POST-EARTHQUAKE CONDITION ASSESSMENT OF RC STRUCTURES PART 1: CRACK SENSOR

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Participants

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Objectives

To introduce a general framework for structural condition assessment of RC members with measured surface crack pattern

To introduce distributed cable sensors and measurement principle

To validate the performance of cable sensors for crack detection for both location and severity

To illustrate the potential applications of sensors

A Framework for Condition Assessment of RC Member

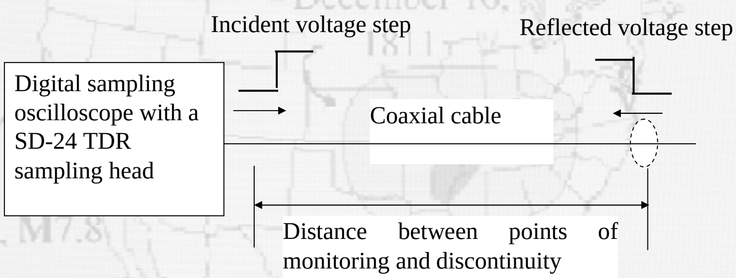
A three-level strategy is proposed in this study to assess the damage of a RC structural system, using electromagnetic wave-guiding tools:

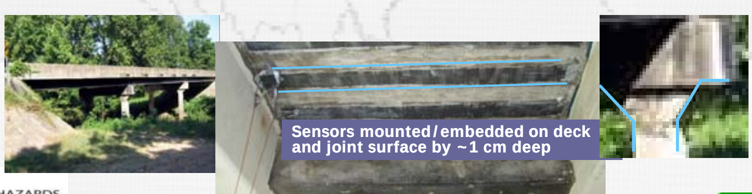
1. to apply the recently-developed, distributed cable sensors to locate and detect the near-surface cracks in any major member of the structure.
2. to apply microwave technology to refine the crack distribution at critical locations, such as near the beam-column joints or where the first-level detection has indicated the occurrence of excessive cracking.
3. to infer the structural condition of the member from the measured crack patterns by applying the mechanical principle [Nazmul and Matsumoto 2003].

Anatomy of a Crack Sensor

- Twisted silver plated copper wire serves as inner conducting core
- Teflon dielectric layer covers inner core
- Steel spiral layer serves as outer conductor
- Thin layer of solder coats the steel spiral layer

Measurement Principle: Electrical Time Domain Reflectometry



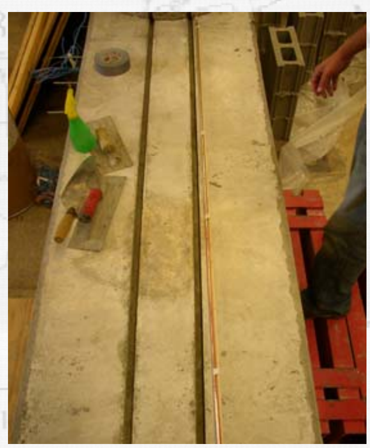


Performance Validation with Static, Cyclic, and Dynamic Tests

- Static testing on beam specimens
- Dynamic testing on column specimens
- Cyclic testing on 80%-scale beam-column specimens
- Load tests of the RC deck of Dallas County Bridge, MO

Installation of Distributed Sensors

- Sensors are near surface mounted on a member and installed in a 1.25cm x 1.25cm groove.
- Sensors are grouted into place with grout materials that are more brittle than concrete.



Data Acquisition

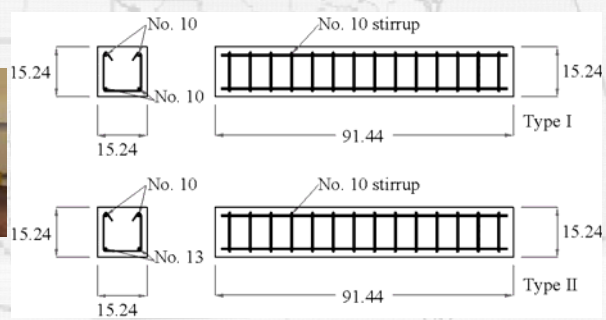
- Signals are acquired using the Electronic Time-Domain Reflectometery (ETDR)
- A Time Domain Reflectometer (TDR) digital oscilloscope is used in data acquisition
- Sampling rate is 200 kHz, corresponding time needed to retrieve full signal is on the order of 2.6 milliseconds

Equipment

Typical Reflected Waveform

Static Tests on Beam Specimens

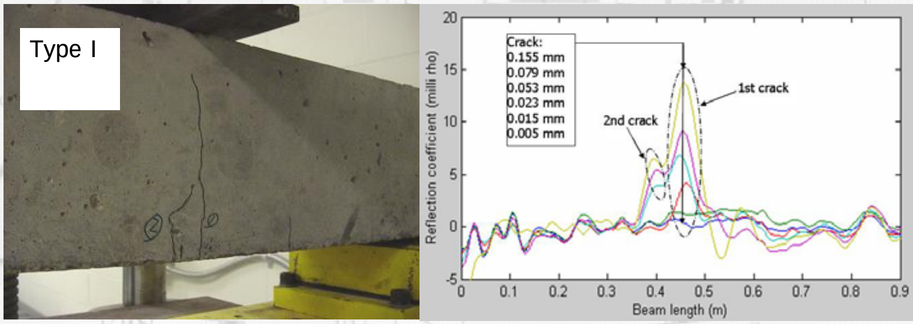
- Sensor installed on 91-centimeter beams tested in flexure under static loads



Design Details of RC Beams

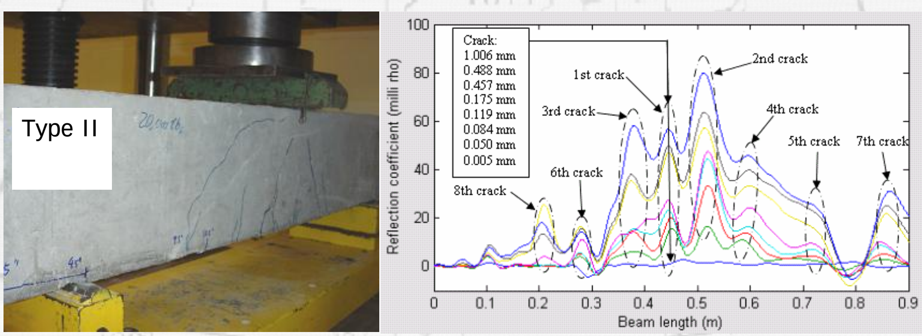
Static Tests on Beam Specimens

- Crack pattern and reflected waveform



Static Tests on Beam Specimens

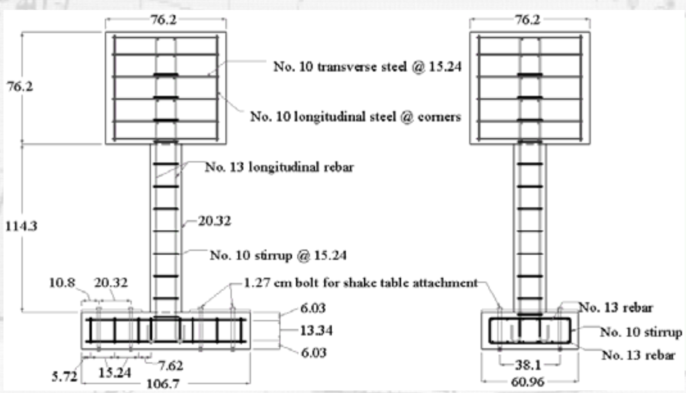
- Crack pattern and reflected waveform



Dynamic Test Specimen

- 1.9m tall 20cm x 20cm square concrete column
- Rectangular footing for attachment to shake table
- 76cm x 76cm x 76cm mass of concrete on top of column to give the column a fundamental frequency of around 8 Hz
- 27.6 MPa concrete used in construction of column
- 1.25cm x 1.25 groove in face of column for sensor installation

Dynamic Test Specimen



Dynamic Test Specimen Retrofit Schedule

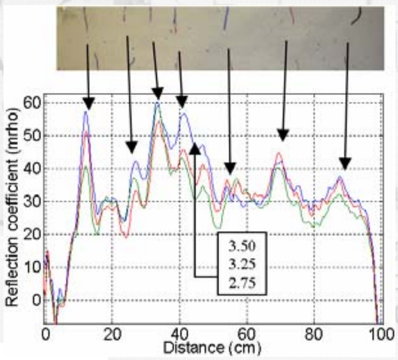
Column	Retrofit	Stroke (mm)	Rubber-Sensor	Teflon-Sensor	Crack
C1	No	1.78	N/A	T1	Surface
C2	No	1.78	N/A	T2	Surface
C3	Yes	1.78	N/A	T3	Hidden
C4	Yes	1.78	N/A	T4	Hidden
C5	Yes	0.76	N/A	T5	Hidden
C6	No	0.76	R1	N/A	Surface

Purpose for Dynamic Tests

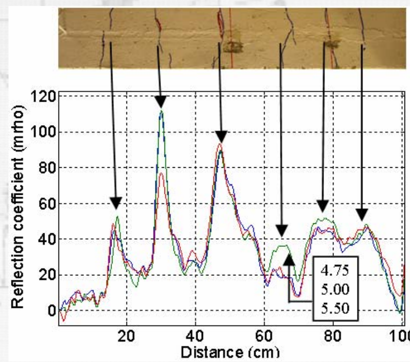
- Investigate the behavior of the sensor in a dynamic application (harmonic excitation)
- Investigate the ability of the sensor to detect cracks beneath retrofit (FRP)
- Investigate any fatigue effects
- Study the "memory" feature of the sensor

Results of Dynamic Tests

- Shows location and size of crack in column
- Detects crack in advance of visual detection
- Detects crack beneath FRP reinforcement

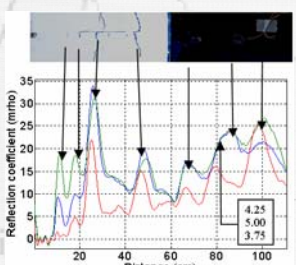


(a) Column C1

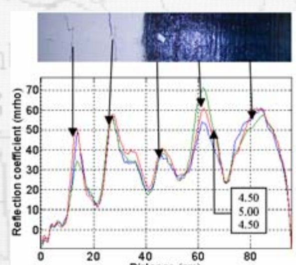


(b) Column C2

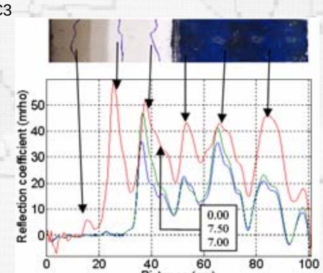
Results of Dynamic Tests



(c) Column C3

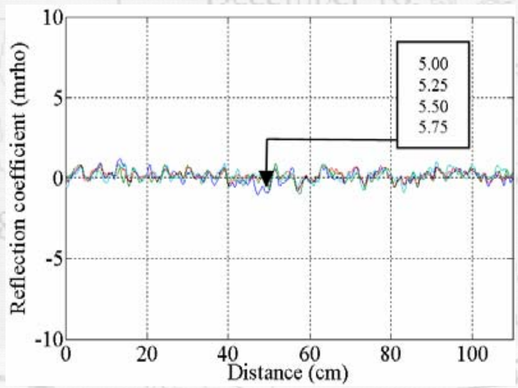


(d) Column C4



(e) Column C5

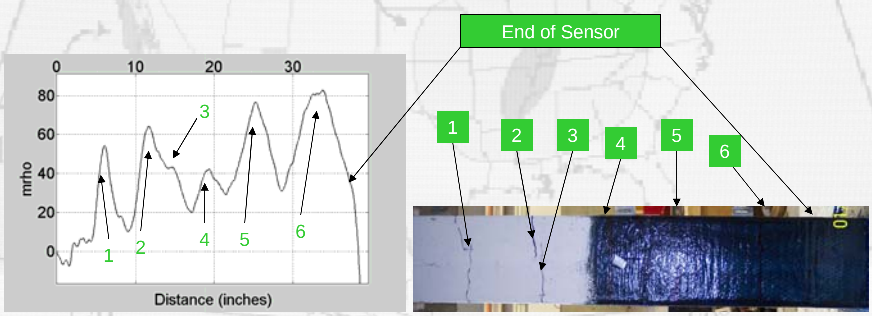
Results of Dynamic Tests



Column C6 with rubber-type sensor

Results of Dynamic Tests

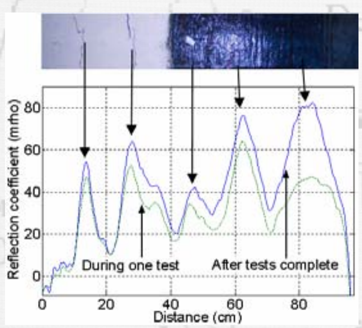
- Shows the location of cracks beneath FRP



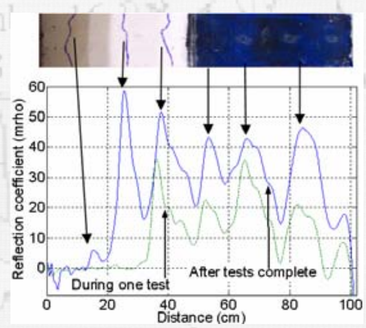
Fatigue of Sensor

- Sensor continues to operate after several test cycles (upwards of 20,000)
- Only one sensor ceased to operate, reason was because of connector, not actual sensor
- Sensor shows location of cracks after testing ceases (column reinforcement failure)

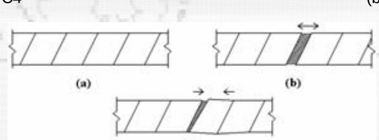
Discovery of Memory Feature



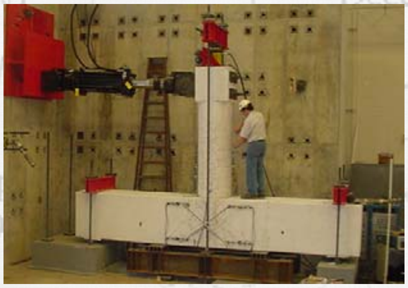
(a) Column C4

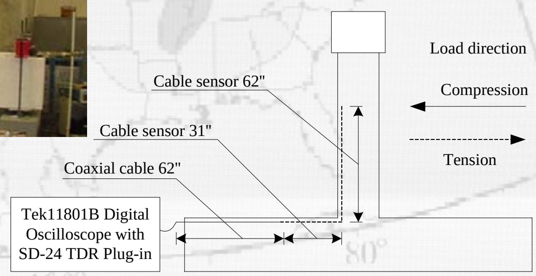


(b) Column C5

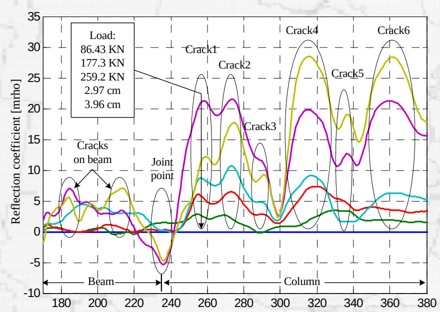


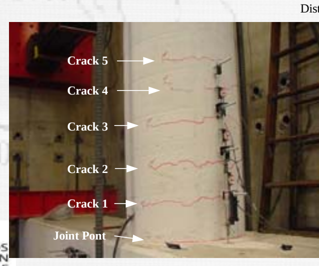
80% Bridge Column-Beam Specimen



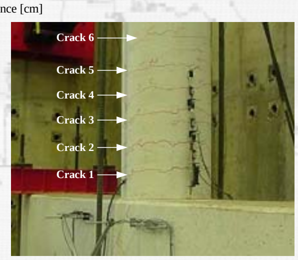


Specimen # 1 (Rubber Sensor)





(a) Crack pattern at 177.3 kN

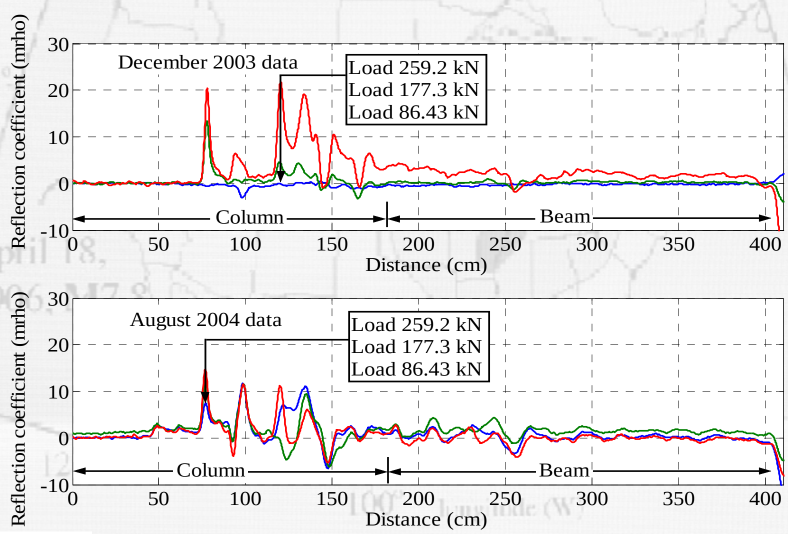


(b) Crack pattern at 1.98 cm

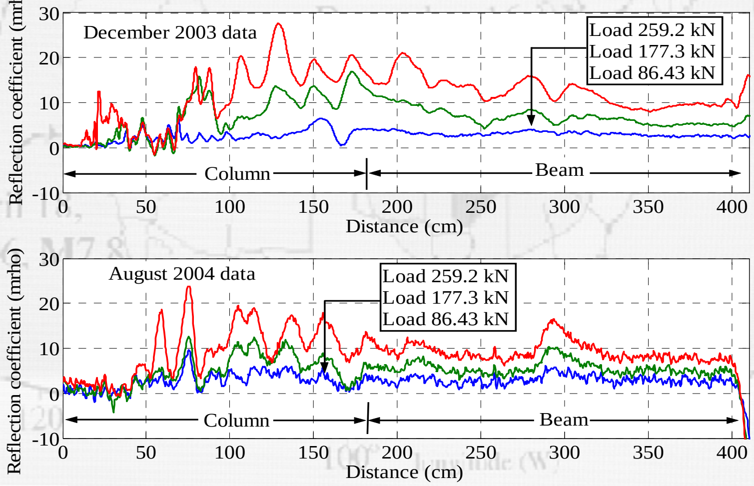
Specimen # 3

- Both rubber and Teflon sensor installed into specimen
- Specimen tested in December of 2003 without any retrofit
- Testing resumed August 2004 with retrofit scheme

Specimen # 3 Results (Teflon)

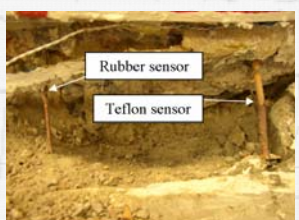


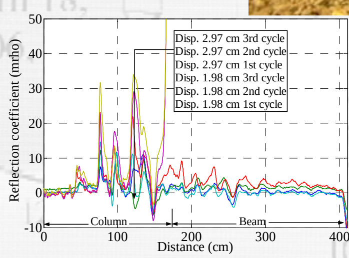
Specimen # 3 Results (Rubber)



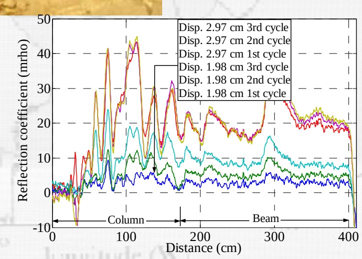
Cable Sensor - 27

Specimen # 3 Results





Teflon Sensor



Rubber Sensor

Cable Sensor - 28

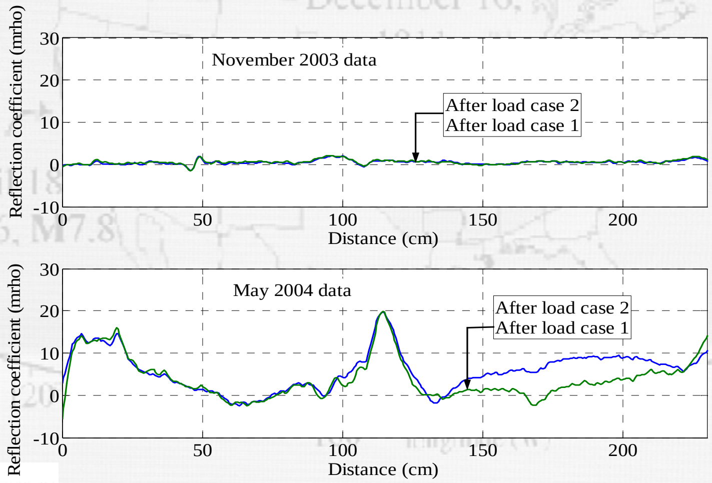
Specimen # 3 Results

- After six months of inactivity sensors still show comparable results at same loading levels
- Both detect location and relative size of cracks
- 90^{o} bend at construction joint is a detriment to sensor performance

Monitoring of Bridge Deck under Load Testing

Dallas County Bridge, MO

Difference Signals Taken at Zero Loading (Sensor 1)



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Cable Sensor - 31

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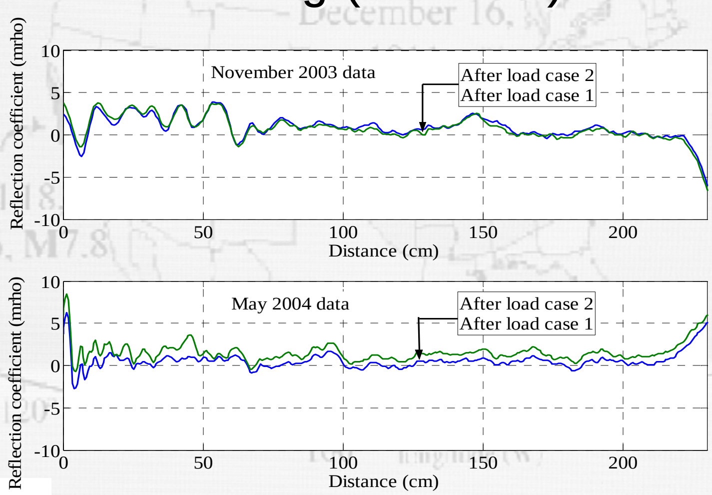
Difference Signals Taken at Zero Loading (Sensor 2)



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Cable Sensor - 32

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Results of Bridge Tests

- Sensors show no degradation after several months of exposing to the elements

Conclusions

- Sensors are demonstrated to be able to detect location and relative size of cracks
- Rubber type sensors are not recommended for dynamic application
- Sensors are rugged, surviving over 20,000 cycles of loading
- Teflon sensors have ability to record the most severe crack
- Sensors can detect cracks beneath retrofit schemes
- It is not recommended to install sensors across construction joints where large displacements are prone to occur
- No degradation is observed in sensors over a period of months in both lab conditions and in field conditions