A Study of Instruments used for Dam Instrumentation in Gravity and Earthen Dams

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Abstract— **The importance of monitoring programs for dam safety is hugely accepted. There are many cases of dam failures where early warning signs of failure must have been discovered if a good dam safety-monitoring program had been in place. The monitoring program gives the information that is required to develop a good understanding of the on-going performance of the dam. The ability to discover a change in this performance is integral because the dam performance is directly responsible for the after-effects of a dam failure.**

The use of instrumentation as part of dam safety programs is increasing as the technology of instrumentation and ease of use advances. Instrumentation can be used to put into effect a monitoring program that provides more absolute and appropriate information in regard to the on-going performance of the dam. For this purpose use of proper instruments is thus very important phenomenon therefore we must know the various instruments used to find different parameters.

Thus it has been concluded from the present study that the study of all the instruments is very essential to successfully implement a dam instrumentation program for dam safety. All instruments to study different parameters are thoroughly studied in this paper.

***Keywords*— Assumptions; Dam; Instruments; Failure; Monitoring programs; Remedies; Safety; Study etc.**

I. Introduction

The importance of monitoring programs for dam safety is hugely accepted. There are many cases of dam failures where early warning signs of failure must have been discovered if a good dam safety-monitoring program had been in place. The monitoring program gives the information that is required to develop a good understanding of the on-going performance of the dam. The ability to discover a change in this performance is integral because the dam performance is directly responsible for the after-effects of a dam failure.

One of the key objectives of a monitoring system is to be able to detect any sign of abnormality in the behaviour of the structure reasonably early so that immediate corrective actions can be taken to prevent serious damages or even a major disaster from occurring. To achieve this objective a monitoring program has to be structured such that the numbers of measurements are sufficient to detect the abnormality and yet not overly abundant that it becomes uneconomical. The frequency of measurements generally vary depending on the quantity measured (e.g., in embankment dams, seepage measurements are taken more often than horizontal displacement) and in which stage the measurement is taken (i.e., during construction, first filling, first 3 to 5 years or normal operations, or after a significant event such as a flood or an earthquake). In the case where a fully automatic data acquisition system is used, the frequency of measurements does not impose any problems.

The use of instrumentation as part of dam safety programs is increasing as the technology of instrumentation and ease of use advances. Instrumentation can be used to put into effect a monitoring program that provides more absolute and appropriate information in regard to the on-going performance of the dam. For this purpose use of proper instruments is thus very important phenomenon therefore we must know the various instruments used to find different parameters. The study of all the instruments is very essential to successfully implement a dam instrumentation program for dam safety. All instruments to study different parameters are thoroughly studied.

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II. Objectives of Instrumentation

1. Instruments embedded in or installed at the surface of the dam keep a constant watch over their service and indicate the distress spot which call for remedial measures. Thus instruments play an important role in checking the safety of the dams.
2. The observations of the instruments form a cumulative record for structural behaviour of dams. The study of structural behaviour provides an important aid in modifying theoretical assumptions and includes the effect of field observations. Most hydraulic structures are built on rather conservative assumptions to provide for unknowns in the designs. Observations from the instruments help to reduce these unknowns and place future designs on sounder footing.
3. The Instrumentation data also helps in the process of research and developments and also advancing the state of art.
4. The present age instrumentation has become necessity to insure proper functioning, safety as well as the optimum utilization of resources.
5. Safety of the dam is not the sole objective of instrumentation. Instruments provide the information to the engineer about the health of the dam constructed by him as well as treat that dam as a salve.

III. Necessity of Dam Instrumentation

1. To collect basic parameters like forces and material properties in quantitative form to help designs.

2. To keep constant watch over performance of the structure during service and obtain a timely warning.
3. To assess the real significance of various parameters used in designs and thereby modify designs procedures and criteria leading to increased economy and safety.
4. The casing soils are of what permeability and their performance in sudden draw-down condition on the upstream side needs to watch.
5. Similarly, in general, the pore pressures within the body of the dam in other zones would be of interest.
6. The dam is located in a which seismic zone, with this point of view, and even otherwise, the vertical settlement of the dam as well as its horizontal settlement.
7. Spread on the upstream and downstream needs to be monitored, particularly in its early life.
8. The behaviour of dam for comparison with the design, assumptions is to be observed.
9. If the dam lies in heavy rainfall zone both in intensity and quantum. It would be interesting to ascertain as how far does the heavy rainfall affect the saturation of downstream slope even after provision of pitching, backed by quarry spalls on the downstream slope.
10. With the advent of finite element analysis method, it is possible to predict stresses, settlements and pore-pressures to a greater degree of accuracy. Comparison of the results of such analysis with observations on prototype will be possible by providing the instrumentation.
11. In short, the instrumentation in dam will give an excellent opportunity for checking design assumptions made and parameters assumed in the stability analysis.

IV. Instrumentation Planning

The planning and significance of a comprehensive suite of instruments involve a logical sequence of decisions:

1. Definition of the purpose and objectives.
2. Definition of observations appropriate to dam considered.
3. Determination of locations & numbers of measuring points for the desired observation.
4. Consideration of time period to be spanned, i.e. long-term or short-term monitoring.
5. Consideration of optimum sensing mode in relation to the desired rapidity of response, required accuracy etc.

V. Selection and Location of Instruments for Dams

Instruments are discontinuities, non representative objects introduced into dam material systems their presence and the flows or displacements required to generate an observation alter the very quantities they are intended to measure. The alternations may be significant or negligible its extent depends on the nature of the phenomenon being observed. On the design of instrument and on observations required for installation. The engineer embarks on a program of field instrumentation needs to understand the fundamental physics and mechanics involved' and how the various available instruments will perform under the conditions to which they will be subjected In addition the engineer needs to know whether corrections can be made by calibration or by theoretical calculations or whether under the circumstances no valid result is possible.

Every instrument installed in a dam should be selected and placed to assist in answering a specific question. It is easy to install instruments. Collect the reading and then wonder if there are any questions to which the results may provide an answer. Instrumentation is currently in vague some design agencies and many regulatory bodies mandate instrumentation whether the results may be useful or not. It is widely held dogma, for instance that every dam should be instrumented, in the hope that some unsuspected defect will reveal itself in the observations and give warning of an Impending failure. Instruments cannot cure defective designs nor can they Indicate signs of impending deterioration or failure unless they happen to be of the right type and in the right place.

Peck comment, “Instrumentation, vital for obtaining quantitative answers to significant question, is too often misused, especially in earth and rock fill dam. In some countries regulations concerning the safety of dams demand the incorporation, of inclinometers, settlement indicators and Piezometers in the cores of virtually all new dams, but for what purposes? Not for research because the patterns of deformation and pore pressure development for ordinary geometries and materials are now well known and can be predicted by calculation. Only under unusual circumstances can it be said that design assumptions in these regards require verification. Yet installation of instruments, even under the best of circumstances, introduces inhomogeneties into the cores and occasionally is the direct cause of such local defects as sinkholes. The potential weakness introduced by an installation should be balanced against the potential benefit from the observations. In contrast to those located in cores, piezometers in foundation materials near the downstream toes detect upward seepage pressures that cannot be predicted reliably, and can thus give timely warning if measures are need to ensure safety. There is danger that instrumentation may be discredited because of indiscriminate use.

Notwithstanding its vital role, instrumentation is not an end in itself. It cannot guarantee good design or trouble free construction. The wrong instruments in wrong place provide information that may at best be confusing and at worst divert attention from telltale signs of trouble. Too much instrumentation may be wasteful and may disillusion those who pay the bills, while too little, arising from a desire to save more can be more than false economy, and it can even be dangerous.

VI. INSTRUMENTS IN DAM

Instruments are very much important to determine this parameter & to keep constant watch over performances of structure. By collecting this information check design assumption & modify it. In this chapter we see which type of instrument is to be used to obtain this parameter.

Following table shows the instruments used to obtain parameters:

TABLE I. Instruments used in Dam

A.	Pore Water Pressure	Open stand pipe piezometer
B.	Displacement	Tiltmeter
C.	Seepage	v - notch weir
D.	Strain	Strain gauge
E.	Stress	Total Pressure Cells
F.	Dynamic Loads	Seismometer
G.	Temperature	Temperature Sensors
H.	Uplift Pressure	Instruments For Structures on Permeable Foundation.

A. Instruments to Measure Pore Water Pressure

1. Open stand pipe (Casagrande) piezometer

The basic concept of open standpipe piezometer and also known as porous tube piezometer was presented by Dr. A. Casagrande in the journal of the Boston Society for Civil Engineers, April 1949 AD. With certain modifications this piezometer has been installed most frequently in drill holes in foundations or body of dams. The pressure of the pore water surrounding the porous tube cause a flow through the piezometer until the pressures are equalised by the head of water in the standpipe. The elevation of water in the standpipe is determined by the sounding device. Open standpipe piezometers are generally considered to be more reliable than any other type of piezometers. These are more sensitive to foundation pressures or ground water fluctuations and are more resistant to plugging due to silting than the conventional observation wells which these replaces. Because of its independent installation, the porous tube piezometer may be utilised to provide pore pressure data at locations which are inaccessible or impracticable to contact with other types of piezometers. The standpipe piezometer offers a low cost alternative to borehole pressure transducers and is simple to read. In case of multiple installations and a need for a high reading frequency, borehole pressure transducers offer lower operating costs.

Casagrande Piezometer

The standpipe piezometer system comprises a sealed standpipe tube connected to a porous element - the filter tip. The filter tip is placed at the desired zone and a bentonite plug is placed above the zone to isolate it from the other layers. Water now enters the installation through the filter tip making it possible to take readings by lowering a dip meter from ground level. A sound can be heard (and/or a light starts blinking) as soon as the dip meter encounters the water level. The graduated tape with cm markings gives the operator an indication of the water depth.

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Applications

Standpipe piezometers are used to monitor piezometric water levels in soils and rock. Typical applications include:

1. Monitoring pore-water pressure to determine the stability of slopes, embankments, and landfill dikes.
2. Monitoring ground improvement techniques such as vertical drains, sand drains, and dynamic compaction.
3. Monitoring dewatering schemes for excavations and underground openings.
4. Monitoring seepage and ground water movement in embankments, landfill dikes, and dams.
5. Monitoring water drawdown during pumping tests.

Limitation:

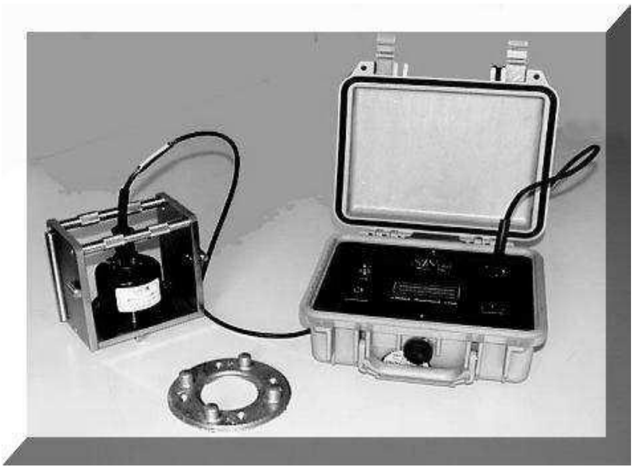
1. The main limitation of piezometer of this type is that some flow of water in or out of the piezometer system is necessary in order to accommodate it to range in pore water pressures. Consequently there is a time lag before the piezometer reflects the change of pressure, though for the majority of soils from which earth dams are constructed, experience has indicated that this lag is not important unless the pre pressure changes rapidly.
2. The second major limitation is caused by the existence of the standpipe, when embankment fill is placed around the standpipe, nearby compaction tends to the inferior, interruptions to normal filling operations is costly and the standpipe is subject to damage by construction equipment.

B. Instruments to Measure of Displacement in Dam

1. Tilt meter

One of the most potentially valuable instruments though not yet widely used to measure the internal movements for earth dam is the portable tilt meter of electrical type. A portable tilt meter for measuring tilt in both horizontal and vertical plane. Portable tilt meter is provided with accelerometer transducer. A measurement is made by placing the tilt meter in an exactly reproducible position on a reference plate. Reference plate may be either fixed in place or arranged as portable devices by meeting reference.

The device consists of a mass suspended in the magnetic field of a position detector. When the mass is subjected to a gravity force along its sensitive axis, it tries to move and motion induces a current change in the position detector. This current change is position through a servo amplifier to a restoring coil, which imparts an electromagnetic force to the mass that is equal and opposite to the initiating gravity force. The current through the restoring coil is measured by the voltage is directly the precision resistor. This voltage is directly proportional to the gravity force. In turn, this gravity force is proportional to the amount of tilt of reference plates. Hence the voltage is directly proportional to the amount of tilt. Typical range of tilt is ± 30° from the horizontal or vertical and precision is typically ± 50 sec.



Portable Tiltmeter

The main advantage of tilt meter is, during a short time period. It provides a rapid indication of deformation trends.

Features:
1. Suitable for hostile & severe environment.
2. Provides reliable and high resolution readings.
3. Rugged & robust construction and excellent temperature stability.
4. Easy to install and take readings. Can be removed and reused
5. Reliable readings Low cost.
6. Readings can be taken by remote data logger.

Applications:
1. Monitoring vertical rotation of retaining walls.
2. Monitoring inclination and rotation of dams, piers and piles, etc.
3. Monitoring stability of structures in landslide areas.
4. Monitoring tunnels for convergence and other movements.
5. To evaluate performance of bridges and struts under load.

C. Instruments to Measure Seepage through Dam

1. V - Notch Weir

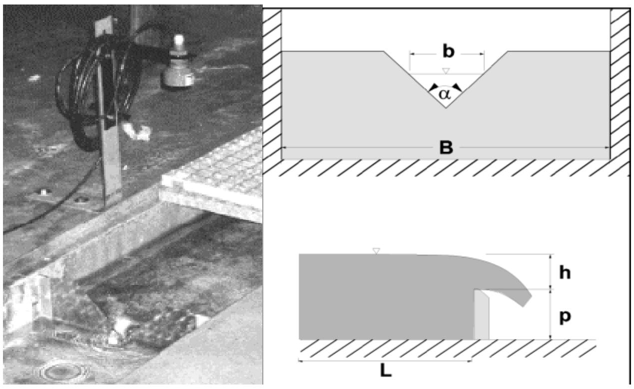
Each large dam construction is equipped with internal observation tunnels. Along these tunnels small open channels are running which take up the seepage water entering the dam construction and leading it outside. In order to get exact information on the amount of water entering the dam, a seepage water measurement system needs to be installed. A specially designed V- notch weir installed within an open channel will increase the water level on the upstream side by partially blocking the discharge. The height of the upstream water level is a direct measure for the total discharge in the channel. Each V-notch weir has a geometry which is calibrated to exactly fit the channel shape and the expected amount of discharge. The water level can be measured manually using a tape measure or automatically using ultrasonic distance transducers.

Automatic Measurement

Automatic measurements generally are preferred to manual ones due to the fact that online monitoring and an alarm function make it a much easier task to have constant control of the discharge. Each measuring location is equipped with an ultrasonic sensor connected to an electronic flow meter.

Ultrasonic Sensor

Ultrasonic sensors are normally installed in such a way that no objects are in the sound path between the sensor and the measuring surface. Any unwanted object in the sound path will cause the signal to stop at the level where the object is located when the surface of the media is lowered.



Flow Parameters:

α = angle in degrees	μ = flow constant
h = measuring height [m]	Q = discharge or flow
p = weir height [m]	[m3/sec]

Most ultrasonic sensors have a built in temperature sensor to compensate for the change of sound speed in air due to temperature variations.

Flow meter

Interfile is using microprocessor controlled flow meter for open channels. All commonly used open channels and weirs, where the flow is a function of the measured water depth can easily be set. All settings, measured and accumulated values are displayed by a 2 x 16 digit illuminated display. The sensor inputs are of the high resolution type (14 ¼) which gives a very high accuracy in the flow calculation even at low flows. The industrial standard analogue 4-20 mA output with its high resolution is galvanic ally separated and provides a common interface for most data acquisition systems. A special data acquisition system for the use with a standard PC is also available e.g. for installation in control rooms. All units are equipped with high and low level alarm outputs.

Weir

Our most commonly used weir type is the V-notch weir or Thomson weir. Special designs include straight weirs without side contraction and rectangular weirs.

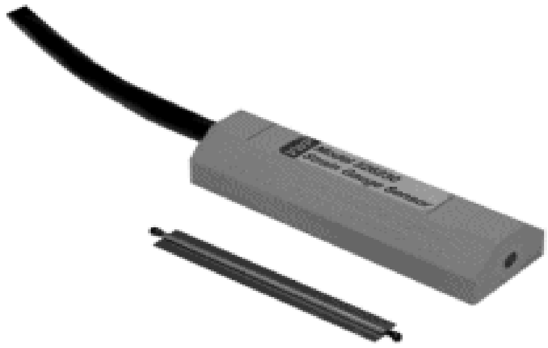
Applications

V-Notch Weirs are used to monitor discharge in small open channels. The most common application is the use as seepage water monitoring system inside large dams.

D. Instrument to Measure Strain in Dam

1. Strain Gauge

When strain gauges are easily accessible, the strain gauge sensor can be carried from gauge to gauge with the vibrating wire indicator, eliminating the cost of multiple sensors and cable runs. In other installations, sensors are fixed permanently to the structure. On flat surfaces, the sensor is typically held in place by weld-down straps. On reinforcing and tieback bars, cable-ties and tape often secure the sensor.



Strain Gauge

Features

1. Pre-Tensioned Wire: Slope Indicator's weld able strain gauges are delivered pre-tensioned, ready for spot welding. Pre-tensioned gauges eliminate the time-consuming, process of tensioning the vibrating wire element in the field. Gauges can be ordered in three tension ranges to match virtually any application.
2. Full-Length Welding Flange: The full length welding flange allows reliable coupling of the gauge to the structural member and prevents misalignment of the end points of the gauge, a common problem with other strain gauges.
3. Very Low Profile: The vibrating wire element is positioned only 0.96 mm above the measured member. This patented, low profile design reduces errors caused by bending of the structural member.
4. Stainless Steel Construction: The welding flange and the protective tube that seals the vibrating wire are constructed from stainless steel for corrosion resistance. The wire itself is steel, selected to match the thermal characteristics of structural steel.
5. VW Strain Gauge Sensor: The strain gauge sensor plucks the strain gauge and returns a frequency signal to the VWP indicator, where it is converted to units of micro strain or period. The VW strain gauge sensor also incorporates a temperature sensor, which supplies data for temperature compensation.

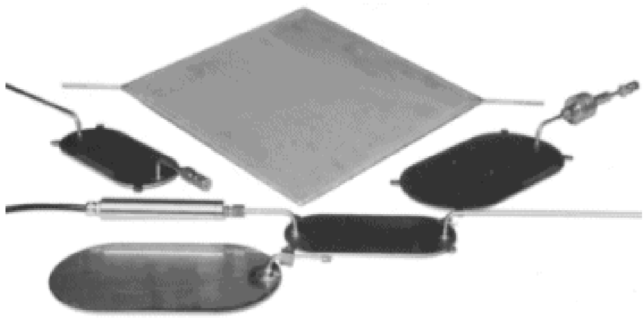
E. *Instrument to Measure Stress in Dam*

1. *Total Pressure Cells*

The total pressure cell is formed from two plates of stainless steel. The edges of the plates are welded together to form a sealed cavity, which is filled with fluid. Then a pressure transducer is attached to the cell. The cell is installed with its sensitive surface in direct contact with the structure or soil. The total pressure acting on that surface is transmitted to the fluid inside the cell and measured by the pressure transducer. Tangential and Radial Cells are made from two oval shaped stainless steel plates. The edges of the sensitive top plate are bent towards the base plate and laser welded to form a sealed cavity which is later filled with de- aired oil. This construction minimizes tangential stiffness and prevents stiff weld joints and sharp edges.

Transducer Options

Three different types of transducers can be attached to a total pressure cell.



Total Pressure Cell

Membrane Switch

This unique interfels product is extremely robust and is the best choice for a cost-effective manual measurement with a compensation pump. Special design requires measuring line consisting of only one hydraulic line and one two-wire electric signal cable.

Vibrating Wire Pressure Transducer

The VW pressure sensor eliminates incorporated hydraulic lines, provides more consistent readings and has an RTD or thermistor temperature sensor.

Piezo-Resistive Transducer with a standard 4...20 mA output signals this pressure transducer can be read easily with most automatic data acquisition systems available on the market.

Applications

Total pressure cells are used to monitor stress changes in concrete, soil and fills, contact joints and in boreholes. Typical areas of application include the monitoring of:

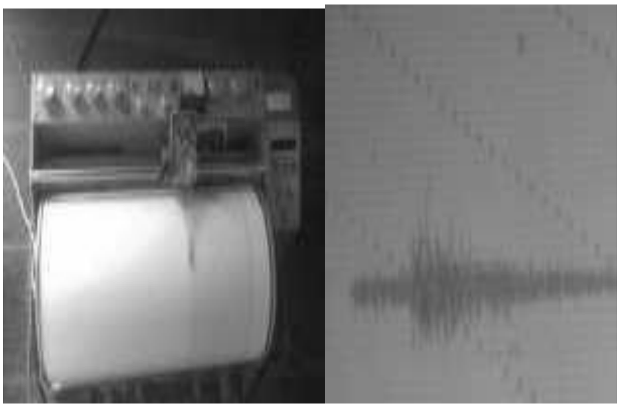
1. Radial and tangential pressures in tunnels
2. Load measurements at head and toe of pile construction
3. Earth and foundation pressures in foundation engineering
4. Secondary stress state in geomechanics.
5. Total soil pressures in landfills and dams.

F. *Instrument to Measure Dynamic Loads*

1. *Seismometer*

In all large dam projects the monitoring of seismic activities is mandatory. A strong motion accelerograph is used for measuring ground movement due to earth quakes. The transducer used for monitoring is a servo accelerometer concept using a mass spring resonator and acceleration- sensing element with optical mass movement sensor. The instrument housing is attached to the dam structure and will move with it, therefore generating a relative displacement referred to the mass element inside the housing. Transducers are generally installed at the base of the dam and at its crest. The instruments are independent from outside power with internal memory capable of recording several events. The recording itself is event triggered, which means that the detection of small movement will trigger the recording.

The instrument that measures earthquake shaking, a seismograph, has three components – the sensor, the recorder and the timer. The principle on which it works is simple and is explicitly reflected in the early seismograph– a pen attached at the tip of an oscillating simple pendulum (a mass hung by a string from a support) marks on a chart paper that is held on a drum rotating at a constant speed. A magnet around the string provides required damping to control the amplitude of oscillations. The pendulum mass, string, magnet and support together constitute the sensor; the drum, pen and chart paper constitutes the recorder; and the motor that rotates the drum at constant speed forms the timer.



Seismometer & Seismograph

One such instrument is required in each of the two orthogonal horizontal directions. Of course, for measuring vertical oscillations, the string pendulum is replaced with a spring pendulum oscillating about a fulcrum. Some instruments do not have a timer device (i.e., the drum holding the chart paper does not rotate). Such instruments provide only the maximum extent (or scope) of motion during the earthquake; for this reason they are called seism scopes. The analogue instruments have evolved over time, but today, digital instruments using modern computer technology are more commonly used. The digital instrument records the ground motion on the memory of the microprocessor that is in-built in the instrument.

Advantages

1. Simple construction
2. Easy recording
3. Easy to install

Applications

1. To measure the earthquake intensity.
2. To obtain a seismograph of particular area.

G. Instrument to Measure Temperature

1. Temperature Sensors

A change in temperature causes a change in the frequency signal output by the VW temperature sensor or a change in resistance in case of the PT100 and AD592 temperature sensor. The readout device processes the signal, applies calibration factors, and displays a reading in degrees Centigrade or Fahrenheit.

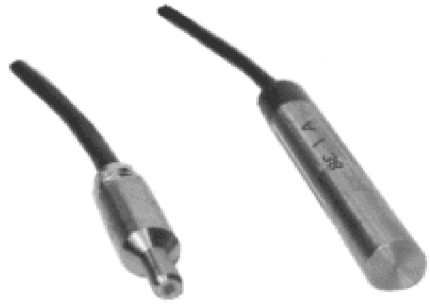
High Resolution: Resolutions up to 0.05°C are possible depending on data logger or readout unit.

Manual or Automatic Readings: The sensors connect easily to a data logger for unattended monitoring.

Applications

Typical areas of application include the monitoring of:

1. Curing temperatures in concrete



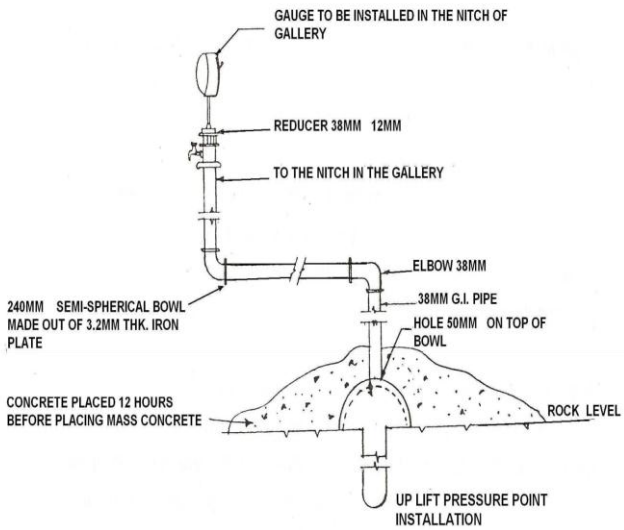
Temperature Sensors

2. Water temperatures at dams and arch dams
3. Air temperatures in machine or transformer halls and cavities
4. Ground temperatures in freezing excavations.

H. Instrument to Measure Uplift Pressure

1. Structures on Permeable Foundation Instruments

For uplift measurements of structure on permeable foundation, the instruments describe below is suitable. It consist of brass filter on of 50 mm inner diameter and 100 mm length connected by 38 mm. GI pipes to suitable stand pipe located in the superstructure for measurement water level. The water level is measured by super level indicator or a bell sounder & water head above the tapping point indicates the uplift pressure. The bells sounder make sound when it touches the water circuits in the pipe. Arrangement of pressure tapping points under a typical structure is indicated in when the tapping point is located in soil of medium to low permeability, stand pipe or twin tube piezometer installation described specially for earth dams is more suitable.



Instrument to measure uplift pressure on permeable foundation

Methods of Observation

When the reservoir water surface reaches an appreciable level necessitating observation of uplift at the base of the dam, the plugs are remove, and the pipes are filled with water in case of pipe in which the prevailing uplift level is lower than the top of pipe the water will see into foundation and stabilize at a level indicative of the actual uplift level. Depth of the water is such pipes (non- flowing pipes) may be measured by the means of bell sound or any other suitable electrical water level indicator, capable of being lowered into 35 mm. dia. hole. It is obvious that in case of band pipes the water level is lower than bend-elevations the pipe will appear dry (it is evident that under such conditions, it is not possible to observe the prevailing uplift pressure at locations of such bend pipes).

In case of pipes which flow when plugs are remove, the plugs are removed and altitude gauges are connected to a stopcock. to the 12 mm. pipes that terminate in the gutter The first set of reading is made after the stopcock have been opened for about two weeks, to enable stabilization of the uplift.

VII. Conclusion

Various instruments are typically required in the construction of large, highly hazardous dams, and may be necessary on existing dam rehabilitation projects. Instruments can be installed to monitor the performance of the dam during construction, during initial reservoir filling, and during the life of the structure. Other less common instrumentation may be considered for unusual conditions. Any instrumentation selected should target specific items to be evaluated, establish critical thresholds that suggest the need for a specific action, and establish the details of the monitoring programs.

Foundation and embankment performance may be monitored with piezometers, settlement devices, inclinometers, and seepage measuring devices, displacements may be measured with tilt meters, seepage can be monitored and calculated using v - notch weirs, strain may be measured by using strain gauges, stress in the dam body may be monitored by installing total pressure cells, dynamic loads can be monitored using seismometers, temperatures can be monitored by using temperature sensors.

Recommendations:

From above discussion it can be suggested that dam instrumentation is an emerging technique which ensures safety of dam if properly utilized. Different advance instrument can be used for safety and stability. Dam instrumentation can be used for minimizing power and energy loses in dam. It can be used for small to large energy producing dam in world. Proper design and design criteria should be established for any future work of dam construction which will be fruitful for nation's prosperity.

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