INSTRUMENTATION FOR MONITORING AND MITIGATION OF LANDSLIDES

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ABSTRACT

The effect of landslides is generally well known. What is probably not universally known is that land sliding is a predictable geological hazard and that landslides can be studied scientifically, classified into different types and diagnosed methodically.

Any worthwhile plan for corrective and preventive measures in a landslide or an area susceptible to landslides must be based on a detailed integrated geological and geotechnical investigation. Present landslides or those expected in future require an engineering geologist to exactly evaluate the type of landslide and take corrective measures based on collected data and experience gained in tackling similar problems. The solution should be based on a well thought of working hypothesis taking into consideration cost involved and effectiveness of the efforts put in.

The Paper describes different types of instrumentation used for monitoring and mitigation of landslides. Monitoring of landslides can be both surface and subsurface. Surface monitoring includes proper monitoring by surveying, geophysical and geotechnical instrumentation. In a number of cases, surveying methods will suffice. Surface measurement used to assess stability of slope may include crack meters, tilt meter and multipoint liquid level gages etc. Surface methods to measure development of cracks, uplift and subsidence include repeated conventional surveying and installation of instruments to measure movements directly. Subsurface deformation measurements is required if sliding occurs and depth of sliding is not apparent from surface measurements and visual observations. Critical movements of slopes in rock are often smaller than critical movements of slopes in soil, and require greater accuracy of deformation measurements.

By proper monitoring, corrective action becomes possible much earlier than occurrence of the landslide. By implementing proper drainage for ground water, using anchor bolts and cable anchors at the right places and building retaining walls, it is possible to contain the landslide to a very large extent. In cases where it is not possible to prevent landslide, the data collected will give sufficient time for evacuation.

SOCIETAL RELEVANCE

We watch nature's fury like helpless spectators and eventually institute corrective action including rescue, relief and rehabilitation operations. Such incidences are a regular feature all over the world, year after year. Despite growing scientific knowledge of landslides, their threat continues to increase due to

increasing development in vulnerable terrain & building construction activity, laying new roads, global climate changes that result in violent & severe weather, and deforestation. Landslides and other "ground failures" worldwide cost more lives and more money each year than all other natural disasters combined. A duty to be performed by engineering geologist and geotechnical engineer is to assess stability of a hillside or slope in order to guard people from injury and property from damage. Instrumentation pre-warns us of these imminent disasters. Instruments for effectively monitoring landslide movements are not expensive. The cost is a small fraction of what is spent later on in rescue operations, removing debris and rehabilitation. By implementing a good prediction and forewarning system coupled with effective efforts to control and mitigate landslides, destruction caused by landslides can be reduced by more than 75 % of what would normally occur.

INTRODUCTION

Hills and mountains have been sculptured over years by violent eruptive formations and slow processes of erosion. They are not permanent and everlasting. Surface of the land is made by nature from decay and our fertile plains are formed by ruins of our mountains. Landslides, denudation and other associated processes of erosion have to be accepted as part of the natural process. They are intractable, being a function of time and gravity. They play an essential role in the synchrony by which uplifting continents are continually worn down, their sediments swept away and deposited somewhere else to start anew. They fit well into the perpetual cycle of creation and destruction. During rainy season and sometimes even otherwise, tons of earth gives away down steep slopes causing devastating landslides. The forces of nature are capable of breaking down mountains. We watch nature’s fury like helpless spectators and eventually institute corrective action including rescue, relief and rehabilitation operations. Instrumentation pre-warns us of these imminent disasters.

Despite growing scientific knowledge of landslides, their threat continues to increase due to increasing development in vulnerable terrain & building construction activity, laying new roads, global climate changes that result in violent & severe weather, and deforestation. Landslides and other "ground failures" worldwide cost more lives and more money each year than all other natural disasters combined. Despite their seemingly less impact, landslides probably cost to a nation like India more than Rs. 5,000 million annually in restoration work and economic losses. Nevertheless, the ignorant continue to build and live in places likely to be consumed one day by avalanches of mud.

Every hill side and slope - no matter how gentle - represents a safety risk as under certain circumstances it can give rise to a slide of lesser or greater speed. A duty to be performed by engineering geologist and geotechnical engineer is to assess stability of a hillside or slope in order to guard people from injury and property from damage.

The effect of landslides is generally well known. What is probably not universally known is as follows:

- Land sliding is a predictable geological hazard. Hazardous conditions existing prior to the landslide event give sufficient information to take corrective action in time.
- Landslides can be studied scientifically, classified into different types and diagnosed methodically.

- Slopes safe for centuries may be unsafe today and those that are safe will not be so for ever.
- Landslides may be dormant during dry times. They can become active during or following extended periods of rain or melting of snow resulting in increased ground-water pressure. This in turn, reduces overall strength of slope and induces downward slope movement.
- Most landslides move slowly, traveling perhaps only a few centimeters over many days. Occasionally, a landslide will move rapidly, traveling hundreds of meters in a matter of minutes. It is like starting a car from standstill and accelerating it to full speed.
- In areas prone to landslides, detection of slope movement in early stages and measurement of ground water pressure is not difficult. It requires visual examination and use of reliable instruments to measure displacement and ground water pressure.
- Instruments for effectively monitoring landslide movements are not expensive. The cost is a small fraction of what is spent later on in rescue operations, removing debris and rehabilitation.
- By monitoring slope movement, corrective action becomes possible much earlier than occurrence of the landslide. By implementing proper drainage for ground water, using anchor bolts and cable anchors at the right places and building retaining walls, it is possible to contain the landslide to a very large extent. In cases where it is not possible to prevent landslide, the data collected will give sufficient time for evacuation.

UNDERSTANDING LANDSLIDES

A landslide may be defined as the movement of a mass of rock, debris or earth down a slope, separated from the underlying stationary part by a definite plane of separation. It also refers to the geomorphic feature that results from the slide. Mass movement, mass wasting, slope failure, slope instability and terrain instability etc. are other terms used to refer to landslides. A majority of the landslides originate from the toe; for example, by erosion due to a water stream or washing away of supporting debris by a flowing river. Some landslide failures occur from within the slope. Landslide failures, which originate at the top of the slope, are invariably caused by the imposition of greater loads on the slope surface.

Classification

Landslides may be active, dormant or stabilized. They have been classified in many different ways due to their wide nature and variety. Some of these classifications are country specific, depending upon the geology of the region. For purpose of this paper, landslides have been classified as follows based upon material type and type of movement.

Material Type

The material involved in a landslide is classified into two groups, ’bedrock’ and ’soil’. Soil, which is generally unconsolidated surficial material, is further subdivided into ’debris’ and ’earth’ depending upon its texture.

Type of Movement

Rock falls and topples are associated with steep, near vertical or overhanging natural bedrock cliffs and steep bedrock excavations. Debris & earth falls and topples are associated with steep, near vertical or overhanging natural soil banks or excavations. Slides involve movement along one or more distinct surfaces. Slides are subdivided into 'rotational slides' and 'translational slides', depending upon the shape of the failure plane.

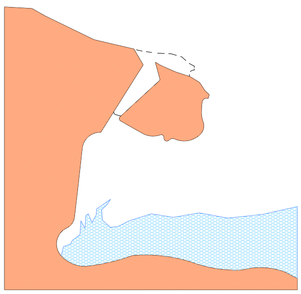


Figure 1 Rock Fall

Figure 2 Topple

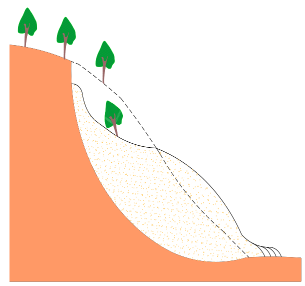


Figure 3 Earth Slump

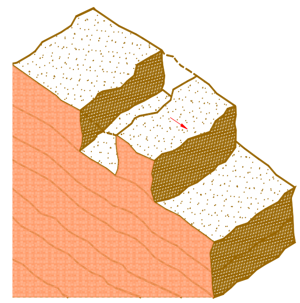


Figure 4 Translational Slide

CAUSES OF LANDSLIDES

Landslides are caused by a combination of various geological, material, geomorphologic, ecological and tectonic factors. Rocks and debris carried by rivers originating in mountains cause enormous landslides in valleys. Seismic activity in mountains also results in considerable landslide movement. On some slopes, heavy monsoon rainfall often in association with cyclonic disturbances, results in considerable landslide activity.

The use of instruments to monitor a hillside or slope can be planned better, if more is known about those factors that cause a slide. The most important of these factors are:

Gravity

On a slope, perpendicular component of gravity tends to hold object in place and the tangential component of gravity tends to push it down by generating a shear stress parallel to the slope. On a steeper slope, the shear stress increases and the perpendicular component decreases. Mass movement consequently occurs more frequently on steep slopes than on shallow ones.

Slope stability is based on interplay between two types of forces; shear stress and resisting forces grouped under the term shear strength. Shear stress promotes down slope movement of material, whereas the shear strength deters movement. When shear stress exceeds resisting shear strength, slope is unstable and results in a landslide. Resistance to down slope movement depends on shear strength of slope material. Shear strength is function of cohesion (ability of particles to attract and hold each other together) and internal friction (friction between grains).

Shear stress component of the driving force due to gravity is affected by:

- Changes of slope angle: These can be natural or man-made (e.g. cuts in the base caused by water erosion or excavations). Occasionally, tectonic processes may also result in a steepening of the slope.

- Change of slope height: Vertical erosion or excavation work leads to a loosening of rock and formation of fissures parallel to the slope, making it easy for surface water to penetrate the hillside.

- Loading existing slopes: Ground movements may be reactivated by construction of a building or road over an old slide area requiring placement of several hundred thousand cubic meters of fill.

Water

Water plays a key role in slope failures. Consider building a sand castle on a beach. In case sand is totally dry, it is impossible to build a steep face like a vertical wall. However, if sand is somewhat wet, it may be possible to build a castle wall. In case sand is too wet, it will flow like a fluid making it almost impossible to build anything.

Water saturated soil

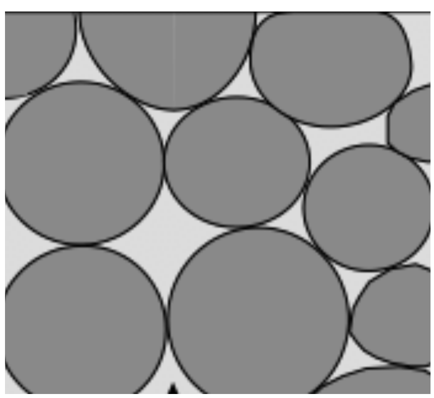


Figure 5 - Pore spaces saturated with water and soil held in place by friction between grains

Liquefaction

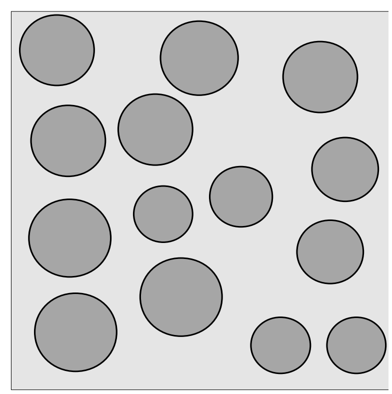


Figure 6 - Soil flows like fluid as grain to grain contact eliminated due to water surrounding grains

Liquefaction can occur as a result of ground shaking, heavy rainfall, melting of ice or snow or by slow infiltration of water into loose sediments and soils. Amount of water necessary to transform sediment or soil from a solid mass into a liquid mass varies with type of material. Clay bearing sediments in general require more water because water is first absorbed onto the clay minerals, making them even more solid-like. More water is then needed to lift the individual grains away from each other.

Weathering, chemical effects and troublesome earth materials

Both mechanical and chemical weathering may lead to landslides by reducing the cohesion of bed rock and soil. Mechanical weathering, for example by wind, results in progressive erosion over years. High velocity wind causes loose sandy soil and boulders to slide down slopes, also resulting in high content of dust and silt in air. Chemical weathering of clayey rock through hydration and ion exchange lead to many landslides.

TRIGGERING EVENTS

Some triggering events that cause a sudden instability to occur are listed below:

- Sudden shock, such as an earthquake may trigger slope instability and even liquefaction. Earthquakes are one of the most potential landslide inducing agents. Seismo-tectonic activity results in crustal movements along faults, folds and flexures and together with effect of gravity may cause havoc. India lies in a very active tectonic activity region with the Indian plate pushing into the Eurasian plate at the rate of around 2-4 cm per year.

- Vibrations such as produced by blasting or operation of heavy machinery can disturb slope equilibrium due to brief changes in rock stress. Vibrations change intergranular bond in loess and sand, reducing cohesion.

- Many of man's activities are directly or indirectly responsible for landslides. Construction of roads is a process directly responsible for landslides, as it involves blasting large chunks of mountainside away to make roads.

- Slope modification either by humans or by natural causes can result in changing the slope angle so that it is no longer at the angle of repose. A mass-wasting event can then restore the slope to its angle of repose.

- Heavy rains can saturate soil reducing grain to grain contact, thus triggering a land slide event. Heavy rains can also saturate rock and increase its weight. Changes in groundwater system can increase or decrease fluid pressure in rock and also trigger mass-wasting events.

- Undercutting by streams eroding their banks or surf action along a coast can make a slope unstable.

- Volcanic eruptions produce shocks like explosions and earthquakes. They can also cause snow to melt or empty crater lakes, rapidly releasing large amounts of water that can mix with soil to reduce grain to grain contact and result in debris flows, mudflows and landslides. Examples are mudflows and debris avalanche produced by the 1980 eruption of Mount St. Helena and the devastating mudflows that killed 23,000 people in Armero that resulted from an eruption of Nevado del Ruiz volcano in Columbia.

- If rock bolts or cables have been installed for slope reinforcement, loss of tension in them can trigger instability. Consequently, general practice in Europe is that one out of every ten rock bolts or cable anchors used for slope reinforcement is instrumented with a load cell. Geotechnical measurement on hillsides and slopes are aimed at monitoring and quantifying as many of the above sources of destabilization as possible.

INSTRUMENTATION

In general, there are four options available in landslide prone areas:

- Do nothing and resign to inevitability of slope failure and eventual destruction caused by it.

- Monitor slope to detect any sign of instability. Remedial measures can then be instituted before alarm conditions are generated.

- Stabilize slopes that need corrective action.

- In case it is necessary, devise a monitoring program to verify that stability of slope is achieved.

Investigation of landslide prone areas

Following approach is recommended:

- Aerial reconnaissance of the mountain terrain to determine places involving habitat, structures, existing road & rail routes, communication channels and where future development is planned.

- Survey area so earmarked and build database pertaining to landslides and landslide prone areas. Prepare suitable topographical maps by aerial photography, global positioning system (GPS) and surveying instruments like total stations, electronic distance measurement (EDM) and theodolites. Simultaneously, carry out test borings, sampling of rocks, mapping of ground water levels and geophysical measurements.

- Once landslide hazard zones are demarcated, monitor stability of hillside from its appearance and knowledge of bedrock. Regular visual observations play an important role. An instrument too often neglected and overlooked is the human eye. Generally certain signs will indicate that a slope is moving, even though slowly. A large number of slides occur and cause devastation even before experts look into it.

Surface monitoring

In case of any signs of deformation, take corrective action. This includes proper monitoring by surveying, geophysical and geotechnical instrumentation. Surface measurement used to assess stability of slope may include:

- Surveying method including aerial photography

- Crack meters

- Tiltmeters

- Multipoint liquid level gages

In a number of cases, surveying methods will suffice. Surface methods to measure development of cracks, uplift and subsidence include repeated conventional surveying and installation of instruments to measure movement directly.

Deformation on surface of entire slope indicates existence of instability. Surveying methods include aerial photography, theodolite surveys and electronic distance measurement (EDM). For slopes in rock, tiltmeters on critical blocks provide assessment of stability if deformation has a rotational component. Creep meters with invar wire or crack gages may be used to monitor movement on hillsides, especially at existing visible cracks.

Land sliding over large areas is effectively determined by air photos. Satellite images are helpful in identifying large landslides and noting changes in soil and vegetation cover associated with land sliding. Conversion of landslide extent from photos to digital database permits easy measurement of changes in landslide areas.

Subsurface monitoring

Subsurface deformation measurement is required if sliding occurs and depth of sliding is not apparent from surface measurement and visual observations. Measurement of subsurface horizontal deformation and groundwater pressure will normally be required. Measurement of subsurface horizontal deformation is more important than measurement of subsurface vertical deformation. For providing basis for effective safeguard, install monitoring instruments that can identify mechanism of movement and any time-related change of stability-affecting factors.

Critical movement of slopes in rock are often smaller than critical movements of slopes in soil, and require greater accuracy of deformation measurement. Fixed borehole extensometers, installed from the face of the slope following excavation of a rock bench, may therefore be selected for monitoring subsurface horizontal deformation of slopes in rock in preference to inclinometers. For slopes in soil, inclinometers are the instruments of choice.

Instrumentation may be required for monitoring reinforcement or other methods of slope stabilization. For slopes in rock, comprehensive structural geologic mapping will indicate critical discontinuities. Particular attention should be given to persistent, adversely oriented joint sets, to possible low strength zones, and to continuous features such as faults and shears at the top of the slope that could allow release of potentially unstable blocks and wedges.

General instrumentation scheme

Note that any instrumentation scheme depends upon the site and is determined by investigations conducted in landslide prone area.

A variety of instrumentation is today available in the market for effectively monitoring of landslides.

Instrumentation and accessories generally used in landslide monitoring are as follows (refer to figure 7):

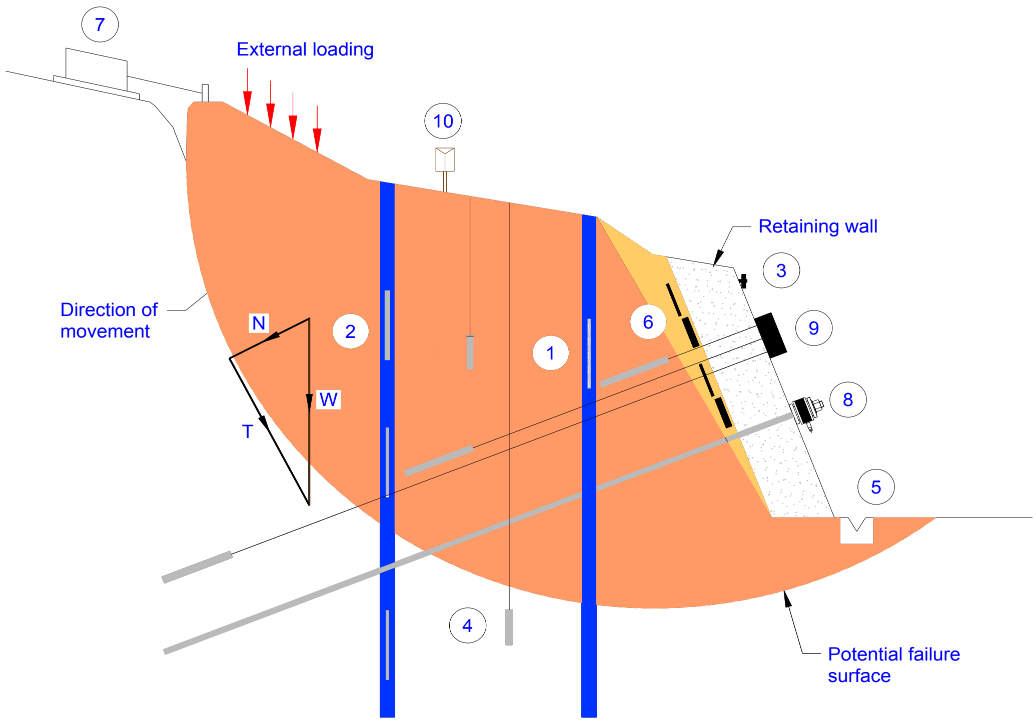


Figure 7 – Landslide general instrumentation scheme

1 Inclinometer system	Monitoring lateral movement - inclinometer system having a probe with two precision accelerometers and data logger. It can also be used with magnetic extensometer system to enable measurement of movements in x, y and z directions.
2 In-place inclinometer	Continuous monitoring of slope stability - In-place inclinometer system.
3 Fixed tiltmeter	Monitoring of tilt on retaining walls or rocks that may topple - tiltmeter.
4 Piezometer	Monitoring of ground water level - vibrating wire or Casagrande piezometer or standpipe with dip-meter water level sounder probe.
5 Flow measurement	Monitoring of seepage – Manual or electronics seepage measurement.
6 Stress meter	Monitoring of stress on interface of soil/concrete or soil/rock - Interface pressure cell.
7 Crack meter	Monitoring of displacement/opening in cracks – manual or electronics
8 Centre hole load cell	Monitoring of tension in anchor.
9 Borehole extensometer	Monitoring of movement inside a slope at various depths - Multi-position bore hole extensometer.
10 Rain gage	Monitoring of rainfall - Tripping bucket rain gage.

11 Read out logger — Vibrating wire and other read-out loggers with data storage capacity with date and time of taking readings

12 Data acquisition system — With or without online web based data monitoring

Advancement in instrumentation

Several advancements have taken place in the last few years in instrumentation used for landslide monitoring. A few of them are discussed below:

Inclinometer system

The most common method of monitoring sub-surface horizontal ground movement is with a traversing type inclinometer system. The operator records the borehole profile with a bi-axial inclinometer probe at 0.5 m intervals on a proprietary read-out logger specific to the manufacturer. At the end of the day the operator goes to a central location, downloads the data to a host computer (PC) which adds it to a database and processes the readings to yield a vertical borehole profile. Finally the PC software computes the difference of the current profile from a reference profile logged at an earlier date and presents the result to the user. This approach prevents the logged data to be monitored in near real time as the operator has to physically go to the central location and download the data.

The mobile phone has changed all that. A newer inclinometer with a digital sensor offered from a manufacturer can work with Android operating system based mobile phones. The data transfer between the inclinometer system and the mobile phone is through a blue tooth connection.

Picture 1 – Data on mobile phone from digital inclinometer

The mobile phone having an 8 GB memory is virtually capable of storing historical data for a large number of boreholes in the phone itself. The operator can see different types of plots for logged data and compare data with all earlier logged data in both tabular and graphical form. Once operator is satisfied that borehole has been correctly logged he can e-mail or transfer the data over the GSM/GPRS network to the central server immediately where it can be published over the internet within a few minutes.

Other advantages in using the mobile phone are:

- Allows the operator to photograph any significant development or accident that can affect or cause an unexpected change in the sensor reading and send it in real time to the central monitoring station.

- With the in-built GPS receiver of a higher end mobile phone the operator can determine the sensor location without requiring help of a surveyor.

- The video clip recording facility of the mobile phone allows the operator to record the installation of sensors if desired. The video clip can serve as a record of the actual method followed to install the sensor, or can serve as a training video for other installation personnel.

- If a proprietary readout unit developed a fault, the unit had to be returned to the manufacturer for repairs that took a lot of time. With mobile phones the user only needs to get another mobile phone and load the application software supplied by the sensor manufacturer. The memory card from the old phone can simply be transferred to the new phone and all the earlier data would be available to the user again.

- As mobile phones are mass produced devices they have many more features and cost much less than proprietary portable readouts and dataloggers used earlier. Use of mobile phones with standard operating system like Android allows users to choose from a wide variety of phones from many different manufacturers around the world.

In-place inclinometer system

The inclinometer system described above is used for taking data at specific intervals of time. Using the mobile phone as a read-out device, the data can be processed and made

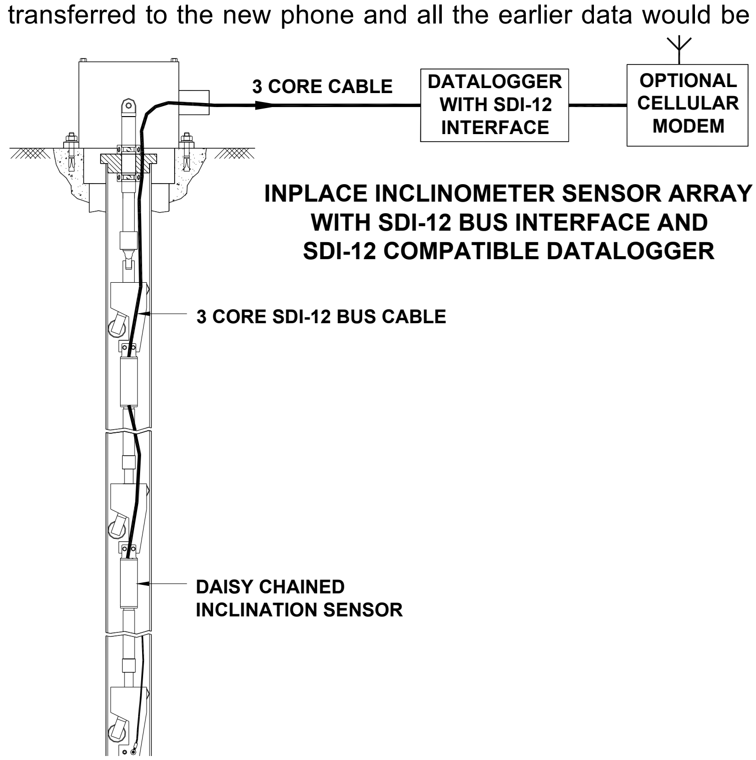


Figure 8 – IPI Schematic

available to the user within a few minutes of the data being taken. However, in a number of applications, the data requires to be monitored online continuously. This requires use of in-place inclinometer sensor chains in boreholes.

In-place inclinometer system consists of a string of inclination sensors which is positioned inside a precision four groove inclinometer ABS casing to span the movement zone. When ground movement occurs, it displaces the inclinometer access tubing, causing change in the tilt of the in-place inclinometer sensors. This results in change in output of the sensors, proportional to the tilt i.e., the angle of inclination from the vertical. The sensors can be connected to a data acquisition system for continuous real-time monitoring of the movement.

Picture 2 - IPI Chain

In most in-place inclinometer systems, there is a six core cable coming to the top of the borehole from each sensor. Therefore, in case 15 sensors with a gauge length of 2 m were placed in a 30 m deep hole, it meant 90 cores coming out of the borehole. This is unwieldy. A multiplexer is used to connect the sensors to the data acquisition system.

In a new system, each in-place sensor is equipped with a SDI-12 interface so that only a single 3 conductor bus cable needs to be threaded in a daisy chain fashion connecting each sensor to its next immediate neighbour and finally to the top of the borehole and directly to the datalogger. A single cable can be used to connect from 10 to 25 sensors.

SDI-12 bus cable from different IPI boreholes can also be connected to same datalogger with some limitations.

In the SDI-12 system, the analog output from the sensor like voltage, current, resistance is replaced by a digital output. The analog output sensors experience loss of accuracy when the output signal needs to be transmitted over long cable lengths. As the digital sensors provide a numeric output to the data collecting device, the accuracy of the output signal never gets degraded irrespective of the distance between the sensor and the data collection device.

The SDI-12 digital sensors store the calibration parameters inside the sensors and output the value of the measured parameters directly in terms of suitable engineering units which was not possible with analog output sensors. Moreover, each SDI-12 in-place digital sensor has a unique address. When addressed, communication takes place on the bidirectional serial data line between the particular SDI-12 sensor and the datalogger. No multiplexer is therefore required for communication between various sensors and the datalogger.

Bus Multiplexer

Generally, cables from sensors in a typical instrumentation network are terminated in a central data acquisition system (DAS). The output of the sensors are measured by the DAS using multiplexers which connect the output from the individual sensors one by one through a single cable to the DAS input. Most current generation DAS after measuring the sensor output would mathematically compute the output in terms of suitable engineering units and store the result in its internal memory. The contents of the DAS internal memory is then retrieved by a PC which displays the measured values as a set of tables or graphs in a suitable format.

The traditional method requires that each and every sensor be connected to the central DAS using individual copper cable with at least two conductors at the minimum. A large number of sensors thus require a large number of conductors between the sensor and the DAS.

The multiplexers are generally installed in the DAS itself. Instead of providing all the multiplexers required by the DAS at a central location, the use of bus multiplexer allows the multiplexers to be placed nearer to each cluster of sensors. The output of the bus multiplexers can then be connected to a single eight core cable that is finally connected to the central DAS. A typical schematic is illustrated in figure 9.

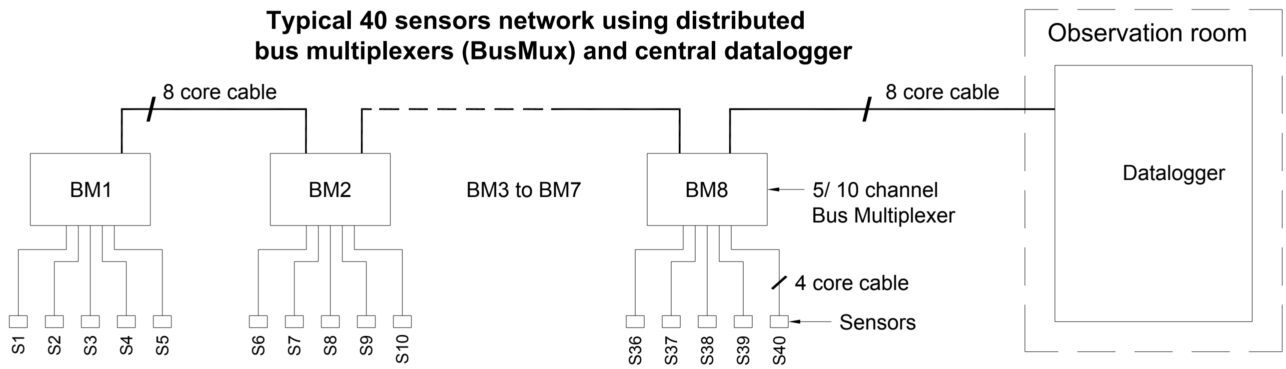
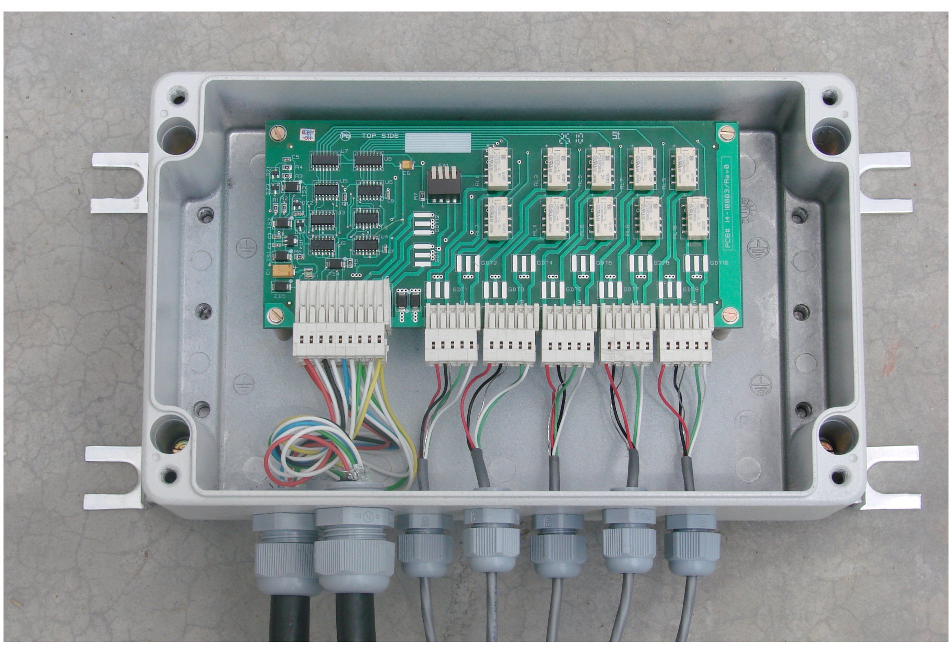


Figure 9 – Several Bus Multiplexers connected through one 8-core cable to the Central DAS



Picture 3 – A field mounted Bus Multiplexers in IP-67 weather-proof housing with cover removed

__Web data monitoring service (WDMS)__

In landslide monitoring, there will be many stake holders interested in the safety status of the landslide. Typical stake holders could be the government, owners, designers or consultants, NGOs and safety monitoring personnel. Stake holders or their empowered personnel may be located hundreds of kilometers away from the actual site. Consequently there is a need to provide the stake holders with near real time access to data from safety monitoring instrumentation network irrespective of their actual location.

Another important function of safety instrumentation network that is becoming an essential part of landslide monitoring is providing means for alerting authorized personnel about development of potential hazardous development in near real time so that remedial actions can be started without delay.

Web based data monitoring service (WDMS) is offered by many service providers. It allows to monitor data from the site collected by a data acquisition system (DAS), remotely from an internet connected computer located anywhere in the world. It also allows multiple authorized users at different locations to view any data or report from the same site simultaneously. Several sensors like the SDI-12 based in-place inclinometer, piezometer, anchor load cell, rain gages etc. can be connected to a DAS as per requirement of the site.

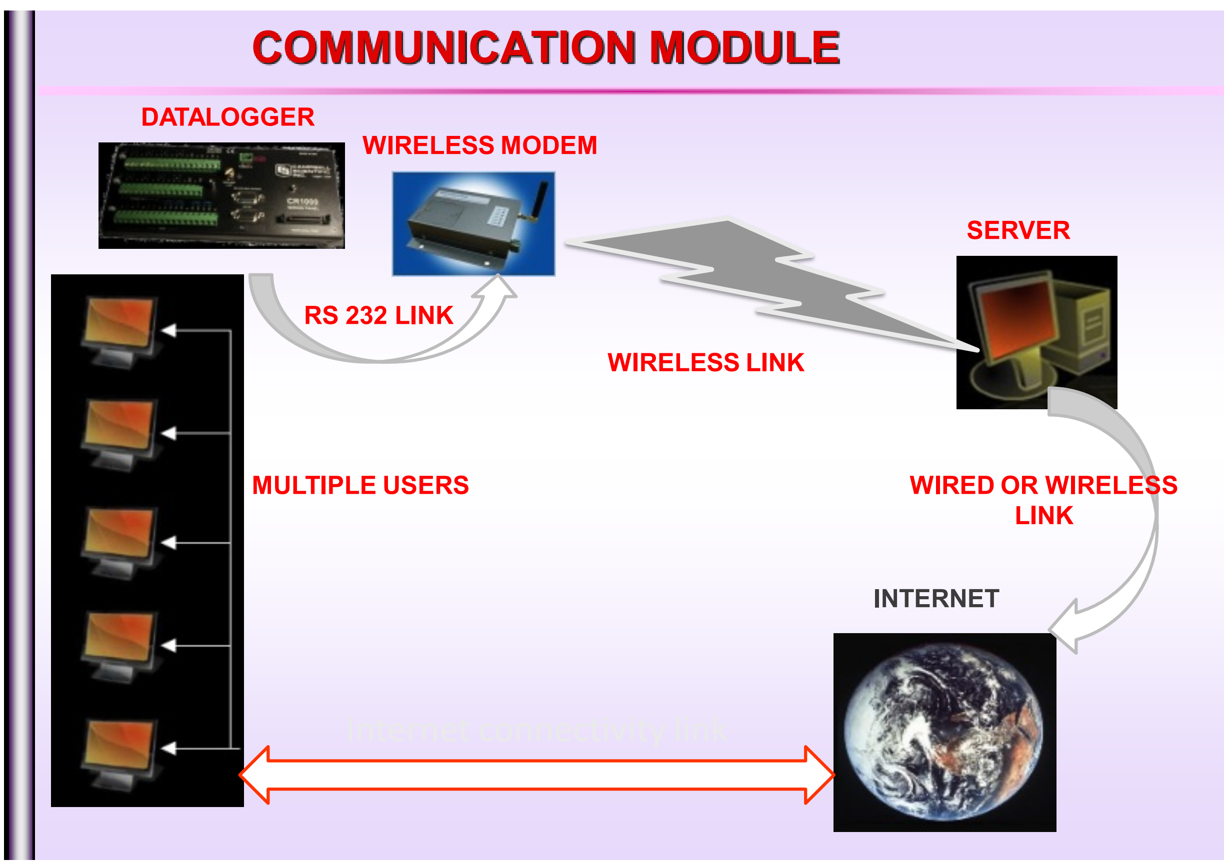


Figure 10

The WDMS system then uses GSM/GPRS cellular services to transmit data from the individual data acquisition systems wirelessly to a remote monitoring computer (host). As long as a reliable GSM/GPRS cellular service is available at the data logger site, the data loggers can be located virtually anywhere in the world. WDMS can support multiple data loggers and the individual data loggers can be spread out over a wide geographical area.

Essentially WDMS consists of software such as a data collection agent, a data base server and a web server hosted on a high reliability 24 x 7 server computer. The host computer periodically collects data from remote data loggers spread over a large area, over cell phone network. Web server software then makes data available over the internet so that a user can view the logged data or report using a suitable web browser, like Microsoft Internet Explorer or Mozilla Firefox, from virtually anywhere in the world.

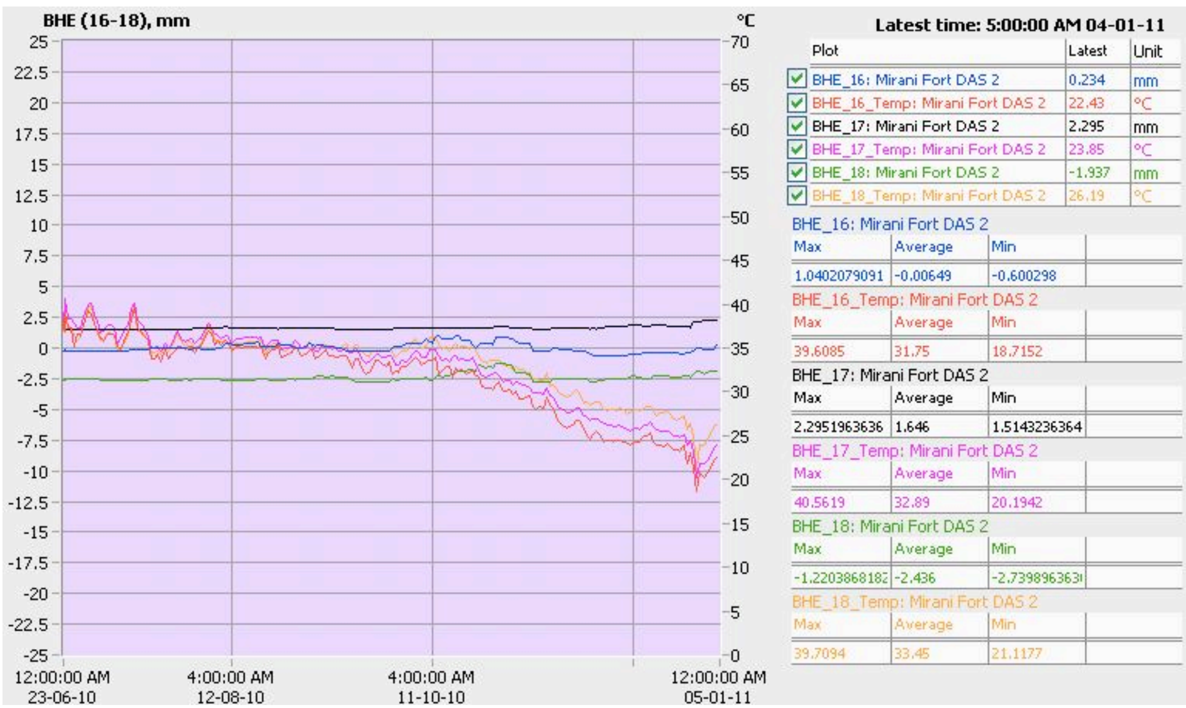


Figure 11 – screen shot of data from a borehole extensometer

The WDMS allows the user to view the data from any sensor connected to the remote DAS over a selected time period in either a tabular spread sheet type format or as a graph. Values of the programmed alert levels can be set. The WDMS can also be programmed to send SMS alert messages to selected users as soon as any sensor data crosses its predefined alarm levels, either while going above or going below the alarm level. It can also be programmed to send the health status of the system to selected users. Figure 11 is a screen shot of typical temperature and displacement data available through WDMS from a 3-point borehole extensometer over a period of time.

Similarly, figure 12 is a screen shot of typical data available through WDMS from an in-place inclinometer system.

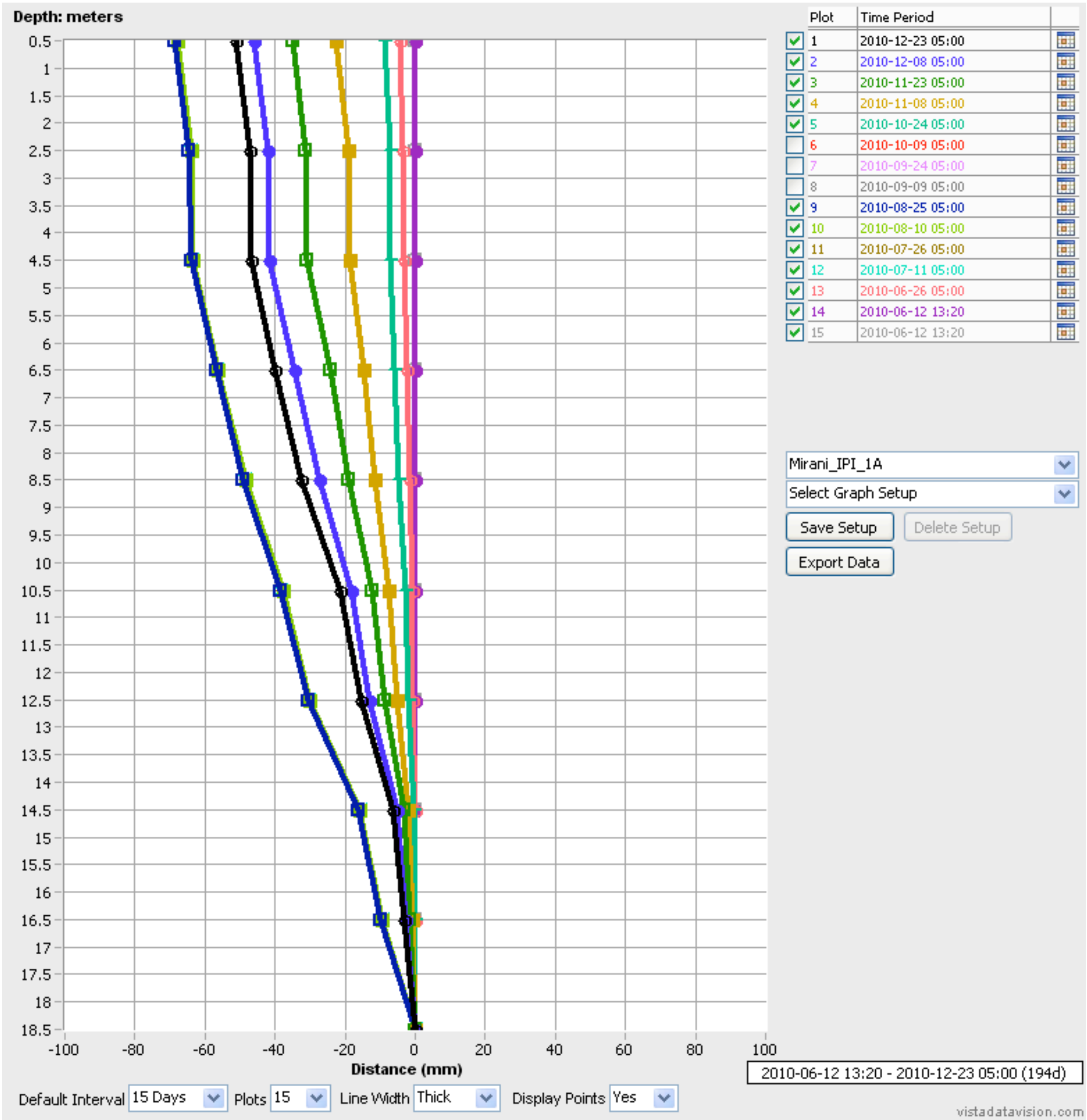


Figure 12 – screen shot of data from an in-place inclinometer system

CONCLUSION

Data acquisition and monitoring system provides near-continuous measurements on hydrologic conditions and ground movement of landslides. Sensors are installed in or on the landslide and data transmitted via cables or radio telemetry to computers. The data increases understanding of dynamic landslide activity and behaviour and enables geologists to detect changes in landslide movement, monitor rainfall & groundwater conditions and hopefully anticipate possible catastrophic movement at the landslide. The data acquisition and monitoring system can be programmed to allow for remote and automated management of landslide prone areas setting off alarms if set thresholds are exceeded.

By implementing a good prediction and forewarning system coupled with effective efforts to control and mitigate landslides, destruction caused by landslides can be reduced from what would normally occur. Any worthwhile plan for corrective and preventive measures in a landslide or an area susceptible to landslides must be based on a detailed integrated geological and geotechnical investigation. Landslide problems, present or expected in future, require an engineering geologist to exactly evaluate type of landslide and take corrective measures based on collected data and experience gained to tackle similar problems. The solution should be based on a well thought of working hypothesis taking into consideration cost involved and effectiveness of the efforts put in.