TECHNICAL NOTE 008

# Measurement of Groundwater Table & Pore Water Pressure In Deep Excavations

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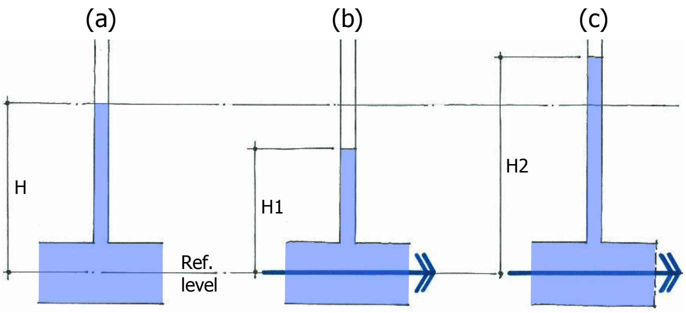
**Keywords**
Perforated standpipe, standpipe piezometer, groundwater table, groundwater movement, excess pore water pressure, hydraulic instability

**Synopsis**
In deep excavations, it is imperative to understand the effectiveness of water cut-off provided by the cofferdam walls and/or toe grouting, and also the groundwater movement and pore water pressure both inside and outside the cofferdam. The latter is of particular importance because the build-up of excess pore water pressure on the passive side (excavation side) of the cofferdam walls could lead to hydraulic instability of the cofferdam owing to piping.

## 1.0 Introduction

Prior to discussing the measurement of groundwater table, pore water pressure, and its relevance to deep excavation, it is perhaps useful to look at the following water flow scenarios and the respective water head measured by a manometer.

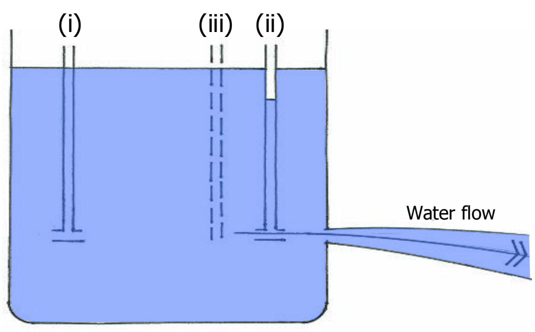



Case (a) – No Water Flow. Water is in a static condition. The water head **H** with respect to an arbitrary reference level is called the <u>Hydrostatic Head</u>.

Case (b) – With Water Flow. When water flows at certain velocity, there will be a corresponding decrease in water pressure. This will be reflected by the water head **H1**, which is <u>lower</u> than the hydrostatic head.

Case (c) – With Water Flow and Outlet Blockage. Water flows at certain velocity but the flow is slowed down by some blockage at the outlet. This will lead to a build-up of water pressure, and the water head **H2** will become <u>higher</u> than the hydrostatic head.

Now that if a manometer is placed inside a water tank (with an orifice), the following scenarios can be observed.

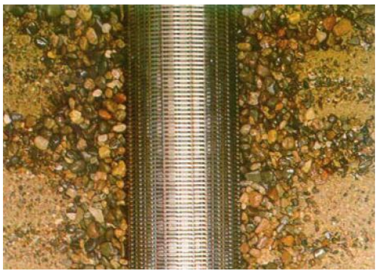



In location (i), which is far from the orifice, the water flow velocity is relatively slow and water is in a near-static condition. The water level measured by the manometer will practically be the same as the water level in the tank. Whereas in location (ii), which is adjacent to the orifice, water flows at much higher velocity. The water level so measured in the manometer will be lower than that in the tank, representing the decrease in water pressure near the orifice.

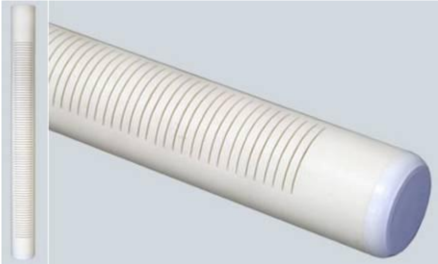
If a <u>perforated</u> pipe is placed in location (iii), albeit close to the orifice, the water level inside the perforated pipe will still be the same as that in the tank. This is because the tank water is free to enter and/or leave the perforated pipe along its entire length, and hence any drop in the water level inside the pipe will be 'recharged' immediately by surrounding water.

## 2.0 Perforated Standpipe & Piezometer

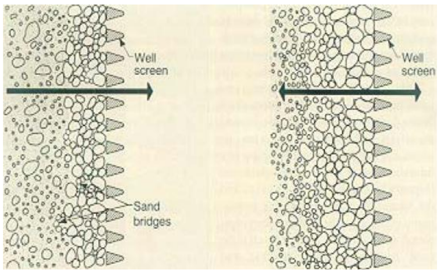
Groundwater is water located beneath the earth surface in soil pore spaces. The pressure of water in the soil pore spaces is called pore water pressure. The groundwater table and the pore water pressure are measured by two different types of instrument, ie, a perforated standpipe and a piezometer. Depending on the types, these two instruments could be very similar looking. They are usually placed together in the same borehole for cost-effective installation, noting the borehole itself is a high cost component of an instrument installation.



Idealised arrangement of gravel around the filter tip for increasing porosity and hydraulic connection



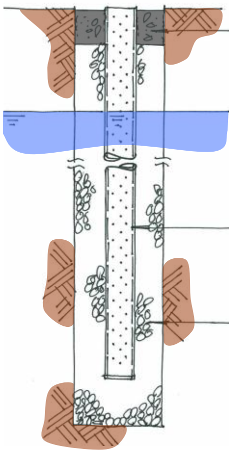
Filter tip of standpipe piezometer




Effective development of piezometer by pumping water under pressure through the filters

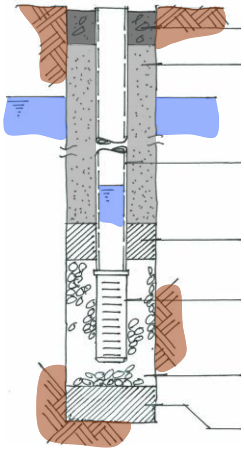
**2.1** Perforated Standpipe

A perforated standpipe installed in a borehole is used for measuring the depth of the free groundwater table below the ground surface. The standpipe is usually formed using a 20mm diameter PVC pipe, and the perforation is provided by 3mm diameter holes at 15mm centres (or other similar configuration). The perforated standpipe should be wrapped by 2 layers of nylon mesh and surrounded by gravel in the borehole to prevent ingress of fine materials into the pipe body that might create blockage. Given the perforation, groundwater is free to enter and/or leave the standpipe. Thus, the water level inside the standpipe should give good indication of the free groundwater level, depending on the permeability of the surrounding soil. In essence, a perforated standpipe is installed to displace the soil so that the water level can be measured by a suitable device such as a dip meter. An indicative arrangement of a perforated standpipe is shown in the figure below (vented cap and protection metal cover not shown).




**2.2** Piezometer

A piezometer is used for monitoring piezometric water levels / pore water pressure. The simplest form of a piezometer is a standpipe piezometer, which is installed in a borehole, consisting of a filter tip joined to a solid (ie, not perforated) riser pipe. There are other types such as vibrating wire (VW) piezometers. The filter tip is placed in a gravel zone and a bentonite seal is placed above and below the gravel to isolate the pore water pressure at the tip. The annular space between the riser pipe and the borehole is backfilled to the surface with grout to prevent unwanted vertical migration of water. The piezometric water level in the piezometer indicates the pore water pressure at the level of the filter tip. Several tips can be installed in one borehole, enabling measurement of pore water pressure profiles. An indicative arrangement of a standpipe piezometer is shown in the figure below.




*2.2.1 Development of Piezometer*

Development of a piezometer (not feasible with many piezometer types) is aimed at ensuring an efficient hydraulic connection between pore water and the piezometer. The development is very crucial since the drilling mud, which inevitably sticks to the walls and inhibits the hydraulic connection between pore water and the piezometer. The development should completely remove the sticking mud and also the fines. Under-developed piezometers will fail to provide the true information of the pore water pressure being monitored. The development, for instance, can be carried out through air compressor by alternately surging and pumping with air. The air should be injected into the piezometer to lift the water. As the water level reaches the top of the riser pipe, air supply should be shut off allowing the aerated water column to fall.

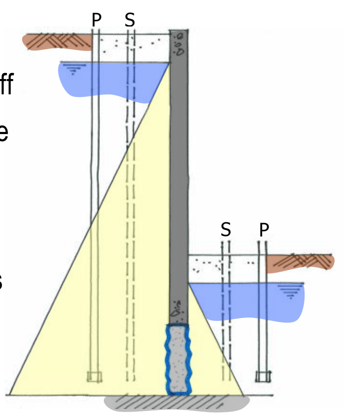
*2.2.2 Field Notes on Piezometer Installation*

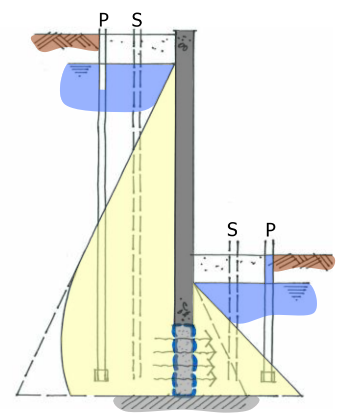
It is good practice to prepare field notes on installation of piezometers. The notes could be very simple in format, recording the following information:
• Start and stop times for drilling • Names of field personnel • Drill cuttings details - colour, texture, shape,

(i) 100% Effective Water Cut-Off

Groundwater inside and outside cofferdam is in hydrostatic condition, ie, no groundwater movement;

Pore water pressure at depth is the same as the hydrostatic pressure




(ii) Ineffective Water Cut-Off

Groundwater flows into cofferdam owing to difference in hydrostatic head;

Pore water pressure outside cofferdam drops, and inside rises (excess pore water pressure)

mineral assemblage, rock type • Diameter of drill bits • Depth at which water encountered and discharge variations with depth • Drilling rate • Casing depth • Drill completion depth • Screen position • Gravel pack position • Well completion depth • Water bearing zones • Development time • Discharge after development • Depth to water upon completion

The above factual information would be very useful when one encounters anomalies during excavation/dewatering.

## 3.0 Groundwater Flow & Pore Water Pressure

In deep excavations, water cut-off to a sufficient depth below the final excavation level is required to prevent significant ingress of groundwater into the cofferdam. The water cut-off could either be provided by the cofferdam wall itself or by means of toe grouting. Varying degrees of effectiveness of the water cut-off gives rise to different patterns of groundwater movement and pore water pressure distribution as discussed below.

### 3.1 100% Effective Water Cut-Off

For the purpose of this discussion, it is assumed possible to achieve 100% effective water cut-off. This being the case, groundwater inside and outside the cofferdam is completely disconnected, and is in a hydrostatic condition. The difference in the hydrostatic head cannot cause groundwater flow through the cofferdam walls and/or toe grouting.

In this condition, the water pressure distribution depends solely on the hydrostatic heads as shown in the simplified water pressure diagram above. If a perforated standpipe (S) and a piezometer (P) are placed both inside and outside the cofferdam, the water level inside the standpipes simply represents the level of the free groundwater table, whereas the water level inside the piezometers represents the pore water pressure at the depth of the piezometer tip, which in this case is the same as the hydrostatic water pressure.

### 3.2 Ineffective Water Cut-Off

In the case where the water cut-off is not 100% effective, there will be a flow of groundwater into the cofferdam. Such groundwater flow will continue until the water level on both sides of the cofferdam wall is the same. Outside the cofferdam, the pore water pressure will start to decrease owing to the groundwater movement at depth. Inside the cofferdam, owing to the ingress of groundwater, the water table will start to rise (if no dewatering). If the water table inside the cofferdam is not rising owing to, for example, the presence of less permeable materials blocking the rise, the pore water pressure in the soil will start to build up as shown in the simplified water pressure diagram above.

In the perforated standpipe (S) outside the cofferdam, the water level measured represents the free groundwater table. Theoretically, a drop in the groundwater table will be seen. However, if the cofferdam is close to an environment where natural groundwater recharge is quick, it would be difficult for one to notice any substantial drop in the groundwater table. In the piezometer (P) outside the cofferdam, a drop in the piezometric water level will be seen, representing the drop in the pore water pressure caused by groundwater flow at depth.

In the perforated standpipe (S) inside the cofferdam, again the water level measured represents the free groundwater table. In the case where groundwater ingress is substantial, a rise in the water level will be seen. In the piezometer (P), depending on the magnitude of the pore water pressure, it would be possible to see the piezometric water level rising above the free groundwater table. This is the so-called excess hydrostatic water pressure (or excess pore water pressure). It is crucial to reduce the excess pore water pressure, if it exists, by effective means of dewatering to prevent hydraulic instability at the toe of the cofferdam walls.

**NB –** Excess pore water pressure tends to lift soil particles. If the upward water pressure is high enough the effective stresses in the soil disappear, no frictional strength can be mobilised and the soil behaves as a fluid. This is the so called quick or quicksand condition and is associated with piping instabilities around excavations.

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