# CURRENT WIRELESS TECHNIQUES FOR MONITORING OF SLOPE STABILITY IN OPENCAST MINES - FIELD EXPERIMENTAL TRIAL

**Prof.Singam Jayanthu**
Professor, Mining Engg Dept.,NIT Rourkela,Odisha,
sjayanthu@yahoo.com

## ABSTRACT

This paper presents field experimental trial of modern technique including wireless system for online monitoring of sub-surface movements in atypical opencast metal mine in India. Innovative real time monitoring of ground deformation was accomplished with Time Domain Reflectometry (TDR) to interrogate coaxial cables installed in three Holes. Surface monitoring was also conducted with total station measurements at these locations. Coaxial cables were connected to a TDR system that automatically recorded and these measurements transferred to mine office by RF module which was connected to TDR. The integrated indigenous RF modules along with microcontroller are tested in ground control laboratory of NIT Rourkela and also in mine site before final installation. A GUI developed using the Python software for automatic storing and plotting of real time data. Based on this received information mine official could alert the persons who are working near to prone area. This study describes the integration of TDR directly with Arduino boards and XBee modules for real-time transmission of slope monitoring data as a part of Ministry of Mines, Government of India (GOI) sponsored project. On the basis of the experimental trial in vogue, the TDR system appears to be a reliable measuring system for estimation of the subsurface movements, and an experimental trial of system of Slope Stability Radar (SSR) for online surface movements combined with TDR may be more useful for complete understanding of the slope behaviour for improving safety in opencast mines.

### INTRODUCTION

The economic concerns and operational problems associated with unstable slopes state the need of suitable slope monitoring and management measures. Available Geotechnical sensors include vibrating wire piezometers, wire line extensometers, borehole extensometers, inclinometers; tilt meters etc. for sensing the changes in slope conditions, besides widely practiced total station monitoring. These geotechnical instruments are monitored by technicians in the field. Figure 1 shows the Slope Disaster at Rajmahal opencast mine, Eastern Coal Limited (ECL), India on 29-12-16 and Bingham Canyon Mine [2], southwest of Salt Lake City. The analysis of accident in open pit mine publicized that slope failure and dump failures have upward trends in the recent time[1]. Few examples of fatal accident involving slope and dump failure are mentioned in table 1.

Available electronic instrumentation includes vibrating wire piezometers, wire line extensometers; borehole extensometers, electrolytic bubble Inclinometers and tilt meters for sensing the changes in slope conditions, besides widely practiced total station monitoring. Technicians in the field can monitor these instruments. This research work is focused on the application of electronics and communication work deals with the elimination of manual slope monitoring in the industry with the help of Wireless Network Infrastructure replacing the need for physical cables.

### TIME DOMAIN REFLECTOMETRY (TDR)

TDR can be called as cable-based radar and consists of two major components which are namely cable tester and coaxial cable. The cable tester works like a Transceiver. The TDR cable tester produces electric impulses which are sent down the coaxial cable. The coaxial cable is grouted into the ground (Figure 2). When these pulses approach a deformed portion of the coaxial cable, an electric pulse is reflected and sent back to the TDR Cable Tester. When the pulse runs across a change in cross-sectional cable geometry (e.g. due to a shear deformation), a portion of the signals is reflected back to the TDR device. The distance between the cable tester and deformity (x) can be accurately determined by the round-trip travel-time ($T_R$) and propagation velocity (Vp) of the cable.

$$x=VpT_R/2 \qquad (1)$$

The TDR is used for finding the ground movement and it requires reading of the cable signature at regular time intervals. Ground movement such as slip along a failure zone, will deform the cable and result in a change in cable characteristic impedance and a reflection of energy. This change in the shape of cable can be used to determine the location of shear movement[3].


**Fig.1 Slope Disaster at Rajmahal opencast mine, ECL, India on 29-12-16 and at Bingham Canyon Mine southwest of Salt Lake City, USA on 10-04-13.**

**Table.1. Few Examples of Fatal Accident involving Slope and Dump Failure**

| Sl. No | Date | Name of Mine | Incidence | Fatal |
|---|---|---|---|---|
| 01 | 24.06.2000 | Kawadi Open Cast (OC) Mine of M/s Western Coalfields Limited(WCL) | Slope failure of 31m high OB benches. | 10 |
| 02 | 09.12.2006 | Tollen Iron Ore Mine of M/s Kunda R Gharse in Goa | Failure of Slope 30m to 46m high Dump. | 06 |
| 03 | 17.12.2008 | Jayant OC Project of M/s Northern Coalfields Limited(NCL) | Failure of Dragline Dump. | 05 persons 01 Shovel Buried |
| 04 | 04.06.2009 | Sasti OC Mine of WCL. | Dragline OB dumps of 73m height failed and slided down the pit. | 02 Persons 02 Excavators Buried |
| 05 | 25.02.2010 | Hansa Minerals and exports Granite Mine. | Granite mass slided along an inclined joint plane and failed from height varying from 10m to 55m. | 14 Persons |
| 06 | 22.06.2014 | Amlai Opencast Mine, South Eastern Coalfields Limited (SECL). | Dump failure due to sudden development of cracks in the embankment and Unstable Ground Conditions | 2 Persons 1 Dumper 1 Dozer 1 Crane |

| | | | | |
|---|---|---|---|---|
| 07 | 29.12.2016 | Rajmahal OCP of Eastern Coalfields Ltd(ECL) | Dump failure due to development of cracks and Unstable Ground Conditions | 23 Persons 12 Tippers 6 excavators & 1 dozer |

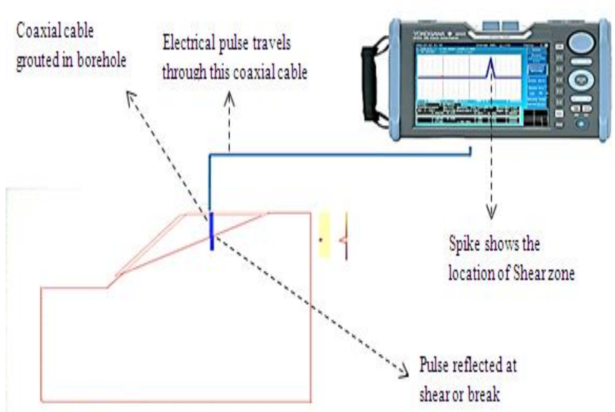


**Fig.2. Functional Representation of TDR**

**HARDWARE AND SOFTWARE MODULES**

Software protocols and transmission algorithms using Arduino-Integrated Development Environment (IDE) Software were developed. RF module was utilized in Transparent Mode (AT) mode along with Arduino at transmitter and receiver side[4]. Data Communication was established between PC to PC wirelessly. Figure 3 shows the connection Diagram of the Integrated System. No packet loss was observed during the transmission. In the final communication model Arduino Uno board is replaced with Arduino Mega board and the RF module is replaced with advanced RF module. The upgraded Arduino Mega controller system succeeds to transmit the data wirelessly directly from the TDR to the system through RF module. Thus, it successfully removes the need for the PC from transmitter side of the RF transmission system. TDR data is transmitted wirelessly to the developed system with three coaxial cables connected to three different channels of Multiplexer (MUX). TDR generates three strings successively one for each of the channel of MUX continuously one after other. Each of the string contains 240 points representing the reflection coefficients along the length of the particular cable. As TDR works at a very high baud rate of 57600, so it generates the very large amount of data continuously[5,6].

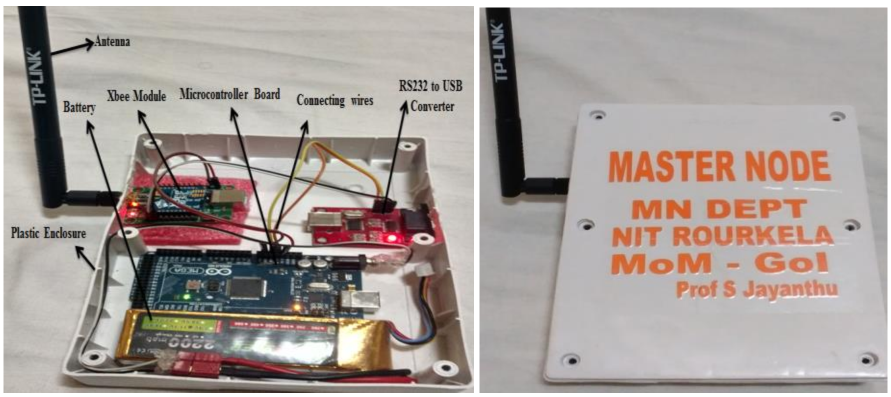


**Fig.3. Integrated Master node for real-time monitoring**

**ROUTER**

Though the Xbee PRO module is specified to provide the range of the 1 Mile (1.6 Km) by the manufacturer practically it fails to provide it due to various reasons. It includes the environmental condition, rough weather conditions, signal loss (attenuation) while transmission due to Earth Surface. One more serious problem with the RF wireless transmission is the line of sight issue. Same is concluded after the field trial carried out at the Dongri Buzurg Mine. The line of sight issue occurred while field trial as the distance between transmitter and the receiver side increases. The best way to overcome the line of sight issue is to install Router units between the two end devices wherever needed. Figure.4.shows the Router Module for increasing the Range of communication.

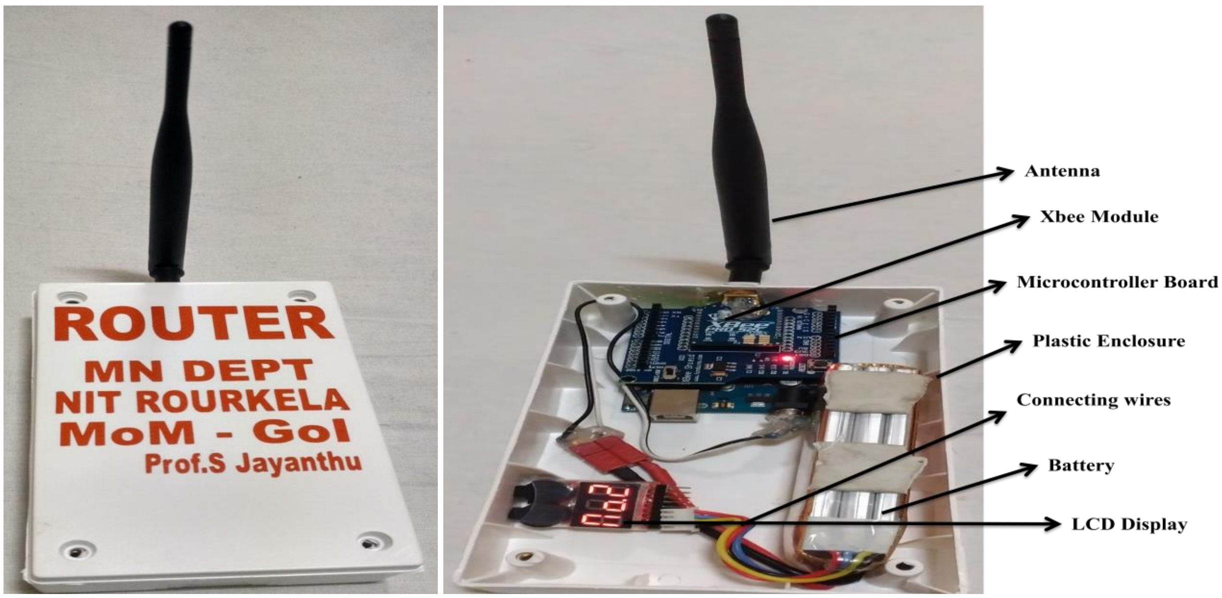


**Fig.4.Router Module for increasing the Range of Communication**

Python is a flexible, simple coding programming language. Python is a very high-level, dynamic, object-oriented, general purpose programming language that uses interpreter and can be used in a vast domain of applications. This language can support different styles of programming including structural and object-oriented. Other styles can be used, too. Python is very flexible, because of its ability to use modular components that were designed in other programming languages. For example, you can write a program in C++ and import it to python as a module. Then add something else to it (for example design a GUI for it). It includes an internal standard library that is called "batteries inside" among Python lovers. It provides all facilities that are needed for programming from the basic operations to advanced functions. These third-party tools make everything possible in Python[7]. For example, by writing just 3 lines of codes you can create a web server. It can support COM, .Net, etc objects. Also, some alternatives and complements were created for python that make it easier to work with these objects in an integrated mode. Figure.5 shows the Real time data of three coaxial cables using Python Software.

**FIELD EXPERIMENTAL TRIAL**

The instrumentation was installed to provide a real time monitoring system and to provide quantitative information about ground movements [8-16]. The locations and range requirements for installation of instrumentation were determined on the basis of various field visits and Geotechnical investigations and numerical modeling of selected mine. Automation was accomplished by connecting the Campbell Scientific TDR to a NIT Rourkela integrated RF module. TDR is controlled by a Campbell Scientific CR1000 datalogger.

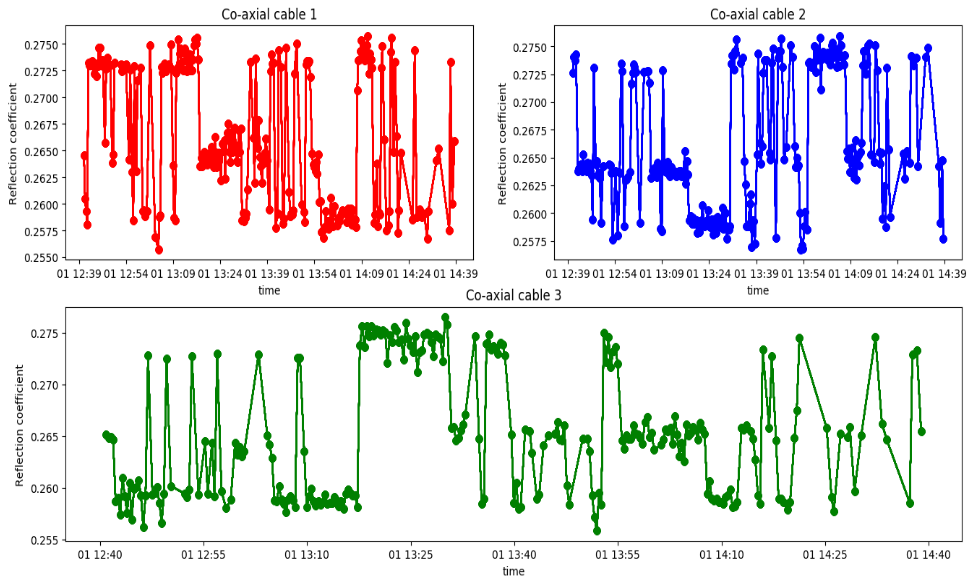


**Fig.5. Representation of Real time data of three coaxial cables using Python Software**

As per the conditions of the mine site it is proposed to install Time Domain Reflectometry for real time monitoring of slopes.In the selected method, TDR along with three coaxial cables are installed for the primary monitoring (Figure.6.). The depth of the hole is 11m and each coaxial cable is inserted in PVC pipe and grouted with cement. The PVC pipe is used for keeping the coaxial cable in dry condition and separate room was constructed for protecting the instrument.RG-6 type coaxial cable used for installation and three coaxial cables connected to TDR100 through SDM8X50 Multiplexer. This cable has been used in the field to monitor rock mass deformation with TDR. RG-6 coaxial cable having the 75 ohm characteristic impedance and the propagation velocity (VP) of this cable is 0.75. The Diameter of the cable RG-6 is 8.43mm and Operating temperature between the $-40^{0}$C to $+80^{0}$C[8]. TDR100 is connected to master node which is developed by scientific team of NIT Rourkela. The Generated real time data of TDR100 is directly sends to mine office through RF module (master node). Three Locations for the monitoring system were selected and coaxial cables were installed at those location. All the electronics were placed in a room which is specially constructed near to the cable locations and power is also available at that location. Measurements were taken weekly and three no of TDR monitoring cables that were grouted into drill holes to monitor precursor movement within the rock mass. The TDR measuring system, which was installed at the foot wall benches of DB Mine, MOIL and started operation in August 2017, is continuously working since August 2017, and has been conducting continuous measurements since August 2017. Figure.7 shows the Installed TDR instrument in Protecting Room at mine site.

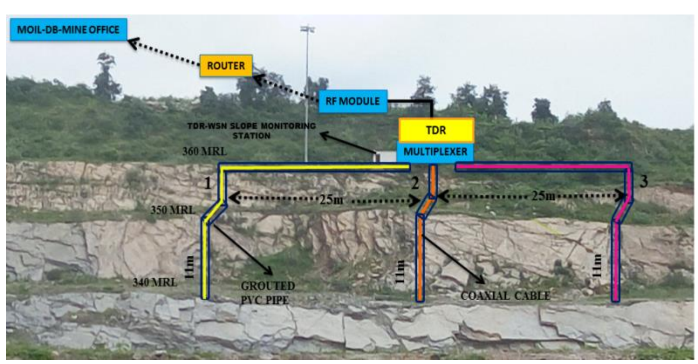


**Fig.6.The method for the installation of the cables**


**Fig.7. Installed TDR instrument in Protecting Room at mine site**

The Generated real time data of TDR100 is directly sends to mine office through RF module (master node). Figure.9 shows the Demonstration of TDR instrument at MOIL Headquarters, Nagpur and Dongri Buzurg Mine.Figure.7 10 shows the arrangement for Drilling, Grouting and installation of Coaxial cable with PVC pipe in borehole. Figure.11 shows the Constructed room at mine site for protecting the equipment. Figure.11 shows the initial response of the coaxial cable at location.1 and length of cable is 67m. Fig. 8 shows graphical representation of TDR data for the coaxial cable at location.2 and length of cable is 39m during 1-8-17 to 31-8-17., and during 1-9-17 to 15-9-17, respectively.

## CONCLUSIONS

TDR along with developed RF module measurements proved to be reliable and cost effective for real time slope monitoring at the experimental site of a typical opencast metal mine in India. Conceptually, it would be possible to create an alarm system based on reflection coefficient (RC) values inferred from TDR measurements. But this would require a more number of days to observe the response from RG6 type coaxial cable in the field and calibration of RC in terms of deformation and further evaluation. In the TDR time series, no measurable deformations are visible and only a slight characteristic noise could be seen. Altogether, the TDR system appears to be a reliable measuring system for estimation of the subsurface movements, and an experimental trial of system of Slope Stability Radar (SSR) for online surface movements combined with TDR may be more useful for complete understanding of the slope behaviour for improving safety in opencast mines.

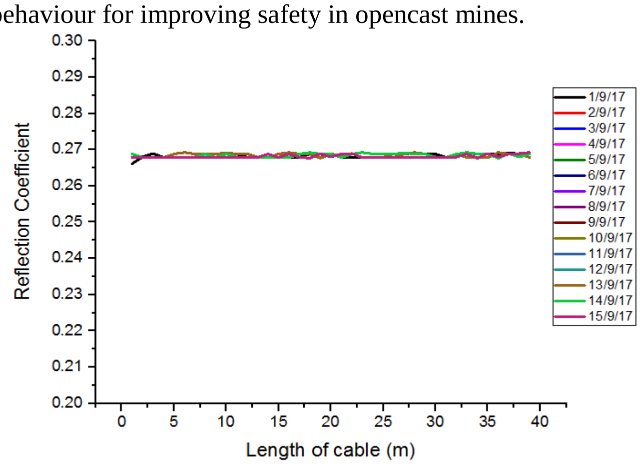


**Fig.8. Graphical representation of TDR data for the coaxial cable at location.2 and length of cable is 39m during 1-9-17 to 15-9-17.**

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