Performance Monitoring Of Dams through Piezometers - A Case Study

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ABSTRACT- This paper presents development of the pore-pressure measuring device as a tool in performance monitoring for study of behavior of dam. The installation of test apparatus involves numerous innovations that have been developed over the years, and the methods for such installation continue to be improved with each project. The emphasis in this presentation is on the development of the piezometer device. Dams impound large amount of water, and its failure may be catastrophic leading to large scale destruction of property and loss of human lives. In such case, instrumentation plays a vital role as any change in the structural behavior can be established well in time based on the data observed by the instruments and remedial measures can be taken up so as to avoid failure of the structure. Adequate instrumentation in earth fills and their foundations provide significant quantitative data indicating the magnitude and distribution of pore pressures and their variations with time and other patterns of seepage, zones of potential piping, proper functioning of the filter media and effectiveness of under seepage control measures.

Index Terms: - Annulus, Pore Pressure, Pneumatic, Hydraulic, Electric etc.

1. INTRODUCTION

Water pressure is a general term that includes pressure within a reservoir or other body of water, pore pressure, and uplift pressure. Water pressure within soils and within concrete is commonly referred to as pore pressure. Water pressure acting upward on the base of concrete dams is commonly known as uplift pressure.

Water pressure usually varies from headwater level on the upstream side of a dam to tailwater level, ground water level, or atmospheric pressure on the downstream side of a dam. The headwater, tailwater, and varying pressure across the dam produce forces on a dam that must be properly accounted for in stability analyses.

Water level is commonly measured with staff gages, float-type water level gages, and ultrasonic sensors. Water pressure is commonly measured with bubblers, observation wells, and several types of piezometers.

Piezometers are used to measure pore water pressure i.e. piezometric level in the ground- the soil, earth/rock fills, foundations and concrete structures. It provides significant quantitative data on the magnitude and distribution of pore pressure and its variations with time. It also helps in evaluating the pattern of seepage, zones of potential piping and the effectiveness of seepage control measures undertaken.

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Proper evaluation of pore pressure helps in monitoring the behaviour after construction and indicates potentially dangerous conditions that may adversely affect the stability of the structure, its foundation and appurtenant. It also provides basic data for design improvement that will promote safer and more economical design and construction.

2. PURPOSE FOR MEASURING WATER PRESSURE

Under an externally applied stress, soil grains are forced into more intimate contact, and the soil mass volume decreases. Because soil grain volume cannot be changed appreciably, this volume change must take place primarily in the soil voids or pores. If these pores are completely filled with water, their volume cannot be changed unless some water is drained from the soil mass, because water is considered incompressible. If drainage is prevented or impeded, pore water pressure will develop in the pore water opposing the externally applied stress. Pore water pressures are a controlling factor on stability during construction.

Excessive pore-water pressures in either the embankment or in the foundation directly affect the stability of the dam. Devices used to measure pressure include various types of piezometers and total pressure cells. Piezometers are commonly used for measuring water pressures that may be induced by embankment loading during construction of a dam, also used to measure pore water pressure in the soil, earth/rockfills, foundations and concrete structures.

Piezometers are also used to measure the water pressure and phreatic surface caused by seepage in relatively pervious portions of embankments and foundations. Such measurements can be critical because of possible piping or other seepage-induced instability conditions, such as the presence of excess hydrostatic uplift pressures. Piezometers may be designed to operate either as a closed system or as an open system. Total pressure cells are used to monitor total static pressure acting on a plane surface. These cells help define the magnitude of major stresses in earth embankments and against pipelines, dam control structures, building foundations, and retaining walls. It provides significant quantitative data on the magnitude and distribution of pore pressure and its variations with time. This also helps in evaluating the pattern of seepage, zones of potential piping and the effectiveness of seepage control measures undertaken.

3. TYPES OF PRESSURE MEASURING DEVICES & PIEZOMETERS

Many styles and types of pressure measuring devices have become available over the years. The open system devices include the PTP (porous-tube piezometer), SPP (slotted-pipe piezometers), and OW (observation well).

The closed system devices include the HPI (hydrostatic pressure indicator), hydraulic TTP (twin-tube piezometer), PP (pneumatic piezometer), VWP (vibrating-wire piezometer), pneumatic TPC (total pressure cell), and other electrically operating piezometers. The advantages and limitations of various piezometer types are indicated in Table 1. Frequency of taking periodical readings with different types of piezometers is suggested in Table 2.

3.1 Staff Gauges/ Water Level Gages

Staff gages are the simplest method for measuring reservoir and tail water levels. Staff gages are reliable and durable. For automated monitoring, a float and recorder, ultrasonic sensor, bubbler, or one of the other instruments is necessary.

Water level gages can be used to measure flow in rivers (e.g. minimum instream flow), when the relationship between river flow and river stage is known. Stream bed erosion or sedimentation can change the calibration and cause inaccurate measurements. Water level gages used for flow measurements in channels with moveable beds should be periodically re-calibrated.

3.2 Observation Wells

Observation wells are usually vertical pipes with a slotted section at the bottom or a tube with a porous tip at the bottom. They are typically installed in boreholes with a seal at the surface to prevent surface water from entering the borehole. The depth to the water level is measured by lowering an electronic probe or weighted tape into the pipe.

Observation wells are appropriate only in a uniform, pervious material. In a stratified material, observation wells create a hydraulic connection between strata. As a result, the water level in the well is an ambiguous combination of the water pressure and permeability in all strata intersected by the borehole. Observation well data may lead to erroneous conclusions regarding actual water pressures within the dam and foundation.

3.3 Open Tube or Standpipe Piezometers/ Open Chamber Piezometer (OCP)/ Porous Chamber Piezometer (PTP)

Open tube piezometers are the simplest instrument for measuring pore water pressures in ground. These are observation wells with subsurface seals that isolate the strata to be measured. These are also known as Casagrande-type piezometers and, in concrete dams, as pore pressure cells.

This piezometer is a small (usually 19mm) diameter plastic pipe with a porous section at the bottom. The pipe is installed inside a borehole and the porous section is positioned at the depth where the pore water pressure is to be measured. The annulus between the porous filter and the borehole is filled with sand, the top and bottom surfaces of the sand are sealed with bentonite and the rest of the borehole is filled with a cement/bentonite grout. Riser standpipe joints should be watertight to prevent leakage into or out of the pipe, which could change the water level in the pipe. The top of the standpipe should be vented and the inside diameter should be greater than about 8 mm (0.3 inch) to be self de-airing. Figure 1 shows a typical open type piezometer. The pressure of the ground water pushes water into and up the standpipe until the level of water inside the standpipe (h) is equivalent to the pore water pressure in the ground at the elevation of the porous filter. Readings are obtained with a water level indicator (Fig. 2).

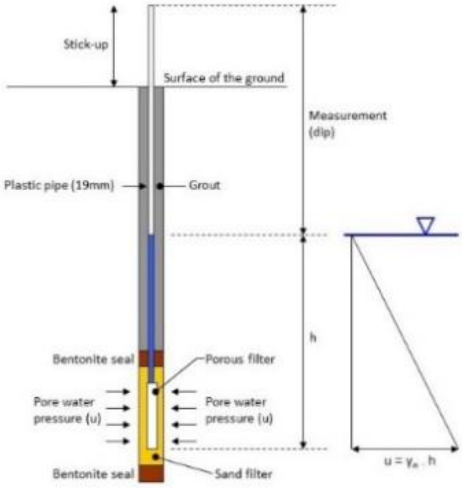

Fig 1-Open Tube Piezometer

Fig 2-Water Level Indicator/Sounder

3.4 Closed Standpipe Piezometers

Closed standpipe piezometers are identical to open standpipe piezometers, except that the water level being measured is above the top of the standpipe (artesian condition) and the pressure is measured with a pressure gage (or pneumatic, or vibrating wire piezometer) fitted to the top of the pipe. In concrete dams they are also known as pore pressure cells. Closed standpipe piezometers installed in concrete dams during construction usually have riser pipes that are not vertical, but rather routed to a gallery for ease of monitoring. Provisions for venting gas trapped inside of the riser pipe are often made, but are not required on most common sizes of riser pipes.

3.5 Twin-tube Hydraulic Piezometers

Twin-tube hydraulic piezometers (as shown in Fig. 3) are similar in principal to closed standpipe piezometers. These consist of a porous filter enclosing a reservoir of water, which is separated from a pressure gauge by two flexible, water filled tubes. The tubes are used to circulate water through the system, removing air and ensuring that the reservoir remains full of water. The tubes are extended more or less horizontally in trenches through the fill or foundation to a readout point. Two tubes are used to allow the system to be flushed to remove trapped air. Water pressure is calculated using the average pressure head of the gages on each tube. Geotechnical Observations' flushable piezometer is a hydraulic piezometer that can measure positive and negative pore water pressures.

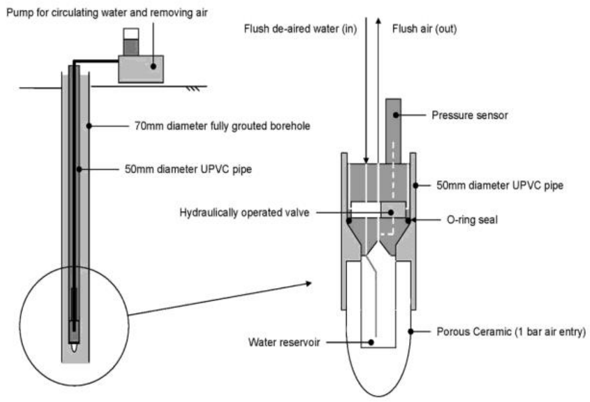

Fig 3-Hydraulic Piezometer

3.6 Pneumatic Piezometers

Pneumatic piezometers consist of a porous filter connected to two tubes which have a flexible diaphragm between. The diaphragm is held closed by the external water pressure. The end of one of the tubes is attached to a dry air supply and a pressure gage. Air pressure is applied until it exceeds the external water pressure acting on the diaphragm, which deflects the diaphragm and allows the air to vent through the other tube. The air supply is shut off, and the external water pressure and internal pressure equalize allowing the diaphragm to close. The residual internal air pressure is taken as the external water pressure. Alternatively, the water pressure can be taken as the air pressure required to maintain a constant flow through the tubes. Some constant flow types use a third tube connected to a pressure gage to measure pressure at the diaphragm rather than at the inlet to reduce potential errors and eliminate the need for individual calibration curves. Pneumatic piezometer consists of a pneumatic pressure transducer and pneumatic tubing. It can be installed in a borehole, embedded in fill, or suspended in a standpipe. Readings are obtained with a pneumatic indicator.

3.7 Vibrating Wire Piezometers

Vibrating wire Piezometer (as shown typically in Fig 4 & 5) is high precision instrument, which have been designed to measure pore water pressures. Its advantages are long lead lengths and very fast response time to changes in pore water pressure. It converts water pressure to frequency signal by VW technology. It's range is 2 to 100 Kg/cm2.

The piezometer is inserted into a borehole and the annulus between the porous filter and the borehole is filled with either sand or cement/bentonite grout. Readings are obtained with a portable reader/ readout unit /logger (Fig 6).

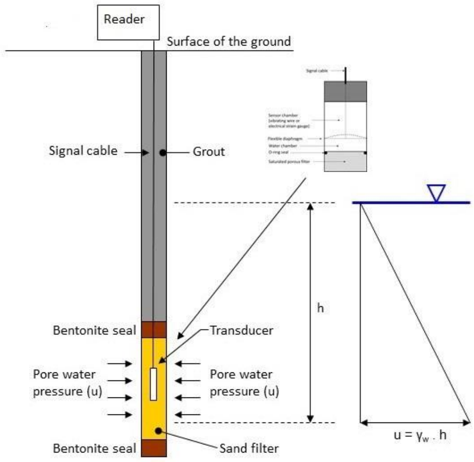

Fig 4-Vibrating Wire Piezometer

Fig 5-Vibrating Wire Piezometer in CSMRS

Fig 6- Vibrating Wire Read out unit

3.7.1 Working principle of a VW piezometer

The vibrating wire Piezometer contains a steel wire stretched between a fixed anchorage and a sensitive stainless steel diaphragm. One end of the wire is anchored to ensure excellent long-term stability and the other end fixed to a diaphragm that deflects in some proportion to applied pressure. An electromagnetic coil assembly, located close to the wire, is used to pluck the wire and also to sense and convert the subsequent wire vibrations into an electrical AC output whose frequency is related to the tension of the wire. Change in pore water pressure cause the diaphragm to deflect, thus altering the tension of the wire and consequently the frequency of the output (pore pressure is proportional to frequency). This frequency is measured using a Digital Readout Unit and readings can be displayed in units of pressure. Since only frequency is measured, changes in the length, resistance or temperature of the connecting cable have a minimal effect on the signal (as assumed). The wire resonates at a frequency 'f', which can be determined as follows:

$f = \{[\sigma g/\rho]^{1/2}\}/ 2l$ Hz

Where σ = tension of the wire
g = gravitational constant
ρ = density of wire
l = length of wire

The resonant frequency, with which wire vibrates, induces an alternating current in the coil magnet.

The pore pressure is proportional to the square of the frequency and the readout logger (data logger) is able to display this directly in engineering units.

TABLE- 1
ADVANTAGES AND LIMITATIONS OF COMMON WATER LEVEL AND PRESSURE INSTRUMENTS[8]

TYPE	ADVANTAGES	LIMITATIONS
Staff Gage	Simple device, inexpensive, reliable.	Cannot be automated.
Float-Type Water Level Gage	Simple device, inexpensive, reliable. Easily automated.	Requires readout device. Sensor must be in water. Must be protected from ice.
Ultrasonic Water Level Sensor	Simple device, inexpensive, reliable. Sensor does not touch water. Easily automated.	Requires readout device. Must be corrected for air temperature. Debris, foam, and ice can cause false readings.
Bubbler	Simple device, inexpensive, reliable. Easily automated.	Requires readout device. Sensor must be submerged in water.
Observation Well	Simple device, inexpensive. Easily automated.	Applicable only in uniform materials, not reliable for stratified materials. Long lag time in impervious soils.
Open Standpipe Piezometer	Simple device, inexpensive, reliable. Simple to monitor and maintain. Standard against which all other piezometers are measured. Can be subjected to rising or falling head tests to confirm function. Easily automated.	Long lag time in impervious soils. Potential freezing problems if water near surface. Porous tips can clog due to repeated inflow and outflow. Not appropriate for artesian conditions where phreatic surface extends significantly above top of pipe. Interferes with material placement and compaction during construction. Can be damaged by consolidation of soil around standpipe.
Closed Standpipe Piezometer	Same as for open standpipe piezometers.	Same as open standpipe piezometer but appropriate for artesian conditions.
Twin-tube Hydraulic Piezometer	Simple device, moderately expensive, reliable, long experience record. Short lag time. Minimal interference with construction operations.	Cannot be installed in a borehole, therefore, generally not appropriate for retrofitting. Readout location must be protected from freezing. Moderately complex monitoring and maintenance. Periodic de-airing required. Elevation of tubing and of readout must be less than 10 to 15 feet above piezometric elevation. Can be automated, but moderately complex.
Pneumatic Piezometer	Moderately simple transducer, moderately expensive, reliable, fairly long experience record. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems.	Moderately complex monitoring and maintenance. Dry air and readout device required. Can be automated, but not over long distances. Sensitive to barometric pressure. Automation is complex. Moderately expensive readout.
Vibrating Wire Piezometer	Moderately complex transducer. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Frequency output signal permits transmission over long distances. Easily automated.	Lightning protection required. Expensive transducer and readout. Sensitive to temperature and barometric pressure changes. Risk of zero drift, but some models available with in-situ calibration check.
Bonded Resistance Strain Gage Piezometer	Moderately complex device, expensive. Simple to monitor. Very short lag time. Elevation of readout independent of elevation of tips and piezometric levels. No freezing problems. Easily automated.	Lightning protection required. Subject to zero-drift, therefore, not recommended for long-term monitoring. Expensive transducer and readout. Voltage or current output signal sensitive to cable length, splices, moisture, etc.

4. SELECTION OF PIEZOMETER

The primary factors influencing the distribution of water pressures in soil are the permeability of the soil, the ratio of horizontal to vertical permeability, and the variation of permeability within different zones and strata. The primary factors influencing the distribution of water pressures in rock are the joint permeability and the variation of the permeability due to the variation of the orientation, spacing, persistence, interconnection, and aperture of the joints. Where impervious strata exist in soil or rock, different pressures may occur in adjacent strata. Water pressure distribution is also affected by drains, abutment water tables, strata variations, and occasionally grout curtains. Rainfall and regional water levels may change local water levels, which in turn may affect water pressure distribution. All these aspects must be properly understood and accounted for when selecting and locating piezometers.

Relatively high excess pore water pressures may develop in impervious zones and compressible foundation strata during construction of embankment dams as the height of the dam increases. The inability of the dam or foundation to maintain effective strength during construction may lead to deformation or, in extreme cases, slope or bearing capacity failures. Consolidation testing and analyses, and pore pressure measurements during construction provide guidance for regulating the rate of fill placement and/or moisture control in the fill during construction to prevent instability. These pressures change to steady-state seepage pressures with time, depending on the permeability and length of drainage paths of the system.

The location of the phreatic surface for steady state seepage conditions in embankment dams is commonly established by theoretical analyses, and the variation of pressure beneath the phreatic surface is estimated by flow nets or is assumed to vary hydrostatically. Alternatively, pressures are estimated by finite element or finite difference models. Steady state seepage conditions may take years to develop.

Uplift pressure beneath concrete structures is generally assumed to vary linearly from headwater to tailwater or downstream ground surface. If foundation drains exist and are adequately maintained, the uplift pressure is usually reduced at the line of drains in accordance with the effectiveness of the drainage system. The linear pressure distribution can be affected by the factors influencing the distribution of water pressures in soil and rock that are discussed above. Common uplift pressure assumptions are illustrated in Chapter III of these guidelines.

Seasonal water pressure variations can occur as a result of seasonal reservoir level and temperature variations. Concrete dams and foundations deform slightly to adjust to these changing loads. In some cases, the deformations are sufficient to alter the aperture and permeability of foundation rock joints, which changes the pressure distribution. In a closed, perfectly rigid hydraulic system, changes in water pressure are transmitted, nearly instantaneously, by pressure waves. Piezometers are not perfectly rigid, or closed. Therefore, some water must flow for a pressure change to be measured. The time required for the flow to occur is known as lag time. Lag time is influenced by the degree of saturation, the permeability of the materials surrounding the piezometer, the design of the instrument, and the magnitude of change in pressure. Open standpipe piezometers require a relatively large volume of water to fill the standpipe and, in low permeability soils, lag time can range up to several months. Pneumatic and diaphragm type piezometers installed in sealed and saturated zones require negligible flow, and lag time for these types of piezometers is generally short. If the sensor is not sealed in a saturated zone, the lag time is controlled by the filter pack or material surrounding the piezometer. Lag time is usually only significant for piezometers installed in impervious materials.

Below the phreatic surface, soils are usually assumed to be saturated. Above the phreatic surface, soils contain both gas and water within the pore spaces. In partially saturated soils, piezometers measure pore air pressure rather than pore water pressure, unless high air entry porous tips are used. In cohesion less materials, the difference between pore air pressure and pore water pressure is minimal. In fine grained cohesive materials with high capillary pressure, pore air is always greater than pore water pressure. In some instances the difference can be significant with respect to evaluating the stability of a dam (Sherard 1981).

Piezometer tubing and cables should be installed to avoid development of seepage paths along them, or through them as they deteriorate. Special attention must be paid to sealing tubing and cables where they cross zones of an embankment dam. Adequate filters must be used around tubing located outside of the core and where tubing exits from the dam to prevent piping along the tubing or through damaged or deteriorated tubing.

5. INSTALLATION OF PRESSURE CELL

5.1 Installation of Pore Water Pressure Cells in the Drill Holes

Pore pressure cells may be installed in bore holes drilled, below the foundations or through already completed embankments as directed by the Engineer. Separate bore holes of 100 mm diameter or as approved by the Engineer shall be drilled for each cell. Depending on local conditions and the type of equipment proper casings shall be provided to protect the bore holes during installation. The casing should be removed after the pore pressure cell is placed in position. The following procedures shall be adopted for installation in drill holes:

- Remove the high air entry filter from the cell and boil it in clear water for five minute to saturate the filter with water.
- Reassemble the pore pressure cell under cool water by assembling the same in a bucket of clean water. The bucket should be large enough to allow pore pressure cell to be reassembled and the placement of the cell inside the cloth bag in submerged condition.
- Place a cloth bag in the bucket of water mentioned above and place some clean sand in the bag, place the pore pressure cell in the bag and pack the sand above it.
- Tie the top of the bag by a suitable string and place the same into the bronze metal screen keeping the assembly submerged in water.
- Take zero reading at this time to check proper functioning of the cell.

- Clean the drill hole and fill up the bottom 300 mm of hole with clean saturated sand.
- If the hole is provided with the casing, fill up the sand up to required depth and remove the casing from the bottom 300 mm prior to backfill operation.
- Lower the cell assembly into the hole up to the top of the sand. Test the pore pressure cell whether it is working satisfactorily, if yes, continue with the steps below.
- Pour additional clean saturated sand to fill the hole up to 300 mm above the top of the cloth bag.
- Follow backfilling.

5.2 Installation of Pore Pressure Cell in Embankment

Pore pressure cells shall be placed in embankment in shallow trenches lay at right angles to the main trenches which carry the connecting cable from all the cells. The main trenches shall have offset 300 to 600 mm from the location of cells. Main trenches shall be 600 mm wide and the depth should provide for a minimum of 100 mm of selected material over the connecting cables and a 300 mm thick protective cushion of selected fine material in the bottom of the trenches, below the connecting cables. A minimum of 450 mm of embankment material should then be placed to complete the backfill to existing embankment level. The following procedures shall be adopted in general:

- Remove the high air entry filter from the cell and boil it in water for five minutes to saturate the filter with water.
- Reassemble the pore pressure cell in a bucket of cool water under submerged conditions.
- Take zero reading at this time to check proper functioning of the cell.
- Carry the cell to its desired location in submerged condition.
- Place 100 mm thick layer of selected fine material of the same type as that of the surrounding embankment and compact.
- Place the pore pressure cell at its designed location as shown in the Drawings.
- Place selected fine embankment material up to a thickness of 300 mm over the pore pressure cell taking care so as to avoid large size particles which can damage the pore pressure cell or the cable.
- Test the pore pressure cell for satisfactory operation.
- Backfill the rest of the trench with typical fill material and compact the same by manual tamping.

5.3 Cable Connections

5.3.1 Laying of cables

The cable shall be laid in main trenches, where bed is cleared of sharp edge objects and replaced with selected material, in slight wave lines. The trench shall then be filled with selected fine material up to a depth of 300 mm and hand compacted. The main cable trenches should be provided with a cross cut-off trench filled with 1:3 soil-bentonite mixtures to prevent formation of a possible seepage path in the body of the earth / rockfill dam.

At locations where the cable passes in transition zones of the embankment, differential settlement of fill materials may shear the cable, adequate provision shall therefore be made by providing extra loose length of cable in that portion.

While routing of cables through rockfill, the main trenches carrying cables shall be filled with coarse-to-fine sand completely passing 5 mm sieve. The relative spacing between individual layers of cables may be maintained. The graded material surrounding the main trench shall be provided with properly graded layers to prevent migration of sand filling in the main trench.

The cables shall be protected against prolonged exposure to sun and mechanical damage. It is therefore, necessary that the cable is properly covered at all times.

The free ends of the installed cable shall be terminated immediately in water-tight connections. Entry of moisture through open ends of cable can ultimately result in making the pore pressure cell inoperative.

5.3.2 Insulation Tests

After completion of the cable connections, test the pore pressure cell for insulation by means of an ohmmeter, the value shall not be less than 500 mega ohms at 12 V. There must be no electrical connection between each of the conductors and the metal braiding or the body of the pore pressure cell. After this the pore pressure cell shall be checked for proper functioning. These tests should be performed immediately after the sealing resin has been applied.

5.3.3 Identification of Cable Ends

After connecting the cable to the pore pressure cell the free end of the cable should be marked or identified with permanent marks by use of a minimum of 3 tags at a maximum spacing of 10 m over the entire exposed length of cable with non-corrosive metal tags engraved or embossed with appropriate transducer number.

5.3.4 Cable termination Arrangement

The number of cable joints should be minimized, using continuous lengths wherever possible. The cable shall be of sufficient length to reach the permanent readout station. In case of necessity of joining the cables, proper splicing kit shall be used. The cables should be looped where they cross an interface and at joints, to reduce the strain in cables and joints due to differential movement. The cables shall be suitably grouped together and connect to the terminal unit in the Instrument House.

Precaution against Atmospheric Over-Voltages: Suitable over-voltage protection shall be provided to safeguard the transducer and the terminal unit from atmospheric over-voltages.

6. PRESENTATION OF DATA

The data from piezometric observations shall be duly processed and the following graphs prepared:

- Pore pressure, reservoir level and embankment height versus time;
- Pore pressure versus total stress; and
- The distribution of the above parameter along with geometry of the place with the contours and cross sections.

Such presentation of data shall be continued and report thereof submitted to the Engineer till final acceptance.

Table 2: Suggested Frequency of Readings [7]

Type of instrument	During Construction		During initial filling	During Period of Operation		
	Construction	Shutdown		Year 1	Years 2	Regular
Vibrating wire piezometers	Weekly	Monthly	Weekly	Biweekly	Monthly	Monthly
Hydrostatic uplift pressure pipes	Weekly	Monthly	Weekly	Weekly	Biweekly	Monthly
Porous-tube piezometers	Monthly	Monthly	Weekly	Weekly	Monthly	Monthly
Slotted-pipe piezometers	Monthly	Monthly	Weekly	Weekly	Monthly	Monthly
Observation wells	Weekly	Monthly	Weekly	Weekly	Biweekly	Weekly
Vibrating-wire total pressure cell	Weekly	Monthly	Monthly	Monthly	Monthly	Monthly
Pore pressure meters	Weekly	Weekly	Weekly	Biweekly		Monthly

7. CASE STUDY: SARDAR SAROVAR PROJECT, GUJARAT

Sardar Sarovar Project is an inter-state multi-purpose joint venture of four states - Gujarat, Madhya Pradesh, Maharashtra and Rajasthan - with a terminal major dam-Sardar Sarovar Dam (as sown in Fig. 7) on river Narmada near village Navgam in Bharuch District of Gujarat. This dam is the second highest concrete dam (163 m high with a length of 1210 m (at top RL of 146.50 m).) in India. The project on full completion has created additional irrigation potential of 17.92 lakh hectares and serve 12 districts and 62 talukas of the state. Power benefits of 1450 MW are being shared among MP, Maharashtra and Gujarat in the ratio of 57:27:16.The dam has a reservoir of 214 km length with an average width of 16.1 km. Total generation capacity of the project is 1450 MW.

Fig. 7: Sardar Sarovar Dam

7.1 Installation of Vibrating wire type Piezometer at Sardar Sarovar Dam, Gujarat

4 Nos vibrating wire piezometer (pore pressure meters) were installed at downstream side of the dam. Figure.8 shows the graph of Pore water pressure variation in correlation with reservoir water level. These graphs are updated till September 2010.

As per graph maximum and minimum pore water pressure are 5.23 kg/cm² on 29.10.02 and1.01 kg/cm² on 31.01.06, while reservoir level varied from 97.41 m to 110.75 m for the same period.

7.2 Pore Water Pressure Monitoring DATA Analysis (As per CSMRS Report 2011)

Pore water pressure readings were taken with the help of vibrating wire Piezometers, which were installed at 4 different locations. The monitoring shows alternate pressure variation more or less due to variation in reservoir water level or due to seepage.

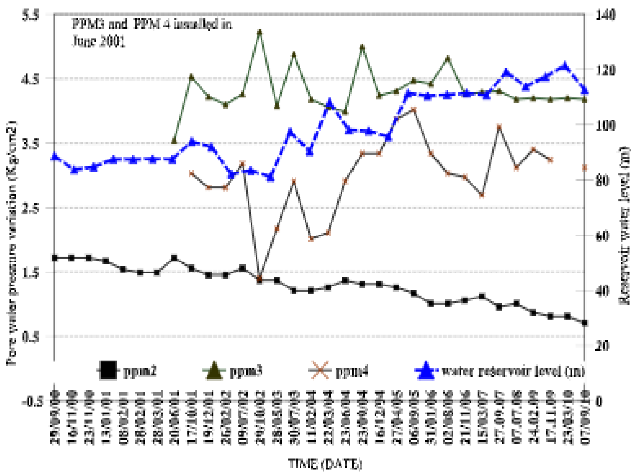

Fig 8[6]: Pore water pressure variation graph in correlation with reservoir water level

8. Conclusion

Piezometer observations are of prime importance for measurement of Pore water pressures in performance monitoring study of dam behaviour which indicate whether the various zones in an earth/rock fill dam are functioning properly. In that capacity the piezometers are required to be installed at critical points of a cross-section and locations.

Stand pipe piezometer, though durable and reliable, is not generally used during construction to measure pore pressures, there being no water flow. Installation of a stand pipe in impervious or semi-pervious soils will lead to more time lag. Installation of twin-tube hydraulic piezometers has been a standard practice. Factors considered in its favour include relative economy and availability of materials and ease of installation. But presence of air-bubbles in the tubing which may become difficult to remove is one of the disadvantages. Vibrating Wire piezometers have instantaneous response and are available indigenously. A final choice regarding selection will be best judged upon the accuracy of results required, the importance of such records, and the cost involved.

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