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Dam Safety & Instrumentation-A Case Study

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Abstract - **Safety of Dam infrastructure is important to avoid adverse transboundary impacts and destructive consequences on lives, property and environment. It is emphasized that the safety of the dam should be maintained throughout its different life phases i.e. design phase; construction phase; first filling phase; and operation phase, with some detail of the types of readings to be taken during the last one.**

Dam surveillance and instrumentation provide data for monitoring the safe performance during the various phases of a dam's life including design; construction; first filling of the reservoir; evaluation of long-term, in-service performance (normal operation); and to manage or predict unsatisfactory performance. The use of instrumentation to monitor the performance of dams is widely accepted as a prudent component of a successful dam safety program to manage and minimize the risks to the public posed by dams.

The paper aims at highlighting the importance of geotechnical instrumentation as the tool for dam safety study which provides the information necessary to evaluate the performance of dams and gives early warnings of changes that could endanger their safety.

Index Terms— **Dam Safety, Dam, Design, Instrumentation, Monitoring, Planning, Reliability, Surveillance, Dam health etc.**

1. Introduction

Dams are used to manage surface water for irrigation, flood prevention, agriculture, and power generation. The safety of the dam is a very important aspect for safeguarding the national investment and the benefits derived by the nation from the project. In addition, an unsafe dam constitutes a hazard to human life and property in the downstream reaches.

A well designed and executed instrumentation and surveillance monitoring program can provide information that is needed for a solid understanding of the ongoing performance of a dam and may help to detect early warning signs of trouble. Monitoring programs, including instrumentation, surveillance and visual inspection, provide dam owners with the knowledge that a dam is performing as expected and the ability to detect a change in performance. For the safety and normal operation of a dam, precise information is required from instrumentation and monitoring of dam's body, the surrounding foundations, the reservoir and the river basin. Their behavior during each stage of investigation, design, construction and operation are very important information for engineering decisions. An early warning system through measurement of various parameters which may cause distress in the dam in future, gives very important timely information about the dam behaviour. This early warning system consists of set of instruments, regular data acquisition, analysis of acquired data and thereby monitoring dam behavior on long term basis.

This paper describes the structural performance being monitored through analysis and interpretation of instrumentation data of Vyasi Dam in Uttarakhand. Vyasi Dam is very well instrumented and dam structural behavior is continuously being monitored by analyzing the data obtained by the installed instruments. The paper brings out the highlights of structural monitoring of the dam through analysis and interpretation of the data obtained by the various instruments installed around 2015.

2. Objective

The objective of dam instrumentation and surveillance is to make a timely and precise diagnosis of dam behavior that allows for the prevention of undesirable consequences. The monitoring system and surveillance programmes have to be designed or redesigned considering potential failure modes associated with the higher levels of risk and for enabling to identify any abnormal behavior which could lead to potential reduction of safety. Data collected from instrument can be extremely valuable in determination of specific cause of failure.

3. Purpose of Instrumentation and Monitoring

Instrumentation and proper monitoring and evaluation are extremely valuable in determining the performance of a dam.

Specific reasons for instrumentation include:

■ **Warning of a Problem**

Often, instruments can detect unusual changes, such as fluctuations in water pressure within the dam that are not visible. In other cases, gradual progressive changes in seepage flow, which would go unnoticed visually, can be monitored regularly. This monitoring can warn of the development of a serious seepage problem.

■ **Analyzing and Defining a Problem**

Instrumentation data are frequently used to obtain engineering information necessary for analyzing and defining the extent of a problem. For example, downstream movement of a dam because of high reservoir-water pressure must be analyzed to determine if the movement is uniformly distributed along the dam; whether the movement is in the dam, the foundation, or both; and whether the movement is constant, increasing, or decreasing. Such information can then be used to design corrective measures.

■ **Proving Behavior is as Expected**

Instruments installed at a dam may infrequently (or even never) show any anomaly or problem. However, even that information is valuable because it shows that the dam is performing as designed, offering peace of mind to the owner. Also, although a problem may appear to be extant or imminent, instrument readings might show that the deficiency (for example, increased seepage) is normal (merely a result of higher than normal reservoir level) and was foreseen in the dam's design.

■ **Evaluating Remedial Action Performance**

Many dams, particularly older ones, are modified to allow for increased capacity or to correct a deficiency. Instrument readings before and after the change allow analysis and evaluation of the performance of the modification.

Items of monitoring

Items of monitoring for dam safety are selected according to the scale and condition of each dam. Fundamental items are:

- Concrete dam: leakage, deformation, uplifts pressure, earthquake motion, stress meters, strain gauges and thermometers.
- Embankment dam: leakage, deformation, pore pressure (seepage line), earthquake motion, earth pressure gauges, piezometer, internal displacement.

4. Types of Measurements and Instruments

Details of some types of measurements and instruments for determining the performance of dam are as follows:-

4.1 Pore Pressure

The measurement of pore water pressure takes a very important role , which enables to know the seepage pattern set up after impounding of reservoir and also valuable information about behaviour of dam during construction and draw-down condition is obtained. Under an externally applied stress, soil grains are constrained 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. In the event if these pores are fully filled with water, their volume cannot be altered unless some water is depleted from the soil mass, because water is considered incompressible. If drainage is prevented or impeded, stress will create in the pore water (i.e. pore water pressure) counter reacting the externally applied stress. Pore water pressures are a controlling factor on stability during construction.

Vibrating Wire Piezometer is used for accurate and long term measurement of pore water pressures in fully or partially saturated soil and rock. Open Stand Piezometer is utilized to measure water Pressure in Spillway / Dam body.

4.2 Movements/ Deformation

Measurement of movements is as imperative as the measurement of pore pressures. Movements conforming to normal expectations are essentially pre-requisites of a stable dam. An exact measurement of internal and external movements is of esteem in controlling construction stability. The measurement of the plastic deformation of the upstream and downstream slopes under the cycles of reservoir operation may indicate the likely development of shear failure at weak points.

Joint Meter is used typically to measure relative movement across joints.

Bore-Hole Extensometer is used for measuring deformation and measures longitudinal displacement between two points in fill and lateral strains in earth dams.

4.3 Seepage

Ceaseless movement of water through the soil of a structure may result in removal of soluble solids or may result in internal erosion called channeling. Channeling must especially be protected against since it happens gradually and is often not frequent until the structure's failure is imminent. Seepage and erosion along the lines of destitute compaction and through cracks in foundations and fills may extraordinarily be shown by such measurements.

3-types (rectangular, triangular and trapezoidal) of Seepage measuring weir is used to measure the seepage and leakages in the dam.

4.4 Strains and Stresses

Design analysis of earth and rock fill dams are based on radical simplifications of the stress pattern and the shape of the rupture planes. In this way, stress measurements involve a large amount of interpretative judgement. It is difficult to measure stress accurately, because the distribution of stress in earth and rock fill dams is complicated. Strains can be computed from displacements or directly measured.

Stress and strain meters are installed in dam body to monitor the variation in stresses and strains during construction.

4.5 Dynamic Loads (Earthquakes)

Investigating the behaviour of dams that have experienced seismic tremors in the past, there are evidences too that outstandingly strong seismic tremors have produced remarkable damages. Sudden dynamic loading is brought on by seismic tremor, and measuring vibrations in dams situated in seismically active locations is crucial for improving design standards for such circumstances. In any case there are evidences too that outstandingly strong seismic tremors have produced remarkable damages.

Seismometer is used to record ground motion in horizontal as well as vertical direction and getting the output in seismographic manner. The instrument consists of accelerometer, seismometer and associated data acquisition

4.6 Measurem*ents of Reservoir and Tail Water Level*

The measurement of reservoir and tail water levels is essential for interpretation and reasonable assessment of the structural behaviour of the dam, since reservoir and tail water heads are one of the vital loading to which a dam is subjected.

Staff gauge is a device used to measure the water level in stream or dam to record highest water elevation.

5 Selection of Instruments

Different kinds of instrumentation and monitoring are required for the different types of dam, reservoir and river basin. While selecting instruments, the following requirements must be taken into considerations-

1. Precision is within the acceptable range;
2. Operation is easy
3. Durability is high, and
4. Repair and replacement are possible
5. Reliability and less complication

6.0 Case Study- Vyasi Dam

Vyasi HE Project (as shown in fig. 1) is a run-of-the river scheme on river Yamuna, powerhouse of which is located near Hathiari village in the district of Dehradun in the state of Uttarakhand. The scheme envisages construction of concrete dam of 86 m height known as Vyasi dam located near Judo village (5 Km downstream of Lakhwar dam), 7 m dia and 2.7 Km long Head Race Tunnel (HRT), 18 m dia and 63.5 m high Surge Shaft, 2 nos. 4 m dia. 209 m long each Pressure Shafts and a Surface Power House to install two units of 60 MW each. Water from Vyasi reservoir was diverted by construction of Vyasi dam through a HRT and this water will be further carried through 2 nos. Pressure Shafts to Surface Power house at Hathiari to generate 120 MW from 2 units of 60 MW each.

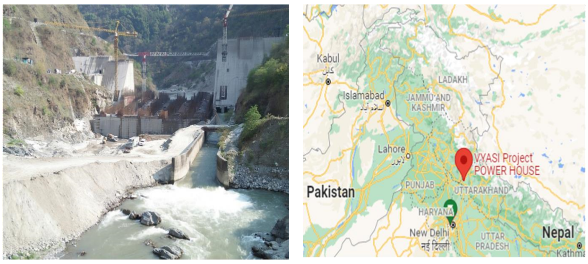

Figure 1: Location of Vyasi Dam

6.1 Salient Features of Dam

Table 1: Salient Features of the Project

Feature	Description
River	Yamuna
Type of Dam	Concrete Gravity
Dam Height	86.00 m above deepest foundation
Top Length	207.00 m.
Top of Dam	EL 634 .0 m
River Bed Level at Dam Site	EL 584.0 m
Deepest Foundation Level	EL 548.0 m
Upstream Slope	0.3 (H): 1 (V)
Downstream Slope	0.7 (H): 1 (V)
Other Appurtenant Structures and Features	
Intake	Bell Mouth Intake 27.5 m from Dam Axis
Head Race Tunnel	2.7 km long, 7.0 m dia. circular (119.78 m^3/sec design discharge)
Surge Shaft	18 m dia., 63.5 m deep
Pressure Shaft	02 nos., 4.0 m dia., 209 m each
Power House	Surface, 72 m (L) x 24 m (W) x 40.2 m (H)
os and Size of Units	2 Nos. of 60 MW each
Type of Turbine Units	Francis Type
Design Head	111 m
Draft Tubes	2 Nos. 7.0 m (W) x 4.48 m (H)
Annual Energy Generation (90% dependable year with Vyasi standalone operation)	375.24 MU

6.2 Types of Instruments installed

For monitoring the structural response, various geotechnical instruments were installed in various blocks of dam at different elevations. Type of instruments installed in Vyasi dam Project include stress meters, strain meters, temperature meters, joint meters, pore pressure meters, uplift pressure meters and load cells in abutment galleries etc.. Apart from these, normal and inverted plumb lines were also installed to monitor the horizontal and tangential deformations of dam during filling and operational stages. Seepage measurements at various elevations and locations helps in identification of sections with abnormal seepage discharge. V-Notches were installed in the dam inspection galleries to measure the seepage.

A total of 313 instruments as presented in table 2 have been installed in various blocks of Vyasi dam at different elevations. Both overflow and non-overflow blocks have been selected for instrumentation. Figures 2 and 3 show the location of instruments installed in block no.4 (non-overflow block) and block no 8 (overflow block) respectively.

Table-2 -Details of Instruments

S. No	Type of the Instrument	Qty.
1	Strain Meters (SM - 23x5)	115
2	No Stress Strain Meter (NSSM)	23
3	Stress Meter (S)	23
4	Temperature Meter	33
5	Pore Pressure Meter(PP)	33
6	Uplift Pressure Meter	15
7	Load Cell (CC)	7
8	Joint Meter(14 x 3) (JM)	42
9	V Notch for seepage monitoring	12
Total		313

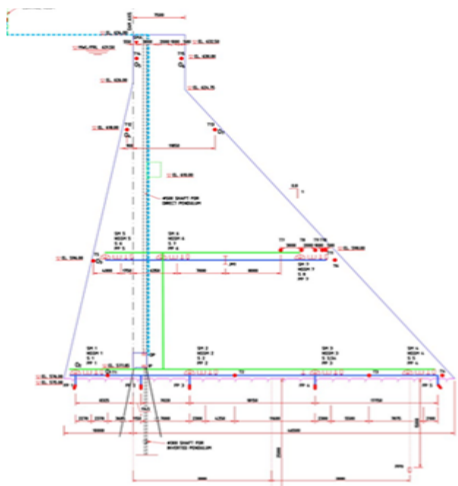

Figure 2: Locations of Instruments installed in Dam Block 4 (Non-Overflow Block)

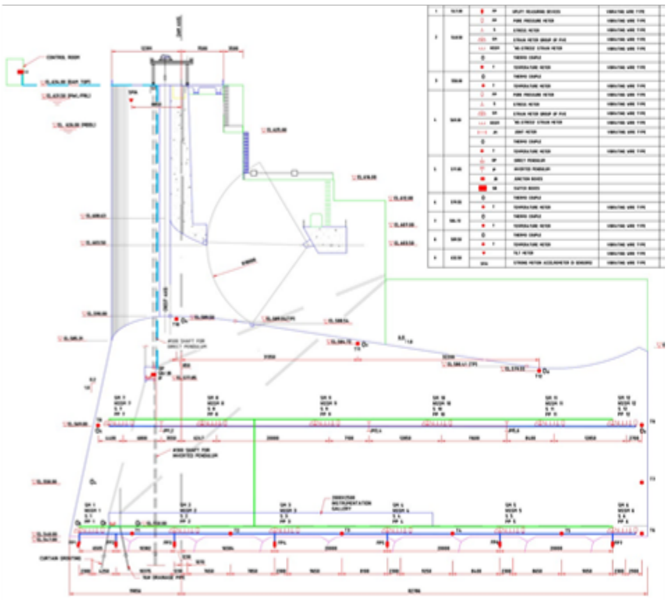

Figure 3: Location of Instruments in Dam Block 8 (Overflow Block)

6.3 DATA ANALYSIS & INTERPRETATION

Some of parameters such as variations uplift, pore water pressure, temperature and joint movement with time along with variation in reservoir water have been explained through graphical presentation in the further paragraphs. The data from the related instruments monitored during its construction and first filling stages as recorded by UJVNL was analyzed subject to limitations of monitored data.

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6.3.1 Measurement of Uplift Pressure

Uplift pressure and its variation at the contact plane of the dam and foundation is an input parameter for the design of gravity dams. Increase in uplift pressure is observed with rise in water level during first filling of reservoir. The uplift pressure data helps the designers to verify the design assumptions and to check that the measured uplift pressure is within the safe limits.

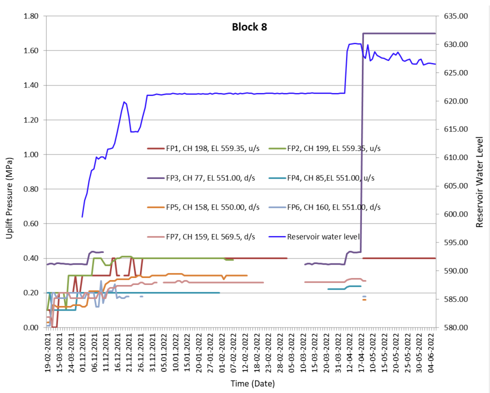

Figure 4: Uplift Pressure variation in Block 8

In figure 4, Uplift Pressure variation in Block 8 indicate maximum and minimum uplift pressures of 0.43 MPa (around dam axis) and 0.18 MPa (near toe of dam), respectively.

6.3.2 Measurement of Pore Water Pressure

Pore water pressure meters are installed in the foundation and dam body for monitoring the pore water pressures developed during first filling and operational stages.

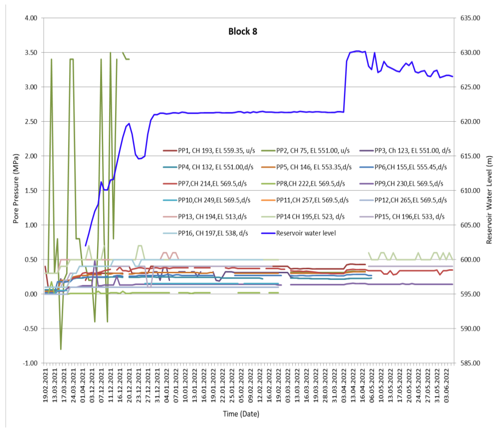

Figure 5: Pore Water Pressure Variation in Block 8

Maximum number of pore water pressure meters (16 Nos) have been installed in central overflow (OF) block 8. Observed pore pressures in this block as per the figure 5 vary from 0.1 to 0.43 MPa.

6.3.3 Measurement of Temperature

Temperature measurement inside the mass concrete is important for concrete dams as it leads cracks from the inside and water entry further propagates the cracks. Mass concrete temperature varies with respect to ambient temperature i.e. reduces during winter and increases in summer season. In addition, temperature of mass concrete is not much affected due to rise in reservoir water level. The maximum temperature rise does not pose any danger towards cracking of the concrete on account of development of thermal stresses in the body of non-overflow blocks as well as spillway blocks.

Temperature meters were installed in Block Nos. 4, 8 and 12 for monitoring the temperature changes in concrete in dam body at different elevations. Figure 6 shows the temperature variation at Block 4. From the figure 6, it is clear that most of the instruments are currently indicating temperature in the range of 20 °C-30 °C.

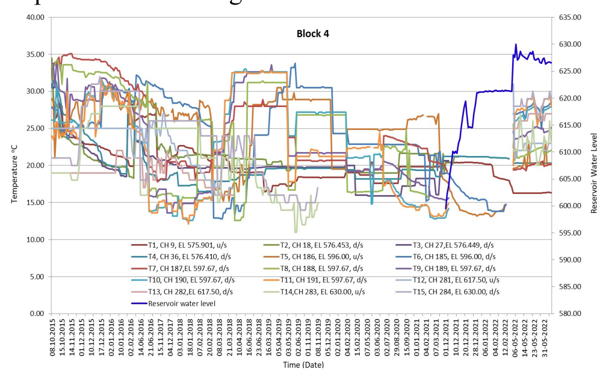

Figure 6: Temperature Variation in Block 4

The instrumented data helps in scheduling of placement of concrete in subsequent lifts in different blocks as the

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next lift is laid once the concrete in lower layer has cooled down.

6.3.4 Measurement of Joint Movement by Joint meters

To know the relative movement between two adjacent blocks, joint meters were installed. Variation in movement between Block 4 and 5 recorded by Joint Meter has been plotted in figure 7.

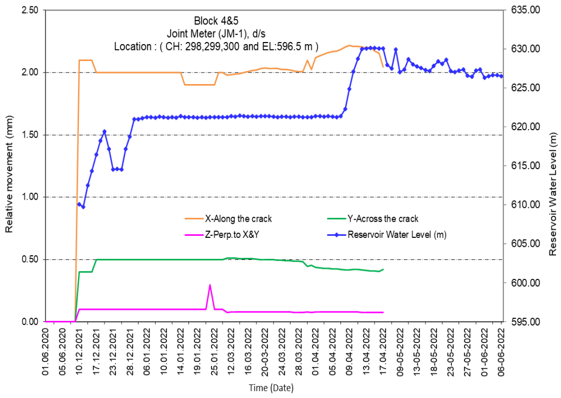

Figure 7: Variation in Movement in Joint Meter between Blocks 4 and 5 (EL 596.5 m)

From the figure 7, it has been seen that maximum relative movement of 2.0 mm was recorded in joint meter installed between Blocks 4 and 5 at EL 596.5 m.

6.4.5 Inference on Data Analysis

Based on the monitoring of various instruments installed at different elevations in dam blocks and the analysis/interpretation of data, the following inferences can be drawn:

1. Monitoring of uplift pressures during first filling is crucial for verifying the design assumptions as well as performance of grouting operations. Barring a few, majority of the vibrating wire uplift pressure meters were found to be working satisfactorily. Maximum uplift pressure of 0.43 MPa was observed near heal of the dam. The measured uplift pressures along the base width of the dam (As per IS 6512) were observed to be within safe limits.
2. In block 8, central overflow block, 16 pore water pressure meters have been installed. Pore pressures in this block vary from 0.1 to 0.43 MPa.
3. The maximum temperature of 38.60^0C has been recorded which reflects the heat of hydration. Most of the instruments are currently indicating temperature in the range of 20^0C-30^0C.
4. Majority of the joint meters are working satisfactorily. None of the joint meters in any block are showing abnormal signs of movement.

7. CONCLUSION

Dams are national assets and their Safety is an area of prime importance and instrumentation is also vital part of Safety Programme. The purpose of the instrumentation program and underlying geotechnical and structural problems that create the need for instrumentation must be clearly defined. The instrumentation program must be so comprehensive and carefully planned to include measurements of all the quantities which are essential in the problem to be studied. Instrumentation is important in all three stages of Project i.e. Pre-Construction, During Construction and Post Construction (Operation Phase). Instrumentation greatly helps in checking the theories used in design and validating them. Such a comparison between prediction and performance become invaluable for indicating the directions in which design principles can be improved and erroneous concepts discarded. 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.

There should be close co-operation between the designers, instrumentation specialist, expert analysis and site authorities to achieve the goal of instrumentation.

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