QUANTIFICATION OF SLOPE MOVEMENT USING TIME DOMAIN REFLECTROMETRY -AN EXPERIMENTAL TRIAL

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ABSTRACT

Time Domain Reflectometry (TDR) is gaining widespread attention as a cost-effective method to monitor mass movements in both soil and rock. It has been used successfully for a number of years to monitor deep-seated failures in soil deposits and for monitoring many different kinds of movements in rock masses. A chief benefit of using this technology is that it can be a cost effective means of remotely monitoring the effectiveness of slope hazard remediation measures. TDR cannot determine the actual amount of movement. In this paper, laboratory results of an experiment using opencast mine model with two types of coaxial cables indicated a relationship between the reflection coefficient and the shear displacement.Increase in the deformation was proportional to the reflection coefficient. reflection coefficients were 0.93 to 0.98 for RG6 coaxial cable, for displacement of 0 to 7 mm in the model. Attempts are being made to implement the above TDR system of slope monitoring in the opencast mines in India as part of Ministry of mines, Government of India(GOI) sponsored project.

Keywords: *Time Domain Reflectometry (TDR), coaxial cable, reflection coefficient, opencast model.*

INTRODUCTION

cable is perhaps the most commonly used transmission line type for RF and microwave measurements and applications. Apart from the communication application coaxial cable is working as a sensor in Time Domain Reflectometry (TDR) for pre-detecting ground deformations in underground and opencast mines. There are different types of coaxial cables available with different characteristic impedances [1,2]. The basic principle of TDR is similar to that of radar. In TDR, a cable tester sends a pulse voltage waveform down a cable grouted in a borehole. If the pulse encounters a change in the characteristic impedance of the cable, it is reflected (Figure.1). This can be caused by a crimp, a kink, the presence of water, or a break in the cable. The cable tester compares the returned pulse with the emitted pulse and determines the reflection coefficient of the cable at that point. Electrical energy travels at the speed of light in a vacuum but travels somewhat slower in a cable. The TDR generates a very short rise time electromagnetic pulse that is applied to a coaxial system which includes a TDR probe for rock mass deformation and samples and digitizes the resulting reflection waveform for analysis or storage [3]. The elapsed travel time and pulse reflection amplitude contain information used by the onboard processor to determine quickly and accurately rock mass deformation for slope stability measurement or user-specific, time-domain measurement.A 250-point waveform should be collected and analyzed in approximately two seconds. Each waveform should have approximate up to 2,048 data points for monitoring long cable lengths used in rock mass deformation or slope stability. TDR for determining ground movement requires reading 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 impedance and a reflection of energy. This change can be used to determine the location of shear movement.

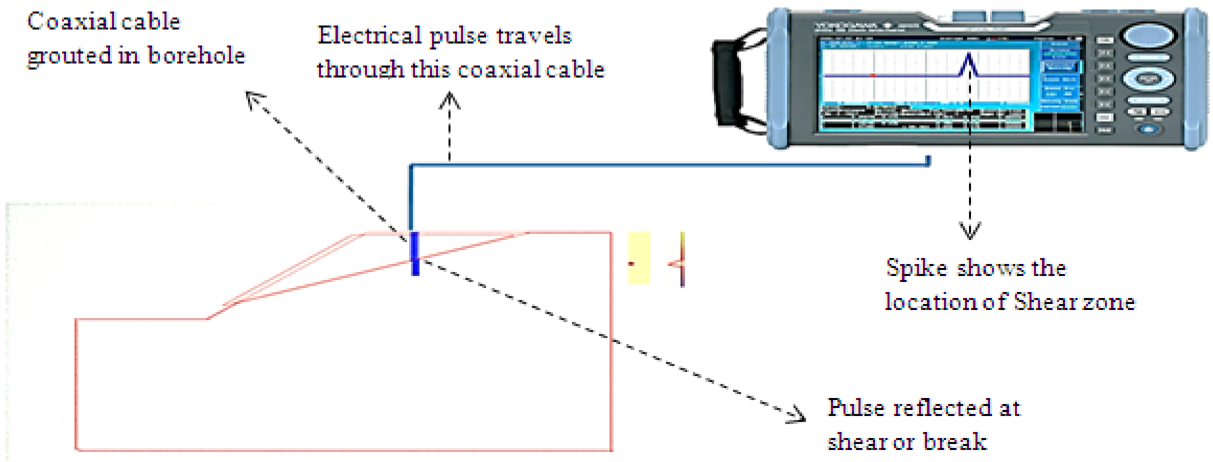

Fig.1. Basic Principle of TDR

REFLECTION THEORY

A signal travelling along an electrical transmission line will be partly, or wholly, reflected back in the opposite direction when the travelling signal encounters a discontinuity in the transmission line, or when a transmission line is terminated with other than its characteristic impedance. Reflection coefficient describes the ratio of reflected wave to incident wave at point of reflection, where circuit parameter has sudden change. This value varies from -1 (for short load) to +1 (for open load), and becomes 0 for matched impedance load [3]. The coaxial cable used in a TDR system provides a one-dimensional path for propagation of an electromagnetic wave which is generated by a voltage pulse from the TDR. The cable consists of outer and inner conductors separated by a material with a known dielectric constant. Propagation of the voltage wave along the coaxial cable is controlled by four fundamental properties of the cable: inductance *(L)*, resistance (*R*), capacitance (*C*), and conductance (*G*). For relatively short cables (< 100 m), resistance and conductance can be assumed to be constant. The PC-TDR Software presents the graphically as a plot of reflection coefficient, versus Length of cable. The distance between the TDR and deformity (X) can be precisely determined by the round-trip travel-time (T_R) and propagation velocity (Vp) of the cable.

$$X = V_p T_R/2 \text{-----------} (1)$$

LABORATORY EXPERIMENT

A laboratory test was carried out on the TDR system to check out the response of the TDR with the applied deformation. RG-213 type of co-axial cable is selected, and the reading is taken in the serial monitor of the IDE software. Deformation is applied successively at the interval of 1m along the complete length of the cable manually. Laboratory set-up used to test the response of the TDR to applied deformation is shown in Figure.2.

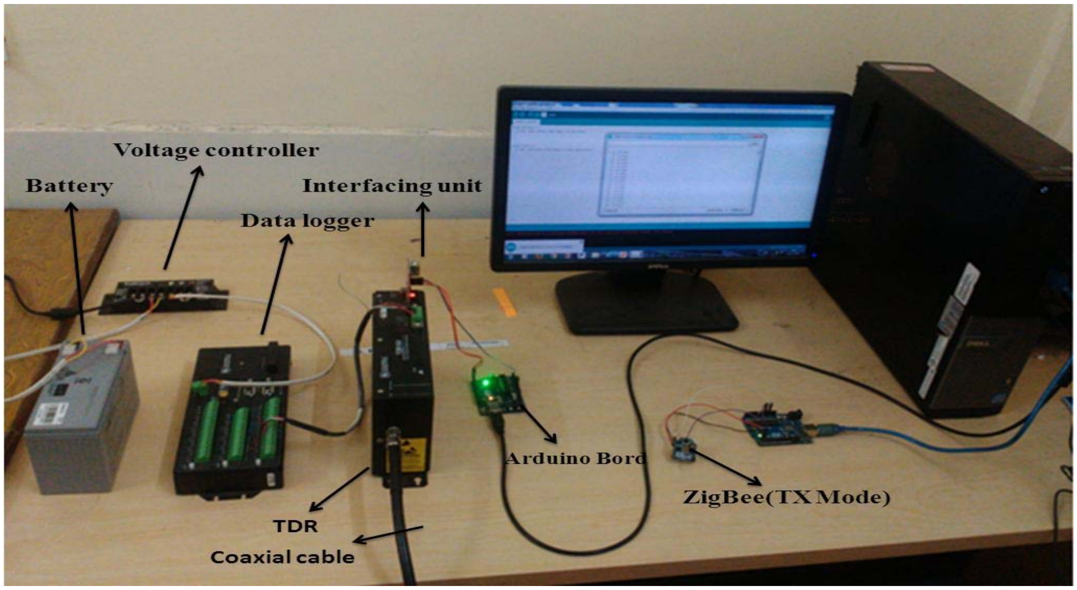

Fig.2 Laboratory set up to test response of the TDR to applied deformation

The measured reflection coefficients by TDR are shown in the table below. The reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. It is equal to the ratio of the amplitude of the reflected wave to the incident wave [4]. The impedance of the coaxial cables changes with the applied deformation so we get a higher value of the reflection coefficient at the length where deformation is applied comparing with other points of the cable.

RG-213 is used for test with the specifications:

i) Velocity of propagation (V_P) = 66% = 0.66
ii) Maximum Operating Frequency = 1 GHz
iii) Capacitance per Feet = 30.8 PF/ft.

Table.1. Shows the reading of the reflection coefficients taken by TDR system along the length of the coaxial cable with deformation applied at the particular length. Same results are represented in graphical form in Figure.3.

Table. 1 Response of the TDR to applied deformation

	Reflection Coefficients measured at various lengths									
Clink applied at the length	**1m**	**2m**	**3m**	**4m**	**5m**	**6m**	**7m**	**8m**	**9m**	**10m**
TDR-1m	**0.0084**	0.0048	0.0052	0.0003	0.0028	0.0022	0.0051	0.0042	0.0049	0.0032
TDR-2m	0.0045	**0.0078**	0.0004	0.0003	0.0003	0.0035	0.0044	0.0047	0.0046	0.0015

TDR-3m	0.0049	0.0040	**0.0086**	0.0008	0.0007	0.0043	0.0049	0.0053	0.0048	0.0005
TDR-4m	0.0037	0.0031	0.0027	**0.0083**	0.0006	0.0027	0.0032	0.0066	0.0017	0.0045
TDR-5m	0.0043	0.0045	0.0040	0.0040	**0.0081**	0.0041	0.0045	0.0059	0.0020	0.0041
TDR-6m	0.0010	0.0042	0.0036	0.0022	0.0025	**0.0078**	0.0040	0.0041	0.0003	0.0040
TDR-7m	0.0045	0.0044	0.0035	0.0024	0.0021	0.0043	0**.0073**	0.0043	0.0003	0.0043
TDR-8m	0.0040	0.0043	0.0049	0.0031	0.0025	0.0041	0.0042	**0.0077**	0.0007	0.0042
TDR-9m	0.0048	0.0048	0.0036	0.0020	0.0007	0.0048	0.0048	0.0049	**0.0082**	0.0047

The obtained reflection coefficient from TDR shows all negative values here negative sign represents that there is a phase difference of an 180º between the transmitted signal and the reflected signal of TDR. This phase difference is practically meaningless as for slope stability movement TDR needs the only magnitude of the reflection coefficients. So that all the reflection coefficient values obtained from the TDR are considered positive.

The obtained results can be seeing graphically using the PCTDR software as shown in Figure.3 The peak value in the graph indicates the deformation at that particular distance.

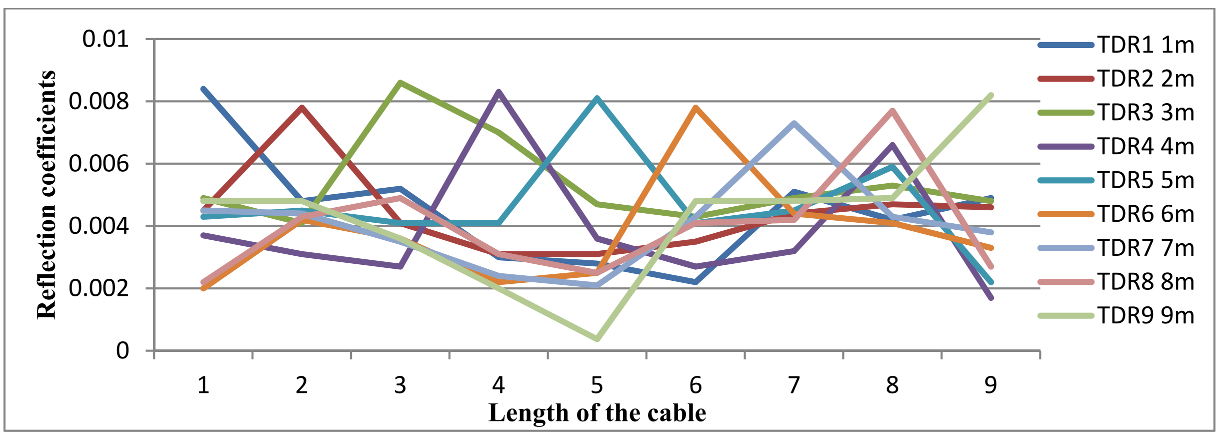

Fig. 3: The response of TDR system with applied deformation

It can be concluded from the results of the above test that TDR senses the deformation occurring along the coaxial cable sensitively. It can be used successfully for the slope stability monitoring of the open cast mines. Changes in reflection coefficient caused by deformation of the cable are best modeled in terms of changes in impedance, and expressed as follows:

$$\text{Reflection Coefficient } (\rho) = (Z_1 - Z_0)/(Z_1 + Z_0) \text{------------}(2)$$

where Z_1 = characteristic impedance of the deformed section of cable and Z_0 = characteristic impedance of the unreformed cable. Changes in ρ caused by deformation in the cable. From the Eqn (2) change in the characteristic impedance of coaxial cable at the location of deformation was shown in Table.2. The characteristic impedance at deformed locations are presented in following table at different lengths. The characteristic impedance increases due the applied deformation so that reflection coefficient also increases.Figure.4 and 5 shows the Change in reflection coefficient, characteristic impedance values with applied deformation at various lengths. Table.3. gives the changes in Characteristic Impedance and Reflection Coefficient value along the cable with deformation applied at the 1m length. Figure.6 and 7 shows the changes in Characteristic Impedance and Reflection Coefficient value along the cable with deformation applied at the 1m length.

Table.2. Changes in impedance of the cable to applied deformation

Clink applied at the length	Corresponding Reflection Coefficient Values	Characteristic impedance with deformation (ohm) (Z_l)
TDR-1m	0.0084	50.847
TDR-2m	0.0078	50.786
TDR-3m	0.0086	50.867
TDR-4m	0.0083	50.837
TDR-5m	0.0081	50.817
TDR-6m	0.0078	50.786
TDR-7m	0.0073	50.735
TDR-8m	0.0077	50.802
TDR-9m	0.0082	50.827

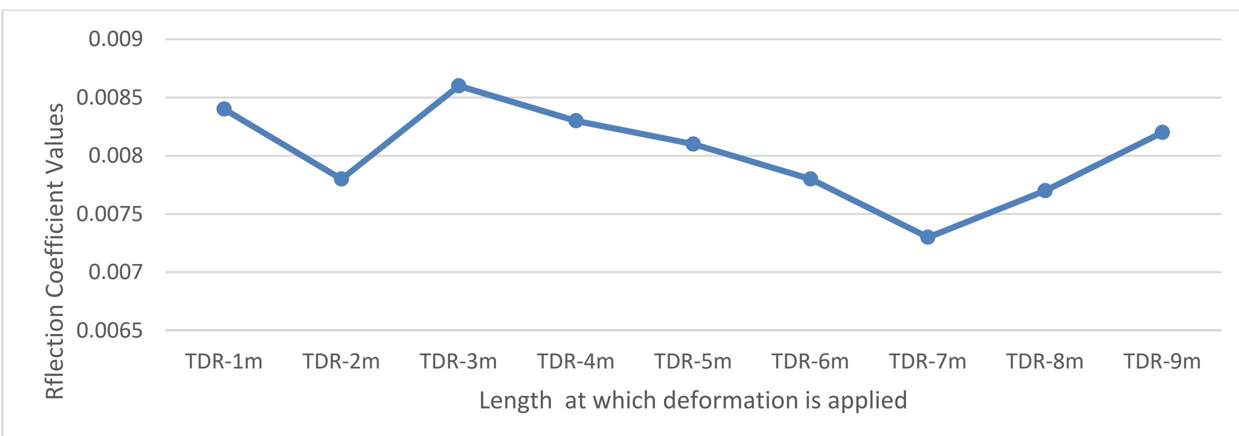

Fig.4.Change in reflection coefficient values with applied deformation at various lengths

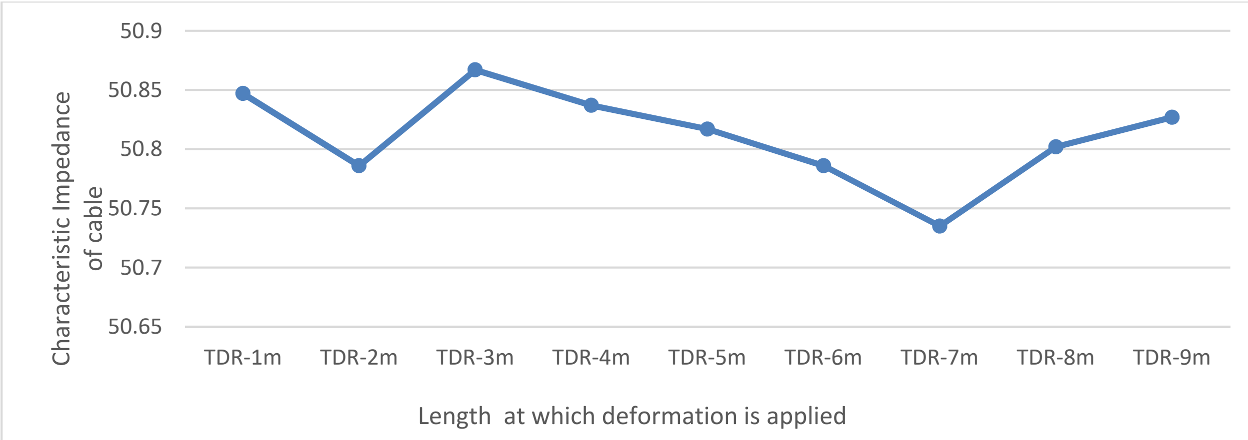

Fig.5.Change in Characteristic Impedance values with applied deformation at various lengths

Table.3. Changes in Characteristic Impedance and Reflection Coefficient value along the cable with deformation applied at the 1m length

Reading taken at length	Corresponding Reflection Coefficient Values	Characteristic impedance with deformation (ohm) (Zl)
1m	0.0084	50.847
2m	0.0048	50.482
3m	0.0052	50.522
4m	0.0003	50.030
5m	0.0028	50.281
6m	0.0022	50.220
7m	0.0051	50.513
8m	0.0042	50.422
9m	0.0049	50.492

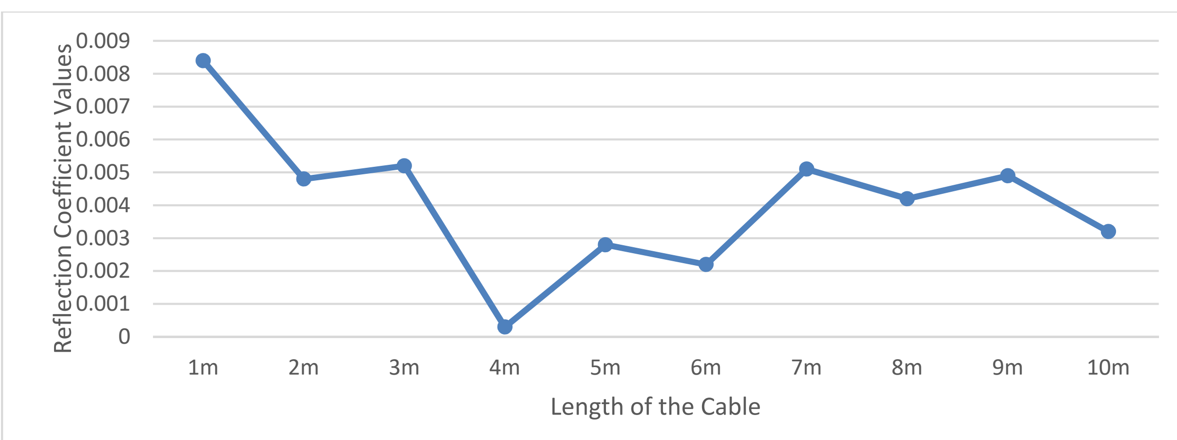

Fig.6.Changes in Reflection Coefficient value along the cable with deformation applied at the 1m length

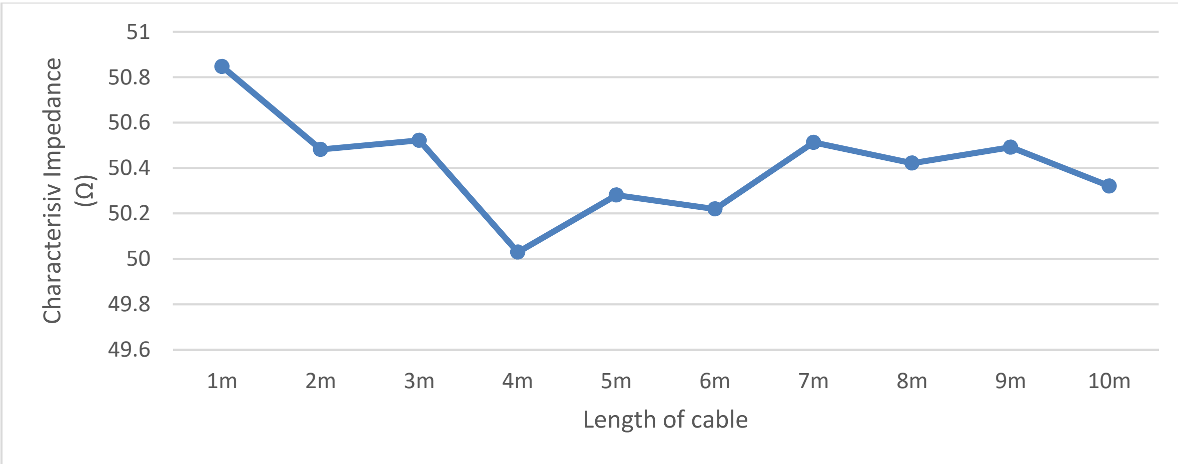

Fig.7.Changes in Characteristic Impedance value along the cable with deformation applied at the 1m length

In the first test with OC Model, RG-213 type of co-axial cable was deformed manually at various points along the cable, and the TDR response was checked. For precise measurement, a model of open cast mine is designed using a Plexiglas. The model represents the open cast mine with three numbers of benches. The arrangement is done so that middle bench can move forward representing the bench movement. The model was having the arrangement of scale so that displacement can be measured. The Opencast Block Model for the laboratory test is shown in Figure.8.

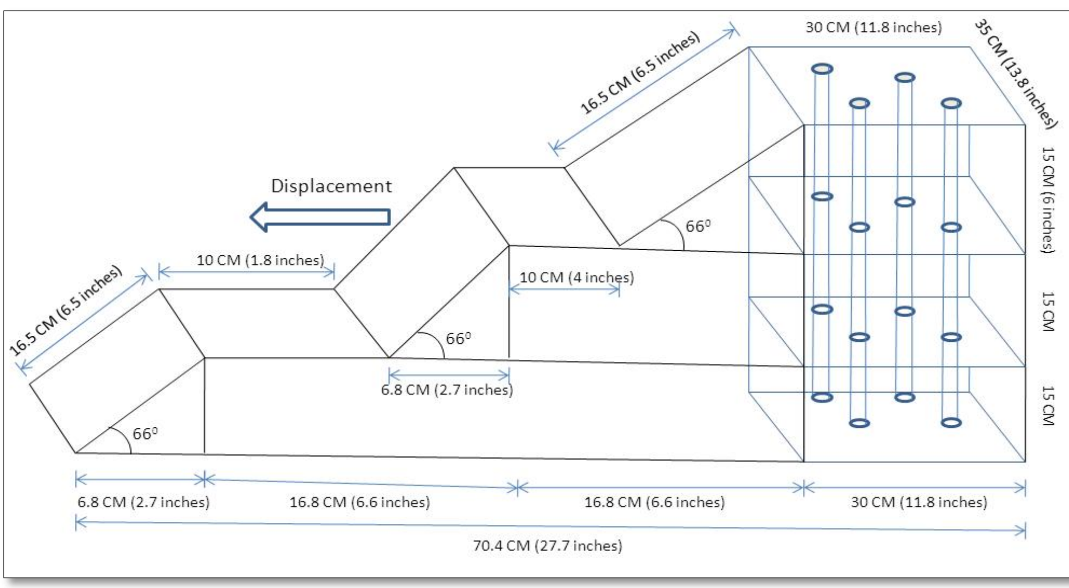

Fig.8. Opencast Block Model for laboratory test

The response of TDR is then to be determined with deformation applied precisely mm by mm using the open cast model. RG-6 is used for test with the specifications:

i) Velocity of propagation (VP) = 66% = 0.66
ii) Maximum Operating Frequency = 1 GHz
iii) Capacitance per Feet = 16.1 PF/ft.

Set up used for this laboratory test is shown in the Figure.9. Deformation can be applied by moving the middle bench of the open cast model in forward direction mm by mm. The results obtained with the precise deformation applied mm by mm from 0 to 7mm are represented in Figure.10. Obtained results with this test show that TDR senses the amount of deformation and presents increased value of the reflection coefficient with increasing deformation. Figure.11 shows changes in the coaxial cable shape with applied deformation.

Fig.9. Set up used for the laboratory test

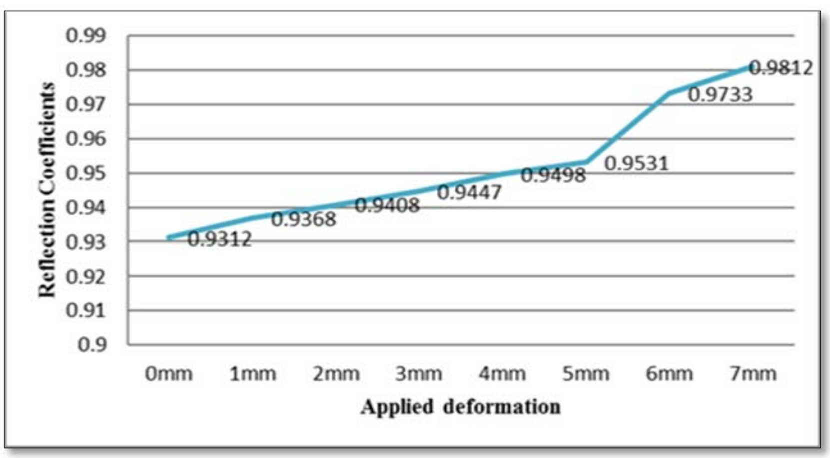

Fig.10.Reflection Coefficient Vs Applied Deformation

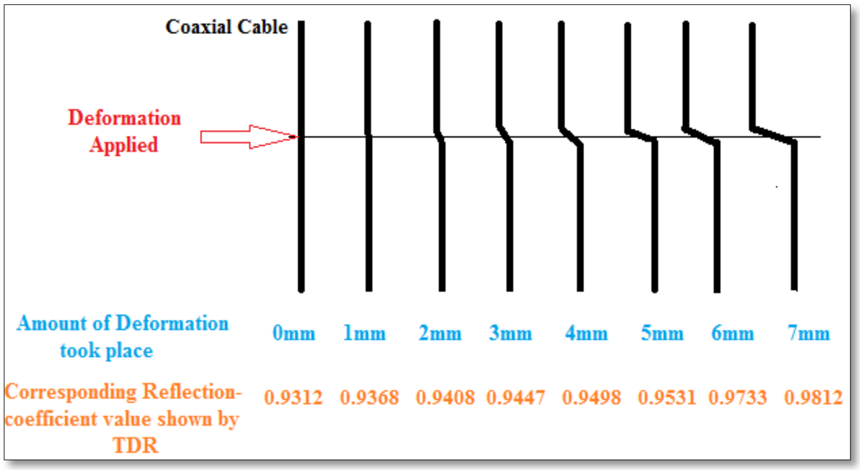

Fig.11.Changes in the coaxial cable shape with applied deformation

From the reflection theory, the applied deformation changes the shape of the cable results into the variation of impedance in the cable at particular location. So some of the energy is reflected back from the shear zone and after capturing the reflected wave, TDR analyses the both signals and gives the output in the form reflection coefficient values.Hence by increasing the deformation manually with reference to scale fixed to the model, the shape is changing as shown in Figure.11. so change in capacitance and characteristic impedance at the location of cable deformation gives the change in the reflection coefficient also. A linear relationship between reflection coefficient and deformation was observed. This result was considered encouraging because it suggests that, for a given type of cable, there is a direct, linear, and measurable relationship between the cable signal and shear deformation.

CONCLUSIONS

The results of TDR behavior with coaxial cables under different test conditions strongly suggest that TDR can be used to determine the rate of ground movement of the slope failure along the TDR cable locations, provided calibration curves are obtained for each location.Testing of the coaxial cable with TDR and OC model indicated the reflection coefficient of 0.93-0.98 vis-à-vis increase in the deformation from 0 mm-7 mm. These encouraging results were considered for implementing the above TDR system of slope monitoring in the opencast mines in India as a part of Ministry of Mines, Government of India (GOI) sponsored project.

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