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TDR monitoring systems for the integrity of infrastructures

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ABSTRACT

Most infrastructures are formed by large amount of parts, like members of truss, decks of bridge, and so on. On the connection, relative movement between members causes load redistribution or even failure. Monitoring the integrity of the structural system can assure its performance and safety. TDR monitoring system is proposed here to be a multiple points monitoring system using only one coaxial cable as the sensing and conducting media all the way through the monitored structure. The cable is fixed at both end of each pairs of adjacent members to be the sensing device along itself. Relative movements between each member at the connecting points are monitored simultaneously by sending a fast rise impulse into the cable. When lateral movement applied, the cable will deform and having the effect of adding an equivalent capacitance at that point and causing the signature to jump up. And, the most important ability for TDR system is the location of the relative movement along the cable is very clearly shown in the time domain signature. The pulse of a TDR tester can go a few thousands feet which gives enough monitoring range for most infrastructure.

Key Words: TDR(Time Domain Reflectometry), Monitoring, Integrity, Infrastructure

1.INTRODUCTION

TDR was developed by electrical engineers as a method to locate discontinuities in coaxial transmission cables[1]. The technique has been extended to measurement of the properties of materials in which conductors are embedded, such as soil water content[2] and evaluation of material dielectric behaviour[3]. In rock mechanics, the technique has been employed to identify zones of rock mass deformation[4], and blasting performance.

This technique can be applied to monitor fracturing within concrete structures[5]. When a coaxial cable is embedded in a concrete structure, it works like a continuous sensor which can detect fracturing and relative movement at any location along its length. An electromagnetic pulse is launched down the cable and reflection from points of cable deformation can be located precisely. TDR fracture monitoring provides a viable tool when fracture locations are not known in advance. This is the major advantage for TDR compared with other monitoring systems. Telemetric monitoring based on TDR theories has been proven to be applicable[6].

2.RELATIVE MOVEMENTS BETWEEN ELEMENTS

Relative movements between concrete blocks can be divided into two categories; shear movement and normal movement. Shearing occurs when two adjacent blocks move parallel to the interface between them. Normal movement occurs when two blocks move perpendicular to the interface. Idealized pictures for block movement and associated cable deformation are shown in Fig.1. The blocks in (a) can deform the cable by shearing (b), or extension (c).

Monitoring system for the integrity of infrastructures is proposed here by monitoring on the connection between blocks. As shown on Fig. 2, coaxial cable is fixed on two sides of a joint or a bearing point. One coaxial cable can have many points monitored simultaneously using TDR technique[7]. If two adjacent blocks move relative to one another, as shown in Figs. 1(b) and (c), the distorted cable no longer has a uniform cross-section. The change in cable geometry causes

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the local cable capacitance, which is inversely proportional to the square of distance between the outer and inner conductors. to increase or decrease. By determining the characteristic of a single shear displacement or a single extension displacement under controlled laboratory conditions, it has been possible to interpret the results to estimate the magnitude of the relative shear or normal movement of the adjacent concrete blocks in which a coaxial cable has been fixed or embedded.

3.TDR BASIC

A coaxial cable. is composed of an outer and an inner conductor normally with plastic dielectric material between them. In the longitudinal view, the coaxial cable may be presented an ideal, two-wire transmission line having forward and return conductors to represent the outer and inner conductor respectively. Propagation of a pulse along a coaxial cable. i.e. the current and voltage propagating along a two-wire transmission line, is controlled by four basic properties of coaxial cables namely, inductance, resistance, capacitance and dielectric conductivity. Among them. inductance and capacitance are used here to explain the phenomena of this technique[7].

Time domain analysis of wave motion is accomplished by looking at the motion of transverse electromagnetic waves. This is the simplest mode of electromagnetic wave field and is restricted to the normal of the wave propagation direction. By assuming the coaxial cable to be a lossless line, resistance and dielectric conductivity are neglected. the governing equation of wave transmission in the system can be represented by (1)

$$\partial^2 v / \partial x^2 = L \times C \partial^2 V / \partial t^2 \qquad (1)$$

The above equation can be recognized as the basic wave equation for voltage pulse V as a function of distance x and time t. By assuming the wave equation governs the behavior of the system. the reflected electrical signal can be analyzed in the time domain in a fashion similar to that of reflected seismic waves.

4.TYPE OF VOLTAGE REFLCETIONS

Coaxial cable deformities produce discontinuities that can be divided into two categories: a change in characteristic impedance Z_0 (type I). or a change in reactive lumped circuit elements (type II)[7]. Either type produce a reflected voltage pulse. Travel time between initiation and reflection of the pulse is converted to distance by specifying a propagation velocity. while the slope and amplitude of the reflection can be related to specific changes in cable properties. Since individual discontinuities are separated in space, they are also separated in time and thus can be analyzed separately. This relation between location and travel time forms the basis of time domain reflectometry.

4.1 Cable Extension

When a metallic cable is deformed in tension, its diameter decreases as necking occurs. A decrease cross-sectional area creates a new characteristic impedance, Z_1, different than the original, Z_0. At the interface. the reflection coefficient can be defined in terms of characteristic impedances as shown type I in Fig. 3 [7]

$$\rho = (Z_1 - Z_0)/(Z_1 + Z_0) \qquad (2)$$

expressed in terms of the original characteristic of the cable.

4.2 Cable shear

When a cable is deformed by shearing, the deformation is localized and change in impedance can be modeled by adding an equivalent capacitance to the lumped circuit system. Then, the reflection. ρ. cannot be expressed simply in terms of impedance, but must be idealized by a localized change in capacitance[6].

For the ideal shunted capacitance case, the reflection coefficient, ρ , can be approximated by[7]

$$\rho = \Delta C \cdot Z_0 / 2 \cdot t_r \qquad (3)$$

where

ΔC = magnitude of the equivalent shunted capacitance,

Z_0 =the cable characteristic impedance, and

t_r =the rise time

5.MULTIPLE REFLECTION

In the proposed set-up for infrastructure integrity monitoring, deformation of joints at different locations are monitored simultaneously along one cable. That means, more than one signal are to be picked up at the same time. Capability to watch and to distinguish between these change is a must herein. Resolution of a TDR system in signal change is a few centimeter depends on system's risetime[8] which is good enough for current application. Risetime of the pulse may change when it passes cable discontinuity. The phenomenum is examined[9] which gives the hint in analyze multiple reflections.

6.VALIDATION TEST

In order to show the applicable of multiple points monitoring at the same time, a semi-rigid coaxial cable is used to evaluate the system. Coaxial cable is grouted into concrete blocks having different size and is arranged as shown in Fig. 4 Different amount of deformation on block joints are given to make the returned signature on TDR oscilloscope visible The purpose of this test set-up was two fold: 1) show the effect of joint deformation is equivalent to a shunted capacitance and 2) test the resolution and effect of multiple discontinuities. Test results are given in Table 1 and Fig. 5 and 6. Fig. 5 is the waveform recorded after relative movement applied to both segments which is taken from left side, i.e. the connecting point "L" as marked on Fig. 4. Fig. 6 is the waveform taken from right (R) side. For each reflection point, waveform is enlarged and inserted to give a detailed look. Magnitude for each reflection point are summarized into Table 1. Measuring items are given as maximum reflection voltage and integrated area of reflection voltage. Differences on magnitude are given as the last column to make the comparison.

7.DISCUSSION OF RESULTS

Locations of joints together with its movements are clearly shown in the waveform. Even joints on sides of 20 cm blocks are clear enough to be seen. Magnitude of the reflected waveform is noticeable and should be treated with care. Procedures proposed in Su and Chen (1996)[9] should be applied.

Waveform did change after passing through cable deformation, i.e., cable's impedance change. Risetime of the waveform changed so is its reaction with next interface. The area integration method did proved to be an acceptable analyze method in multiple reflection situation which makes the monitoring system for the integrity of infrastructure using one coaxial cable possible.

8.CONCLUSION

TDR technique can be applied to monitor the relative movement between elements of an infrastructure so as to guarantee its integrity or to be a warning before too large the local failure. The coaxial cable can be fixed on both side of a joint or grouted into elements depends on the type of the structure. The cable is then working like a multiple points relative movement sensor and waveform transmitting medium. This technique is proved to be able to see multiple deformation simultaneously using one cable and is easy to install.

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Table 1. Summary of test result

Position	Dial reading (0.01mm)	Measure item	Connection at left	Connection at right	Difference (%)
A1	400.0	$E_{r,max}$ (mρ)	22.49	20.09	11.27
		Area (mρ-ps)	1185.4	1180.5	0.41
A2	400.0	$E_{r,max}$ (mρ)	36.22	39.12	7.70
		Area (mρ-ps)	2127.3	2146.7	0.91
B1	511.0	$E_{r,max}$ (mρ)	37.35	48.13	25.22
		Area (mρ-ps)	2983.4	2998.3	0.50
B2	230.5	$E_{r,max}$ (mρ)	21.61	31.31	36.66
		Area (mρ-ps)	1904.6	1908.1	0.18

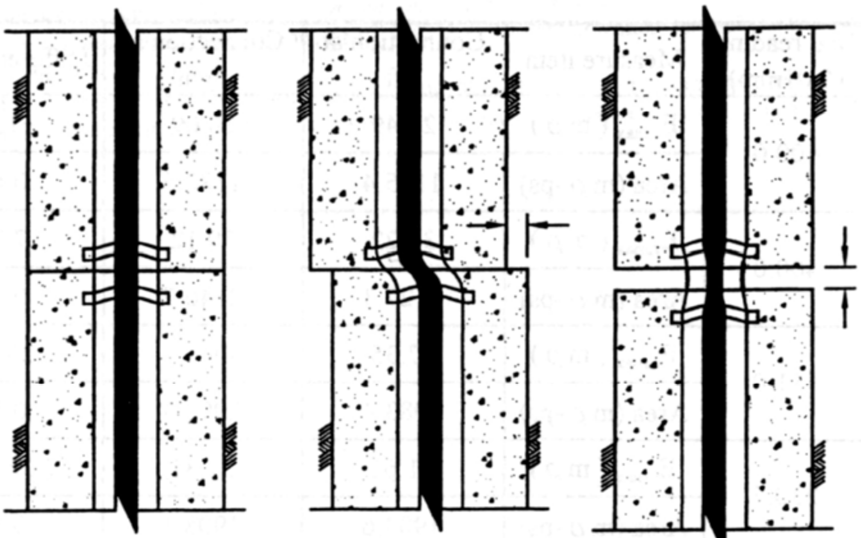
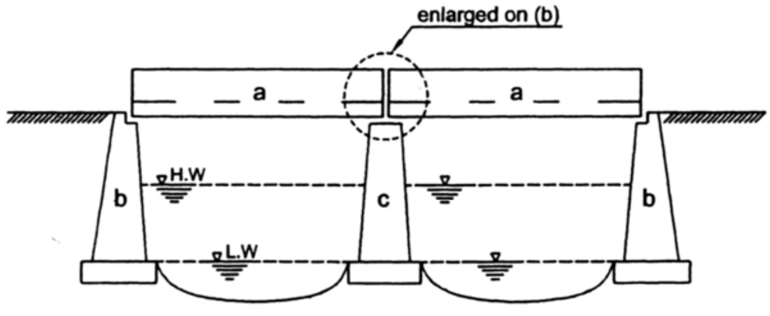
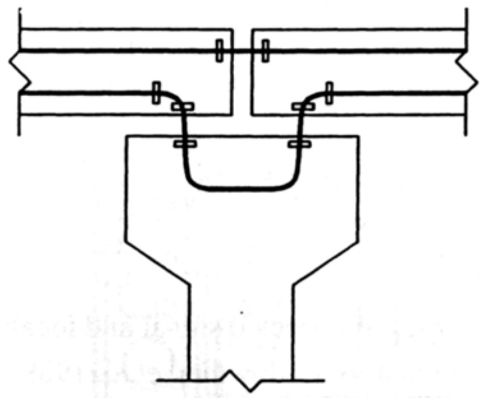


Fig. 1. Types of block movement and change of th fixed cable gemetries



a: elements of superstructure, like bridge deck made of R.C. or steel
b,c: elememts of substruture, like abutment (b) or pier (c)

(a) Schematic plot for a bridge



(b) Sketch of fixation of cable on the connecting points between two elements

Fig.2. Monitoring system for relative movement between bridge deck and deck joint or bridge bearing point

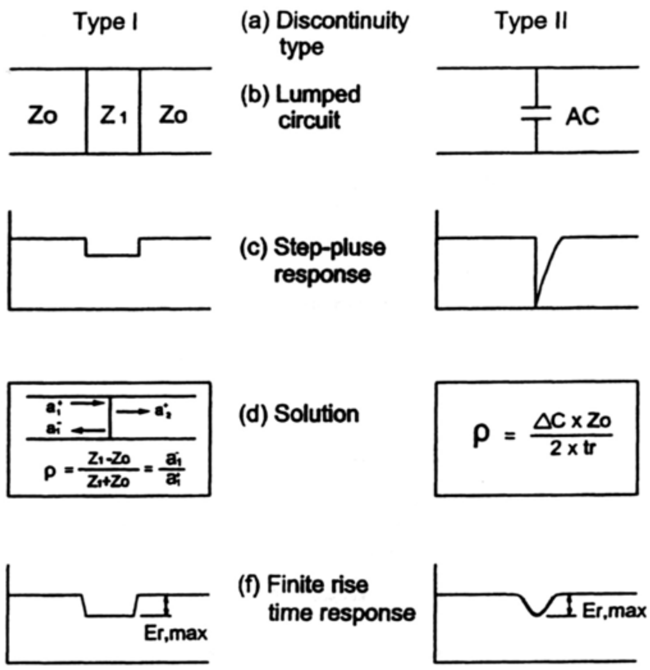


Fig.3. Types of reflected signal and idealization for analysis. (dowding et.al. 1989)

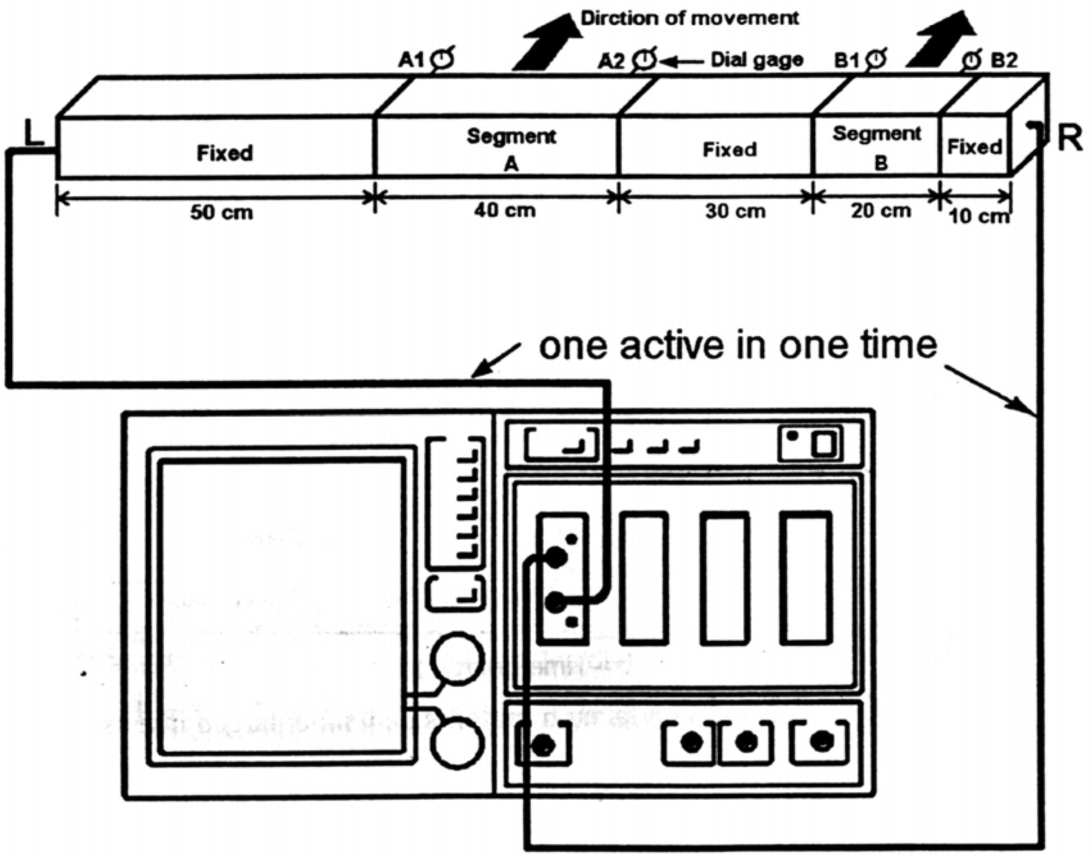


Fig.4. Test set-up and sample dimension

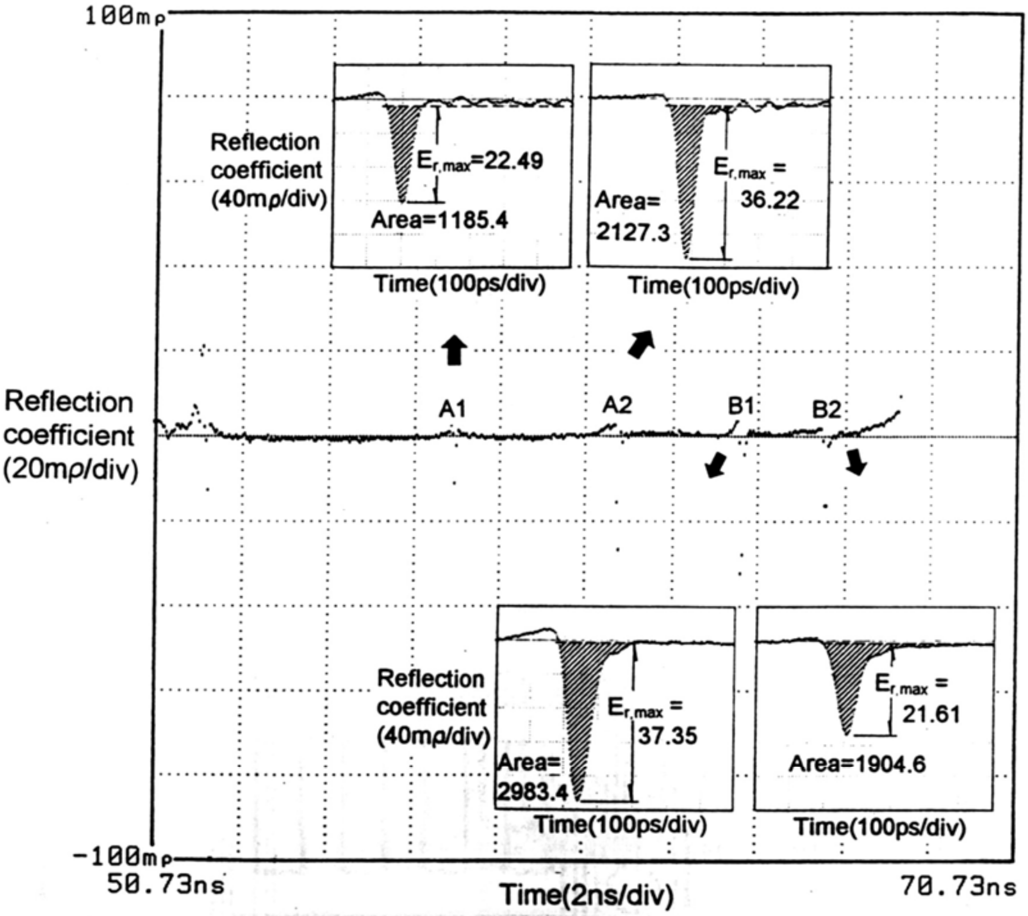


Fig.5. Waveform taken from left side with enlarged inserts

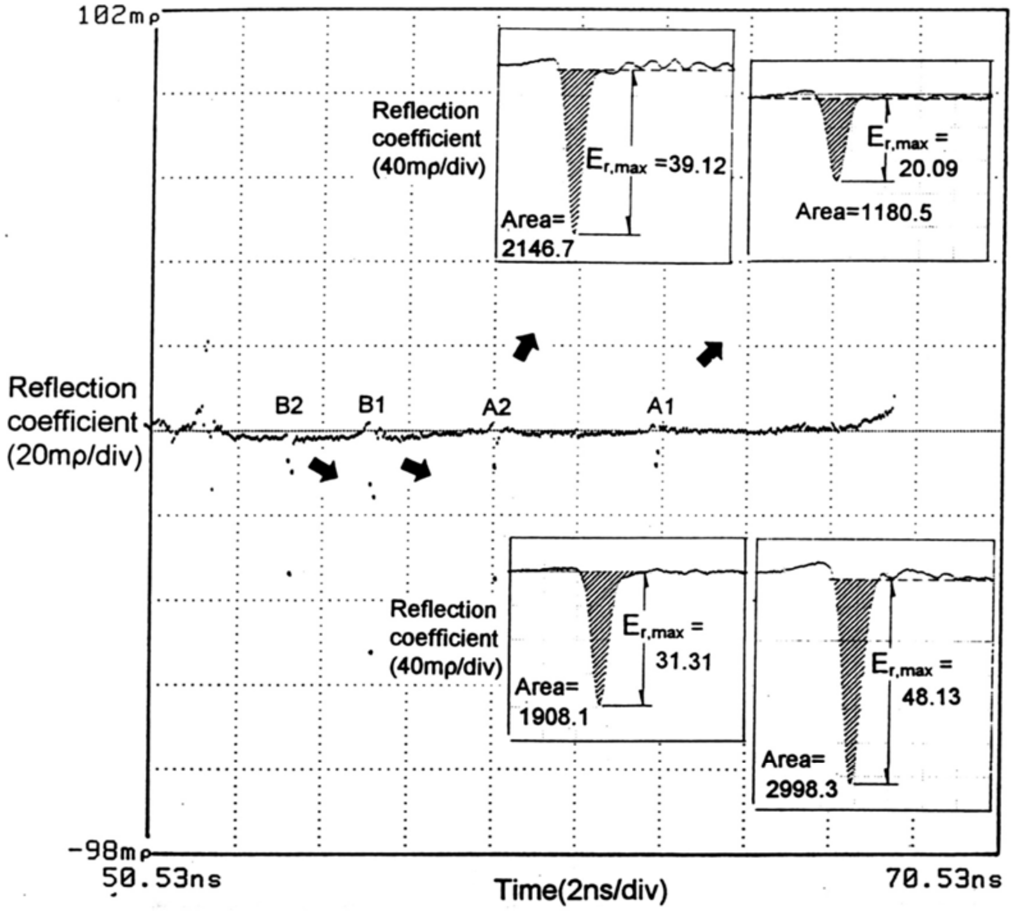


Fig.6. Waveform taken from right side with enlarged inserts