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ARTICLE

Importance of Instrumentation in Hydropower Projects

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ABSTRACT

With the advancement of science and technology, humans endeavored to build massive structures, both on surface and sub – surface taking the advantage of physico-mechanical properties of the construction materials like concrete, steel, wood, rock, etc. Quality is the standard of something as measured against other things of a similar kind. The term itself is subjective until and unless quantified, cannot be controlled. Instrumentation plays a major role to quantify the quality of materials and check if the resources meet the requirements of the structural design. Several types of instruments are developed and used world-wide in different structures to monitor water pressure, seepage, movements, vibration, temperature, stress, strain and other significant parameters. The role of instrumentation specialist lies in understanding the dominating phenomena in the planned structure, designing the instrumentation network, monitoring schedules and timely analysis for cautioning the engineers, designers, quality personnel and the project management to have a check on construction measures vis-à-vis structural performance. This paper describes the role of instrumentation in hydroelectric projects with a brief case study from Bhutan Himalayas.

1. Introduction

Hydropower or hydroelectricity is the power or electricity generated from the flowing water by using rotating turbines and generators. Based on the scale of power generation, the hydroelectric projects can be grouped as Large (>30 MW), Small (100 kW-30 MW) and Micro (<100 kW). Based on the positioning, the powerhouse can be either on surface or underground. In either case, the designers and execution team must deal with rock mass which is a combination of intact rock along with discontinuities. Rock mass is discontinuous, inhomogeneous, anisotropic, and nonlinearly elastic in nature which differentiates it from other engineered materials. A hydropower project typically consists of a dam, head race tunnel and a power-house where geotechnical issues are to be addressed. It is not feasible to record each and every structural feature in such projects and thus the geotechnical designs usually assume values of various rock parameters and every construction job involving earth or rock runs the risk of encountering surprises. All the possible significant properties and conditions of natural materials required by the designer cannot be detected in advance by exploratory procedures. The assumptions made during initial design phase might vary and the parameters requires to be updated continuously as the rock mass is excavated These properties can only be measured through, field instrumentation quantitatively. Instrumentation becomes a working tool for a geotechnical engineer. Wrong instruments, wrong location, excessive or meagre instrumentation can all be

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dangerous for interpretation. Every instrument installed on a project should be selected and placed to assist in answering a specific question. The engineer or the instrumentation specialist should bring the best knowledge and judgement to bear on every geotechnical problem that arises and should analyze the quality of the information on which a design is based. Trained people, good records and correlations help in taking proper engineering judgement. Use of field instrumentation therefore requires a thorough grounding in geotechnical principles, a detailed conception of the variations that may be expected in the natural or artificial deposit in which the observations are to be made.

2. Instrumentation

Instrument is a tool to measure the engineering parameter and quantify its magnitude. The instruments can be categorized into two categories:

●Used for in-situ determination of soil or rock properties, for e.g., strength, compressibility, and permeability during the design phase of a project.

●Used for monitoring performance during the construction or operating phase of project, may involve measurement of groundwater pressure, total stress, deformation, load or strain.

The use of geotechnical instrumentation is not merely the selection of instruments but a comprehensive step-by-step engineering process beginning with a definition of the objective and ending with implementation of the data. Each step is critical to the success or failure of the entire program, and the engineering process involves combining the capabilities of instruments and people. In Steel and Concrete structures, behavioral characteristics in terms of strength, deformation and thermal properties are known to the designer. An accurate analysis can be made, and design plans and specifications prepared. Then, provided construction is in accordance with those plans. The structure is expected to perform as designed. Whereas in rock mass structures, there are a number of unknown parameters some of which can be determined in laboratory while some in-situ. However, assumptions become an integral part of it. The design of geotechnical construction will be based on judgement in selecting the most probable values within the range of possible values for engineering properties which shall be verified during geotechnical construction through geotechnical instrumentation. The instruments provide data that helps engineers in every stage of a project. Role of instrumentation in different stages of a project is mentioned in Figure 1.

Most geotechnical instruments consist of a transducer, a data acquisition system and a communication system between the two. A transducer is a device that converts a physical change into a corresponding output signal. Data acquisition system ranges from simple portable readout units to complex automatic systems. Various components of an instrument are shown in Figure 2 and the working principle of widely used vibrating wire type of sensor is shown in Figure 3.

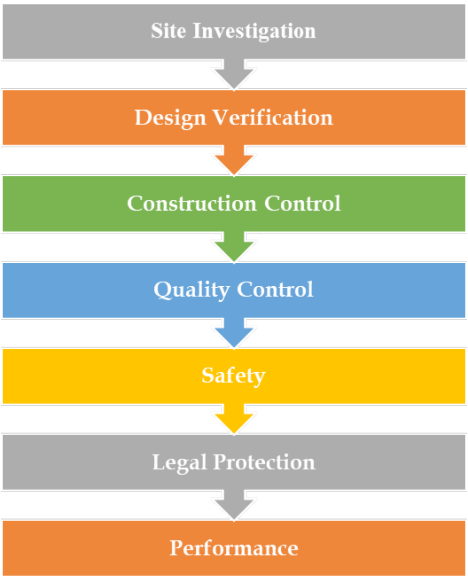

Figure 1. Role of instrumentation in different stages of a project

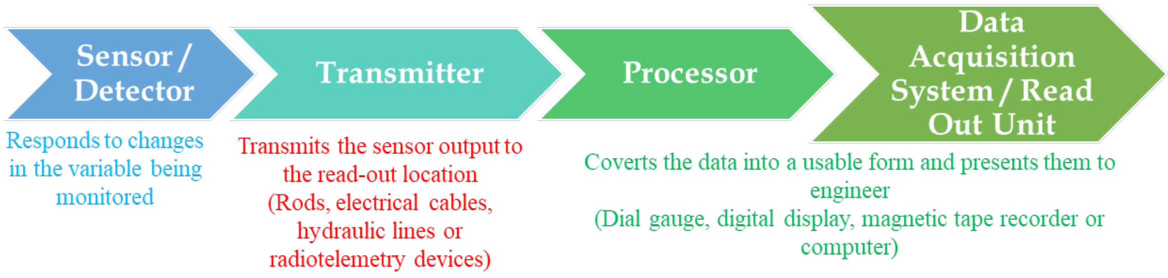

Figure 2. Components of an instrument

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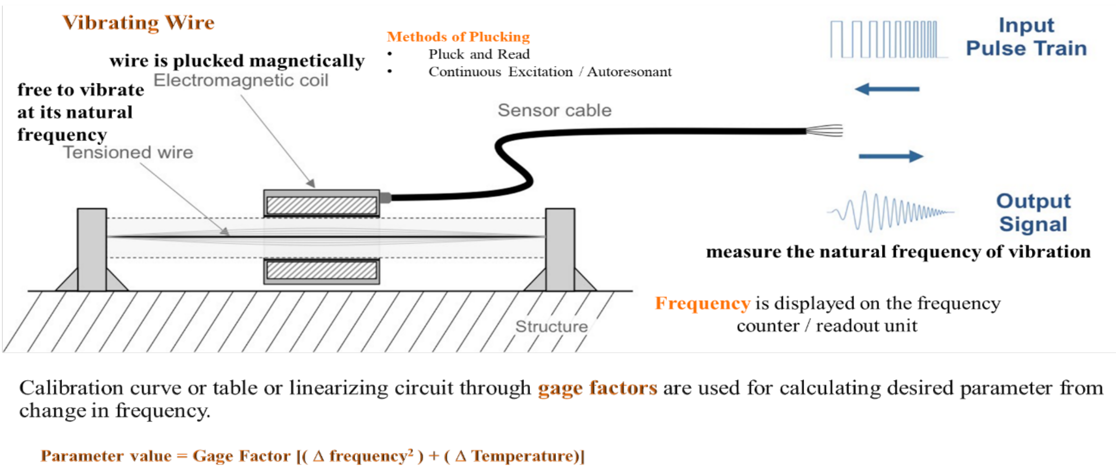

Figure 3. Working principle of a vibrating wire sensor

3. Instrumentation in Hydropower Projects – A Case Study from Punatsangchhu-II Hydroelectric Project, Bhutan

Any hydropower project is cost intensive and involves massive scale of construction activities. Any failure of such massive structure washes away the civilization downstream. Prior to any such catastrophic failure, different signs are shown by the structure itself however, it depends on the experience and alertness of the personnel at site to bring the signs to the notice of the concerned [1]. Sometimes, the change is so gradual that the human eye cannot perceive and with time gets adapted thereby jeopardizing the safety of the structure. Moreover, the personnel may or may not be available round the clock to monitor these changes. It is for these reasons; instruments are installed in structures. The instruments provide valuable data that helps in assessing the structural performance. The hydroelectric project usually consists of a dam or reservoir, conveying tunnels, surface or underground powerhouse structure.

The scale and number of excavations for construction of underground powerhouse caverns have increased tremendously throughout the world, thereby maximizing the utilization of underground space. Excavation destabilizes the surrounding rock mass resulting in development of potentially unstable zones that deforms with time and if not properly treated or supported, leads to progressive failure of the structure itself. All these abnormal behaviour can only be captured from field observations through geotechnical instrumentation [2].

3.1 Dam Instrumentation

Dam forms one of the mega structures in a hydropower project whose stability is of utmost importance. The safety and stability can only be monitored through instrumentation. The primary importance is the collection of data used to judge the safety of a dam. The secondary importance is the information that might help with the structural rehabilitation of a dam and to improvement of other existing dams and the design of new dams. Catastrophic dam failure results in uncontrolled release of the water from the reservoir in huge quantum that will endanger the life and property on downstream of dam. Many historical cases of dam failures were reported where early warning signs of severe problems might have been detected if a good monitoring program had been in place [2][3][4]. Therefore, a good dam safety monitoring program should be a key part of every dam owner's risk management program. Deformation, settlement, water seepage, the diurnal and seasonal changes in reservoir levels, seismic activity and the aging of the structure all affect the health of the dam. Variations in the behavioral characteristics of the structure may be indicative of impending dam failure, and it is the primary goal of the monitoring system to detect such changes. The use of instrumentation as part of dam safety programs is growing as the technology of instrumentation and ease of use improves.

Punatsangchhu-II Hydroelectric Project (PHEP-II) plans for construction of 91 m high concrete gravity dam across Punatsangchhu river in Wangdue dzongkhag in the Royal kingdom of Bhutan [5]. The location of the project is shown in Figure 4. The list of various instruments installed at PHEP-II Dam Complex and their intended purpose of installation are mentioned in Table 1.

A typical longitudinal section along the dam axis, maximum sluice section and the maximum non-overflowing section showing the location of different instruments at are shown in Figures 5, 6 and 7, respectively.

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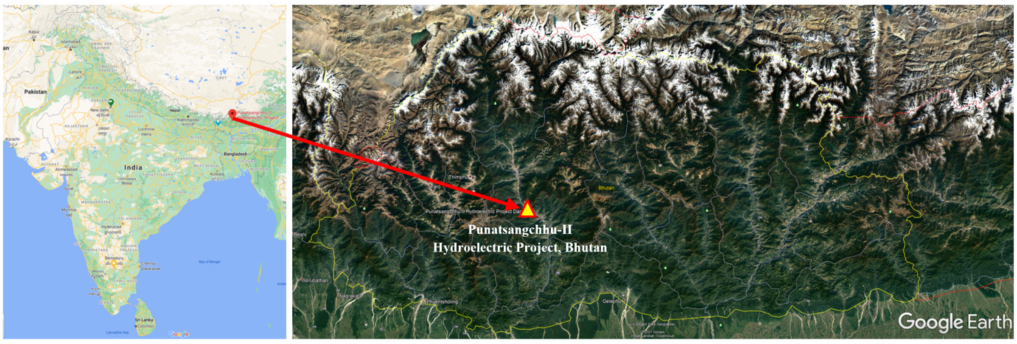

Figure 4. Location of Punatsangchhu-II Hydroelectric Project, Bhutan

Table 1. Instruments installed at dam complex and their purpose

Instrument	Purpose
Uplift Pressure Meter	To measure hydrostatic uplift pressure at the base of a dam due to percolation or seepage of water
Strain Meter	To measure strain / internal movements in concrete
Stress Meter	To determine the magnitude of actual stress
No Stress Strain Meter	To measure strain due to concrete alone without considering the external loads
Piezometer	To monitor pore water pressure
Temperature Meter	To measure temperature of concrete
Direct Plumb Line **Inverted Plumb Line**	To measure the dam movement due to applied reservoir water pressures and temperature changes esp. to monitor verticality of dam
Survey Target	To measure external vertical and horizontal movements on the surface
Multi Point Bore Hole Extensometer	To measure one portion of dam / abutment relative to another portion.
Strong Motion Accelerograph	To measure the vibrations or motion in concrete structure
Tilt Meter	To measure tilt / internal movement of dam
Joint Meter	To measure movements along construction joints
Inclinometer	To measure lateral movements in dam abutments and foundations

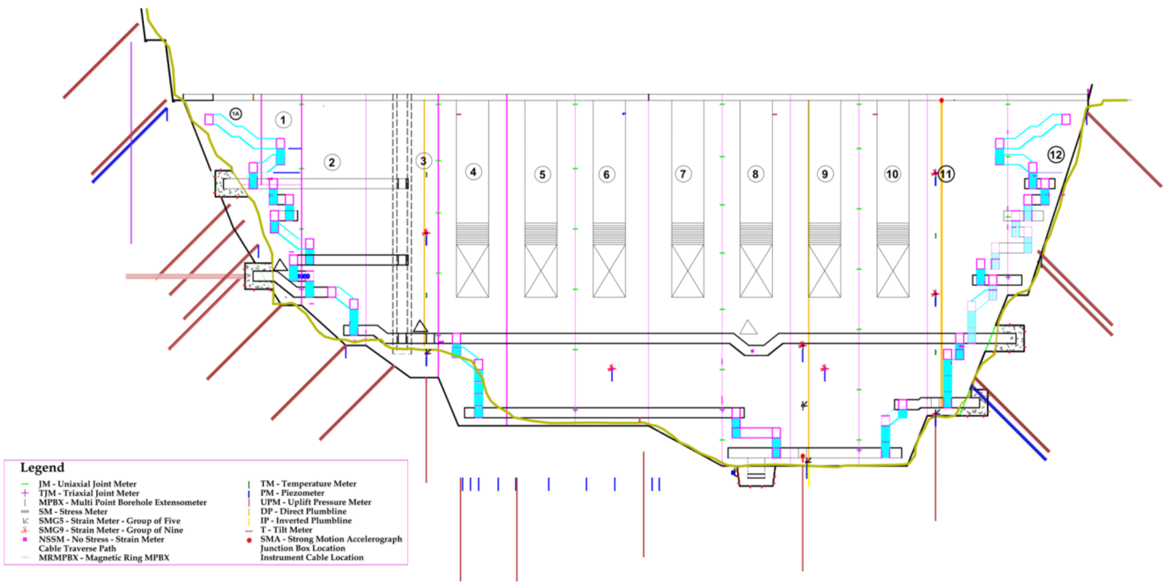

Figure 5. Longitudinal section at dam axis showing location of different instruments at PHEP-II dam (Ref: CWC/INST/PNSC-9810-C-2132(R1)) [7]

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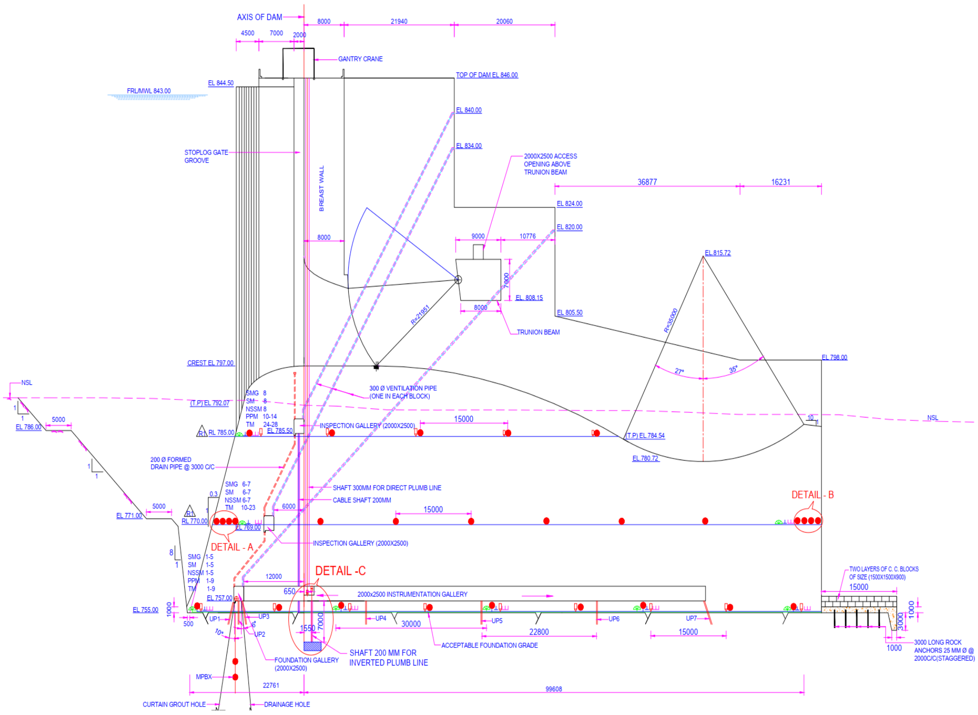

Figure 6. Maximum sluice section showing location of different instruments at PHEP-II dam (Ref: CWC/INST/PNSC-9810-C-2130(R1)) [7]

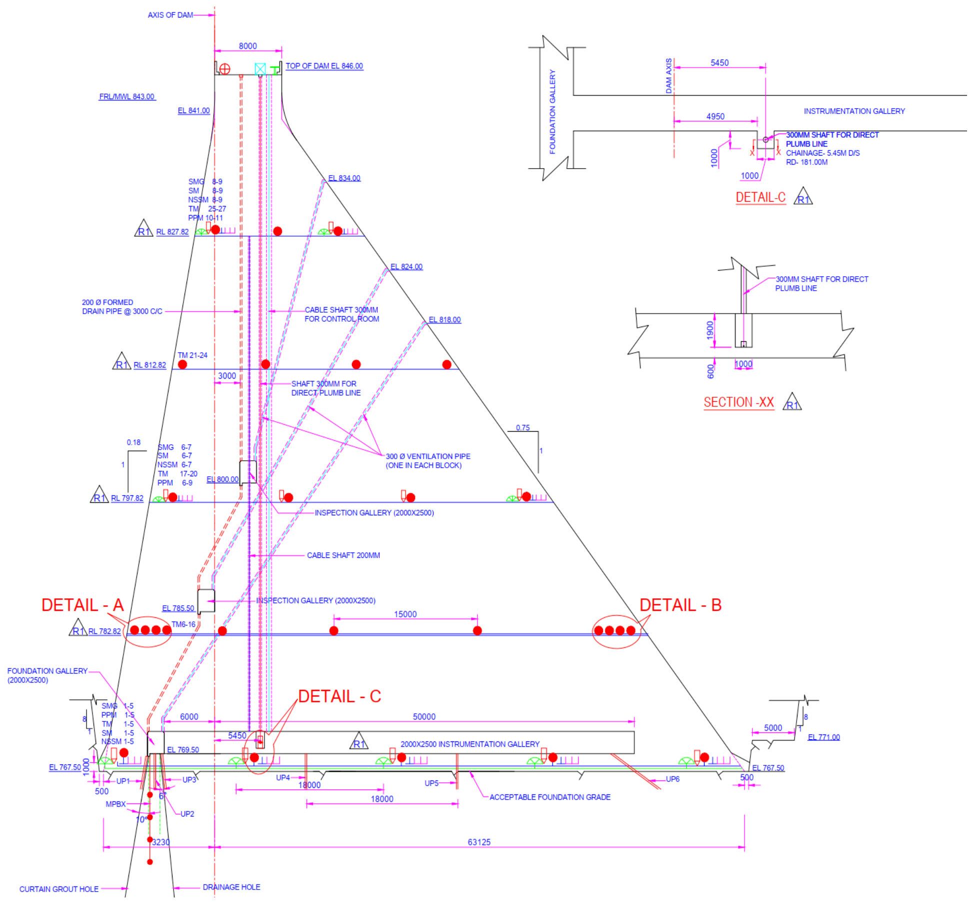

Figure 7. Maximum non-overflow section showing location of different instruments at PHEP-II dam (Ref: CWC/INST/PNSC-9810-C-2131(R1)) [7]

Table 2. Instruments installed at powerhouse caverns and their purpose

Instrument	Purpose
Multi Point Borehole Extensometer (MPBX)	To measure relative displacements, anchors fixed at an interval of 5 m, upto a depth of 25 m
Anchor Load Cell (ALC)	To determine the axial load in the rock bolt
Instrumented Rock Bolt (IRB)	To measure the load in the rock bolt, at an interval of 1 m, upto a depth of 12 m
Vibrating Wire Spot Weldable Strain Gage (SG)	To measure strain in steel ribs
Borehole Stress Meter (SM)	To measure the change in stress in rock mass
Piezometer (P)	To measure pore pressure
Prism Target (PT)	To monitor 3-D surface displacements

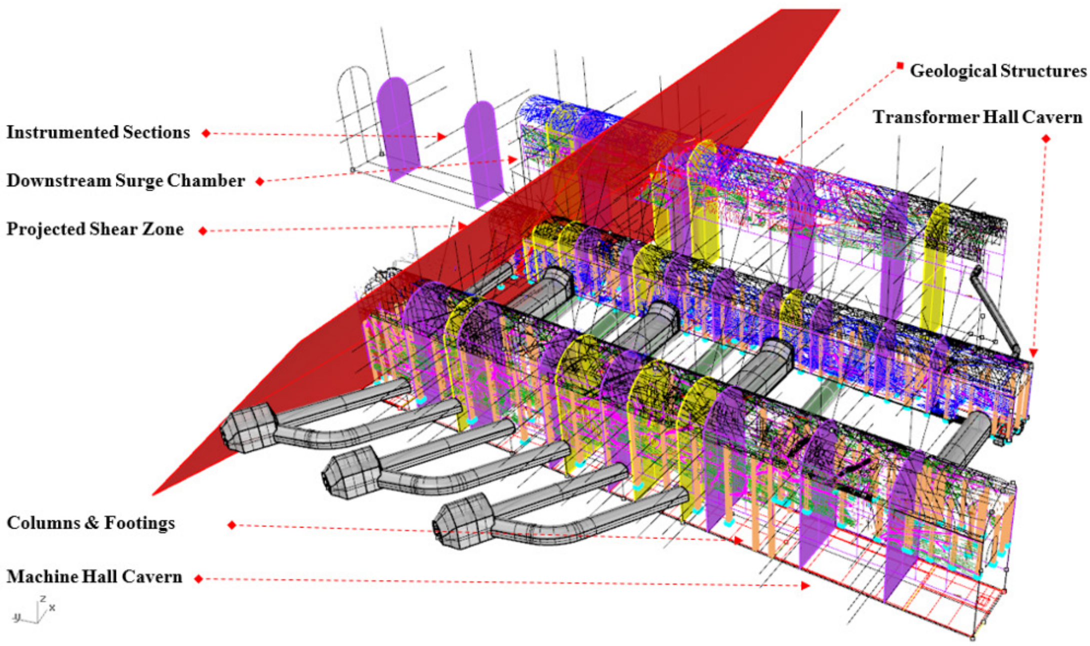

Figure 8. 3-D view of PHC incorporating actual coordinates, civil structures, geological structures and instrumentation layouts (Ref: 3D Instrumentation Model by NIRM) [1][5][8]

3.2 Powerhouse Instrumentation

At Punatsangchhu-II Hydroelectric Project, construction of three major caverns, viz. Machine Hall Cavern (MHC), 240.7 m (L) x 23 m (W) x 51 m (H); Transformer Hall Cavern (THC), 216 m (L) x 14 m (W) x 26.5 m (H) and Downstream Surge Chamber (DSC), 314 m (L) x 18 m (W) x 58.5 m (H) is planned and is under progress [6][8]. The excavations and construction of such mega underground caverns demands extensive network of geotechnical and geodetic instruments installed to alarm the project personnel during any unforeseen incidents. Such instrumentation network needs to be strategically planned, networked, installed, monitored and analysed by the instrumentation specialist pre-during-post construction stages. The list of instruments installed at PHEP-II Powerhouse Complex and their purpose are mentioned in Table 2.

Different instruments like Multi Point Borehole Extensometer (MPBX), Anchor Load Cell (ALC), Measuring Anchor (MA) or Instrumented Rock Bolt (IRB), Strain Gage (SG), Stress Meter (SM), Piezometer (P) and Prism Targets (PT) are installed at different locations in the following components of Powerhouse Complex, PHEP-II:

- Machine Hall Cavern (MHC)
- Transformer Hall Cavern (THC)
- Downstream Surge Chamber (DSC)

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- Butterfly Valve Chamber (BVC)
- Pressure Shafts (PS)
- Bus Duct (BD)

A 3-D view of PHC incorporating actual coordinates, civil structures, geological structures, and instrumentation layout is shown in Figure 8 and a typical cross section of Machine Hall Cavern showing the location of different instruments is shown in Figure 9.

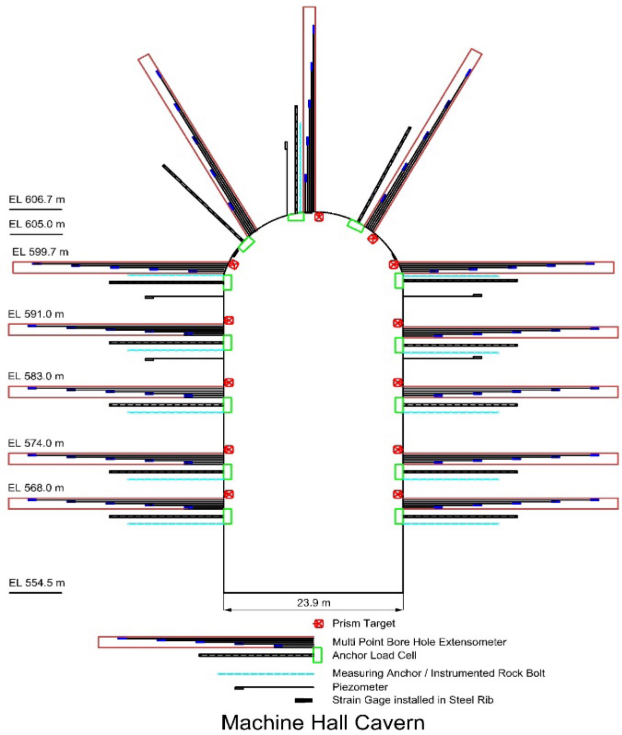

Figure 9. Section showing the location of different instruments in Machine Hall Cavern, PHEP-II [1][5][8]

4. Conclusions

Catastrophic failure of a mega structure in any hydroelectric or geotechnical project imposes a great threat to the life and property. Field instrumentation helps in detecting such abnormal behaviour allowing the execution personnel at site to take suitable remedial measures timely preventing any mishap. Right instrumentation at right location shall yield better results and in order to choose the same. Thorough conceptualization of the structural behaviour is essential. Adoption of right planning, correct specifications of instruments, right installation procedures, scheduled monitoring and timely and rightful analysis will altogether lead to success of any instrumentation program.

Acknowledgement

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