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Role of Instrumentation in Slope Monitoring: A Case Study

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Abstract:- Unstable and high cutting rock slopes are inevitably encountered during the construction of dams, powerhouses, quarries, highways, housing developments works, etc. in the mountainous regions. Monitoring of these slopes through instrumentation and using transmission technology may provide immediate warning to people living in these areas from hazards. Many types of instruments such as extensometers, tilt-meters; inclinometers etc. and their data transmission systems are available for such monitoring. Types/causes of slope failure and need/importance of geotechnical instrumentation have been discussed in this paper. In addition, a case study of slope monitoring of Vyasi dam powerhouse through instrumentation has been also presented.

I. INTRODUCTION

Unstable slopes affect almost every state in all types of geographies, whether the slopes are owned embankments and cut slopes or hazards originating from beyond-the-right-of-way. It is classified into four types:

A. Rotational failure:

- **Face or slope failure:** This failure occurs on the surface of the slope which is passed through the toe of the slope. It happens when the soil is above the toe which contains weak strata.
- **Toe failure**: This is the most common type failure in which the failure plane is passed through the toe of the slope.
- **Base failure:** The failure which is occurred in the weak soil strata and failure plane passes through of base of the slope is called base failure.

B. Translational failure:

This type of failure occurs in an infinite slope (the slope which has no boundaries) in which the movement of the soil is along the level surface. It happens, mostly in the layered material, usually fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between two rock types. They move out or down along a planar surface with little tilting, and can travel great distances.

C. Compound failure:

It is the combination of translation and rotational failure. In this condition, the failure surface is curved at two ends, and plain at the middle portion, and generally, this happens, when the hard stratum is below the toe at considerable depth.

D. Wedge failure:

The wedge failure is also referred to as block failure or plane slope failure and it occurs along an infinite plane. It mostly happens when the wedges and distinct blocks of the soil mass get separated. It is also common when there is a soil layer that has the weak bearing capacity, joints, or fissures and the slope has two different materials.

This is similar to translation failure and the main difference is that the translation failure occurs in the situation of the finite slope only but the wedge failure occurs in both conditions (finite and infinite slopes).

➢ *Some of the major causes are defined briefly as follows:*

- Earthquake.
- Rainfall.
- Erosion.
- Construction Work.
- Geological characteristics.
- External loading.

➢ *Effects of Slope Failure:*

- Slope failure causes landslides that may cause loss of life and properties.
- It reduces the bearing capacity of the soil.
- Damage to the road causes slope failure.
- It significantly affects humans and their lives.

➢ *Prevention of Slope Failure:*

Following measures are taken to preventing the slope failures:

- Proper drainage to reduce the waterlogging and seepage forces.
- Benching
- Terracing
- Build retaining walls
- Rock bolts to maintain the stability of rock.
- Plantation

II. SLOPE MONITORING BY INSTRUMENTATION

The two most important parameters to monitor by instrumentation are ***groundwater levels*** and ***displacement*** those influence the stability of slope. Piezometers allow the determination of ground water levels and extensometers, inclinometers, and tilt-meters allow determination of direction and rate of slope movement an indication of displacement magnitude.

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A. Piezometers:

Piezometers should be considered at sites where frequent groundwater measurements are required (e.g. a site where rapid groundwater fluctuations are suspected or where measurements are required during a critical event i.e. rainfall etc.). Vibrating wire piezometer shows in figure 1, works on the same principle as tuning a guitar or piano (SINCO, 1994).

A steel wire is stretched over a distance. The wire is set to vibrating by "plucking" it with an electromagnetic field. The natural frequency of the wire is a function of the tension in it. By reducing or increasing tension in the wire, the frequency becomes lower or higher. The frequency of vibration can be sensed by the electromagnetic coil and is transmitted to a readout device. One end of the sensing wire is attached to a diaphragm that can be deformed by water pressure entering through a porous tip. An increase in water pressure from elevated piezo-metric levels reduces the tension in the wire by deforming the diaphragm inward. The magnetic coil in the piezometer "plucks" the wire to vibrate it. The wire is plucked using variable excitation frequencies and then allowed to return to its natural frequency. The magnetic coil then acts as a sensor which is used to "count" the number of vibrations. The output signal is then converted into units of pressure or head.

Fig. 1: Vibrating Wire Piezometer

Probe inclinometers, "in-place" inclinometers, tilt-meters, and extensometers can be used alone or in combination to monitor slope movement (Dunnicliffe, 1993).

B. Inclinometers:

It measures angles of inclination from the vertical in two planes oriented at 90° (orthogonal) to each other. The probe senses horizontal deviation between the probe axis and the vertical plane, simultaneously in the 'X' and 'Y' directions.

C. Probe inclinometers:

These require manual operation while the other sensors can be read electronically. The electronic sensors can be coupled with a data logger for automated data collection. These automated systems also can be combined with telemetry to allow remote data collection. Additional programming of the remote data collection system can be used to trigger a warning of critical situations.

D. "In-Place" Inclinometers:

"In-place" inclinometers can detect new movement, an acceleration of movement, and the direction of movement. "In-place" inclinometers are installed in a borehole cased with inclinometer casing. The wiring for the inclinometer can be buried and the boring covered with a locking cap to vandal-proof the installation. The field setup of In-Place Inclinometer is shown in figure 2.

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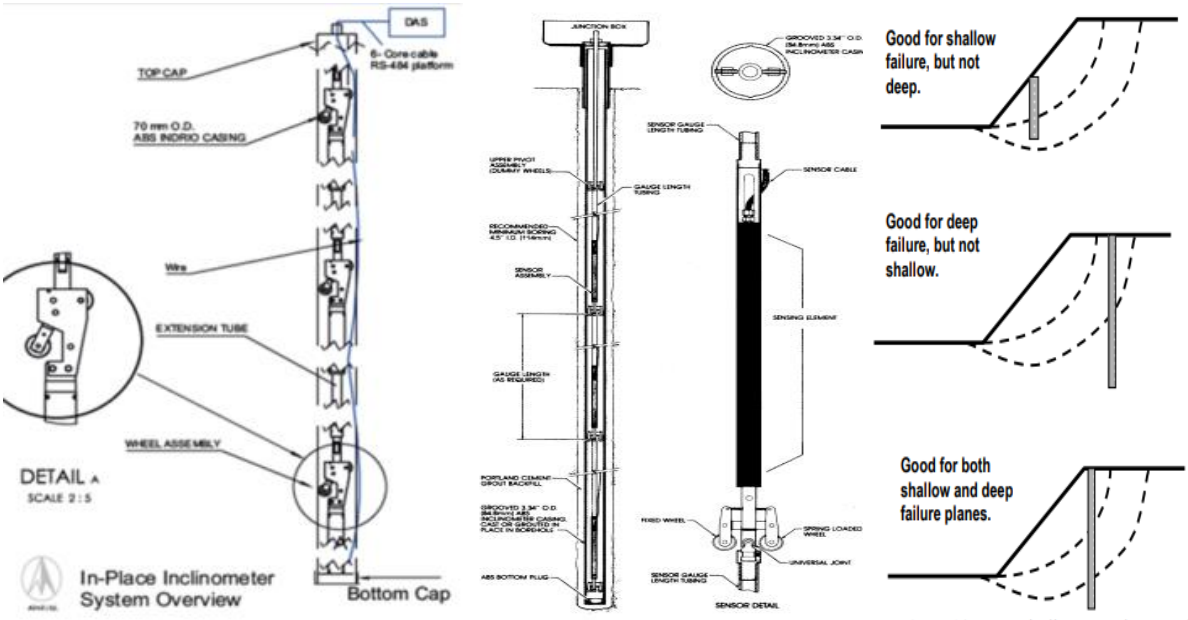

Fig. 2: Field setup of In-Place Inclinometer

E. Tilt meters:

Tilt-meters are also detected new movement, an acceleration of movement, and the direction of movement. Tilt-meters are mounted at the ground surface. They may be portable or fixed in place and they are rapid easy reading device. They are an option for those sites that are too steep for a drill rig or if the project budget does not allow for drilling. Tilt-meters also can be covered with a vandal-proof enclosure and wires can be buried. Details of Tilt meter is shown in figure 3.

Fig. 3: Details of Digital Tilt Meter

F. Extensometers:

Monitor axial movement /deformation in soil and rock at various depths using rods of different lengths with reference to the instrument head shown in figure 4. Simple mechanical extensometers use a steel wireline firmly connected to a fixed location on the slope face on one end and to a track-mounted weight, located off the slide, on the other end. Movement of the slope pulls the weight along the graduated track. The amount and rate of movement can then be measured manually. They are very inexpensive, but critical events can be missed if readings are not taken in a timely fashion. These installations are also susceptible to vandalism and animal damage.

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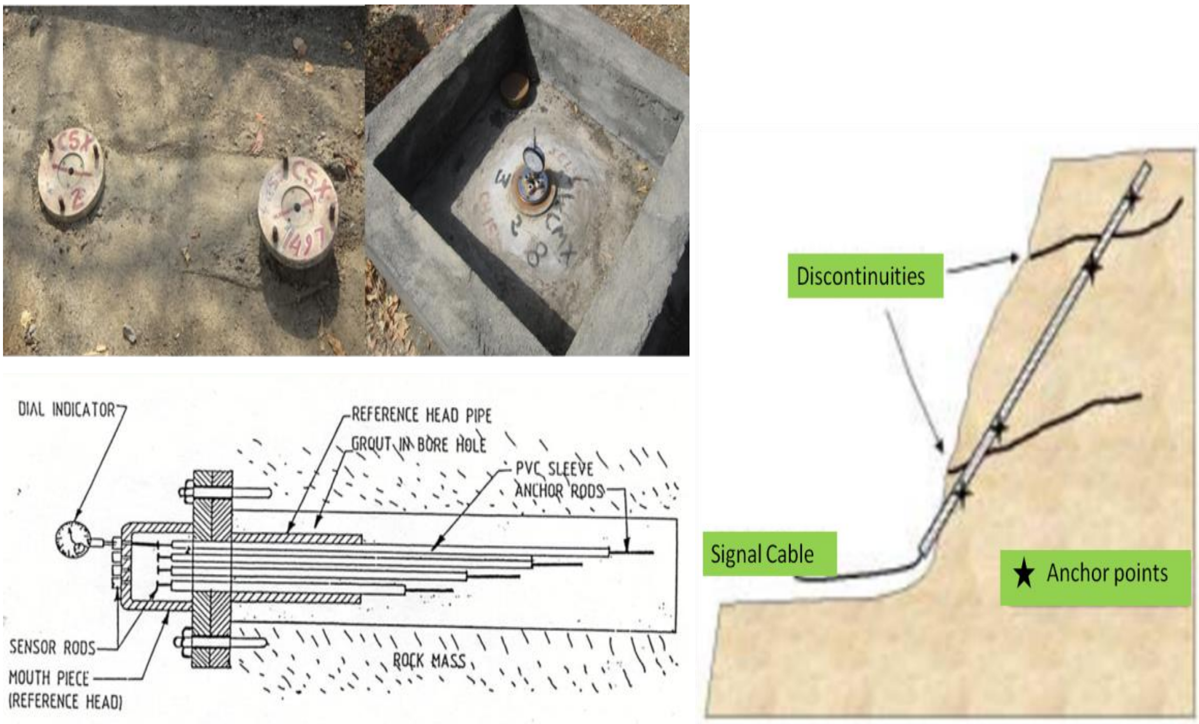

Fig. 4: schematic arrangement of mechanical extensometers

G. Total Station:

A total station is an electronic/optical instrument used in modern surveying. The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point. Total station may also use for the movement of the slope through monitoring some fixed point in a slope. Figure 5 shows the Robotic Total Station with Prism Targets.

Fig. 5: Robotic Total Station with Prism Targets

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III. TIME DOMAIN REFLECTOMETRY (TDR)

Time domain reflectometry (TDR) is a relatively new approach to monitoring slope movement (Beck and Kane, 1996; Kane and Beck, 1994, 1996a, 1996b; Mikkelsen, 1996; O'Connor and Dowding, 1999). Originally developed to locate breaks and faults in communication and power lines, its first geotechnical use was around 1980 to locate shear zones in underground coal mines (Wade and Conroy, 1980).

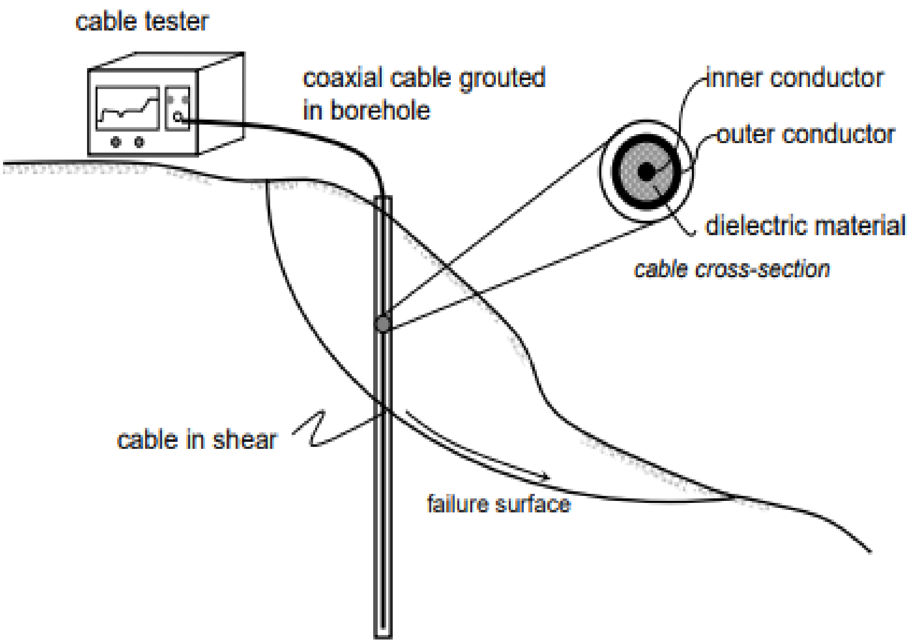

Fig. 6: Components of TDR system for monitoring slope movement

Time Domain Reflectometry is a technique in which electronic pulses are sent down a length of a coaxial cable which has been grouted in a drill-hole. When deformation or a break in the cable is encountered, a signal is reflected giving information on the subsurface rock mass deformation shown in figure 6. TDR cables are gaining popularity and have several advantages over traditional inclinometers (Kane, 1998):

- Lower cost of installation.
- Deeper hole depths possible.
- Rapid and remote monitoring possible.
- Immediate deformation determinations.
- TDR readings can easily be automated.
- Complex installations possible.

Some Disadvantages also:

- TDR cannot determine the actual amount of movement. Relative amounts can Kane and Beck - 6/20 be estimated.
- The direction of movement cannot be ascertained from a TDR signature.
- The cable must be deformed before movement can be located. Simple bending of the cable, without damage, will not indicate any movement.
- If water infiltrates a TDR cable, it will change the cable's electrical properties and may make signatures difficult to interpret.

IV. INSTRUMENTATION CASE STUDY

Vyasi hydroelectric project of 120 (2×60) MW capacity is a run of the river scheme situated on river Yamuna in Uttrakhand. The project consists of powerhouse structures that require stability assessment. It is imperative that long term stability of these structures is ascertained from geotechnical instrumentation program. Due to the project settings in Himalayas, it is anticipated that the project may experience either rock burst conditions or squeezing ground conditions. Therefore, it is important to measure deformation and rock pressure concurrently. The rock pressure measurements started since December 01, 2020 near the power house. Measurements at all the places are continuously observed and their analysis is reported. Total nos. of instruments installed is given in table no.1 and photographs are shown in figure 7 below:

Sr. No	Type of the Instrument	Quantity
1	Inclinometers	06
2	Piezometers	10
3	Load Cells	28
	Total	44

Table 1: Details of Instruments


Surface Power House & back slope


Cables Anchors


Load Cell


Junction Boxes/Nodes

Fig. 7: Photographs of instruments and junction boxes

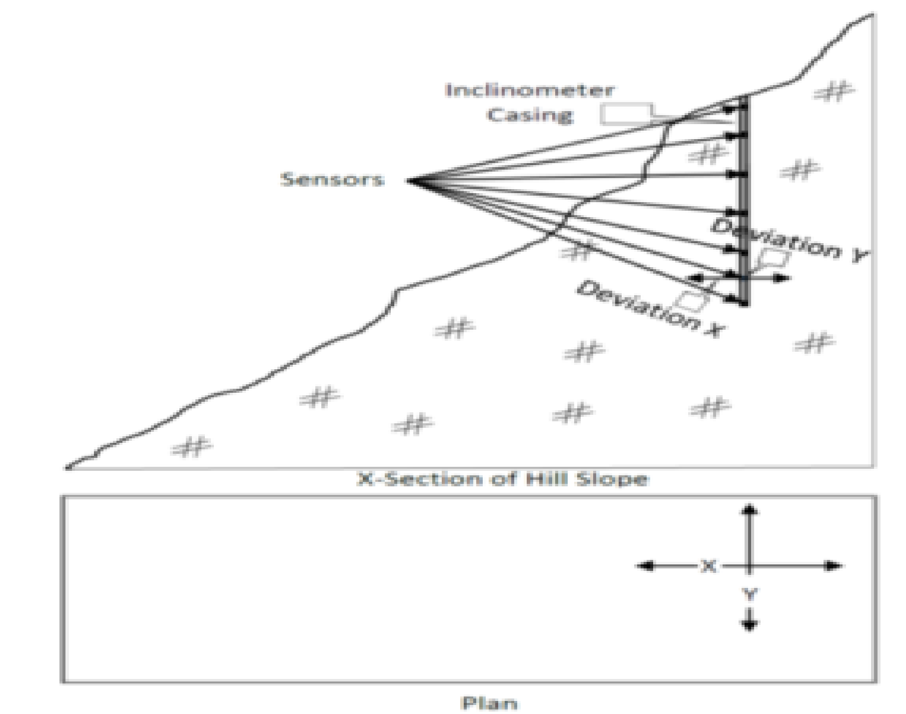

Fig. 8: Schematic View of Inclinometer installation showing in X and Y Directions

V. DATA ANALYSIS AND INTERPRETATION

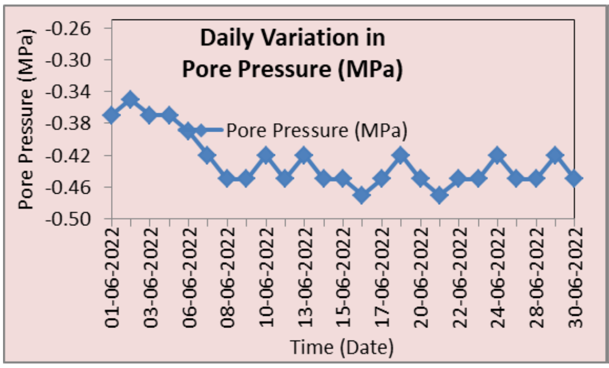

Fig. 9: Daily Variation in Pore Pressure

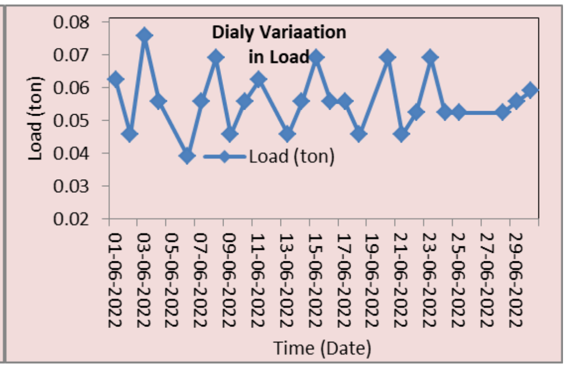

Fig.10: Daily Variation in Load

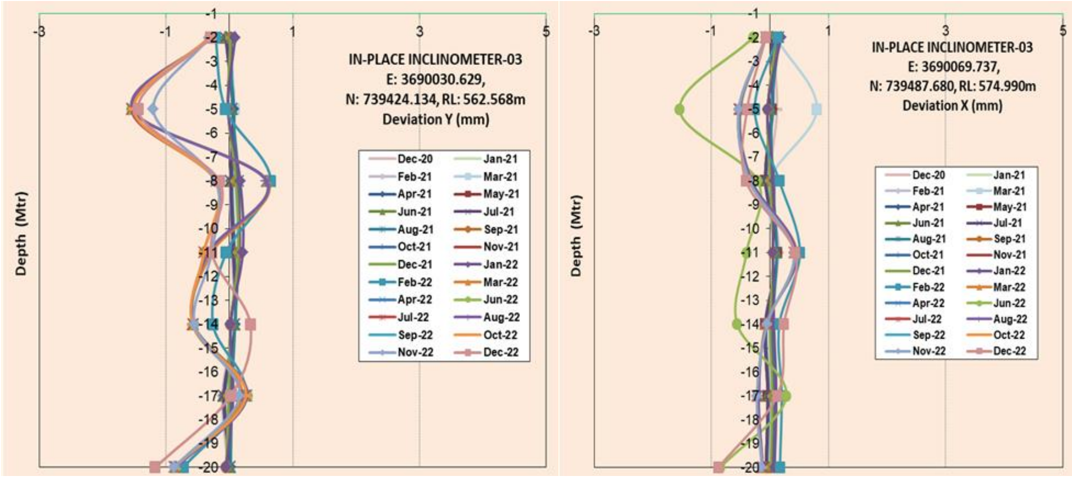

Fig. 11: Cumulative monthly deviations in IPI-3

VI. CONCLUSION

The daily variation of pore water pressure (MPa) of piezometer, load (ton) variation of load cell and monthly deviation with respect of depth of in-place inclinometer is shown graphically in figures 9, 10 and 11 respectively.

As per the geology, folds, faults, joints, and stratified rocks are potential zones for the movement/ deformation and storage of ground water. The pore water pressure is main affecting parameter in case of slope stability analysis. The groundwater level has a major influence on material behavior (drained-untrained), and changes in groundwater level can result in settlements and damage to structures and infrastructure. Geotechnical instrumentation plays an important role in the monitoring of all such parameters like deformation, ground water etc which affects the stability of slope.

It is advisable to monitor the ground water level and movement in the slope area by piezometers, probe inclinometers; “in-place” inclinometers, tiltmeters, and multi point borehole extensometers so that the destruction caused by landslide can be drastically reduced by an effective forewarning above system that can mitigate risks and loss to human lives and infrastructure.

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