



# **DESIGN OF TUBEWELLS AND GRAVEL PACK**

---

# Introduction

- ✓ Proper design of water wells (tubewells and open wells) is essential in order to obtain optimum quantity of groundwater economically from a given aquifer system.
- ✓ The choice of open wells or borewells (tubewells) mainly depends on the economic condition of users, depth to groundwater availability and the quantity of water required.
- ✓ However, the availability of groundwater in a region depends on several factors such as geologic setting, geomorphology, rainfall, climate, topography, soil, drainage density, land use/land cover and vadose zone condition.
- ✓ Therefore, proper groundwater exploration and hydrogeologic investigation are pre-requisite to the design of water wells.

## **Major steps involved in the design of tubewells are:**

- ✓ Selection of suitable size of the well and casing;
- ✓ Length and location of the screen, including slot size and shape, and percentage of opening;
- ✓ Selection of casing and screen material, and
- ✓ Design of gravel pack (if gravel pack is necessary).

# Well Diameter

- The size of a well needs to be carefully selected because it considerably affects the cost of well construction.
- It should be large enough to accommodate the pump used for groundwater withdrawal with a proper clearance (at least 5 cm) for installation and efficient operation.

# Well Depth

- The depth of a pumping well depends on the depth at which aquifer layers exist and the number of aquifers to be tapped; this information could be obtained from the well logs (also called 'lithological logs') of an area.
- Usually, a pumping well is drilled up to the bottom of the aquifer so as to obtain greater well yield.
- If multiple aquifer layers exist in an area and money is not a constraint, pumping wells are drilled to penetrate two or more aquifer layers so that large well yield can be obtained for a longer time period.
- The poor-quality aquifer, if available, is backfilled or sealed in order to avoid the upward migration of the poor-quality groundwater when the well is pumped

# Design of Well Screen

- The design of a well screen (also known as 'strainer') involves the determination of **screen length, location of the screen, percentage open area, size and shape of openings (slots), screen diameter, and the selection of screen material.**

## Location and Length of the Screen

- The length of a well screen is selected in relation to the aquifer thickness, available drawdown and stratification of the aquifer. In homogeneous confined aquifers, about 70 to 80% of the aquifer thickness is screened .
- The screen should best be positioned centrally at an equal distance between the top and bottom of the aquifer. In the case of heterogeneous confined and unconfined aquifers, it is better to screen the most permeable strata.
- On the other hand, in the case of homogeneous unconfined aquifers, the well screen is best positioned in the bottom portion of the aquifer.

- 
- Selection of screen length is actually a compromise between two factors viz., specific capacity of the well and drawdown in the well.
  - A higher specific capacity can be obtained by using as long a screen as possible, while more drawdown results by using short screens. The theory and experience have shown that screening the bottom one third of the aquifer provides the optimum design of a screen.

# Size and Shape of Slots

- The size and shape of the openings (slots) in the screen depend on the gradation, and the size and shape of the aquifer material so as to avoid entering of fine particles into the screen openings and to ensure that all the fine particles around the screen are washed out to improve the permeability of the aquifer material.
- For naturally developed wells, the size of the opening is selected as 40 to 70% of the size of the aquifer material.
- If the opening size selected on this criterion is smaller than 0.75 mm, then the use of an artificial gravel pack becomes essential.

# Screen Diameter

- After the length of the screen and the slot size has been selected, the screen diameter should be selected.
- Well screens (strainers) are available in a range of diameters. Suitable screen diameter is selected based on the desired yield of the well and the thickness of the aquifer.
- Recommended minimum diameters for well screens and casings are summarized in **Table**.
- Also, the entrance velocity near the well screen should not exceed 3 to 6 cm/s in order to avoid incrustation and corrosion and minimize friction losses.

Sl. No.	Well Yield (m <sup>3</sup> /day)	Nominal Pump Chamber Casing Diameter (cm)	Surface Casing Diameter (cm)		Nominal Screen Diameter (cm)
			Naturally Developed Wells	Gravel-Packed Wells	
1	<270	15	25	45	5
2	270 - 680	20	30	50	10
3	680 - 1900	25	35	55	15
4	1900 - 4400	30	40	60	20
5	4400 - 7600	95	45	65	25
6	7600 - 14000	40	50	70	30

Table 16.3. Optimum entrance velocity of water through well screens (Source: Walton, 1962)

Sl. No.	Aquifer Hydraulic Conductivity (m/day)	Optimum Screen Entrance Velocity (m/min)
1	>250	3.7
2	250	3.4
3	200	3.0
4	160	2.7
5	120	2.4
6	100	2.1
7	80	1.8
8	60	1.5
9	40	1.2
10	20	0.9
11	<20	0.6

# Screen Material

- The selection of screen material depends on the diameter and depth of the well, the type of aquifer layer, and the chemical composition of aquifer materials which dictates the quality of groundwater.
- The mineral content of the water, presence of bacterial slimes and strength requirements are important factors, which influence the selection of screen material.
- The screen material should be resistant to incrustation and corrosion, and should have enough strength to withstand the column load and collapse pressure.
- The principal indicators of corrosive groundwater are: low pH, presence of dissolved oxygen,  $\text{CO}_2 > 50 \text{ ppm}$ , and  $\text{Cl} > 500$

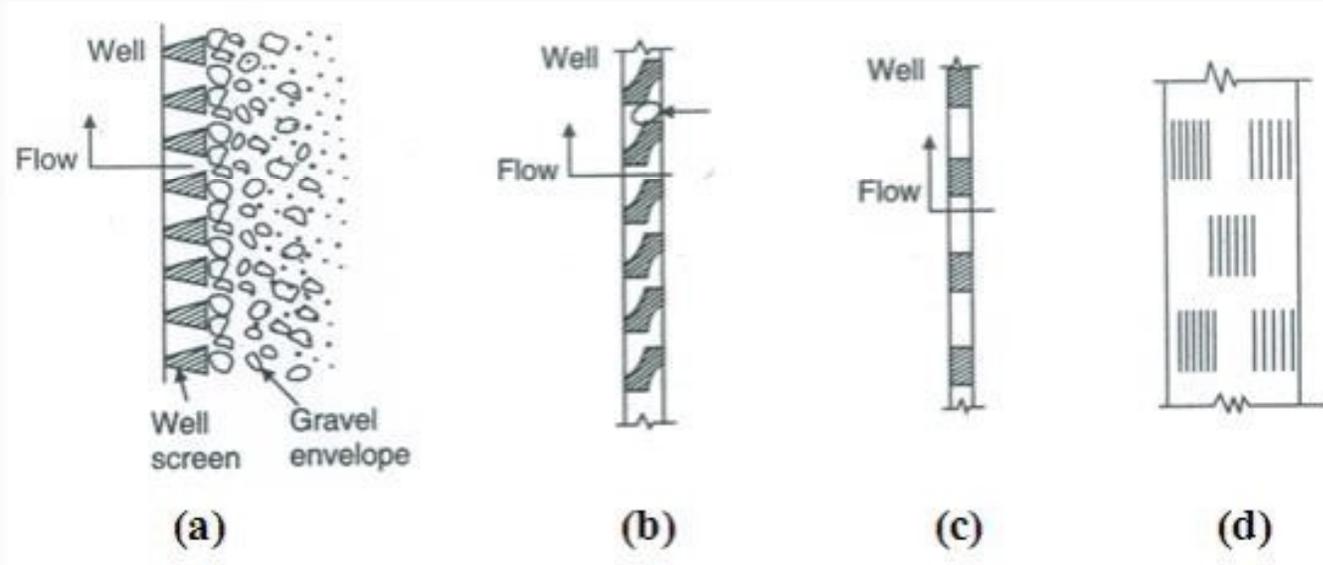
- 
- The principal indicators of incrusting groundwater are: total hardness > 330 ppm, total alkalinity > 300 ppm, iron content > 2 ppm, and pH > 8.
  - Slime producing bacteria are often removed by chlorine treatment.
  - This is followed by acid treatment to redissolve the precipitated iron and manganese.

- 
- As far as the choice of the screen material is concerned, steel has good strength, but it is not corrosion resistant.
  - In contrast, brass has fair to good resistance to corrosion, but it has less strength than the steel.
  - However, the strength of a well-made brass screen is adequate in most situations.
  - Stainless steel has excellent strength and is highly resistant to most corrosive conditions.
  - Well screens of corrosion resistant alloys such as Everdur metal, type 304 stainless steel and silicon red brass could be used for permanent installations.
  - Different metals used for fabricating screens and their suitability in terms of resistance to corrosion are presented in Table.

# Type of Screens

- The types of well screens are mainly decided based on the shape of screen openings (slots). Some of the commonly used screen types are shown in (a, b, c, d).
- The V-shape continuous-slot type of well screen is fabricated by winding cold-drawn wire, approximately triangular in cross-section, spirally around a circular array of longitudinal rods [Fig.(a)].
- The V-shaped openings facilitate the fine particles to move into the well during development without clogging them. This type has the maximum percentage of open area per unit length of the screen, and the area of openings can be varied by adjusting the spacing of the wires wrapped.

- These screens are usually made of galvanized iron (GI), steel, stainless steel and various types of brass.



Types of commonly used well screens: (a) V-shape continuous slot screen, (b) Louver-type screen, (c) Rectangular slot screen, and (d) Pipe-base well screen or Metallic filter point.

- The Louver-type of screen has openings in the form of shutters [fig(b)], which are susceptible to be blocked by the fine particles during well development.
- Hence, this type of screen is most suitable for gravel-packed wells. The rectangular slot screen or the slotted pipe screen [fig (c)] is fabricated by cutting slots, vertical or horizontal, with a sharp saw, oxyacetylene torch, or by punching with a chisel and die or casing perforator.
- Some of the limitations of the slotted type well screens are wide spacing from the strength viewpoint, resulting in a low percentage of open area, lack of continuity and uniform size of the openings; the perforations made in the steel pipe may be more readily subject to corrosion at the jagged edges and surfaces, and the chance of blockage of such openings is high.

- 
- This type of screen is least expensive.
  - These days, slotted PVC pipes are widely used as screens, because especially in developing nations because they are light, cost effective, easy to handle, and free from corrosion.
  - The use of slotted PVC pipes is generally limited to small diameter wells because of their relatively low strength and difficulty in providing proper fittings.

- Furthermore, the pipe-base well screen or metallic filter point is made by using a perforated steel pipe [Fig. (d)].
- A wire mesh is wrapped around the perforated pipe and is in turn is covered by a brass perforated steel. The percentage of open area in this type is normally low and the perforations are blocked by incrustation.
- This type of screen is relatively inefficient. In developing countries (including India), the coir-rope screen is sometimes used as an economical substitute for other types of screens.
- Coir rope is wrapped tightly around a circular array of steel flat, rods or bamboo strips. The life of the coir ranges from 7 to 8 years and can be increased by treating the coir with cashew shell oil

- The best type of screen opening is the V-shaped slot that widens towards the inside of the screen, i.e., openings are bevelled inside.
- A major factor in controlling head loss through a perforated well section is the percentage of open area. For practical purposes, a minimum open area of 15% is desirable, which is easily obtained with many commercial (manufactured) screens but not with pre-perforated casings .
- Therefore, manufactured screens are preferred to pre-perforated casings because of larger open area and the ability to tailor opening sizes to aquifer conditions.

---

# **Design of Gravel Pack**

# Natural Gravel Pack

- In many situations, the grain-size distribution of aquifer material is such that a properly selected well screen allows finer particles to enter the well, and to be removed during well development.
- Thus, after the development of the well, coarser particles are retained outside the well screen and form a permeable envelope around the well screen which is known as a **'natural gravel pack'** and **the well is called a naturally developed well.**

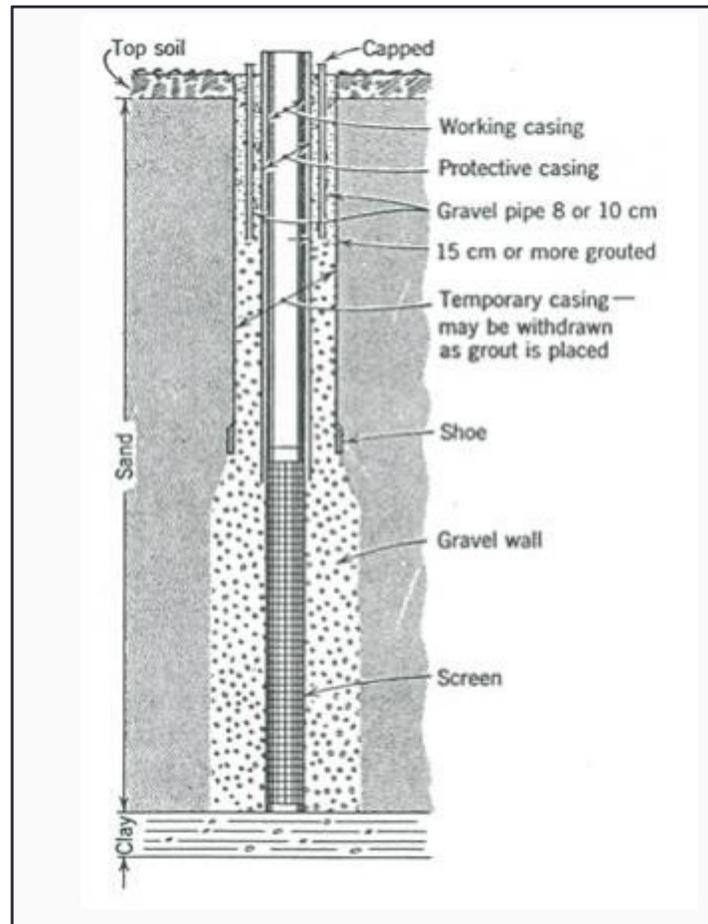
$$\left( C_u = \frac{D_{60}}{D_{10}} \right)$$

- If the uniformity coefficient  $C_u$  of an aquifer material for a naturally developed well (without an artificial gravel pack) is  $\leq 5$ , the selected slot size should retain 40 to 50% of the aquifer material.
- However, if the uniformity coefficient ( $C_u$ ) is greater than 5, the slot size should be selected such that it should retain 30 to 50% of the aquifer material .

# Artificial Gravel Pack

- A gravel-packed well is the well having an artificially placed gravel envelope around the well screen . Salient advantages of the artificial gravel pack are :
  - (i) it stabilizes the aquifer tapped by the well,
  - (ii) it avoids/minimizes sand pumping,
  - (iii) it allows to use a large screen slot with a maximum open area, and
  - (iv) it provides a zone of high permeability surrounding the well screen, which increases the well radius (known as 'effective radius' of the well) and well yield.
- When a well screen of a pumping well is to be surrounded by an artificial gravel pack, the size of the screen openings is decided based on the size of the gravel used for gravel packing.

# Vertical cross-section of a gravel-packed well.



# Artificial gravel pack

- Artificial gravel pack is required when the aquifer material is homogeneous with a uniformity coefficient ( $C_u$ ) of less than 3 and an effective grain size ( $D_{10}$ ) of less than 0.25 mm .
- The pack-aquifer ratio (ratio of the 30 or 50% size of the gravel-pack material to 30 or 50% size of the aquifer material) should be 4:1 if the aquifer material is fine and uniform.
- However, if aquifer material is coarse and non-uniform, the pack-aquifer ratio should be 6:1.
- The gravel-pack material should have a uniformity coefficient ( $C_u$ ) of less than 2.5.
- The design procedure for selecting the gravel material is to determine the point  $D_{30}$  of the gravel pack which is equal to 4 to 6 times the  $D_{30}$  of the aquifer material obtained from the sieve analysis of the aquifer material samples and then drawing a smooth curve through this point (corresponding to  $D_{30}$  of the gravel pack) representing a material with a uniformity coefficient of 2.5 or less.

- This is the gradation of the gravel pack to be used .
- The slot size of the well screen is selected as  $D_{10}$  of the gravel-pack material to avoid segregation of fine particles near the screen openings.
- The width of screen slots ranges from 1.5 to 4 mm and the length ranges from 5 to 12.5 cm.
- A pack-aquifer ratio of 5 (i.e., ratio of 50% size of the gravel-pack material and 50% size of the aquifer material) has been successfully used in water wells

# Criteria for the selection of gravel pack material

Sl. No.	Uniformity Coefficient of Aquifer ( $C_u$ )	Gravel Pack Criteria	Screen Slot Size
1	$<2.5$	<p>(a) <math>C_u</math> between 1 and 2.5 with the 50% size not greater than 6 times the 50% size of the aquifer.</p> <p>(b) If (a) is not available, <math>C_u</math> between 2.5 and 5 with 50% size not greater than 9 times the 50% size of the aquifer.</p>	£ 10% passing size of the gravel pack
2	2.5-5	<p>(a) <math>C_u</math> between 1 and 2.5 with the 50% size not greater than 9 times the 50% size of the formation.</p> <p>(b) If (a) is not available, <math>C_u</math> between 2.5 and 5 with 50% size not greater than 12 times the 50% size of the aquifer.</p>	£ 10% passing size of the gravel pack

# Criteria for the selection of gravel pack material

3	>5	<p>(a) Multiply the 30% passing size of the aquifer by 6 and 9 and locate the points on the grain-size distribution graph on the same horizontal line.</p> <p>(b) Through these points draw two parallel lines representing materials with <math>C_u \leq 2.5</math>.</p> <p>(c) Select gravel pack material that falls between the two lines.</p>	<p><math>\leq 10\%</math> passing size of the gravel pack</p>
---	----	--	---