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Instrumental Monitoring of Mansa Devi Landslide Site and Interpretation of Data

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Introduction

Landslide has the second rank in the amount of damages due to Natural Hazards. It represents one of the natural hazards with most costly catastrophic events in terms of human lives and infrastructure damage in the world , even if often damages caused by mass movements are addressed to other natural phenomenon such as floods or earthquakes which are their main triggering factors. In hilly regions, landslides constitute one of the major hazards that cause losses to lives and property. A slope failure is developed due to progressive external loads and deteriorations of slope geo-materials. This progressive and dynamic development results in occurrence of landslides. During the last decade, it has been observed that phenomenon of localized severe rain and human intervention such as land development has greatly increased the risk of landslide. Landslide cause damages to infrastructure such as roads and railways and the resulting disruption to transport networks makes a major impact on local communities and finally economies. Therefore to minimize the damage caused by landslide is of paramount importance.

Landslide analysis is too complex involving a multitude of factors which needs to be studied systematically. In general many landslides remain inactive during dry times and move only after infiltration of water for extended periods from rain or melting snow. Increased water pressure in ground reduces the overall strength of soil mass and it starts moving downward, but landslide speed and potential destructiveness can vary widely. Some landslides move very slowly, sliding only a few centimeters in many days. While some landslides can transform suddenly into mud or debris flows that moves thousands of meters in a matter of minutes, causing massive destruction of human beings and properties.

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Instrumental Monitoring and observations of particular landslide will enable to understand physics of landslide & to determine the speed of landslide movement and also to determine early indications of catastrophic movement. Sudden fast movement at some landslides is preceded by gradual acceleration. Using real-time data from such slides, geologists can anticipate possible catastrophic movement.

An Overview of Different Instrumentation Schemes for Landslide Monitoring and early Warning

Close Range Photogrammetry

This technique utilizes non metric reflex digital camera photographs and terrestrial metric photographs to determine landslide susceptibility. A Spanish research group has used this technique to monitor a medium dipping slope of approximately sized 80 x 80 meter & 40 meter high on Jaen-Granada motorway in Southern Spain (Cardenal et al. 2008). The main data acquisition instrumentations used in this technique are reflectorless total station for local coordinate system, non metric digital camera and terrestrial laser scanner. In nutshell this technique is successful for monitoring landslides in a slope up to 100 meter size, but at moderate costs with extensive use of a non metric camera and comparison of Digital Terrain Models (DTM's) evaluated at different dates. Although as main drawbacks, terrestrial Light Detection And Ranging (LIDAR) is a high cost technique with an intensive and cumbersome post-processing.

Optical Fiber Technique

This technique utilizes Optical Time Domain Reflectometry (OTDR) method, which measures the total loss of traveling light and identifies where the loss occurs in the optical fiber. The mechanism works by detecting the amount of backscattering of light and analyzing the time domain of reflected light when the optical fiber is bent due to some cause. A Japanese research group has used this technique to monitor Takisaka Landslide located in Fukushima Prefecture in eastern Japan (Higuchi et al. 2007). This landslide is of approximate size of 2100x1300 meter. Optical sensor for landslide monitoring uses OTDR to detect and monitor landslide displacement which causes bending of optical fiber. These sensors can measure minimum displacement of 1 mm. Although this technique is economic but had given an error of several mm in comparison to adjacent extensometer.

Global Positioning System (GPS) Technique

In the last few years GPS technique has become a very powerful tool for the monitoring of landslide movements. This technique provides a relative easiness in acquisition of data with very high precision and accuracy level of 2 mm in measurement (Zhou et al. 2005, Wan-Aziz and Khamarrul 2003, Ueno et al. 2003, Gili et al. 2000). Measurement of landslide displacements can be undertaken by means of either static or kinematic method. The choice depends on the practical considerations: (i) the accessibility, (ii) number of points, (iii) precision and (iv) distance between two measurement points. In nutshell this technique is successful only for superficial displacement & deformation rate determination. For determining deep lateral movements, which are very much essential in landslide forecasting, conventional instrumentation is also required in combination.

Synthetic Aperture Radar (SAR) Interferometry

Synthetic Aperture Radar (SAR) is a powerful remote sensing system, enabling observations of the Earth's surface day & night, in all weather conditions from airborne platforms and space. Unlike optical remote sensing systems, which rely on the sun for illumination, SAR provides its own, illumination via microwave (radar frequency) transmissions from the satellite. In these transmissions both amplitude and phase information are retained. A phase comparison of the two images via interferometric techniques may reveal subtle shifts in the position of the Earth's surface. This technique is known as Interferometrtic SAR (InSAR). While InSAR is a powerful technique for measuring changes in Earth's surface, it does have limitations. Challenges for operational monitoring of slope instabilities due to the limited spatial extant of the landslide areas and rainy conditions usually associated with mass movement events. These include temporal and geometrical decorrelation, and variable troposphere water vapor, which can generate variable phase delay due to the impact of water vapor on the propagation speed of microwave signals. Various researchers are using different types of interferometric techniques such as Ground Based SAR Interferometry (GB-InSAR) (Antonello et al. 2004, Noferini et al. 2007), Differential SAR interferometry (DInSAR) (Refice et al. 2000, Singhroy et al. 2004), Permanent Scatterer InSAR (PSInSAR) (Colesanti et al. 2003) etc.

Ground Penetrating Radar Technique

Ground probing radar (GPR) is a relatively new geophysical technique that has evolved from radio-frequency soundings of ice to determine depth to bed rock. GPR method is capable of generating valuable information concerning shallow subsurface structure. This technique has been found to be highly site-dependent with typical depth of penetration rarely exceeding 10 m with use of 50 MHz GPR (Bichler et al. 2004). Consequently the role of GPR in exploration is limited. It is best suited to geotechnical or engineering geophysics applications such as the detection of underground cavities, foundation studies and the detection of the water table at shallow depths in sandy soils. An Austrian research group had used GPR technique for assessment of rock fall in Salzburg town (Roch et al. 2006). They had stated that results of repeated measurements have shown that technique is well suited for yielding reproducible results under complex conditions. It is possible to reveal changes with time.

Each technique has its own merits and demerits over each other, so any single technique is not adoptable for every landslide. Conventional instrumentation scheme is much more reliable & accurate for all types of landslides, which has been adopted by Central Scientific Instruments Organisation (CSIO) to monitor the Mansa Devi (Haridwar) landslide.

Mansa Devi (Haridwar) Landslide

The Mansa Devi landslide is located on the Mansa Devi hill slope near Haridwar. This slope is composed interbedded claystone, mudstone and sandstone sequence of Middle Siwalik Formation. The inherent strength characteristics of the rock mass combined with the increased pore water pressure due to continuous percolation of water from the two drainage channels located in the area of landslide is the main cause for the initiation of the landslide. The study area is located on the Haridwar bypass road that joins Haridwar township in the south and the village Kharkhari in the north. Mansa Devi temple is situated about 350 m away at the top of the hill, at an elevation of 470m. This active landslide which started almost a decade ago, completely damaged 300m stretch of Haridwar bypass road and posing a serious threat to all the residential and commercial establishments located at the basement. The slided soil mass has tilted road segment at different locations as shown in Plate 1 and Plate 2.

Plate 1 Slided Soil Mass had Tilted the Road

Conventional Instrumentation Scheme Adopted for Monitoring

To monitor Mansa Devi landslide CSIO, Chandigarh had configured an instrumentation network around conventional geotechnical sensors (some sensors developed by CSIO) and indigenously developed data loggers. A segment of developed instrumentation network was installed in June 2006 to monitor a small area of this slide round the clock , in association with Central Building Research Institute (CBRI), Roorkee. This instrumentation network provides data in real time mode.

Design Approach and Network Configuration

Instrumentation has been designed around modern data acquisition system, advanced signal conditioners, digital data communication links and necessary software. Landslide monitoring system (Hanna 1985, Dunnicliff 1993, Moller et al. 1990, Pennell et al. 2005, Mittal et al. 2008) consists of: i) Field Units (FUs) located within landslide zone; ii) Local control station (LCS) at nearby stable area; and iii) Central Data Recording & Analysis Centre. FUs along with LCS make one independent system for a particular site. Data analysis and interpretation is done at LCS to set various alarms and to detect likelihood of occurrence of any landslide. The network can be expanded to cover fairly large area simply by adding more number of FUs to LCS. Likewise, many independent area specific local networks can be hooked up to a master central recording and processing station via Very small aperture terminal (VSAT) connectivity to form 'National Grid for Landslides Monitoring'.

Plate 2 Road Damaged by Mansa Devi Landslide

FU monitors an identified site area by sensing and collecting data for a number of physical variables responsible for causing landslides in this area. At present only five sensors; Crackmeter, Inclinometer, Tiltmeter, Pressure cell and Rain Gauge are installed. At Field station, indigenously developed Data Acquisition System (Sweet & Matthews 1990, Kapur et al. 2006), records the data sensed by a set of geotechnical sensors, and transmits collected data in automated mode to LCS via optical fiber communication link. In case, failure of communication link between FUs and LCS, data can be retrieved from field station by connecting laptop through serial interface. FU can be expanded at any time by just installing new sensors and connecting them with Data Acquisition System.

In CSIO developed instrumentation network (Figure 1), FUs essentially consist of signal conditioner cum sensor interface unit, 16-bit data acquisition module, optical modem, optical fiber, power supply, solar panels, charge controller, battery pack and sensors namely inclinometer, tilt meter, rain gauge, crack meter, extensometer, piezometer, Pressure cell and load cell. The field unit has been hooked up with PC based control station i.e. LCS to realize a full-fledged landslide monitoring system. All the selected components (cables, casing, sensors and other enclosures) are strong enough to withstand severe environmental conditions of landslide site under surveillance and remain operational round the clock over a very long time without quality deterioration. The installed system was operational round the clock on solar panel and was under observation from June 2006 to March 2009.

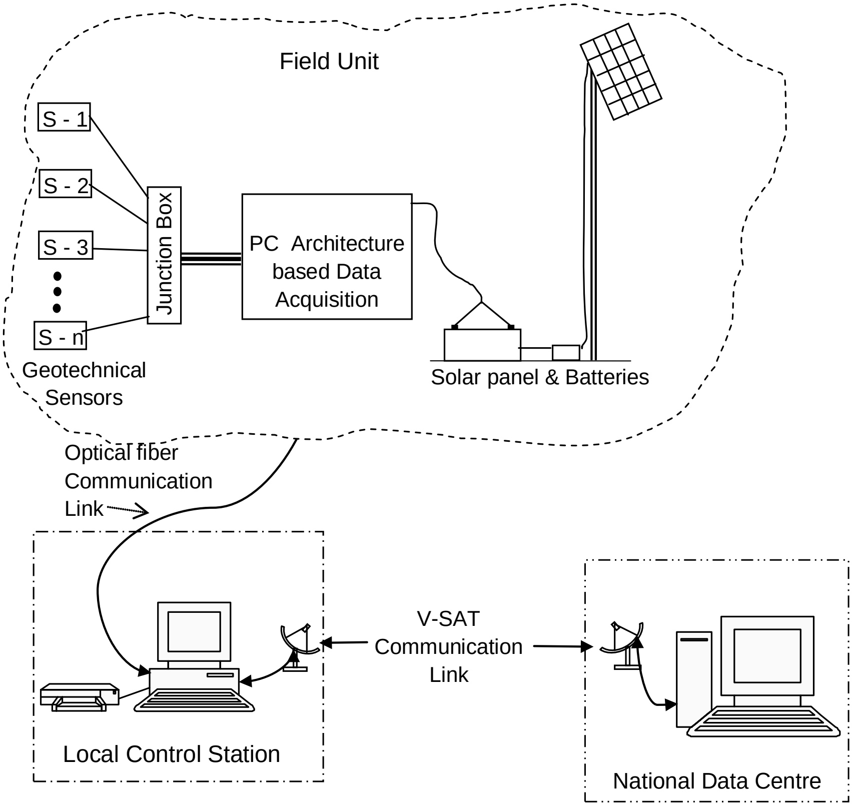

Fig. 1 Block Diagram of Mansa Devi Instrumentation Network

Some of the Important Issues Related to Instrumentation Development, Installation & Sustainability

Environment at the landslide site is usually extremely hostile. The objective in the design & development of the instrumentation scheme is to obtain sufficient information to interpret the site behavior. The judicious use of sensors & instrumentation has an important role to play in understanding particular landslide site. Instrumental Monitoring of slope in the field is always a tedious task. Different types of sensors, equipments & cables are available for landslide monitoring. We have selected instrument with higher resolution, immune to EMI, accuracy and concentrated in a limited region in preference to being spread sparsely over a larger volume. Some redundancy in measurement was to allow for instrument failure, which may occur at installation or be caused by slope movement during the monitoring period. We have provided defence against mechanical damage to sensors, data cables and data acquisition system and to prevent ingress of moisture to all electronic components.

Data cables was carefully labeled and coiled neatly. All the instruments was calibrated & tested before taken to field & great care taken during transportation. Readings was taken prior to and after transport to compare with the readings after installation in the hole and subsequently after grouting the instruments into position. This enabled to check at each step and to identify and correct, where possible, any accidental damage. The positions of all sensors & instruments were accurately recorded and proper care was taken for replacement as installed instrument are usually prone to damage. The most reliable results was obtained when instrumentation was grouted into boreholes as soon after installation as possible and filled from the bottom up to avoid entering air pockets around the sensors. Cable shielding and grounding was taken into consideration the impedances of both the radiating and susceptibility circuit.

Both reliability and maintainability (and hence availability) are performance parameters inherent in the design and operation of the system. Their achievement becomes a challenging design problem whenever the system is required to operate in a hostile environment or for a long period of time, its function requires that system design be very complex with limited maintenance. Typical maintenance actions which include fault diagnosis & isolation, removal and repair of replacement, cleaning & lubrication, securing parts & material & reassembly and check out.

Results & Analysis

Functioning of instrumentation network (Hardware & Software both) designed, developed & installed at the selected site, which is operating round the clock under such an extremely hostile environment is satisfactory. Some minor problems was noted like breakage in wires due to movement of wild animals at the site and blocking of rain gauge due to tree leaves & dust particles etc and that was repaired immediately as the security personnels were in constant touch with CSIO & CBRI. Unfortunately data acquisition system was out of order from 26 Nov 2007 to 19 Dec, 2007 and no data is available for this period. After maintenance & recalibration, data acquisition system was reinstalled on 19 Dec 2007 & new initial data set is obtained.

Net change in the behavior of Inclinometer casing is given in Table 1. This landslide is quite active as superficial deflection in NS axis and EW axis is 24.7069 mm and 62.941 mm respectively. Also the tilt meter has shown net change of 0.667 mm in NS and 0.047 mm in EW direction. (The above analysis of Inclination & tilt is for the recorded data from June 2006 to March 2009). Earth pressure cell was installed at a nearby location to crack meter. A graph of monthly average Crack and earth pressure developed vs monthly Rainfall is shown in Figures 2a and 2b and interpretation of this data is in progress. On the basis of data recorded so far, it is observed that this particular site is still an active landslide site and there is an Inclination in slope & tilt in the surface. However it is found that development of crack & pressure is less at the position of the installed sensors.

Table 1 Net Deflection (mm) in Inclinometer Casing

Depth (m)	Net Deflection in N-S Axis (mm)	Net Deflection in E-W Axis (mm)
0.5	24.7069	62.941
1.0	19.9333	59.012
1.5	16.6659	55.183
2.0	14.195	48.778
2.5	11.5409	42.242
3.0	9.307	35.881
3.5	7.3373	28.151
4.0	4.7293	19.799
4.5	2.249	10.442

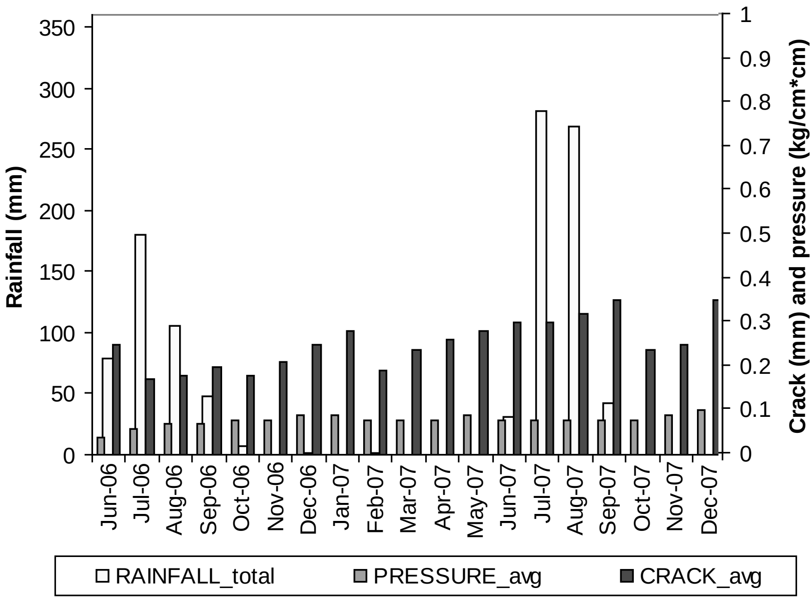

Fig. 2a Plot of Monthly Average Crack and Pressure vs Monthly Rainfall

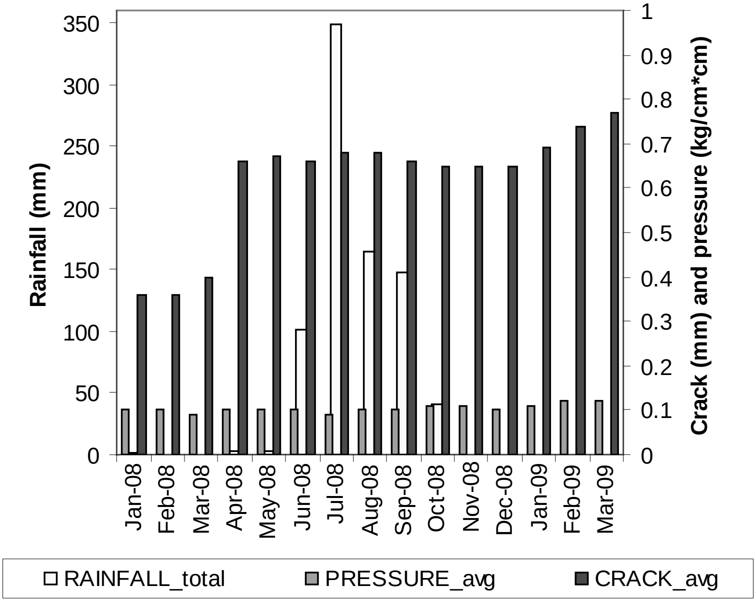

Fig. 2b Plot of Monthly Average Crack and Pressure vs Monthly Rainfall

Conclusion

Initial analysis of recorded instrumental data shows that a decade old Mansa Devi landslide is still active. Further analysis of recorded instrumental data is in progress. This will enable us to develop and early warning system to avoid losses of human life and property. This study also aimed to establish a standard methodology for precise landslide monitoring and provide early warning. The developed system is flexible enough to be easily adopted in other landslide prone areas with minimal modifications. Availability of wireless sensors for Geotechnical applications can be used in future to avoid wear & tear problem of cable in the field.

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