the tubewell :

- a) Results of the tubewell depth and water level measurements,
- b) Report on the chemical and bacteriological analysis of water, and
- c) Results of development and drawdown test as given in Table 1.

**7.2** A typical proforma to furnish the details in accordance with 7.1 is given in Form B.

**Table 1 Test Results**

(Clause 7.1)

A. Normal Test

Sl. No.	Rated Discharge (m <sup>3</sup> /s)	Depression at Rated Discharge (m)	Specific Yield	Total Hours Run (h)	Sand in ppm at End of Test	Static Water Level (m)	Pumping Water Level (m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)

B. Discharge at 1.2 times normal yield or 1.5 times normal depression

Specific Yield	Total Hours Run (h)	Sand in ppm at End of Test	Static Water Level (m)	Pumping Water Level (m)
(1)	(2)	(3)	(4)	(5)



## CHAPTER 11

### WELL MAINTENANCE

#### 1 GENERAL

Wells, like all other engineering structures, need regular, routine maintenance in the interest of a continuous high level of performance and a maximum useful life. The maintenance of wells and pumps is often neglected, since the greater portion of both the well and the pump are located beneath the ground surface. The nature of deterioration which occurs in a well may not be readily discernible during operation and may not be recognized until the well fails. The deterioration usually develops slowly to a critical point and then accelerates rapidly to failure. Therefore, any neglect of well maintenance often results in the complete loss of the well.

#### 2 FACTORS AFFECTING WELL PERFORMANCE

**2.1** Several factors initiate well losses in inefficient wells. Care should be taken to differentiate between those factors associated with the normal wearing of pump parts and those directly associated with changing conditions in and around well. A well may show a reduced yield because of reduction in the capacity of the pump due to excessively worn parts. On the other hand, the excessive wearing of pump parts may be due to the pumping of sand entering the well through a corroded screen. It is also possible for corrosion to affect only the pump, reducing its capacity but to have little or no effect on a properly designed well.

**2.2** The common reasons of decrease in yield of a well include: (a) losses caused by reduction in permeability from mud invasion or by compaction and shearing of the formation face during drilling, and (b) losses from the turbulent flow of water adjacent to the well through the screen or well face and inside the casing to the pump intake.

#### 3 PREVENTIVE DESIGN FEATURES

**3.1** High well losses are unnecessary since they can be minimized by a good well design and construction. Therefore water well maintenance procedures begin with the techniques implemented during the drilling of the original well and con-

tinue with the type of materials used and with the extent of care, or the lack of it, that the well is given over the months and years of operation.

**3.2** A critical well design feature is the entrance velocity through the screen. An ideal entrance velocity is 1.5 to 3.8 cm/s depending upon the average permeability. Maintaining low entrance velocity results in high efficiency, minimizing sand pumping and reducing the rate of corrosion and incrustation in well. The distribution and shape of slot openings is as important as the entrance velocity in influencing well efficiency.

**3.3** A comprehensive design of the well system includes certain features in the discharge and distribution facilities to permit proper monitoring and maintenance of the well and pump. The more important of these features are :

- a) provision of an outlet in the discharge system to permit diversion from the system during future test pumping and water sample collection,
- b) a permanent throttling valve on the discharge,
- c) a permanent airline with valve and gauge for water level reading,
- d) access into the pump chamber casing which can also be used to measure water levels to permit back up water level reading by tape or electric probe, and
- e) ready access to the well to pull the pump and maintain the well.

#### 4 MAINTENANCE PLANNING

**4.1** The planning of well maintenance procedures should be based on a system of good record-keeping. The problems that result in reduced well yield occur at and around the well screen and are very much out of sight. The analysis of good records must, therefore, be relied upon for detection of problems in the well.



**4.2** Among the records kept should be pumping rates, draw-down, total hours of operation, power consumption and water quality analysis. Pumping rates and drawdown are particularly useful in determining the specific yield which is the best indicator of existing problems in a well. The specific yields of wells should be checked periodically and compared with previous values to determine if any significant reduction has taken place. Such a reduction is often due to clogging of well screen and formation around it by incrustation.

**4.3** Power consumption records also provide valuable evidence of existence of problems in wells. An increase in power consumption, not accompanied by a corresponding increase in the quantity of water pumped, indicates problem in either the pump or the well. If an investigation shows no problems in the pump nor appreciable increase in the dynamic head against which the pump is operating, then it is most likely that a problem exists in the well and the problem is causing an increased drawdown. A check on drawdown should then be undertaken and the well checked for incrustation.

**4.4** Regular chemical analyses of water will indicate the type of incrustation that might occur and the expected rate of deposition in the well and its vicinity. The quality of water in some wells changes slowly with time and only a regular analysis would detect such changes.

**4.5** In wells, the waters of which have a high incrustation potential, the frequency of observations of all types should be as high as possible and consistent with the use to which water is being put. Observations should be much more frequent in wells serving a community.

## **5 INTERPRETATION OF OBSERVED OR MEASURED CHANGES IN WELL PERFORMANCE OR CONDITIONS**

**5.1** A decrease in specific yield without a proportional decline in the static water level may indicate blockage of the screen by accumulated sediment in the bottom of the well, blockage of the screen or gravel pack by incrustation, or collapse of casing or screen.

Should the specific yield during a test for yield and draw-down show a decline of 10 percent or more from the original test (see 5 of Chapter 10) at a

given discharge, the well should be surveyed to determine the location and extent of possible contributing conditions. If collapse appears to be the problem, the well should be surveyed to determine the location and nature of the collapse. If collapse is not the problem, the inside of the well should be scraped and the sediment that was subsequently bailed from the bottom should be examined to determine the chemical composition, nature and extent of the encrusting material as a basis for a plan of rehabilitation.

**5.2** An increase in the sand content of the discharge, particularly if it is associated with a measurable accumulation of sand in the bottom of the well, may indicate enlargement of slot sizes by corrosion; settlement of gravel pack beneath a bridge leaving an unpacked zone opposite a screened section; a break in the casing or screen, usually at a joint; or failure of a packer seal. Mechanical and mineralogical examination of a sample bailed from the bottom of the hole and comparison with the original description of the aquifer and gravel pack materials made during construction of the well may give some indication of the nature of the difficulty. If the material is noticeably smaller in grain size than the grain size of any aquifer screened in the well, or if the material contains the full range of sizes of the gravel pack, there is probably a break in the casing or screen. If all the material is smaller than the screen slot sizes, it is probably a bridge. If the above interpretations of grain size and distribution are not applicable, the problem may be due to enlargement of a slot size by corrosion. If the problem is apparently due to bridging, it can frequently be corrected by redevelopment while pouring water down the gravel refill tremies and the addition of gravel pack material. The other problems usually require a photographic survey to be made of the well to more clearly assess the problem. Decisions can then be made concerning the practicability of rehabilitation and the procedures to be followed.

**5.3** Settlement of the land surface around a well, the development on the ground surface of small drainage channels towards the well, and cracking and settlement of pump pads and foundations are all indicative of settlement of the well structure. In some areas, the problem may be associated with land subsidence due to excessive pumping of the

aquifers. Usually, however, the problem is related to poor well design, construction, or development, and results from excessive pumping of sand. In many instances, the sand pumping is complicated by collapse of casing or screen, bridging of gravel packs, and similar deterioration. When such conditions are encountered, the well should be taken out of service, sounded for depth, and surveyed photographically to determine whether any structural damage has occurred. If the well cannot be shut down because of the need for water, the casing should be temporarily supported by welding heavy I-beams to it.

**5.4** Decline in pump discharge and head may be due to deterioration of pump or simultaneous deterioration of both the well and the pump. A common occurrence is a decrease in shut-in head and significant decrease in discharge without a corresponding decline in static water level and specific yield. Such an occurrence is usually due to one of the following conditions : (1) improper adjustment of the impeller due to wear or other causes, (2) a hole in the column pipe, or (3) erosion of the impeller or bowls.

A condition which is usually associated with considerable vibration when the pump is running. If the condition cannot be corrected by adjusting the impellers, the pump should be pulled and repaired or replaced. The cause of the problem should be thoroughly investigated and made a part of the permanent well and pump record.

**5.5** Excessive vibration of the pump may result from imbalance of the impeller or from the pump being installed in a crooked well. A pump which makes a crackling noise similar to gravel being thrown on a tin roof is probably experiencing cavitation at the impellers. This is particularly true if the discharge is surging and irregular and contains considerable air. The condition usually results from a decline in the static water level or reduced well capacity because of incrustation or accumulation of sand in the screen. Either of these conditions results in excessive drawdown for pump and a decline below that required in the available net positive suction head. If the condition is due to a decline in the static water level, it can usually be corrected by lowering the bowls. In severe cases, it may be necessary to add additional stages and a

larger motor in addition to lowering the bowls. The well should also be checked for possible incrustation of the screen or other causes of reduced efficiency.

**5.6** Excessive heating of the motor is occasionally encountered and is usually associated with an overload condition and the consumption of excessive electrical energy. Such heating may be caused by a poorly adjusted impeller which is dragging on the bowls, too tight a packing gland, improper or unbalanced voltage, poor electrical connections, or improper sizing of motor.

Occasionally, an inadequate discharge will be associated with trash that has lodged in the bowls or blockage of the impellers or bowl channels by products of corrosion and incrustation. Correction entails pulling the pump for repair. These conditions may also be reflected in overheating of the motor. Where overheating is encountered, the installation should be first checked by an electrician to determine whether the trouble is in the power system or in the pump, rather than in the well.

**5.7** Occasionally, a noticeable increase in oil consumption is encountered in oil-lubricated pumps. The excessive consumption may be due to a hole in the wall of the oil tubing or excessive wear on a packing gland in the tubing. These conditions can result in a decrease in differential pressure in the oil tubing and loss of oil into the well. The first condition can result in inflow of water into the tubing and formation of an emulsion of water and oil. The emulsion lacks adequate qualities and can result in excessive wear or burning out of the bearings. The escape of oil into the well can result in the accumulation of oil floating on the water surface in the casing. With adequate pump submergence, this latter condition may not cause serious trouble but if draw-down increases due to a decline in water table or deterioration of the well, oil may be drawn into the pump, causing impairment of water quality. In addition, the presence of oil may contaminate the groundwater and preclude accurate measurement of static water and pumping water levels.

**5.8** Small capacity wells usually have discharges of less than 500 l/min. Casing and screen used for such wells commonly are 15 cm in diameter or

smaller, and materials used in their construction are relatively light in weight. While the observations and measurements outlined above are equally applicable for large capacity pumps and wells they are usually difficult to justify economically.

## 6 CHLORINATION

**6.1** Chlorination shall be done at least twice a year before and after monsoons and whenever there is a possibility of pollution having occurred due to natural calamities like floods or damage to platform.

**6.2** In case of the hand pump installation, following procedure shall be followed :

- a) Put 300 g of bleaching powder in a bucket of water;
- b) Mix it thoroughly;
- c) Remove the four bolts from the lower part of the hand pump's water tank. Lift water tank and clamp riser pipe

to the raised position;

- d) Pour chlorine solution into open end of pedestal;
- e) Lower water tank and bolt it back to pedestal. Tighten fully;
- f) Stop pumping when the water smells strongly of chlorine;
- g) The handpump must not be used for at least one hour. But it is better if the handpump is not used for 6 hours or more. So, ask the villagers not to use it until the next day;
- h) The next day, pump until the taste of chlorine is just noticeable in the water;
- j) Collect a sample of the water. Use a sterile bottle. Seal the bottle and label it; and
- k) Send the sample for bacteriological examination.

## CHAPTER 12

## WELL REHABILITATION AND ABANDONMENT

## 1 WELL REHABILITATION

1.1 The rehabilitation of well means repair of wells which have failed because of collapse, broken casing and screen or other similar damage, and the treatment of wells which have begun to pump sand, have experienced a change of water quality or have shown a marked decrease in discharge and efficiency because of incrustation, or other factors which tend to reduce the intake area of the screen and permeability of the adjacent aquifer. It shall be undertaken when the specific yield falls to about 80 percent of the initial value.

1.1.1 The cause and extent of well sickness must be diagnosed before the rehabilitation programme is undertaken.

1.1.1.1 If the decrease in yield is due to the lowering of water table in the aquifer as a result of over pumping or interference from other wells, then nothing can be done.

1.1.1.2 However the failures due to incrustation, corrosion, improper design, gravel placement and faulty construction may be remedied by a suitable rehabilitation programme.

1.1.2 The major problem in rehabilitation is estimating the exact nature of the deterioration since the screen and other components most likely to deteriorate are not open to usual inspection or testing. This may be overcome to an extent by adequate investigation and planning prior to undertaking the work as given below.

1.1.2.1 *Information to be given by user*

The following information shall be made available by the owner:

- a) Initial and present well yield, depression, and water level as observed periodically during the well's service life;
- b) Sand content in ppm, if any;
- c) Grain size distribution of the strata tapped as a result of sieve analysis;

- d) Location of screen, its opening size, percentage of screen surface area to the total open area, screen material, length and diameter of screen and well pipes, etc, and data of acceptance of the well;
- e) Size and quantity of pea-gravel used initially and during its service life;
- f) Method used and details of development with results;
- g) Method of drilling adopted, name of drilling agency, original pump and well test results and results of subsequent tests, if available;
- h) Results of the initial and present chemical analysis of the well water;
- j) Details of any chemical treatment, if ever given to the well and results achieved therefrom;
- k) Sounding of the well observed every year;
- m) Details of repairs to the pumping equipment carried out every year; and
- n) Number of electricity units consumed per kilowatt ratings every year during service life of the well.

1.1.2.2 *Investigations to be carried out by the contractor*

The following data shall be determined for reference when starting rehabilitation of any well:

- a) Date of acceptance of well;
- b) Name of contractor;
- c) Method of drilling;
- d) Method of formation sampling;
- e) Formation log;
- f) Mechanical analyses of aquifer samples;
- g) Mechanical analyses of pack material;

- h) Screen materials, slot sizes, diameters and depth of setting;
- j) Present open area of screen, design inflow velocity;
- k) Depth, diameter and material of pump chamber;
- m) Method and completeness of development;
- n) Original pump and well test results and results of subsequent tests with dates;
  - 1) Static Water level
  - 2) Measured depth of bottom of hole
  - 3) Discharge
  - 4) Draw down
  - 5) Specific yield
  - 6) Step tests
  - 7) Production tests
- p) Ground water hydrographs of the area;
- q) Quality of water analyses of well with dates; and
- r) Resumé of maintenance, rehabilitation and performance.

**1.1.2.3** The following investigations shall be carried out and data determined before starting rehabilitation on any well :

- a) Chemical and bacteriological analysis of the well water shall be carried out and compared with the original one, with regard to its original and the present apparent incrustation potential. If it is high or has increased with time, treatment may be required;
- b) If the well is yielding sand, the discharged sand sample shall be collected and compared with the original formation log so as to locate precisely the position of the possible rupture or loose connection, etc;
- c) If equipment is available, an underwater photographic survey shall be

carried out and location of any evidence of incrustation, organic growth or accumulation on the casing and screen recorded. Also, any filamentous algae, iron bacteria or similar organisms floating in the water shall be noted. Any evidence of mechanical damage to the casing and screen shall be carefully inspected with the camera and recorded with regard to its description and depth;

- d) The present specific yield at design discharge rate and draw down, low enough to permit continuous pumping for 4 hours, without breaking suction, shall be determined. This will give a qualitative measure of the degree of deterioration and by comparison with the later tests, the success of rehabilitation programme;
- e) The pump shall be pulled out and various parts examined immediately as they are removed from the well. The column pipe, drive shaft, bearing spiders and bowl shall be inspected for evidence of excessive accumulations or deposits of ferric or ferrous hydroxides. If the deposits are present, sufficient samples shall be collected to fully fill a bottle capable of being sealed airtight. This shall be done as rapidly as possible and the samples sent to the laboratory immediately, so as to avoid generation of heat in the sample. The samples shall be sent to the chemical and biological laboratories for identification of chemical compounds present and identification, if possible, of organism involved;
- f) The pump parts shall be examined for evidence of pitting, tuberculations, graphitization, cavitation and wear. Pump bowls and impellers shall be inspected for evidence for graphitization in areas where sulphate-bacteria are known or suspected to be present; and

- h) The static water level and depth of the bottom of the well assembly shall be checked when the pump is taken out of the well.

### 1.1.3 Acid Treatment

Acid treatment using hydrochloric (muriatic) or sulfamic ( $\text{H}_2\text{NSO}_2\text{H}$ ) acid is commonly employed for rehabilitation. It efficiently eliminates incrustation due to calcium, magnesium and iron carbonates, or iron hydroxides which can be detected by examining the scrapings from the inside of the screen for chemical composition.

The strongest grade of muriatic acid, designated the 27.92 percent hydrochloric acid, is used in full strength for acidizing. The amount of acid added for a single treatment is 1.5 to 2 times the volume of water in the casing, screen and gravel pack between the bottom of the well and 3 m above the topmost screen slot. It is poured through a black iron or plastic pipe 38 to 50 mm in diameter and long enough to reach the bottom of the well. Acid to fill 1.5 to 3 m of screen is poured first; the conductor pipe raised about 1.5 to 3 m to pour more acid and the process is continued till all the acid has been added to the well. The acid, being heavier than water, displaces it as it is poured.

Iron and manganese hydroxides and oxides, although soluble in hydrochloric acid, precipitate out if pH is above 3. To keep iron in solution, regardless of pH so that it can be pumped from the well with spent acid, a chelating agent like Rochelle salt, citric acid, tartaric acid, phosphoric acid or glycolic acid may be added to the acid. About 900 g of chelating agent may be used for 4.5 l of hydrochloric acid.

To curb the tendency of the acid to attack metallic casing and screen, either inhibited acid or an inhibitor such as Knox gelatine should be used. 2.3 to 2.7 kg gelatine dissolved in warm water and added to 450 l of acid serves the purpose. The acid is left in the well for about 4 to 6 hours. At the end of about 3 h, sufficient water is added to displace the acid from 3 m above the topmost slot to the bottom of the well. While the acid is in the well, it is surged by air or with surge block for 15-20 minutes each hour. The acid is bailed out at the end of about 6 hours.

Hydrochloric acid is dangerous to use unless handled by experienced personnel and suitable equipment. It gives off poisonous fumes and its reaction with carbonates is some times violent spraying around the well. The transport of liquid hydrochloric acid to the field is also not easy.

Hydrochloric acid of adequate strength is readily available at a relatively low price. It has been used observing safety precautions and no injuries or casualties have resulted. Under the circumstances, it appears that hydrochloric acid, despite the danger and difficulties associated with its use, will continue to be used. However, if trained and experienced crew are not available to carry on the acidizing work, consideration shall be given to employing the less dangerous sulfamic acid.

It is for these reasons that sulfamic acid is being increasingly used for well rehabilitation. It is more expensive than hydrochloric acid but less aggressive and safer to use and easily shipped and stored as dry crystal or powder. Its corrosive effect on well screens and pumping equipment is markedly less. It, however, requires about twice as long to treat a well as does hydrochloric acid.

When using sulfamic acid in a well, the same estimates are made regarding the column of water in the well to be displaced and 1.5 to 2 times that volume is poured into the well through a black iron or plastic pipe as described earlier. It is available in granular form and may be poured into the well from the top.

Because sulfamic acid is a milder and less aggressive acid, it is mixed in a black iron or wooden tank at the surface. A tank about 1.2 × 1.5 × 3 m is usually adequate and holds about 5360 l. The tank shall have a bottom valve through which the acid solution is drawn into the well. 41 kg sulfamic acid, 450 g of pluronic F68 and 2.7 kg chelating agent such as Rochelle salt, citric acid, tartaric acid, etc, are added and dissolved in each 450 l of water to be poured into the well. If well is screened with metal, an inhibitor such as Knox gelatine shall be used at the rate of 1.8 to 2.3 kg per 450 litre of solution. The acid shall remain in the well for at least 12 hours during which it shall be surged by air or surge block about 15 to 20 minutes every hour. Then it is bailed or pumped to waste.

The spent acid is bailed or pumped out of the well using a corrosion-resistant pump for the purpose. In many wells, pumping with a centrifugal pump is possible. Close observation of the bailing or pumping discharge and the draw-downs during removal of the acid shall give an indication of the success of the treatment.

During acid treatment of a well the crew shall wear protective clothing and respirators. One or two 250 l drums of concentrated sodium bicarbonate shall be available for quick neutralization of acid with which crew members may come in contact during the operation.

During treatment, incrustation is dissolved and the fines incorporated in the agent remain in the pack and base material. On completion of acidizing the well shall be redeveloped using polyphosphate, sufficient chlorine for a shock treatment and one of the methods of surging or jetting.

#### 1.1.4 Glossy Phosphate Treatment

Glossy phosphates (polyphosphates) act by dispersing clays and salts and loosening their adhesion to sand and gravel so that they may be readily pumped out of the well. Treatment with one of the polyphosphates, coupled with vigorous agitation, effectively breaks up the incrusting material and cleans the well. An important advantage is that polyphosphates are safe to handle.

The polyphosphates are usually used in conjunction with a wetting agent, sodium carbonate and chlorine compound. The wetting agent facilitates the penetration of the polyphosphate solution into the fine-grained material and hastens the operation. Sodium carbonate has a cleaning action on rust on iron screens and pipes and also serves to neutralize the effects of oil and other organic compounds that might interfere with the action of chlorine. Chlorine acts as a catalyst and apparently improves the action of the polyphosphates besides sterilizing the well and the adjacent formations.

NOTE — Under some circumstances, the wetting agents cause too rapid a breakdown of the fabric. Therefore, until more is known of the fabric and composition of the aquifer, it is recommended that wetting agents be omitted from the solutions.

In wells screened with fibreglass-reinforced epoxy, sodium carbonate may be left out of the solution without any loss of efficiency.

1.1.4.1 The following procedure may be adopted for rehabilitation:

Estimate the volume of water in the pack and screen between the water table and the bottom of the hole to the nearest 450 l. On the basis of the following amount of reagents per 450 l of water in the well, estimate the amount of various chemicals required :

- a) For fibreglass-reinforced epoxy screens — Sodium hexametaphosphate 3.6 kg;
- b) For metal screens—In addition to the above 900 g sodium carbonate; and
- c) Should experience show use of a wetting agent is helpful, 450 g pluronic F 68 or equivalent.

Most wells contain between 10,900 to 15,900 l of water. A wooden or black iron tank 1.2 × 1.5 × 3 m is a convenient size for transportation, etc, and holds in excess of 5 360 l of water. Therefore, two or three batches of solution mixed in the tank shall be required for each well. A convenient but not necessary arrangement that speeds up the operation is to use two tanks in order that the next batch of solution may be mixed while the previous one is being placed in the well.

The solution is poured or pumped into the well through a 38 or 50 mm plastic or black iron pipe that initially is installed from the surface to about 1.5 m above the bottom of the well. Sufficient solution is put in the well to displace an estimated 1.5 or 3 m of the water in the casing and pack. The pipe is then raised 1.5 or 3 m and the procedure repeated until all water in the well and pack are displaced by the solution. The solution has higher specific gravity than the water and displaces it upward and outward from the well. When all the solution is installed in the well, a volume of water equal to about one-half that contained in the casing and screen is poured in at the top to displace the solution from the screen and force it out into the formation (see Table 1). A 200mm casing contains about 11 l and 200 mm screen about 18 l of

water per metre of length. A surge block bail or similar tool is then run from the bottom of the well to above the water table two or three times of the inductor pipe for air surging may be replaced to near the bottom of the well and air bubbled up through the well to thoroughly mix the solution remaining in the casing screen.

**1.1.5 Chlorine Treatment**

Chlorine has been found effective in loosening clogging of the intake section of the well and water-bearing formation caused by deposition of iron oxide. Chlorine, when added to water forms hypochlorous and hypochloric acids, which kill the bacteria and produce an effect of 'burning up' the organic slime.

Sufficient amount of calcium or sodium hypochlorite to give a concentration of 100 to 200 ppm of free chlorine is added to the well either directly or in water solutions. Alternatively, chlorine gas may be used but it is dangerous and requires experienced personnel and equipment which may not always be available. It must be put into the well in a water solution as it is both corrosive and toxic when inhaled. Hypochlorite solutions are cheaper, more convenient and safer to use than gas but generally less effective.

**Table 1 Contents of Casing and Screen**

(Clause 1.1.4.1)

Contents of Casing and Screen	
Nominal Pipe Size (mm)	Litre per 300 mm of Length
100	3.0
125	4.6
150	6.8
200	12.0
250	19.0
300	26.4
350	32.2
400	43.0
450	54.0
500	67.0
550	81.8
600	98.0

The chlorine solution is introduced in the well through a small diameter plastic pipe. A quantity of 14 to 18 kg added slowly over a period of 12 hours shall suffice for a large well. The pipe carrying chlorine must be positioned so that the solution does not impinge directly upon any part of the pump, well casing, or well screen. After introduction, the chlorine solution is forced into the water-bearing formation by adding about 50 to 100 times the volume of water standing in the well.

The well shall be surged or the solution agitated vigorously as in acid treatment.

Repeated chlorine treatment will have more chance of flushing the clogged formation around the well. Alternate acid and chlorine treatments are found to be even more effective.

**1.1.6 Dry Ice Treatment**

The use of dry ice, that is, solid carbon dioxide is still in the experimental stage. Dry ice changes from solid to gaseous state rapidly with considerable pressure, when put into well water. The rapidly expanding gas is confined within the well casing and is forced through the screen openings to loosen the clogged material. On account of high pressure developed, provision shall be made for the control and relief of pressure to guard against any damage. As dry ice may cause severe burns, if handled with bare hands, heavy gloves or tongs shall be used in handling the ice.

**1.1.7 Explosives**

These are sometimes employed to develop and enlarge crevices and fissures in tubewells drilled in hard rocks. Charges of 30 to 500 kg are used according to the hardness of the rock and the depth at which the charge is to be detonated.

**1.1.8 Criteria for Acceptance**

**1.1.8.1** An increase in yield of the well by 30 percent of the pre-rehabilitated yield of the well or attainment of 75 percent of the initial yield, whichever is more, shall be the basis of acceptance. Alternatively, it may be agreed to between the contractor and the owner.

**1.1.9 Information to be Supplied by the Contractor to Owner for Future Use**

The contractor shall supply the following information to the owner for future use :



- a) Results of the investigations carried out before taking up rehabilitation;
- b) Result of chemical tests carried out before and after rehabilitation work;
- c) Methods used along with name and quantity of chemicals used and number of treatments given;
- d) Results of rehabilitation, that is, discharge, depression and sand content in ppm at start and after 20 minutes;
- e) Sounding of the well after treatment;
- f) Condition of the pumping unit before rehabilitation and details of repairs carried out to it;
- g) Suggestions, based on investigations, for future upkeep and maintenance of the well including recommended limit to continuous discharge and depression, that is, rate of pumping in order to avoid harmful overpumping and thereby limiting the entrance velocities; and
- h) Any other relevant information desired by the owner.

mental practice in the preservation of high ground-water quality. Permanent sealing of abandoned wells is important because serious groundwater pollution can occur from either contaminated surface water or interaquifer transfer of ground water from a contaminated aquifer.

**2.2** The basic concept in the proper sealing of an abandoned well is the restoration as far as possible of the geologic conditions that existed before the well was drilled. The local geologic conditions must be assessed in detail to determine the most effective method of well sealing. Sealing is usually achieved by grouting; when grouting below the water table, the cementing material should be placed from the bottom up, by methods that would avoid segregation or excessive dilution of the material. The upper portion of the casing should be removed to ensure intimate contact of the grout with the wall of the hole to form a water-tight plug in the upper 5 to 7 m.

**2.3** To seal an abandoned well properly, the type of groundwater occurrence must be considered. Under water table conditions, the objective is to prevent percolation of the surface water through the well or along the periphery of the casing to the water table. Under artesian conditions, the sealing operations must confine the water to the aquifer in which it occurs.

## 2 WELL ABANDONMENT

**2.1** Proper plugging of abandoned wells is a funda-

## ANNEX A

### LIST OF REFERRED AND OTHER RELEVANT INDIAN STANDARDS

#### A-1 INDIAN STANDARDS ON WATER WELLS

##### A-1.1 Glossary of Terms

IS 9439 : 1980 Glossary of terms used in waterwell drilling technology

##### A-1.2 Codes of Practice and Test Methods

IS 2800 Code of practice for construction and testing of tubewells :

Part 1 : 1991 Construction (*second revision*)

Part 2 : 1979 Testing (*first revision*)

IS 6935 : 1973 Method of determination of water level in borehole

IS 11189 : 1985 Methods for tubewell development

IS 11632 : 1986 Code of practice for rehabilitation of tubewell

##### A-1.3 Well Components

IS 4097 : 1967 Gravel for use as pack in tubewells

IS 4270 : 1992 Steel tubes used for water wells (*second revision*)

IS 5494 : 1969 Leaded brass sheets and strips for use in the manufacture of tubewell strainer

IS 8110 : 1985 Well screens and slotted pipes (*first revision*)

IS 12584 : 1989 Bentonite for grouting in civil engineering works

IS 12818 : 1992 Specification for UPVC ribbed screen casing and plain casing pipes for bore/tube wells (*first revision*)

##### A-1.4 Drilling Equipment, Accessories and Methods

IS 7156 : 1974 General requirements for reverse circulation drilling rigs

IS 7206 (Part 1) : 1986 General requirements for direct circulation rotary drilling rigs : Part 1 With rotary table (*first revision*)

IS 8986 : 1978 Dimensions for drill steels in bar form for percussive drilling

IS 9026 : 1978 Rope threaded percussive long hole drilling equipment

IS 10208 : 1982 Diamond core drilling equipment

IS 11180 : 1985 Square and hexagonal kelleys for direct rotary drilling

IS 11312 (Part 1) : 1985 External upset drill pipe assemblies for use in water well drilling : Part 1 Screwed on joints drill pipe

IS 11672 : 1986 Tungsten carbide buttons and inserts for use in down the hole (DTH) bits

IS 11710 : 1986 Code of practice for selection and design of diamond core drills

- IS 11830 General requirements for down-the-hole hammer rigs for water wells :
- Part 1 : 1992 Hydraulic rigs (with or without rotary mode) (*first revision*)
  - Part 2 : 1989 Pneumatic rigs
- IS 12090 : 1987 Dimension of rotary tables for direct rotary drilling equipment
- IS 12097 : 1987 Classification and selection of drilling rigs for water well drilling
- IS 12194 : 1987 Dimensions for rock roller bits and blade drag bits for rock drilling equipment
- IS 12214 : 1987 General requirements for rotary hose for water well drilling equipment
- IS 12629 : 1989 Water well drilling — Rotary hose for rotary drilling — Recommended practice for care and use
- IS 12635 : 1989 Water well drilling — Rock roller bit with non-sealed ball and roller bearing arrangement — Technical supply conditions
- IS 12682 : 1989 Waterwell drilling — Percussion drilling rigs — General requirements

## A-2 OTHER REFERRED STANDARDS

- IS 460 (Part 2) : 1985 Specification for test sieves : Part 2 Perforated plate test sieves (*third revision*)
- IS 554 : 1985 Dimensions for pipe threads where pressure tight joints are required on the threads (*third revision*)
- IS 1622 : 1981 Methods of sampling and microbiological examination of water (*first revision*)
- IS 1894 : 1972 Method for tensile testing of steel tubes (*first revision*)
- IS 2328 : 1983 Method for flattening test on metallic tubes (*first revision*)
- IS 2952 Recommendation for methods of measurement of liquid flow by means of orifice plates and nozzles :
- Part 1 : 1964 Incompressible fluids
  - Part 2 : 1975 Compressible fluids
- IS 3025 : 1964 Methods of sampling and test (physical and chemical) for water used in industry
- IS 3025 Methods of sampling and test (physical and chemical) for water and wastewater
- Part 1 : 1986 Sampling (*first revision*)
  - Part 3 : 1987 Precision and accuracy (*first revision*)
  - Part 4 : 1983 Colour (*first revision*)
  - Part 5 : 1983 Odour (*first revision*)
  - Part 6 : 1983 Odour threshold (*first revision*)
  - Part 7 : 1984 Taste threshold (*first revision*)
  - Part 8 : 1984 Taste rating (*first revision*)
  - Part 9 : 1984 Temperature (*first revision*)

- Part 10 : 1984 Turbidity (*first revision*)
- Part 11 : 1983 pH value (*first revision*)
- Part 12 : 1983 Density (*first revision*)
- Part 13 : 1983 Saturation index (with respect to calcium carbonate) (*first revision*)
- Part 14 : 1984 Specific conductance (wheat-stone bridge, conductance cell) (*first revision*)
- Part 15 : 1984 Total residue (total solids-dissolved and suspended) (*first revision*)
- Part 16 : 1984 Filterable residue (total dissolved solids) (*first revision*)
- Part 17 : 1984 Non-filtrable residue (total suspended solids) (*first revision*)
- Part 18 : 1984 Volatile and fixed residue (total filtrable and non-filtrable) (*first revision*)
- Part 19 : 1984 Settleable matter (*first revision*)
- Part 20 : 1984 Dispersion characteristics (flow patterns) (*first revision*)
- Part 21 : 1983 Total hardness (*first revision*)
- Part 22 : 1986 Acidity (*first revision*)
- Part 23 : 1986 Alkalinity (*first revision*)
- Part 24 : 1986 Sulphates (*first revision*)
- Part 25 : 1986 Chlorine, demand (*first revision*)
- Part 26 : 1986 Chlorine, residual (*first revision*)
- Part 27 : 1986 Cyanide (*first revision*)
- Part 28 : 1986 Sulphite (*first revision*)
- Part 29 : 1986 Sulphide (*first revision*)
- Part 30 : 1988 Bromide (*first revision*)
- Part 31 : 1988 Phosphorus (*first revision*)
- Part 32 : 1988 Chloride (*first revision*)
- Part 33 : 1988 Iodide (*first revision*)
- Part 34 : 1988 Nitrogen (*first revision*)
- Part 35 : 1988 Silica (*first revision*)
- Part 36 : 1988 Ozone residual (*first revision*)
- Part 37 : 1988 Arsenic (*first revision*)
- Part 38 : 1989 Dissolved oxygen (*first revision*)
- Part 39 : 1989 Oil and grease
- Part 40 : 1991 Calcium

- IS 4412 : 1981 Copper wires for general engineering purposes (*first revision*)
- IS 4711 : 1974 Methods for sampling of steel pipes, tubes and fittings (*first revision*)
- IS 4736 : 1986 Hot-dip zinc coatings on mild steel tubes (*first revision*)
- IS 4905 : 1968 Methods for random sampling
- IS 4985 : 1988 Specification for unplasticised PVC pipes for potable water supplies (*second revision*)
- IS 5120 : 1977 Technical requirements for rotodynamic special purpose pumps (*first revision*)
- IS 5382 : 1985 Rubber sealing rings for gas mains, water mains and sewers (*first revision*)
- IS 5494 : 1969 Leaded brass sheets and strips for use in manufacture of tubewell strainers
- IS 6059 : 1971 Recommendations for liquid flow measurement in open channels by weirs and flume weirs of finite crest width for free discharge
- IS 6307 : 1985 Rigid PVC sheets (*first revision*)
- IS 7808 : 1975 Code of procedure for conducting studies on underground corrosion of metals
- IS 8062 (Part 1) : 1976 Code of practice for cathodic protection of steel structures : Part 1 General principles
- IS 8543 Methods of testing plastics :
- Part 1/Sec 2 : 1979 Characterization of polymer structure and size, Section 2 Determination of density of solid plastics
- Part 4/Sec 1 : 1984 Short term mechanical properties, Section 1 Determination of tensile properties
- IS 9108 : 1979 Liquid flow measurement in open channels using thin plate weirs
- IS 9118 : 1979 Method for measurement of pressure by means of manometer
- IS 9119 : 1979 Method for flow estimation by jet characteristics (approximate method)
- IS 10151 : 1982 Polyvinyl chloride PVC and its copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
- IS 10500 : 1991 Drinking water (*first revision*)
- IS 12235 (Part 1 to 11) : 1986 Methods of test for unplasticised PVC pipes for potable water supplies

## ANNEX B

## GLOSSARY

**B-1 ALLUVIUM**

A general term for all detrital deposits resulting from the operation of rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes and estuaries.

**B-2 AQUIFER**

An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

**B-3 ARTESIAN**

Artesian is synonymous with confined artesian water and artesian water body which are equivalent respectively to confined ground water and confined water body.

**B-4 ARTESIAN WELL**

A well tapping from a confined or artesian aquifer in which the static water level stands above the water table. The term is sometimes used to include all wells tapping confined water, in which case those wells with water level above the water table are said to have positive artesian head (pressure) and those with water level below the water table, negative artesian head.

**B-5 BLANK/BLIND PIPE**

The section of pipeline intake section placed against formation not yielding water for the same purpose as casing pipe.

**B-6 BRIDGE**

An obstruction to circulation in the annular space of the well.

**B-7 DRAWDOWN**

Lowering of water level caused by pumping. It is measured for a given quantity of water pumped during a specified period, or after the pumping level has stabilized.

**B-8 DRIVE PIPE**

Drive pipe is a type of casing pipe made of seamless or welded mild steel pipes designed to withstand the driving force and to penetrate into the ground so as to protect the collapse or movement of loose formation which takes place during the drilling operations.

**B-9 EFFECTIVE SIZE,  $D_{10}$** 

Particle diameter corresponding to 10 percent finer on the grain size curve.

**B-10 FINES**

Portion of soil finer than 75-micron IS sieve.

**B-11 FLUID, DRILLING**

The medium, liquid or gas used for flushing cuttings from the hole being drilled, for cooling the bit and for lubricating the bit.

**B-12 HOUSING PIPE**

Housing pipe is the upper portion of the casing section of the well which serves as a housing for pumping equipment and is a vertical conduit through which water flows from the aquifer to the pump. It is water-tight and extends downwards from ground surface to a safe depth below the anticipated pumping water level.

**B-13 RESIDUAL DRAWDOWN**

If a well is pumped for a given period of time and then shut down, the residual drawdown can be approximated as the numerical difference between the drawdown in the well if the discharge had continued and the recovery of the well in response to an imaginary well of the same discharge superimposed on discharging well at the time it is shut down.

**B-14 SPECIFIC YIELD**

Specific yield of a well is the ratio of its discharge to drawdown.

**B-15 UNIFORMITY COEFFICIENT**

The ratio  $D_{60}/D_{10}$ , where  $D_{60}$  is the particle diameter corresponding to 60 percent finer on the grain

size curve, and  $D_{10}$  is the particle diameter corresponding to 10 percent finer on the grain size curve.

#### **B-16 WATER TABLE**

That surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold stand-

ing water. In wells which penetrate to greater depths, the water level will stand above or below the water table, if an upward or downward component of ground water flow exists.

#### **B-17 YIELD**

The quantity of water, expressed as rate of flow, that can be collected for a given use or uses from groundwater.

## ANNEX C

(Clause 3.2.1, Chapter 1)

## FEATURES ON SATELLITE IMAGERY FOR SHALLOW SAND AND GRAVEL AQUIFERS

**Shape or form**

- Stream valleys, particularly broad valleys with low-stream gradients
- Underfit valleys represented by topographically low elongate areas
- Natural levees (levees themselves may be fine-grained materials)
- Meander loops defining locations and relative thickness of point bars
- Meander scars in lowlands, oxbow lakes, articulate dissection of upland areas
- Arc deltas (coarsest materials and other deltas)
- Drainage-line offsets, changes in drainage patterns; or changes in size or frequency of meanders (may be caused by faults or cuestas or by other deposits of coarser-grained materials)
- Braided drainage channels and scars
- Alluvial fans, coalescing fans, and bajadas
- Cheniers, beach ridges, and dunes
- Aligned oblong areas of different natural vegetation representing old offshore bars or dissected beaches

**Pattern**

- Drainage patterns infer lithology and degree of structural control; drainage density (humid regions) and drainage texture (arid regions) infer grain size, compaction and permeability
- Snow-melt : if everything else is equal, anomalous early melting of snow and greening of vegetation show areas of ground water discharge

- Distinctive types of native vegetation commonly show upstream extensions of drainage patterns, areas of high soil moisture, and landforms outlines (humid regions); abrupt changes in land cover type or land use infer landforms that may be hydrologically significant but do not have a characteristic shape
- Elongated lakes, sinuous lakes and aligned lakes and ponds represent remnants of a former stream valley
- Topographically low, elongated, aligned areas represent abandoned stream valleys

**Tone**

- Soil type : Fine-grained soils are commonly darker than coarsegrained soils
- Soil moisture : Wet soils are darker than dry soils
- Type and species of native vegetation : Vegetation is generally well adapted to type and thickness of soil, drainage characteristics, and seasonal period of saturation of root zone
- Land use : For example in areas of periodic flooding, native vegetation tends to occur in lowlands and agriculture on uplands
- Anomalous early or late seasonal growth of vegetation usually occurs in areas of high soil moisture, such as where the water table is close to the land surface

**Texture**

- Uniform or mixed types and species of native vegetation
- Contrast between sparse vegetation on topographic highs and denser vegetation in low (wetter) areas
- Mixed land used, representing local differences in topography, soil type of drainage characteristics, etc



**ANNEX D***(Clause 3.2.1, Chapter 1)***FEATURES OF SATELLITE IMAGERY RELATED TO ROCKY AND OTHER AQUIFERS****Outcropping rock type**

- landforms : topographic relief
- Outcrop patterns; banded patterns for sedimentary rocks (outlined by vegetation in humid regions), plateau or homocline for basalt flows, or curving patterns for folded beds
- Shape of drainage basins
- Drainage patterns, density and texture
- Fracture types and symmetry (as inferred by lineaments)
- Relative abundance, shape and distribution of lakes
- Tones and textures: difficult to describe; best determined by study of known examples
- Types of native land cover

**Lineaments**

- Continuous and linear stream channels, valleys and ridges, discontinuous but straight and aligned valleys, draws, swags and gaps
- Elongated or aligned lakes, large sinkholes and volcanoes
- Identical or opposite deflections (such as doglegs) in adjacent stream channels, valleys or ridges; alignment of tributary junctions
- Elongate or aligned patterns of native vegetation, thin strips of relatively open (may be rights-of-way), or dense vegetation
- Alignment of dark or light soil tones

**ANNEX E***(Clause 3.2.1, Chapter 1)***SEQUENCE OF INVESTIGATIONS USING SATELLITE IMAGERY**

Remote Sensing Studies

Acquisition of Satellite Data

(1:250 000 scale)

Preliminary Interpretation

Base Map Preparation

(enlarged image of data on

1:50 000 scale)

Ground checks

Final Interpretation

Final Hydrogeomorphological Maps

## ANNEX F

(Clause 3.2.2, Chapter 1)

### SURFICAL FEATURES IDENTIFIED ON AERIAL PHOTOGRAPHS THAT AID IN EVALUATING GROUNDWATER CONDITIONS

#### Topography

- Appraisal of regional relief setting
- Appraisal of local relief setting

#### Vegetation

- Phreatophytes and aquatic plants

#### Geological landforms likely to contain relatively permeable strata

- Modern alluvial terraces and flood plains
- Stratified valley-fill deposits in abandoned meltwater and spillway channel
- Glacial outwash and glacial deltas
- Eskerine-kame complexes
- Alluvial fans
- Beach ridges
- Partly drift-filled valleys marked by a chain of elongated closed depressions
- Largely masked bedrock valleys cutting across modern valleys, indicated by local nonslumping of weak shale strata in valley sides
- Local drift-filled valleys in extensive bedrock-exposed terrains
- Sand dunes assumed to overlie sandy glaciofluvial sediments

#### Lakes and streams

- Drainage density of stream network
- Localized gain or loss of streamflow
- Nearby small perennial and intermittent lakes (e.g., lakes in outwash, elongated saline lakes in inactive drainage systems)
- Perennial rivers and larger creeks in valleys having inactive flood plains

- Small intermittent drainages (including misfit creeks in abandoned glacial spillways and meltwater channels)
- No defined drainage channel in former glacial spillways and meltwater channels

#### Moist depressions and seepages

- Moist depressions, marshy environments and seepages (significance depends on interpretation of associated phenomena)
- String of alkali-salt flats or brackish and salty lakes along inactive drainage systems
- Salt precipitates (e.g., salt crusts), localized anomalous-looking 'burn-out' patches in the soil and vegetation associated with salt migration and accumulation

#### Springs (Types tentatively inferred from aerial photographs)

- Depression springs (where land surface locally cuts the water table or the upper surface of the zone of saturation)
- Contact springs (permeable water bearing strata overlying relatively impermeable strata usually along the sides of valleys that cut across the interface between different strata)
- Artesian springs occurring on or near the base of hillsides, valley slopes and local scarps
- Springs where the type could not be reasonably inferred from aerial photographs.

#### Artificial water features

- Wells
- Developed springs
- Reservoirs
- Canals

#### Land use

- Farming practices
- Water filled dugouts in surficial alluvial and glaciofluvial deposits

**ANNEX G***(Clause 4.2.6, Chapter 1)***SALIENT FEATURES OF GEOELECTRIC INSTRUMENTS****G-1 ENERGISATION CURRENT: d.c. vs a.c.****G-1.1 d.c. Resistivity Meter**

## Merits:

- a) Low cost
- b) More compact and portable
- c) Does not suffer from limitations of depth penetration caused by skin effect which is encountered in ac methods

## Constraints:

- a) Requires SP (spontaneous potential) balancing
- b) Needs non-polarising electrodes for potential pick up

Good enough for most of groundwater exploration work up to a depth of about 300 m depending upon subsurface resistivity distribution (geological formations)

**G-1.2 ac Resistivity Meter**

## Merits:

- a) No need for non-polarising electrodes
- b) Generally does not require SP balancing
- c) Lends more easily to sophisticated signal/noise ratio improvement techniques.

## Constraints:

- a) More Expensive for the same volt-ampere input capacity; ac instruments cost 6 to 8 times more than d.c. instruments.
- b) Unless very low frequencies are used (like 0.25 Hz) skin effect problems arise.
- c) EM (Electro Magnetic) coupling may cause some problems if sufficient care is not taken during laying out of the wires on the ground.

## Remarks :

Signal enhancement type is recommended for work in critical areas where  $\Delta V$  signal is small.

**G-2 ANALOG vs DIGITAL RESISTIVITY METERS****G-2.1 Analog Instrument**

## Merits:

- a) Low cost
- b) Simplicity

## Constraints:

- a) Fragile
- b) Lower sensitivity and accuracy
- c) Bulky size

**G-2.2 Digital Instruments**

## Merits:

- a) Compact
- b) Greater accuracy and sensitivity
- c) Sophisticated

## Constraint:

Higher cost

**G-3  $\Delta V$  AND I TYPE VERSUS DIRECT RESISTANCE READING TYPE****G-3.1  $\Delta V$  and I Type**

## Merits:

- a) Simplicity
- b) Low cost

## Constraint:

A little more tedious field calculation

**G-3.2 Direct Reading Type:**

Merits:

- a) Faster field calculation
- b) Ready amenability to some empirical methods of layer parameter estimation

Constraint:

More expensive

Remarks:

In both  $\Delta V$ -I and resistance type of instruments, one should prefer the non-balancing type with least number of scale multipliers and with reading hold facility. This type of instrument will ensure faster field operation and bring about lesser field costs by doing away with an assistant operator who is usually employed solely for noting down readings.

**G-4 DEEP RESISTIVITY METER**

Remarks:

Suitable to delineate deeper aquifer (more than 300 metres) and in desert areas where contact resistance is high.

**G-5 SALIENT SPECIFICATIONS OF GEOELECTRIC INSTRUMENTS**

**G-5.1 d.c. Resistivity Meters**

$\Delta V$  and I Type:

- Voltage measuring range : 0 to  $\pm 1\,999$  mV
- Sensitivity/ resolution : 0.1 mV up to 180 mV and 1.0 mV beyond it
- Accuracy :  $\pm 1$  digit  $\pm 1\%$
- Current measuring range : 0 to 1 999 mA
- Sensitivity/resolution : 0.1 mA up to 180 mA and 1.0 mA beyond it
- Accuracy :  $\pm 1$  digit  $\pm 1\%$
- SP balance range : 1 000 mV approximately
- Upper limit to contact : 1 M $\Omega$
- Resistance for energisation

Ground energising source : External by 5  $\times$  90 dry battery packs or d.c-d.c electronic convertor

Maximum energising : 450 V d.c.

Source

Source voltage current : 2 A d.c.

**G-5.2 Direct Resistance Measuring Type**

Same as in (G-5.1) except that there is no display of voltage.

Resistance measuring range : 0.000 1 to 20 000 $\Omega$

Sensitivity :  $\pm 0.000\,1\ \Omega$

**G-5.3 Analog Type**

Voltage measuring range : 0 to 1 018 mV

Accuracy of measurement :  $\pm 1\%$

Read out : Potential off two dials and current off a meter

Null indication : Centre zero, transistorised micro voltmeter

Maximum energising current : 2 A d.c.

Ground energising source : 90 V dry battery packs for d.c. excitation

**G-5.4 a.c. Resistivity Meters**

a) Non Stacked Type

Operational frequency : 2.5 Hz square wave generated by a highly stable crystal controlled oscillator

Voltage output : 10 to 400 volts in ten steps

Resistance measuring range : 0.000 2 to 20 000 $\Omega$  in twelve steps

Indicator : Digital display

Accuracy	: 1% ± 1 digit
50 Hz noise rejection	: 90 dB
b) Stacked Type Resistivity Meter	
Selectable current settings	: 5 to 250 mA in 7 ranges
Voltage setting	: 400 V (800 V pp)
Frequency	: 0.5 Hz
Input impedance	: 2 MΩ
Resistance range	: 0.0001 to 1999 Ω
Accuracy	: ± 1%
Data averaging	: 1,4,8,16 cycles stacking

**G-5.5 Deep Resistivity Meters (not yet Indigenously Manufactured)**

a) Transmitter	
Output power	: 10 kW maximum
Output voltage	: 500 to 3 300 V in 10 steps
Output current	: 20 A maximum
Output current stability	: ± 0.1 %
Current reading resolution	: 1 mA on fine range
Time domain cycle	: T:T:T:T on:off : on:off automatic
Pulse duration in s	: T=1,2,4,8,16 or 32
b) Receiver	
Voltage Measuring	: 30 μV to 30 V
Display	: 3½ digit display
Averaging time	: 3 cycles