DEPARTMENT OF CIVIL ENGINEERING

IIT DELHI

LEC 3

STRUCTURAL HEALTH MONITORING:

SENSING TECHNOLOGIES

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FOR STUDENTS OF CVL 864 IIT DELHI

SENSING TECHNOLOGIES FOR STRUCTURAL MONITORING

CONVENTIONAL SENSORS (STATIC/ DYNAMIC)

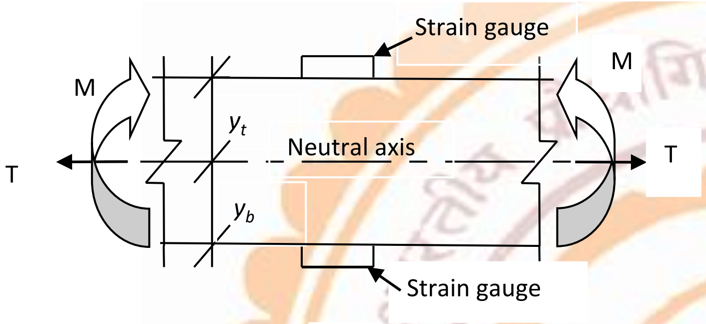
** Electrical strain gauge (ESG) **

** Vibrating wire strain gauge (VWSG) **

** Accelerometers **

SENSORS BASED ON SMART MATERIALS

DETERMINATION OF AXIAL LOAD AND BENDING MOMENT THROUGH STRAIN MEASURMENT



$$\varepsilon_t = \frac{T}{AE} - \frac{My_t}{IE}$$

$$\varepsilon_b = \frac{T}{AE} + \frac{My_b}{IE}$$

Tensile strain considered +ive here

where *A* is the cross sectional area, *I* the moment of inertia of the section and *E* the Young's modulus of elasticity.

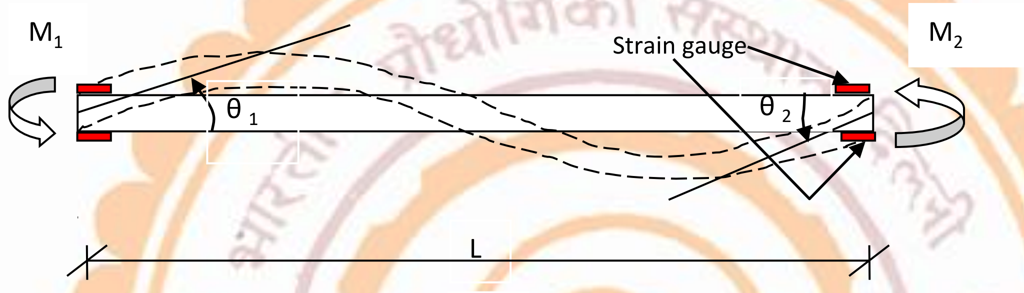
Combining, the two equations:

$$T = \frac{EA(\varepsilon_b y_t + \varepsilon_t y_b)}{(y_t + y_b)}$$

$$M = \frac{EI(\varepsilon_b - \varepsilon_t)}{(y_t + y_b)}$$

$y_t + y_b =$ TOTAL DEPTH OF THE SECTION UNDER CONSIDERATION

MEASUREMENT OF MEMBER END ROTATIONS



$$\theta_1 = \left(\frac{L}{6EI}\right)\left[2(M_1 - M_1^F) - (M_2 - M_2^F)\right]$$

$$\theta_2 = \left(\frac{L}{6EI}\right)\left[2(M_2 - M_2^F) - (M_1 - M_1^F)\right]$$

From elementary slop-deflection equations

where M_1^F and M_2^F represent the fixed ended moments, resulting from the member loads. It is assumed here that there is no relative displacements between the two member ends (i.e columns are inextensible).

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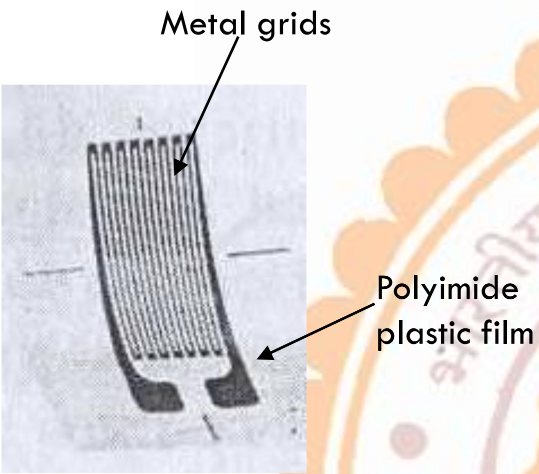
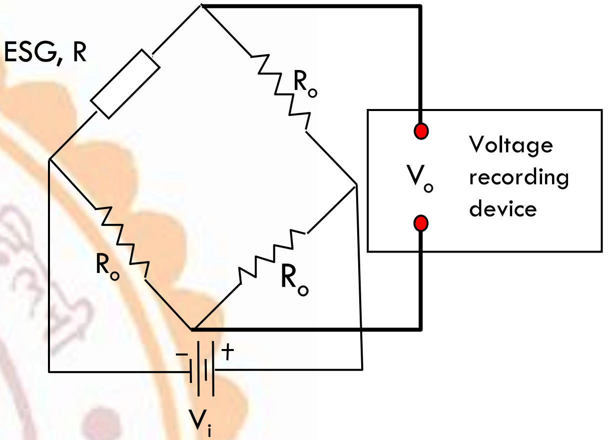
SENSORS BASED ON SMART MATERIALS

ELECTRICAL STRAIN GAUGE (ESG)



$$\frac{\Delta R}{R} = S_g \varepsilon$$

Gauge factor



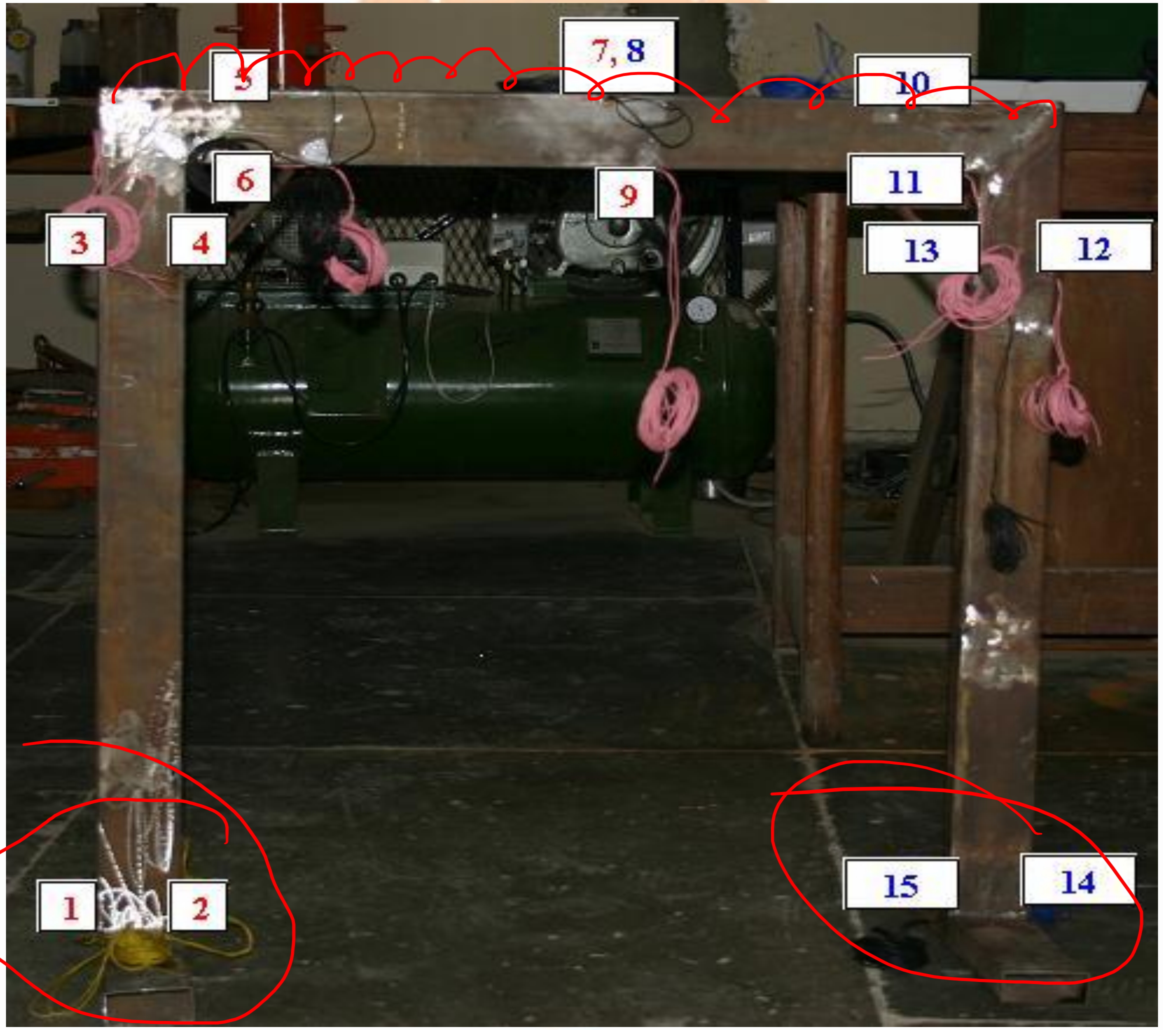
KEY ADVANTAGES

* Low- cost (~ Rs 100)

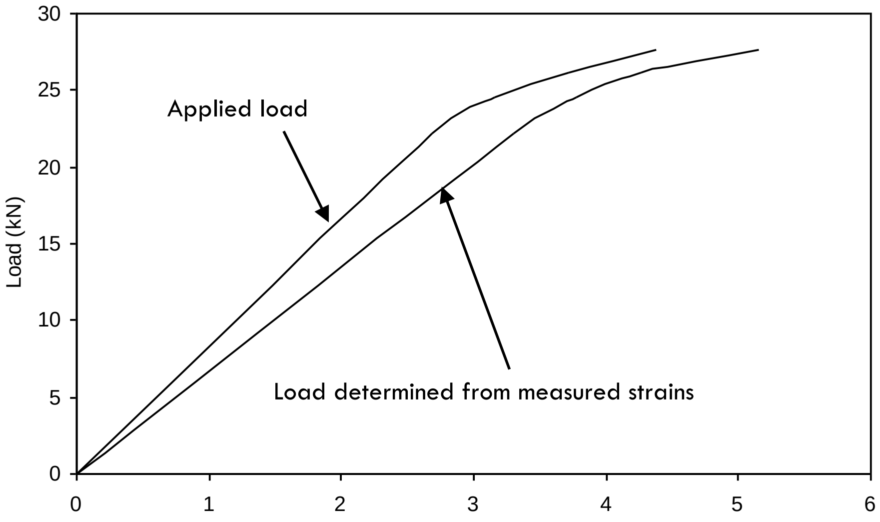
* Easy to install and handle

* Simple wheat stone bridge circuit coupled with amplification circuit sufficient for measurement

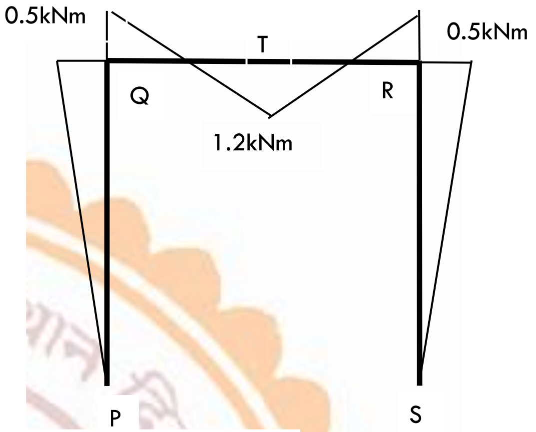
MONITORING OF STEEL FRAMES

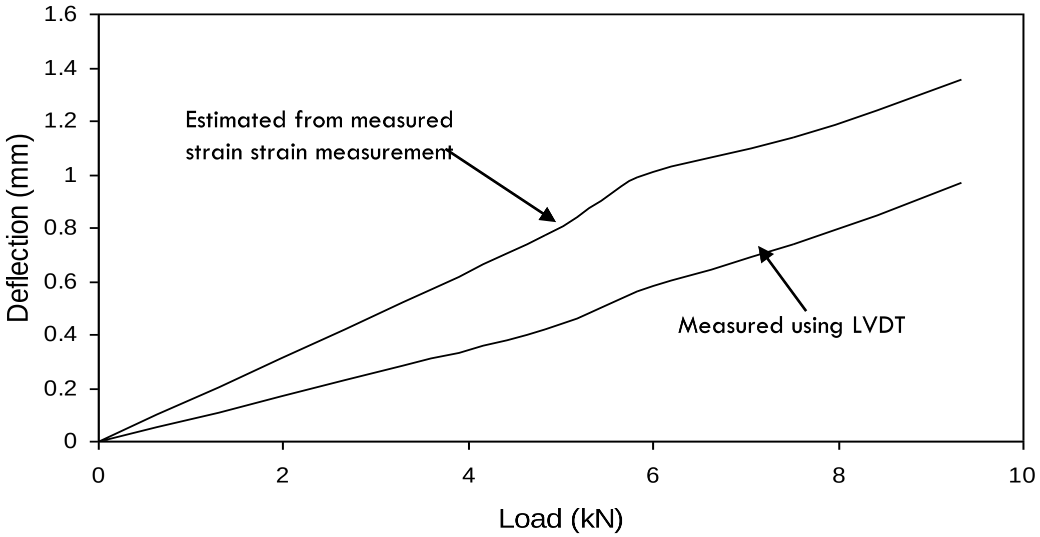


Load Estimation



Bending moments



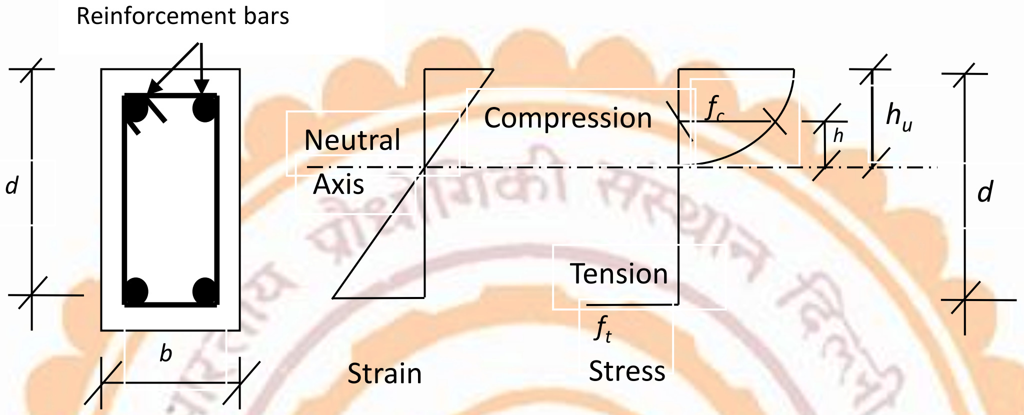


Deflections

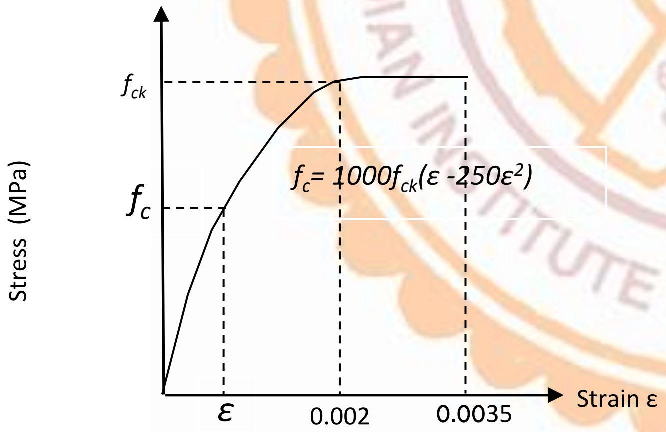
By double integration of (M/EI) curve

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$

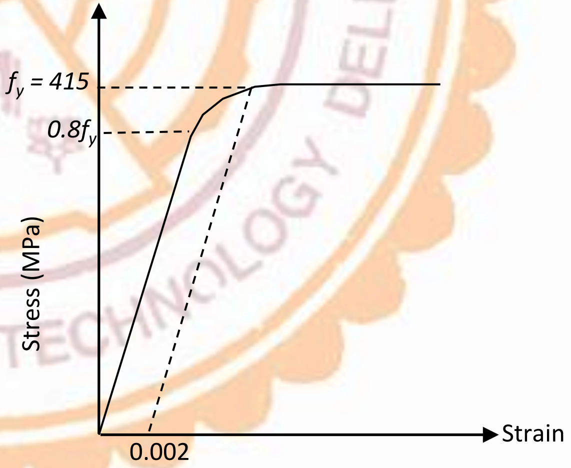
MONITORING OF RC STRUCTURES



We need to measure strain distribution along the section, use the available stress-strain relations of concrete and steel to determine internal moment and axial force.

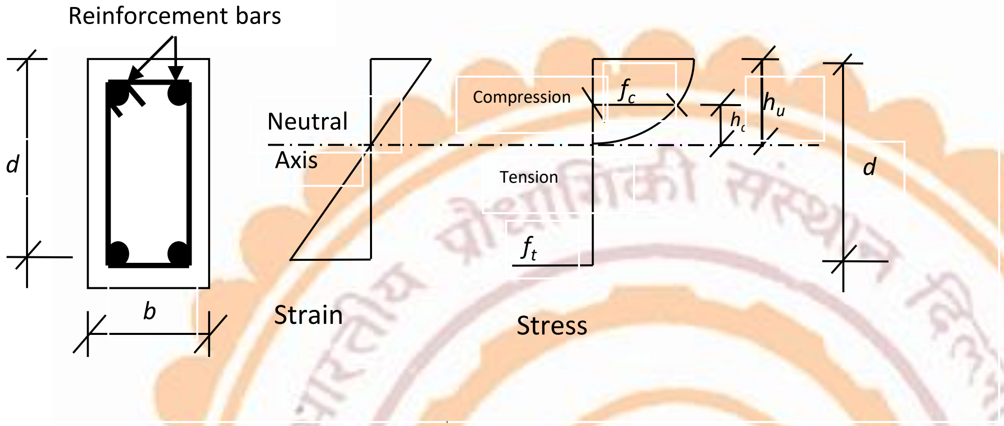


Concrete



Steel

MONITORING OF RC STRUCTURES

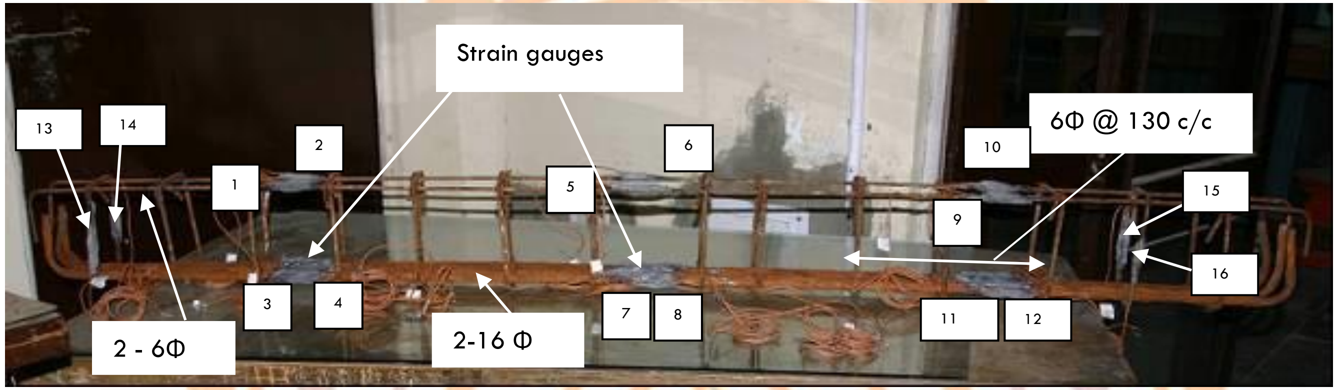


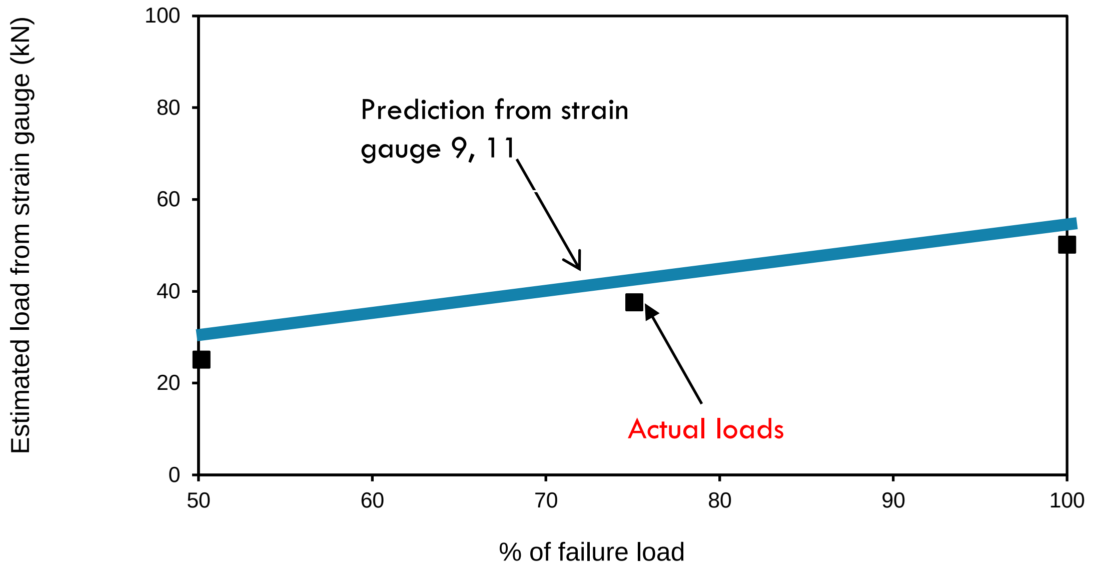
$$C = \int_{h=0}^{h=hu} f_c b dh \qquad h_c = \frac{1}{C}\int_{h=0}^{h=hu} f_c bh dh$$

The internal bending moment at the section can be obtained by taking the moment of the compressive stresses about the centroid of the tensile stresses (bottom reinforcement) as

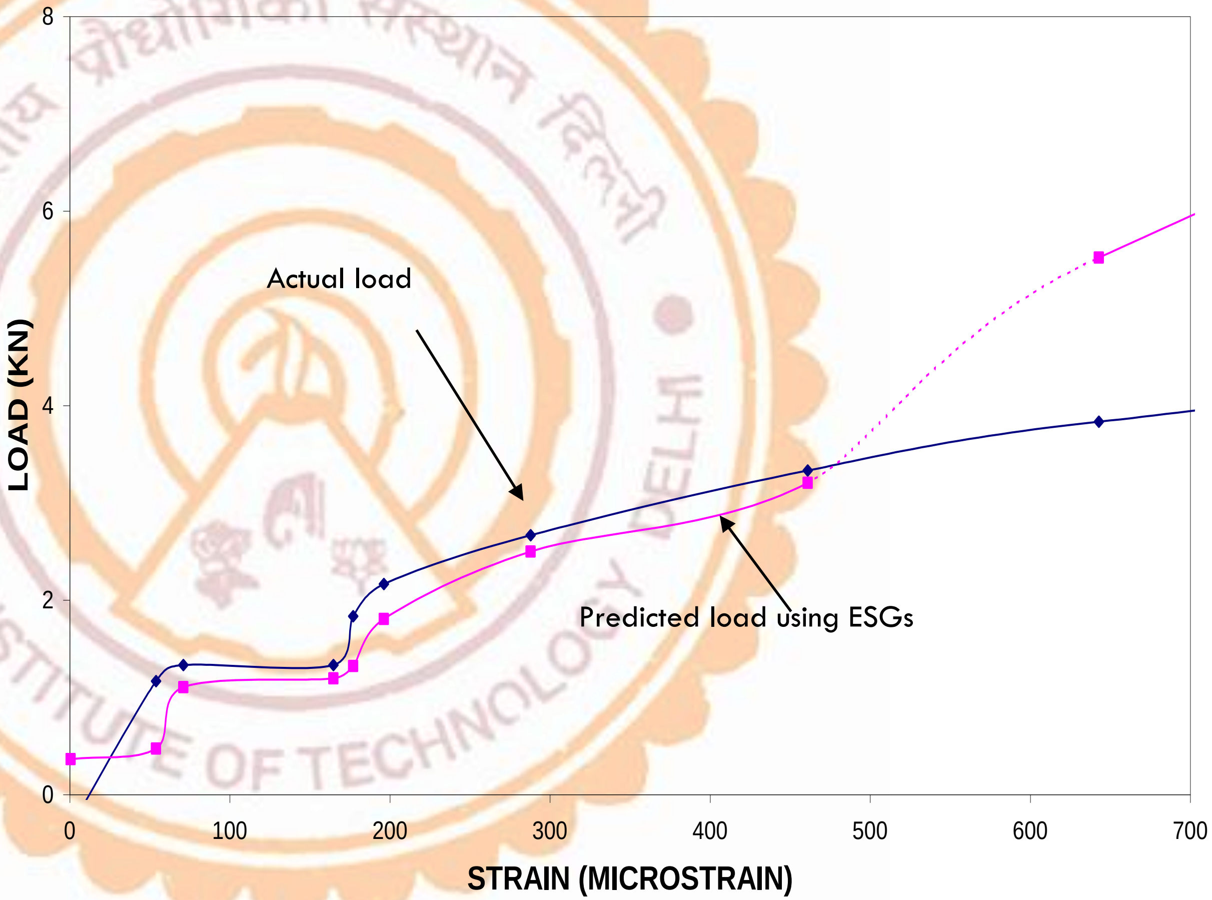
$$M = C(d - h_u + hc)$$

MONITORING OF RC STRUCTURES USING ELECTRICAL STRAIN GAUGES

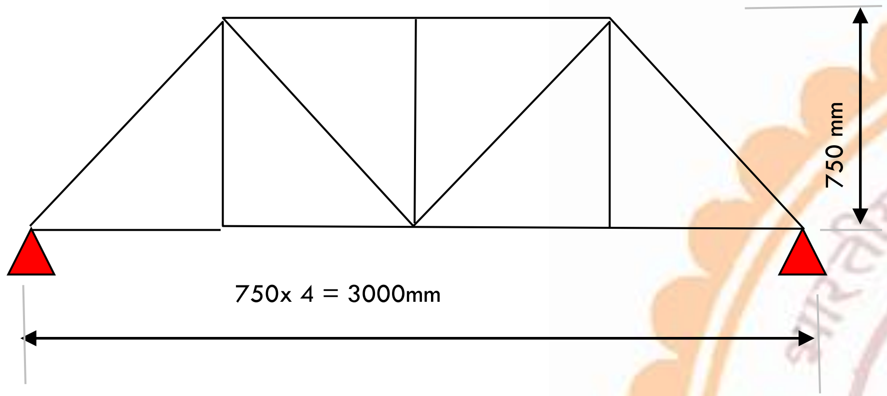


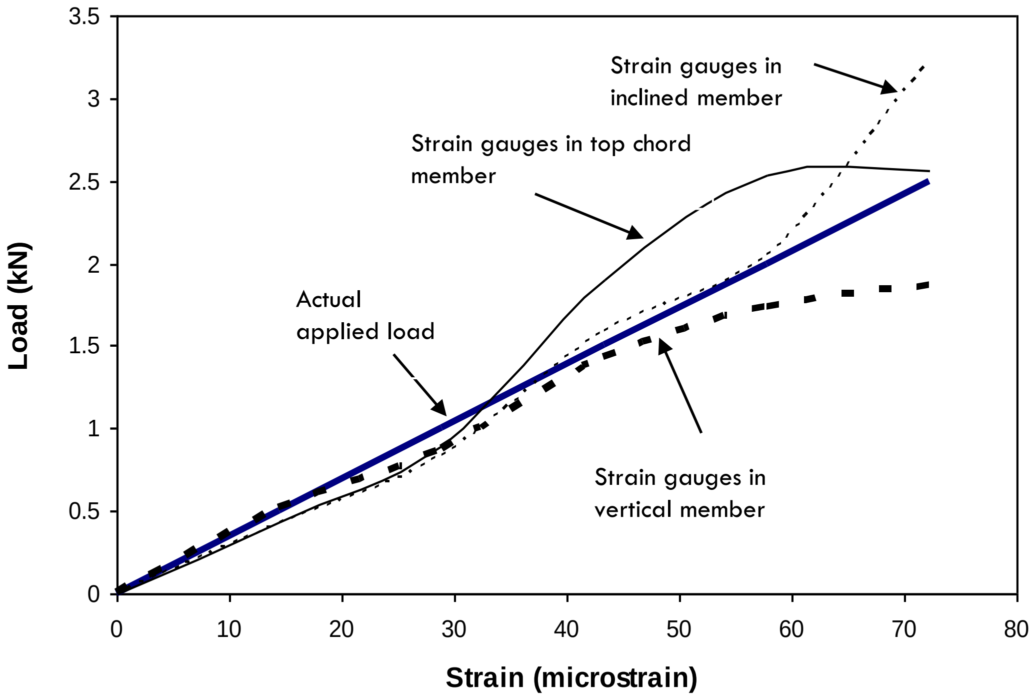


MONITORING OF TUNNEL LINING



MONITORING OF STEEL TRUSS





ELECTRICAL STRAIN GAUGE (ESG): DRAWBACKS

* Too many wires to handle

* Prone to electrical noise (electromagnetic interference)

* Prone to deterioration by water

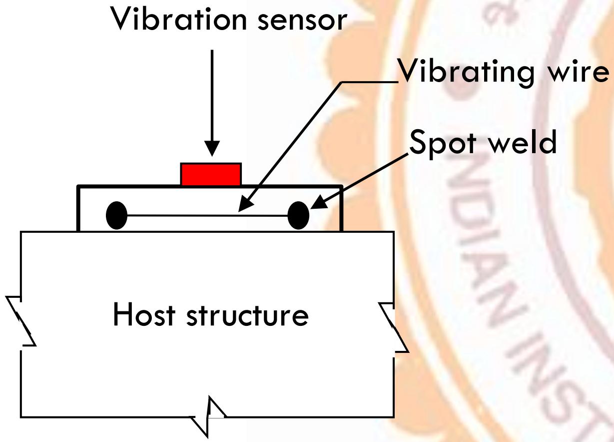
* Suffer from decay if loaded for prolonged periods.

* Best for preliminary short term STATIC monitoring.

VIBRATING WIRE STRAIN GAUGE (VWSG)

A VWSG essentially consists of a pre-tensioned stainless steel wire, with its ends fixed to lugs that are spot-welded to the monitored component.

A sensor coil, positioned over the wire, when energized, plucks the wire and measures the frequency of the resulting vibrations.



$$\Delta\epsilon = \frac{4l^2\rho}{Y}\left(f_2^2 - f_1^2\right)$$

initial

$$f = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

$T \rightarrow AY\epsilon$, $m \rightarrow A\rho$

$$\epsilon = \left(\frac{4l^2\rho}{Y}\right)f^2$$

Expand further in terms of strain

T is tension in the wire, *l* the length and *m* the mass per unit length

Bakker et al. (2000): Monitoring tunnel linings in Denmark

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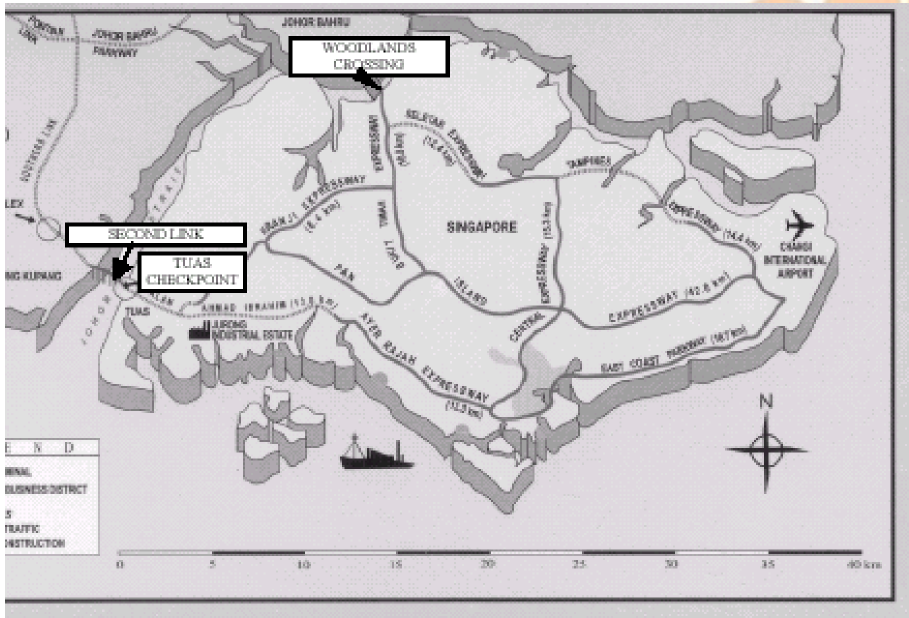
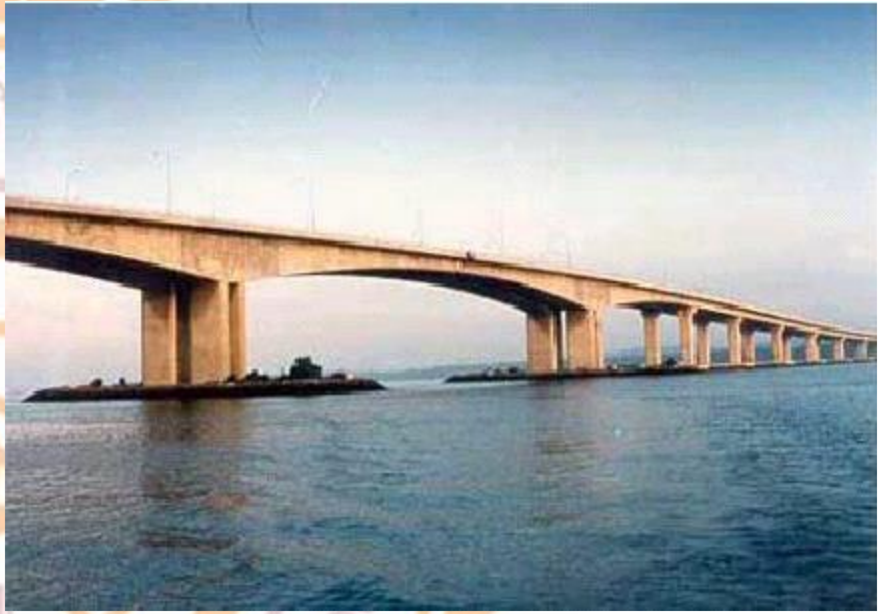
INSTRUMENTATION OF SECOND LINK BRIDGE (MOYO, 2002)





1.9 KM LONG COMPRISING 27 SPANS

The bridge was completed in 1997. It was instrumented during construction with vibrating wire strain gauges and continuously monitored.

INSTRUMENTATION OF SECOND LINK BRIDGE (MOYO, 2002)

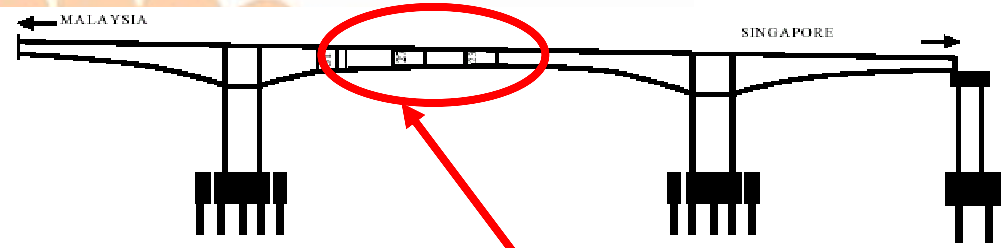
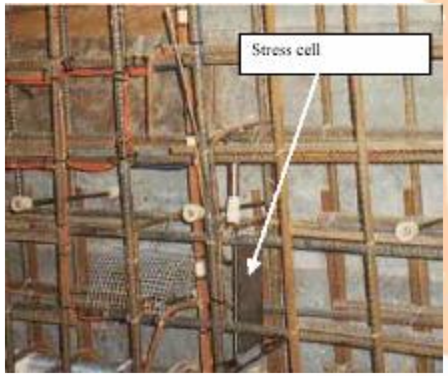


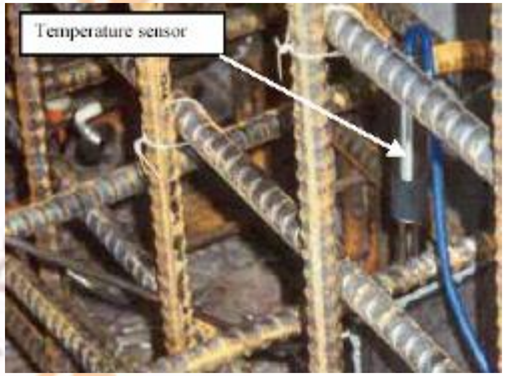
Figure 5.9 : Bridge Layout

Instrumented segment



12 stress cells

12 vibrating wire strain gauges



40 thermocouples

ALL STATIC DATA WERE RECORDED HOURLY

STRAIN IN SEGMENT 31 DURING CURING

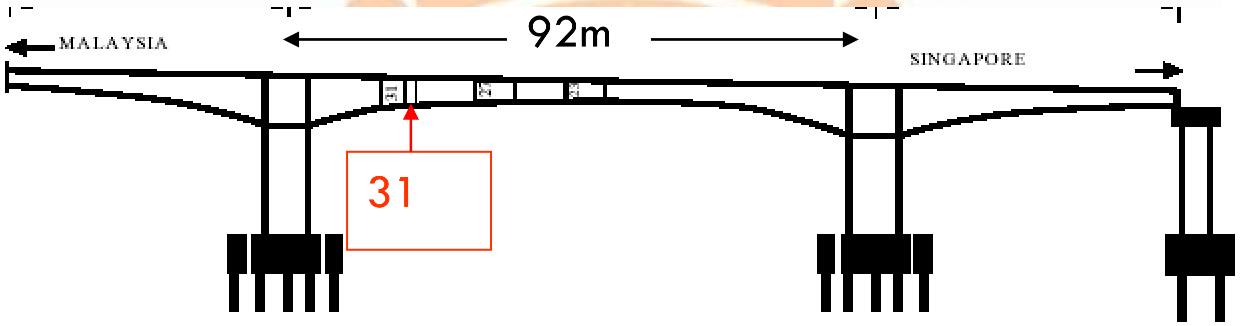
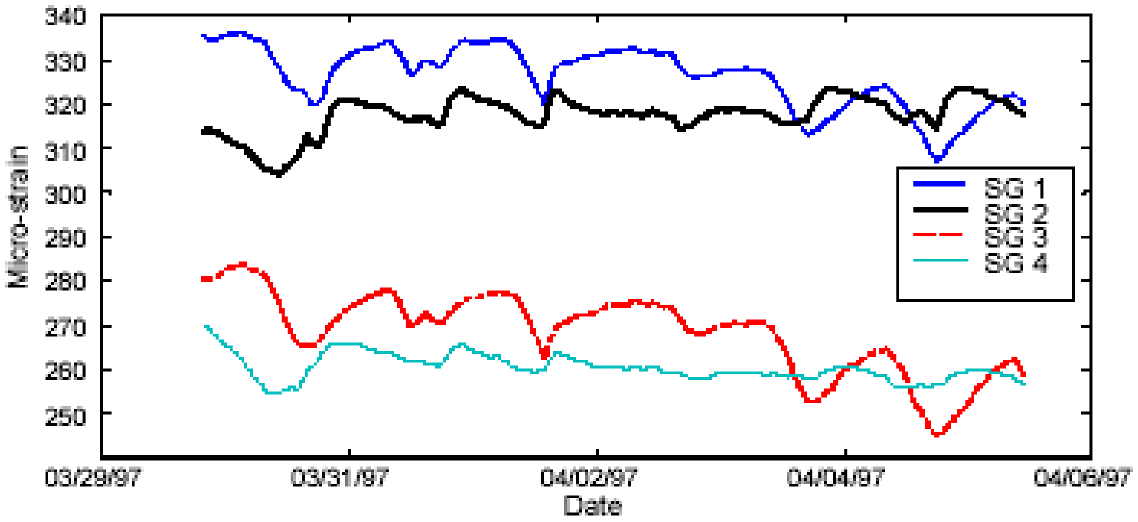


Figure 5.9 : Bridge Layout



Gradually decreasing strain => Shrinkage and hydration

MONITORING CONSTRUCTION EVENTS FROM STRAIN DATA (SEG 27)

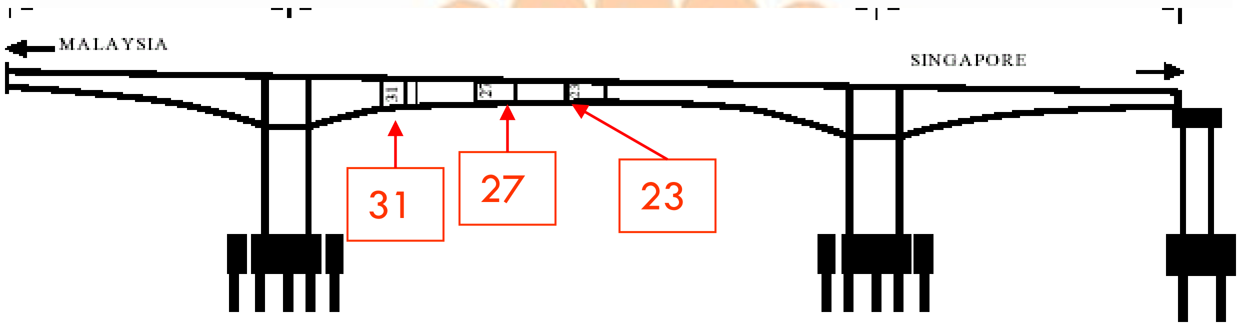
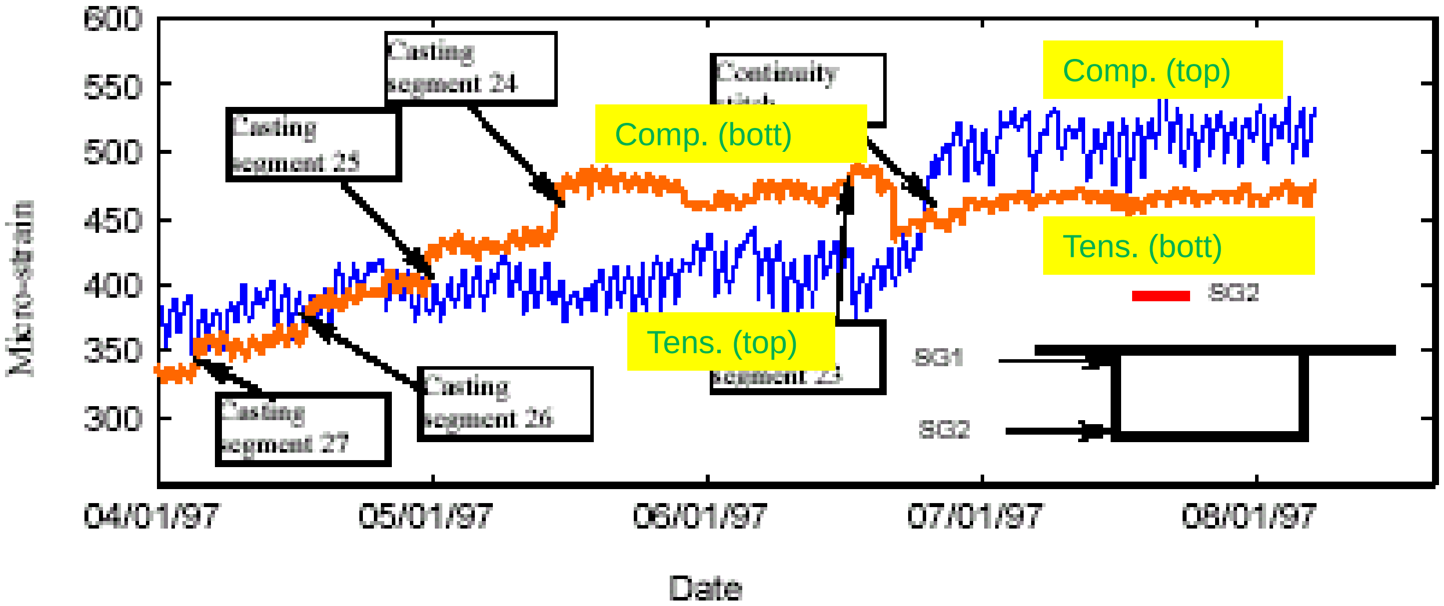


Figure 5.9 : Bridge Layout



All major construction phases can be easily identified

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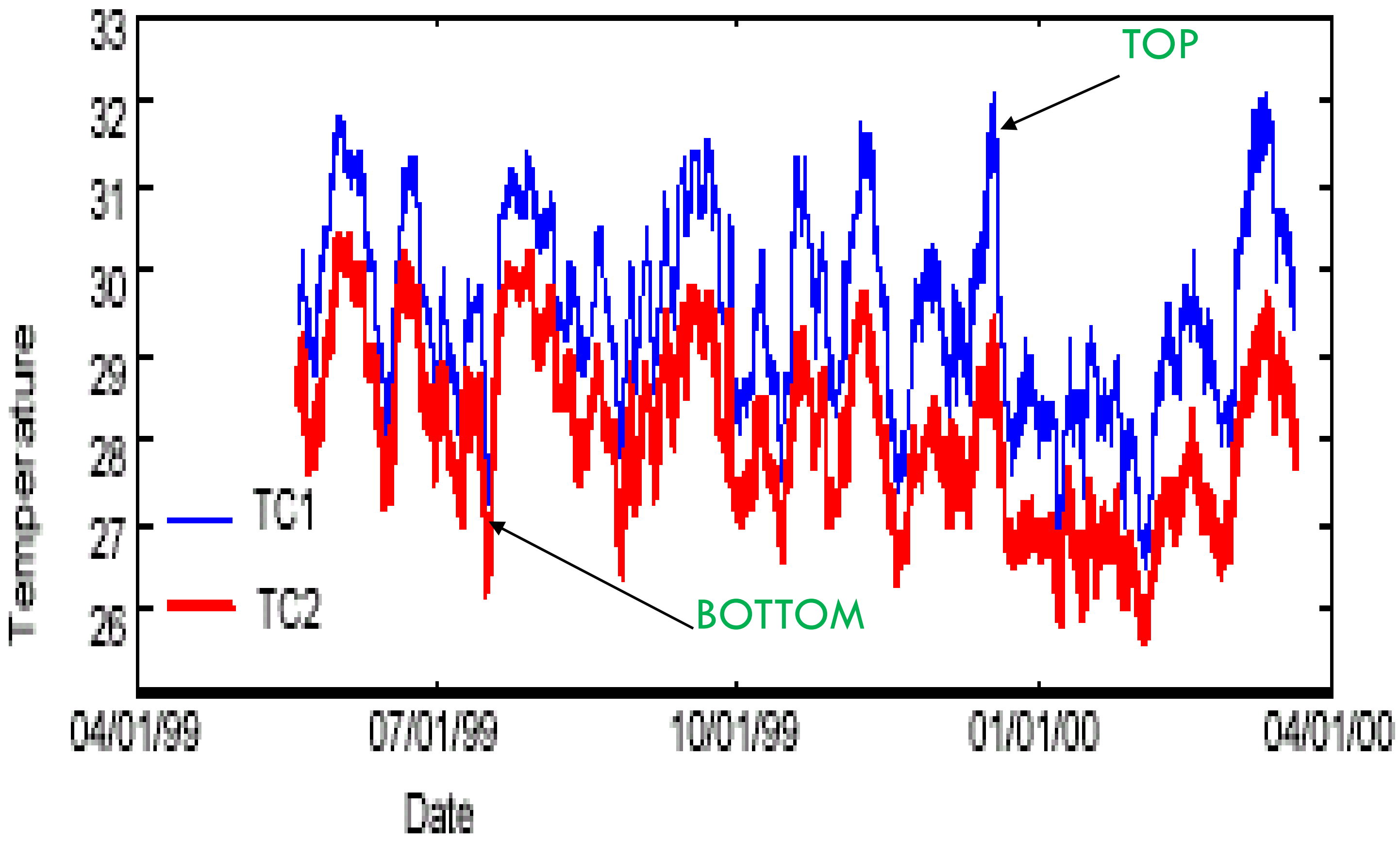
MONITORING OF TEMPERATURE



VIBRATING WIRE STRAIN GAUGE: DRAWBACKS

* Too many wires to handle

* Suitable for measuring static strains only

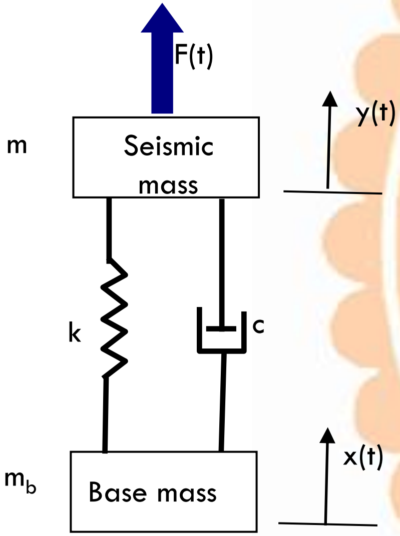
* Prone to noise (ambient vibrations), so not good for dynamic measurements

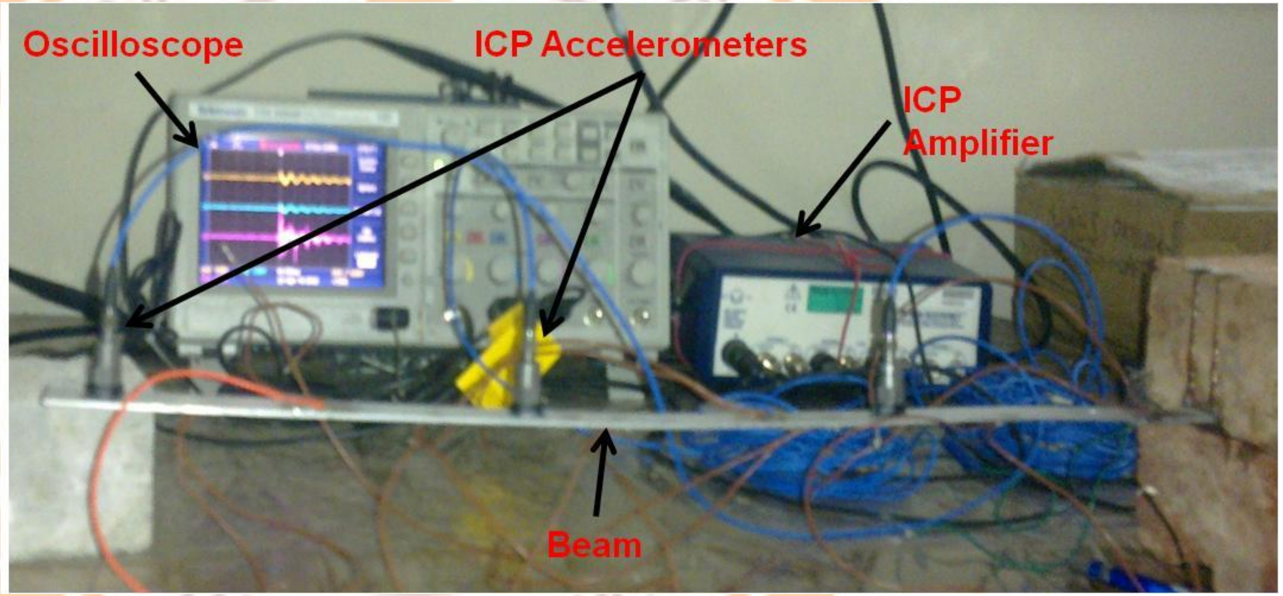
* Very expensive ($ 100 / Rs 7000)

ACCELEROMETER

$$m\ddot{y} + c(\dot{y} - \dot{x}) + k(y - x) = F(t)$$

$$y - x = z$$





For the limiting case of very small frequency ratios

$$\omega << \omega_n \qquad \ddot{x} \approx -z\omega_n^2$$

ACCELEROMETER: DRAWBACKS

* Very expensive (Typically over $500 or Rs 35, 000)

* Low bandwidth

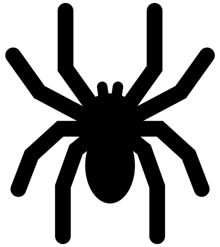
* Very fragile

* Vandalism is an issue

SMART MATERIALS

SMART MATERIALS **possess the ability to change SPECIFIC physical PROPERTY when subjected to a SPECIFIC STIMULUS input**

U.S. Army Research Office Workshop on *Smart Materials, Structures and Mathematical Issues*, September 15-16, 1988, Virginia Polytechnic Institute & State University.



Stimulus

Response

- ***Optical Fibres***
- ***Shape Memory Alloys***
- ***Electro-Rheological Fluids***
- ***Piezoelectric Materials***

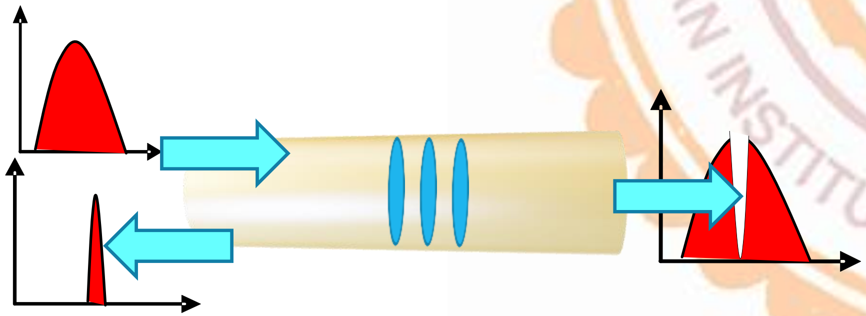
OPTICAL FIBRES

- **Flexible glass (silica) fibres (0.25 to 0.5 mm diameter)**
- **Used in communication**
- **Total internal reflection**

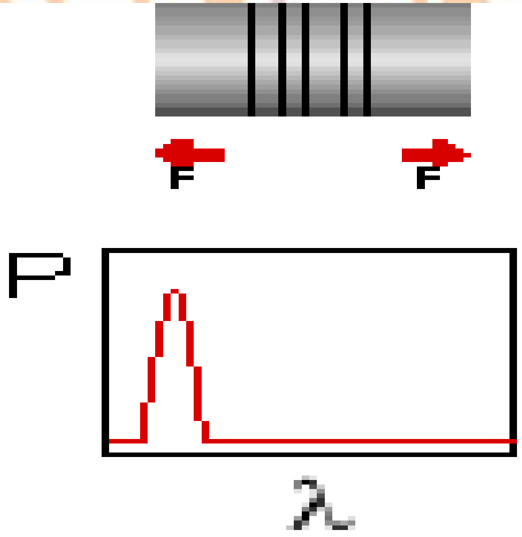
https://www.elprocus.com/

FIBRE-BRAGG GRATING (FBG) BASED SENSORS

- **FBG:** Set of gratings imprinted in a small segment of optical fibre.
- **Reflects** a particular wavelength **of light**

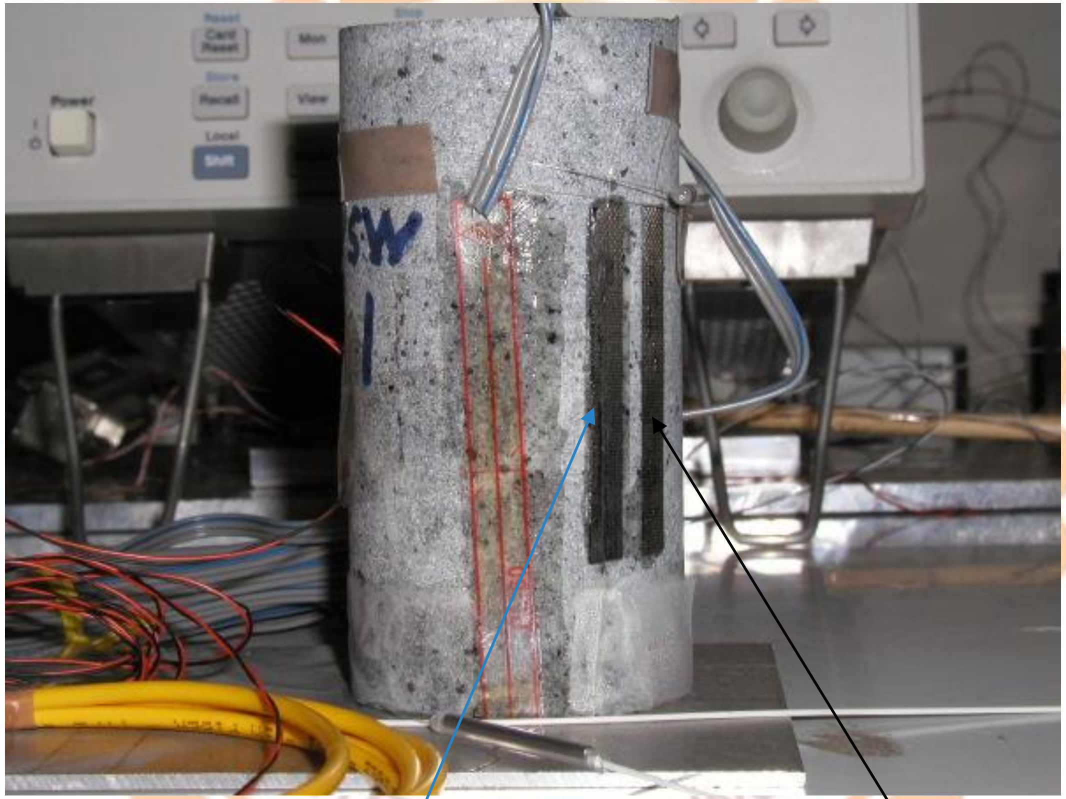


Bragg wavelength (λ_B)



- **Strain**
- **Temperature**
- **Pressure**

COMPRESSION TEST ON GRANITE SAMPLES USING FBG SENSORS

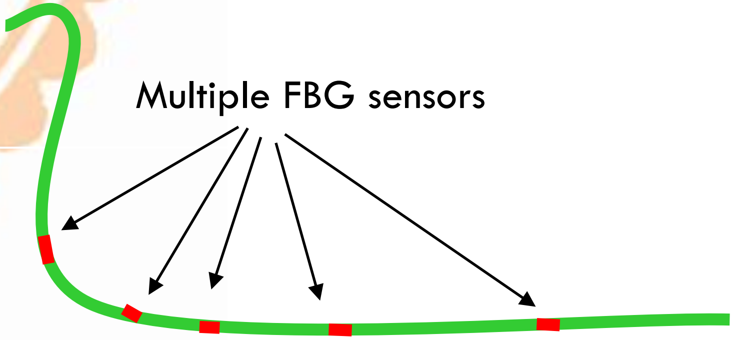


FBG strain sensor

FBG temperature sensor (strain-free)

ADVANTAGES OF FBG SENSORS FOR STRUCTURAL HEALTH MONITORING

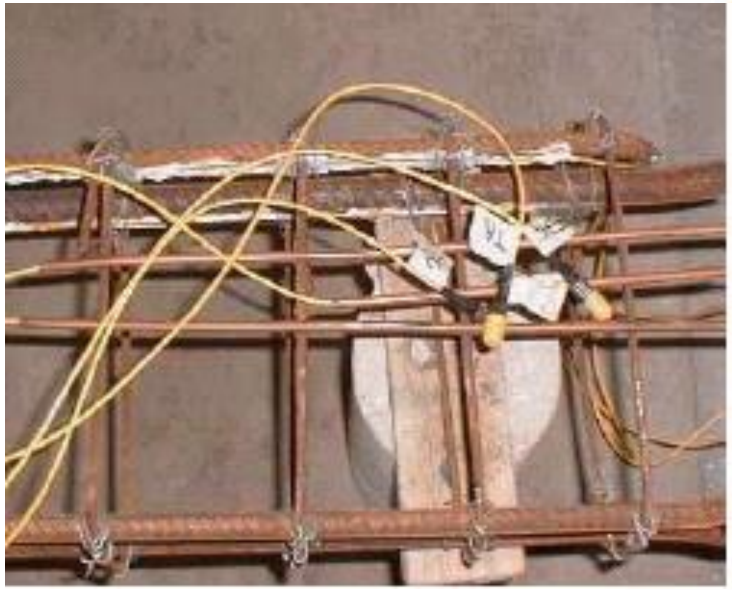
1. Multiplexing potential.
2. A number of FBG sensors on a fiber string can be addressed simultaneously.
3. Small-size (125μm), lightweight
4. Immune to EMI, durable under harsh environment and resistant to corrosion.
5. No problem of decay, since based on wavelength and not intensity.

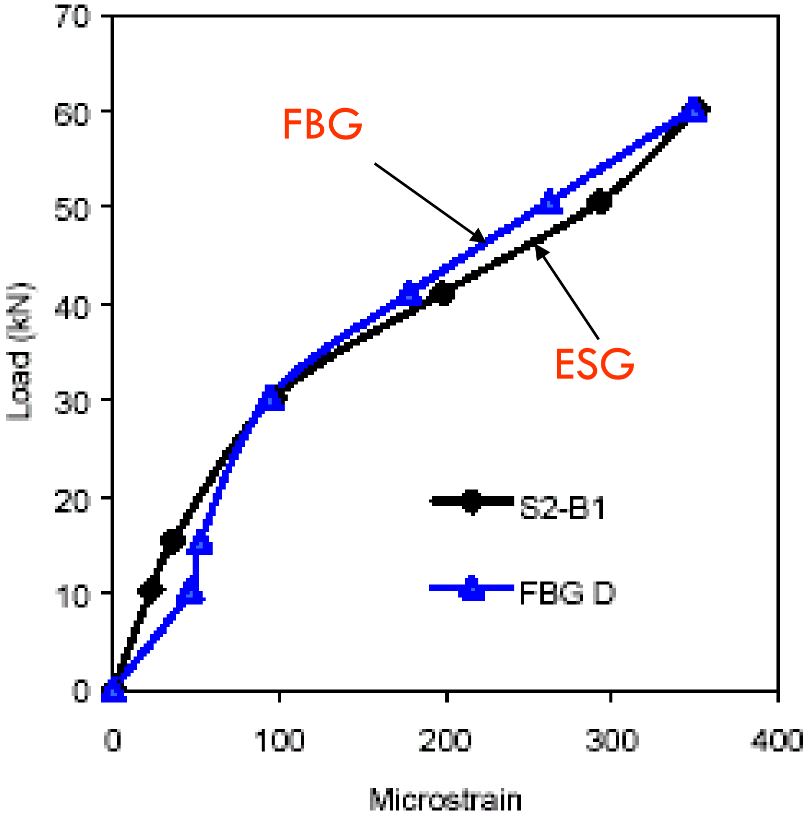


LIMITATIONS?.....Snapping, frequency…

EXPERIMENTAL EVALUATION OF FBG STRAIN SENSORS (MOYO, 2002)

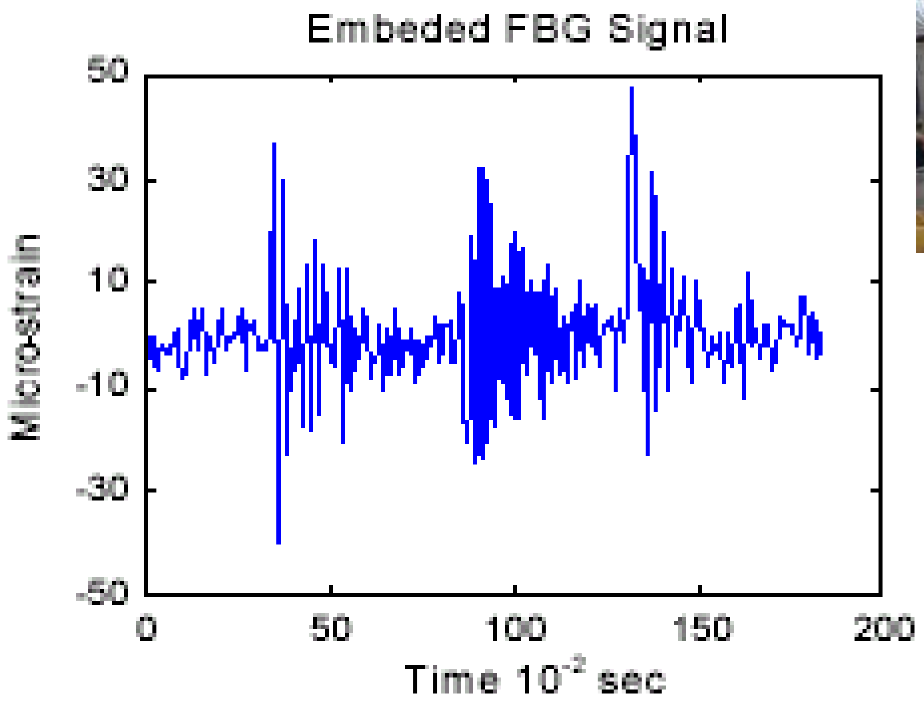
STATIC TEST

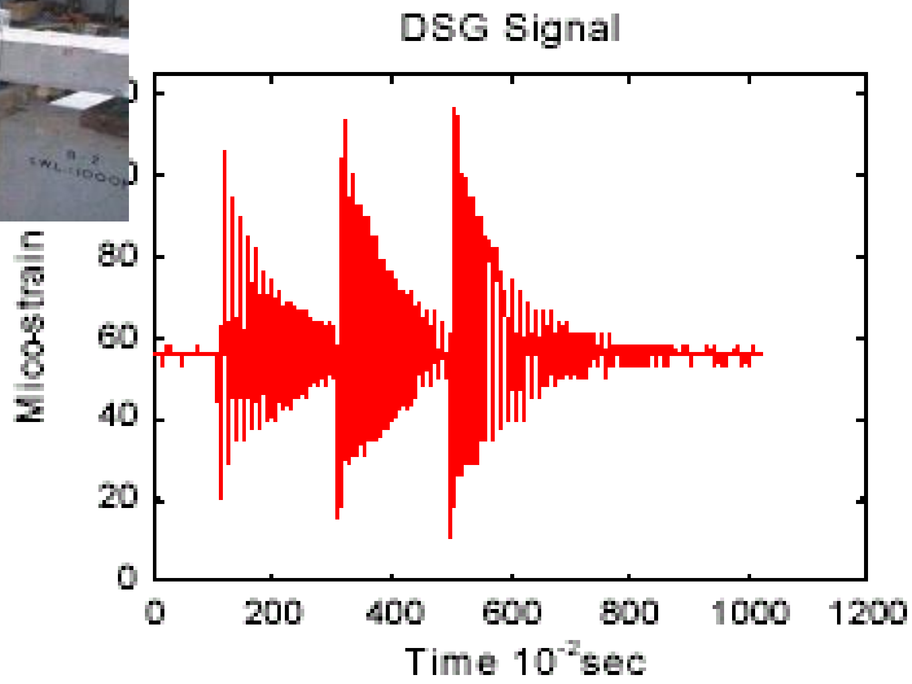




EXPERIMENTAL EVALUATION OF FBG STRAIN SENSORS (MOYO, 2002)

DYNAMIC TEST



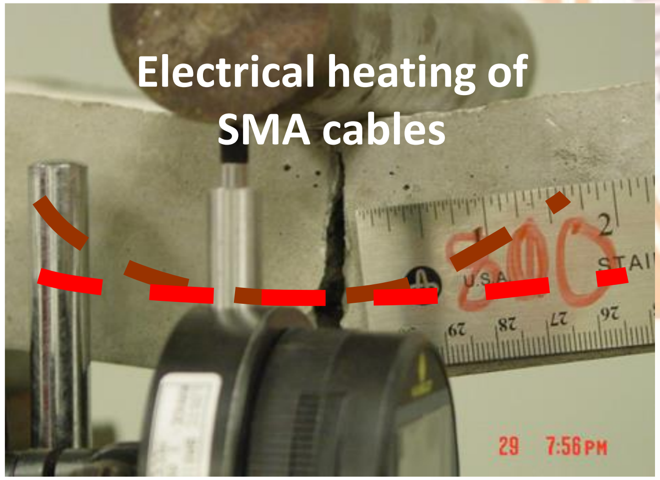


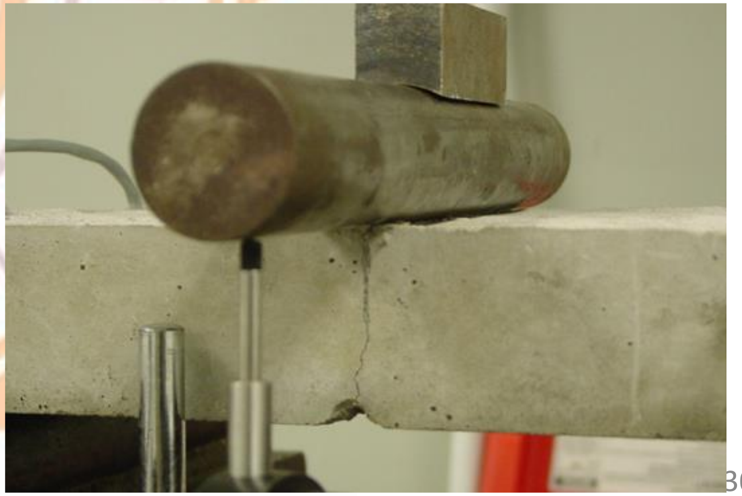
SHAPE MEMORY ALLOYS (SMA)

Possess capability to return "memorized" shape when heated

- **Bio-medical application: stent insertion to unblock arteries**
- **Futuristic application: damage healing**
- **Futuristic applications: structural control, aircraft wings**


http://www.vhlab.umn.edu/





Song et al. (2006)

ELECTRO-RHEOLOGICAL (ER) FLUIDS

ER fluids undergo change in viscosity under an electric field

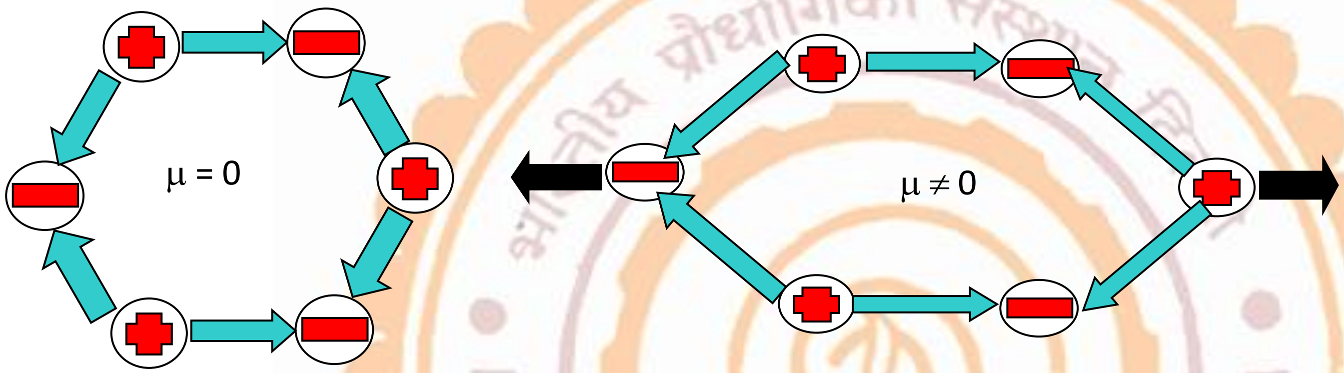
Applications:

- Shock/ vibration absorption in vehicle suspension
- Hydraulic valves
- Futuristic: Earthquake response control of structures

https://www.123rf.com/

PIEZOELECTRIC MATERIALS

The phenomenon of piezoelectricity was discovered by Curie brothers in 1880



Noncentro-symmetric crystals: the act of stretching causes dipole moment in the crystal (μ = Dipole moment).

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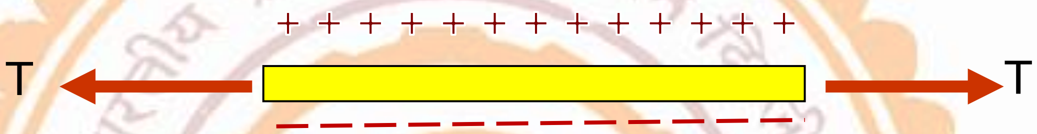
It occurs in non-centro symmetric crystals, such as:

- **Quartz (SiO_2)**
- **Lithium Niobate ($LiNbO_3$)**
- **Lead Zirconate Titanate PZT [$Pb(Zr_{1-x}Ti_x)O_3$)]**
- **Lead-Lanthanum-Zirconate-Titanate PLZT [$(Pb_{1-x}La_x)(Zr_{1-y}Ti_y)O_3$)]**

PIEZOELCTRIC MATERIALS

Mechanical Stress → Electrical Charge

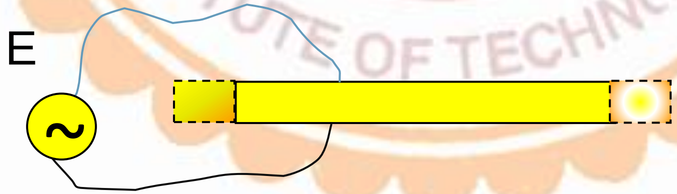
Direct Effect



SENSING

Electric Field → Mechanical Strain

Converse Effect



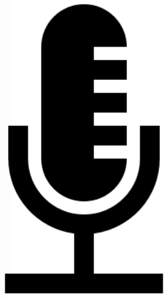
Elongation/ contraction

ACTUATION

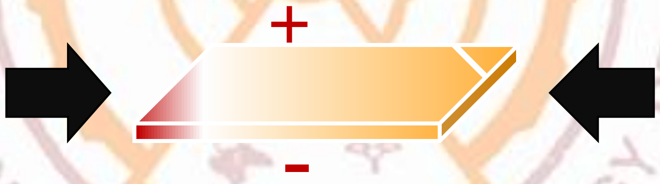
APPLICATIONS

DIRECT EFFECT

Igniters/ detonators, accelerometers, tactile sensors, pressure transducers, dynamic strain sensors, mobile phones (mic), structural health monitoring, energy harvesting

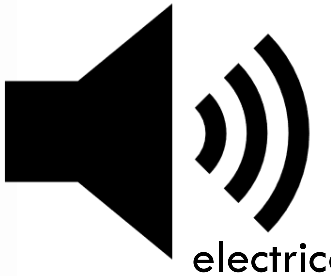


Sound to electrical pulses



CONVERSE EFFECT

Mobile phones (speaker), fuel injectors, musical cards, inkjet printers, vibration control, turbo-machinery, actuators, precision positioning



electrical pulses to sound

PIEZOELCTRIC MATERIALS

There are over 200 types of piezoelectric materials available commercially: **ceramics and polymers**

Lead Zirconate Titanate (PZT) is the most widely used ceramic type piezoelectric material. It has **high stiffness** but is at the same time **brittle**.

Polyvinvylidene Fluoride (PVDF) is popular polymer. It is **ductile** but has **less stiffness**.

COMMERCIAL FORMS

CERAMICS

LEAD ZIRCONATE TITANATE (PZT)

Higher strength, stiffness, but brittle

Suitable as sensor and actuator

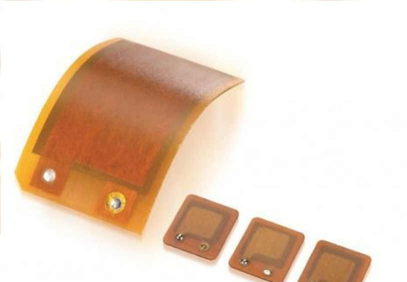
POLYMERS

POLYVINVYLIDENE FLUORIDE (PVDF)

Lesser strength, stiffness, but ductile, shape conformability

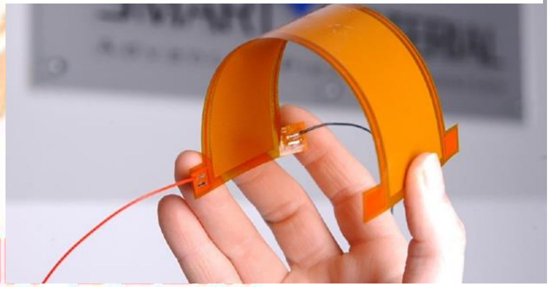
Suitable as sensor

OTHER SPECIAL TYPES

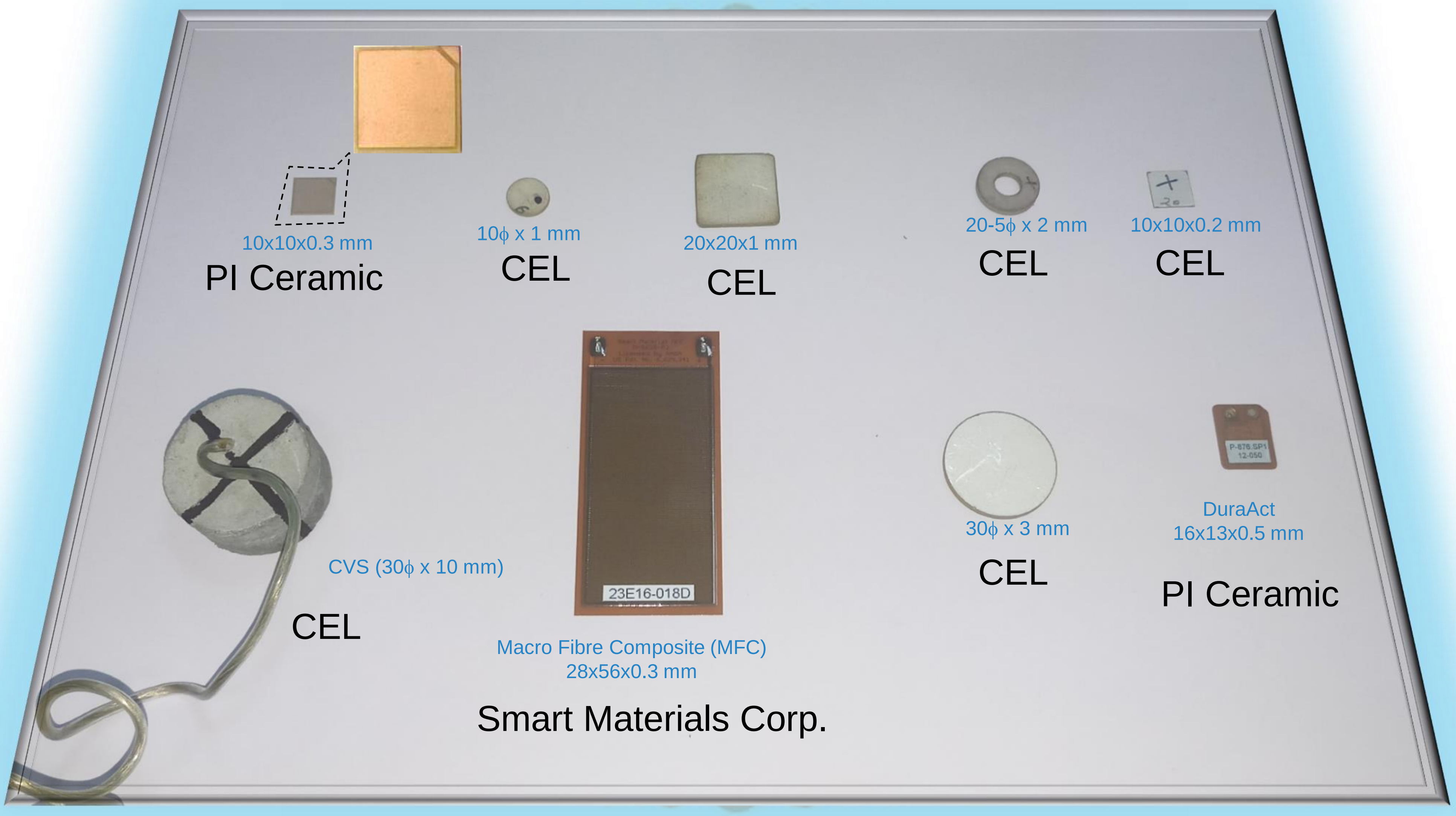


DuraAct

Macro Fibre Composite (MFC)



COMMERCIAL FORMS OF PZT



SPECIAL FLEXIBLE FORM

Macro Fibre Composite (MFC)

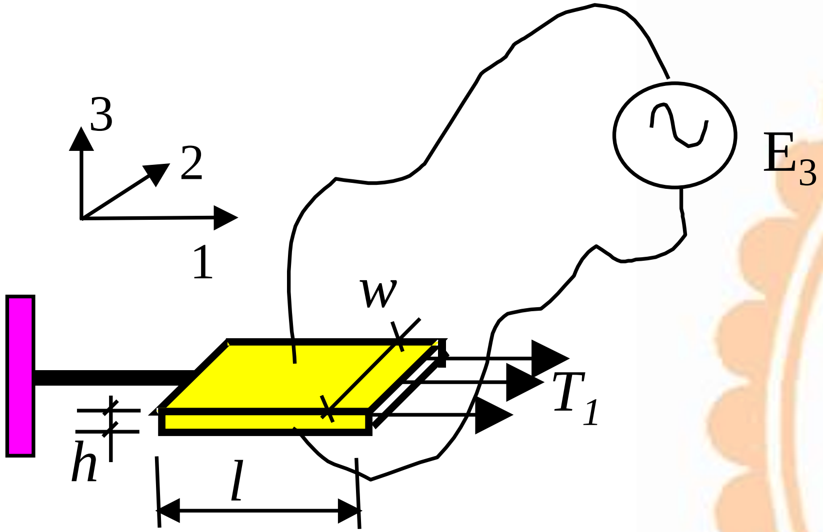
Smart Materials Corp.

COMPOSITE CONFIGURATION

Ready to use PZT-cement composite sensor, developed by SSD Lab, for concrete structures

Concrete Vibration Sensor (CVS)

CONSTITUTIVE RELATIONS



Converse Effect

$$S_1 = \frac{T_1}{\overline{Y^E}} + d_{31}E_3$$

Strain — Stress — Electric field

Linearly elastic material

Piezoelectric strain coefficient

Direct Effect

$$D_3 = \overline{\varepsilon_{33}^T} E_3 + d_{31}T_1$$

Charge density — Electric field — Stress

Dielectric material

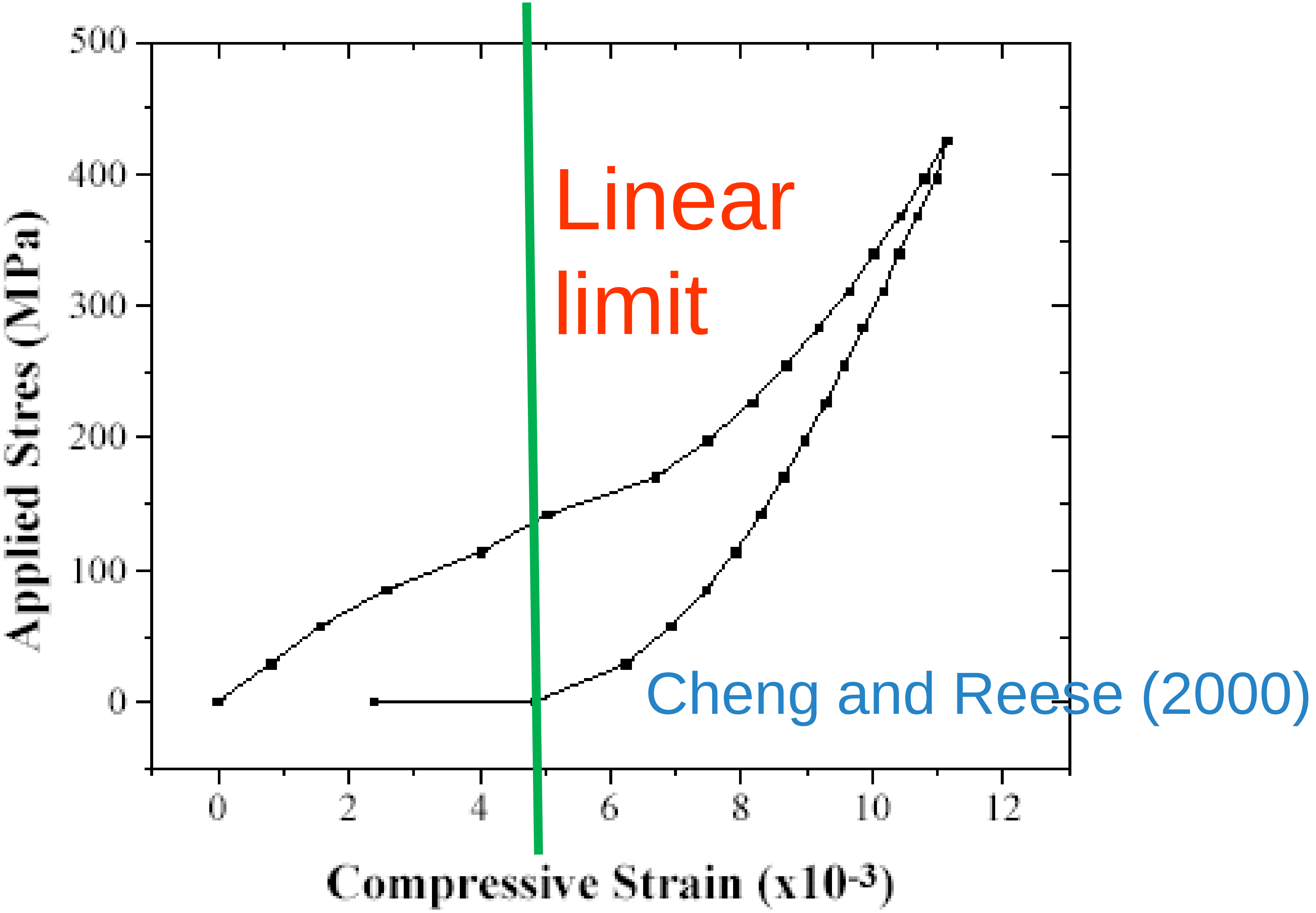
d_{31}

Electric field axis

Strain axis

$\overline{Y^E}$ Young's modulus under constant (zero) electric field

$\overline{\varepsilon_{33}^T}$ Electric permittivity under constant (zero) stress

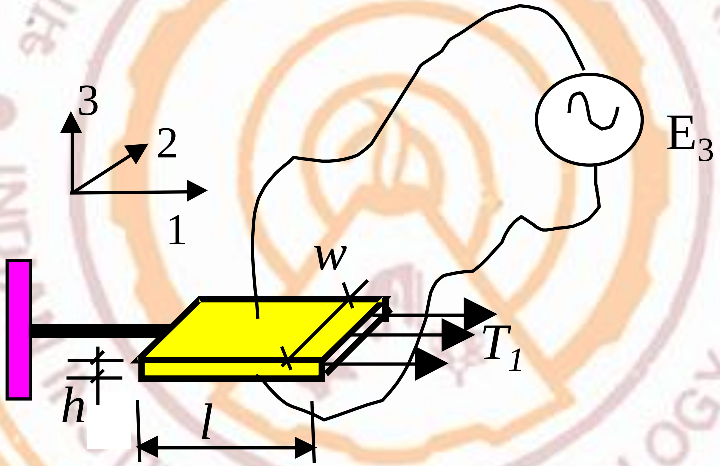


FOR STUDENTS OF CVL 864 IIT DELHI

PIEZOELCTRIC STRAIN COEFFICIENT d_{31}

d_{31} = Strain per unit electric field under zero (constant) stress conditions (unit m/V)

$$S_1 = \frac{T_1}{\bar{\bar{Y}}_{11}^E} + d_{31}E_3$$



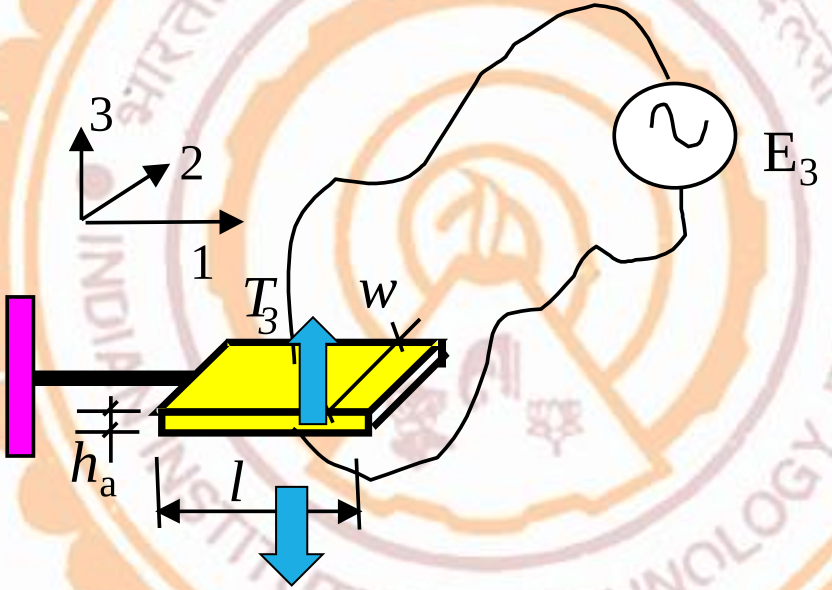
d_{31} = Charge density induced by unit stress under zero (constant) external electric field (unit C/N)

$$D_3 = \bar{\varepsilon}_{33}^T E_3 + d_{31}T_1$$

PIEZOELCTRIC STRAIN COEFFICIENT d_{33}

This comes into picture when both electric field and stress are along axis “3”

$$S_3 = \frac{T_3}{\overline{\overline{Y_{33}^E}}} + d_{33} E_3$$

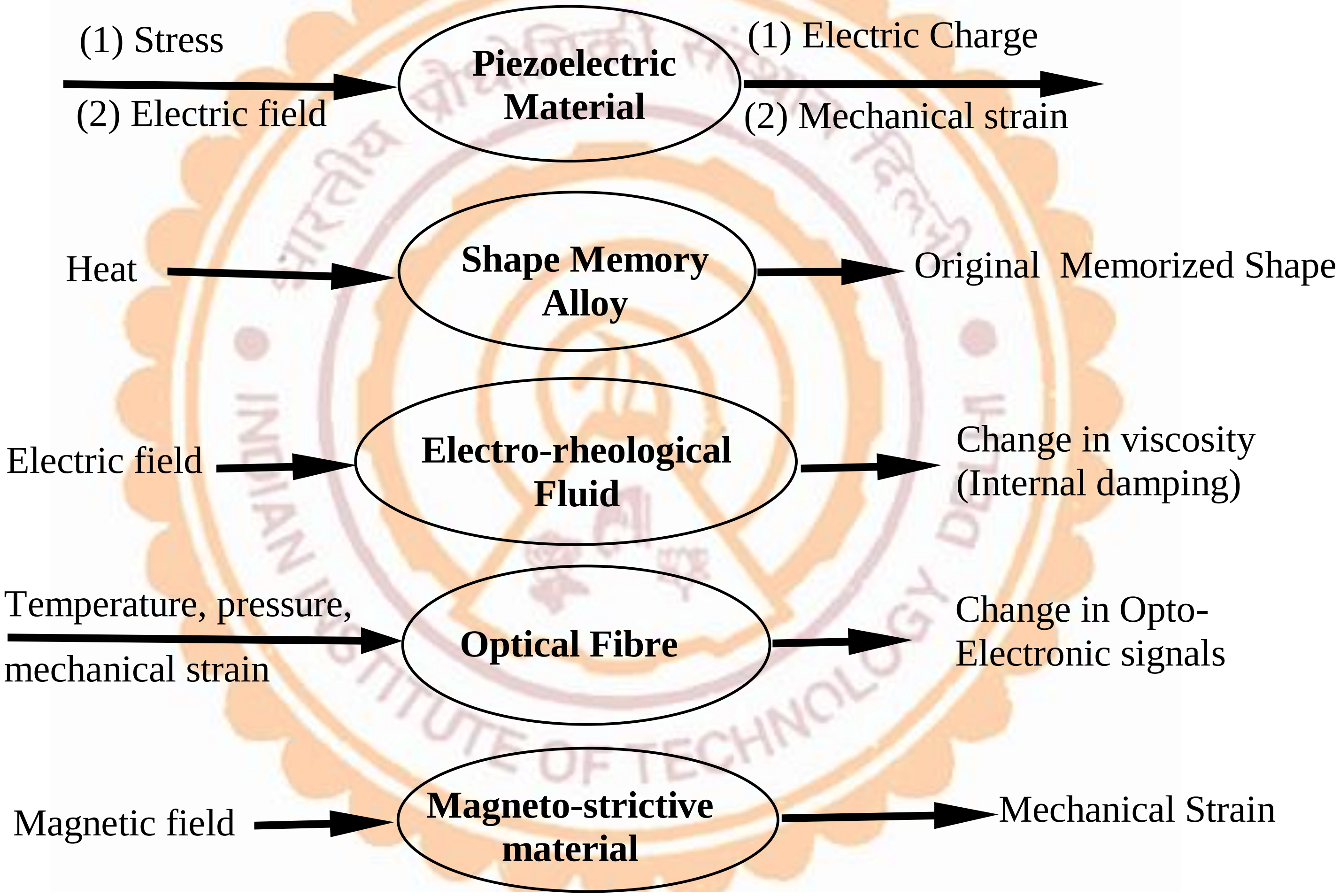


$$D_3 = \overline{\varepsilon_{33}^T} E_3 + d_{33} T_3$$

In general for PZT material, d_{31} is negative, which means an electric field in positive “3” direction induces compressive strain along axis “1”

In contrast, d_{33} is positive

SUMMARY: SMART MATERIALS



DYNAMIC STRAIN SENSOR

Direct Effect

$$D_3 = \overline{\varepsilon_{33}^T} E_3 + d_{31} T_1$$

Charge density — Electric field (zero) — Stress

Potential difference across terminals

Thickness of PZT patch

$$V = \left(\frac{d_{31} h \overline{Y^E}}{\overline{\varepsilon_{33}^T}} \right) S_1 = k S_1$$

$$Q = CV$$

Charge — Capacitance — Voltage

Voltage α Strain

Sensitivity = 200mV/(μm/m)

DYNAMIC STRAIN SENSOR

PZT PATCHES ARE SUITABLE FOR DYNAMIC STRAINS AND NOT STATIC STRAINS….

The piezoelectric effect is dynamic, i.e.,

- Charge is generated only when the forces are changing
- The initial charge will decay in circuit if the force remains constant…..

EXERCISE

Material Data

SPECIFIC PARAMETERS OF THE STANDARD MATERIALS

Soft PZT materials

			Unit	PIC151	PIC255/ PIC252[1)]	PIC155	PIC153
				Soft PZT materials			
Physical and dielectric properties							
Density		ρ	g/cm^3	7.80	7.80	7.80	7.60
Curie temperature		T_c	°C	250	350	345	185
Relative permittivity	in the polarization direction	$\varepsilon_{33}^T/\varepsilon_0$		2400	1750	1450	4200
	⊥ to polarity	$\varepsilon_{11}^T/\varepsilon_0$		1980	1650	1400	
Dielectric loss factor		$\tan\delta$	10^{-3}	20	20	20	30
Electromechanical properties							
Coupling factor		k_p		0.62	0.62	0.62	0.62
		k_t		0.53	0.47	0.48	
		k_{31}		0.38	0.35	0.35	
		k_{33}		0.69	0.69	0.69	
		k_{15}			0.66		
Piezoelectric charge coefficient		d_{31}		-210	-180	-165	
		d_{33}	10^{-12} C/N	500	400	360	600
		d_{15}			550		
Elastic compliance coefficient		S_{11}^E		15.0	16.1	15.6	
		S_{33}^E	10^{-12} m^2/N	19.0	20.7	19.7	

$$V = \left(\frac{d_{31} h \overline{Y^E}}{\overline{\varepsilon_{33}^T}}\right) S_1 = k S_1$$

Determine : K

ORIGIN OF TERM

$$D_3 = \overline{\varepsilon_{33}^T} E_3 + d_{31} T_1$$

$$Q = CV$$

$$D_3 A = \left[\frac{\overline{\varepsilon_{33}^T} A}{h} \right] V$$

$$D_3 = \overline{\varepsilon_{33}^T} E_3$$

A bar above a parameter implies it is measured under dynamic conditions

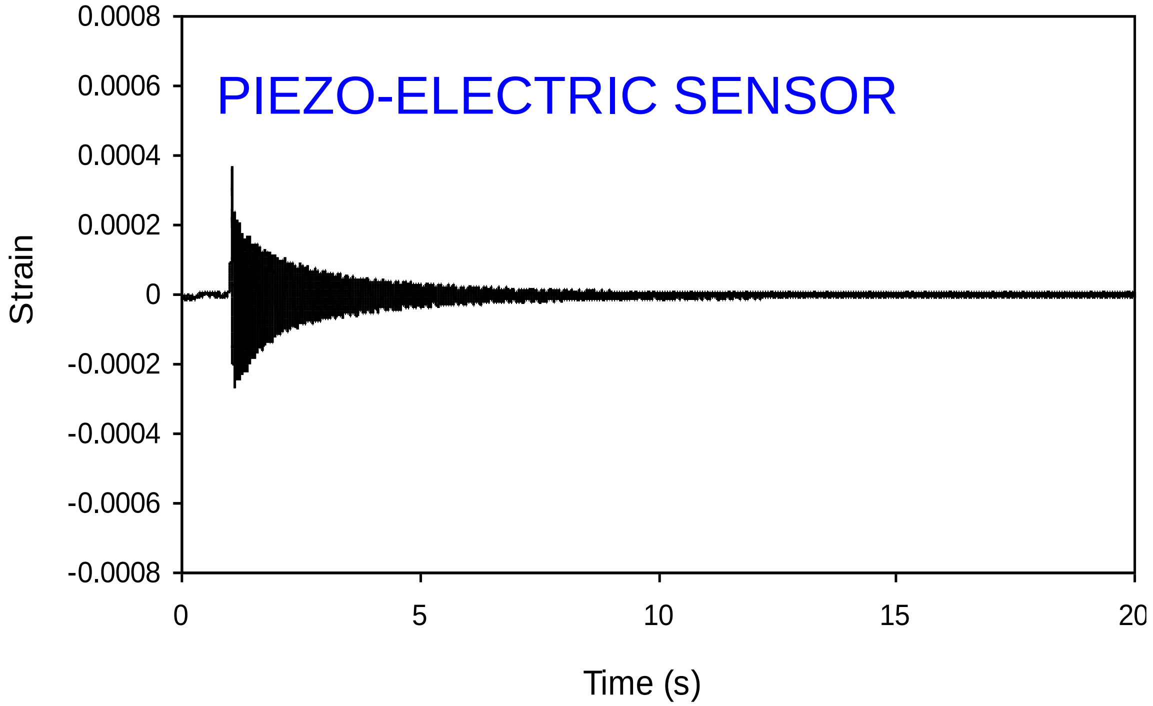
COMPARATIVE STUDY

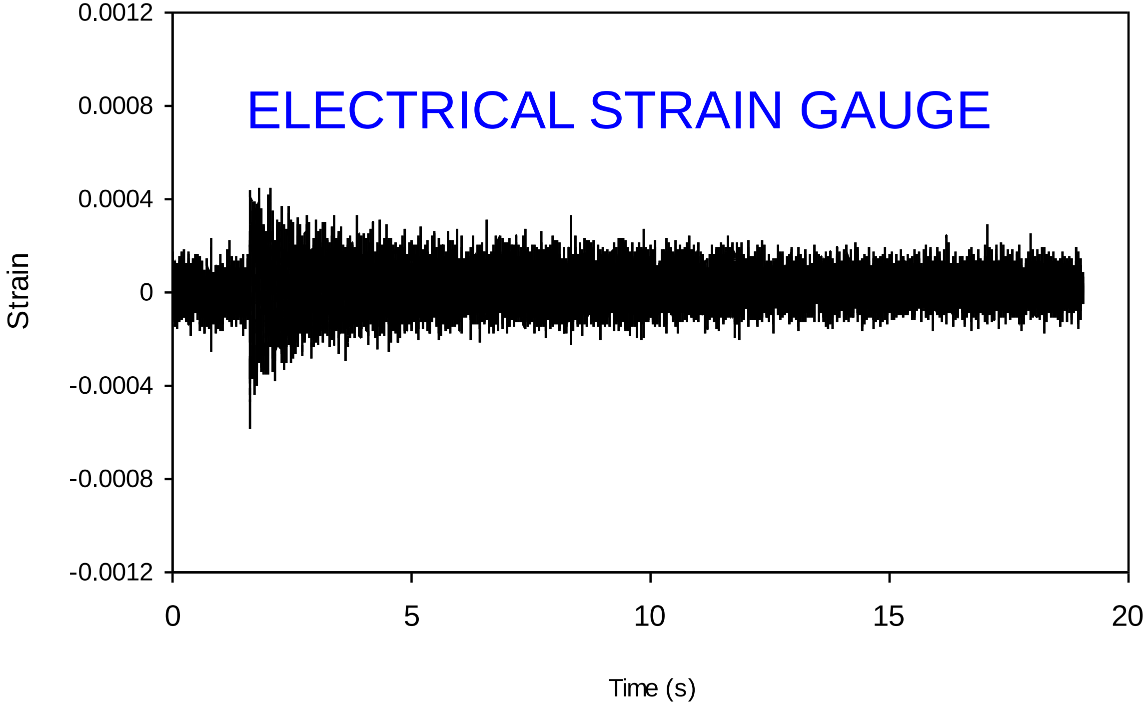
FOLLOWING SENSORS EVALUATED FOR DYNAMIC RESPONSE

Electrical strain gauges (ESG)

Piezoelectric ceramic (PZT) sensor

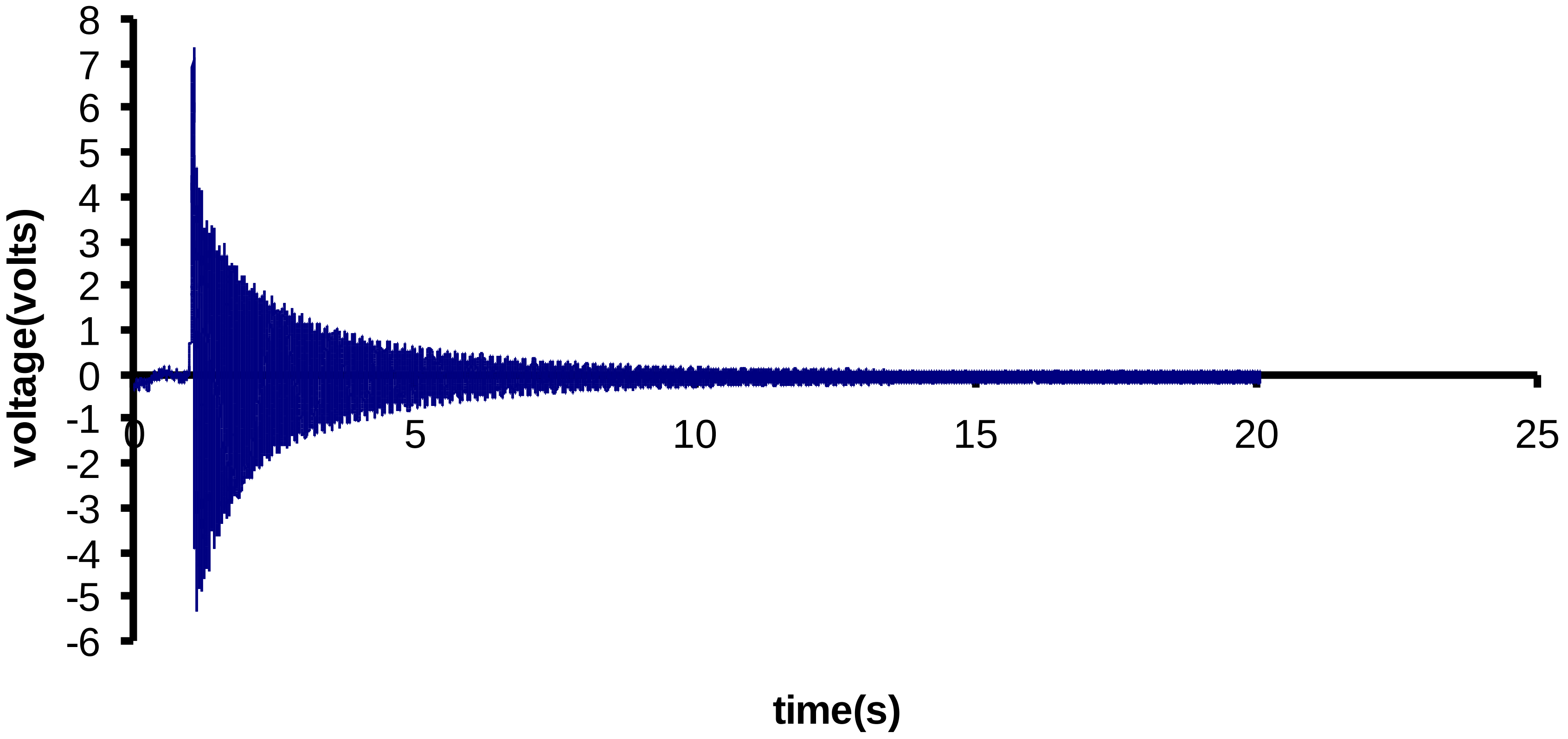
Accelerometers



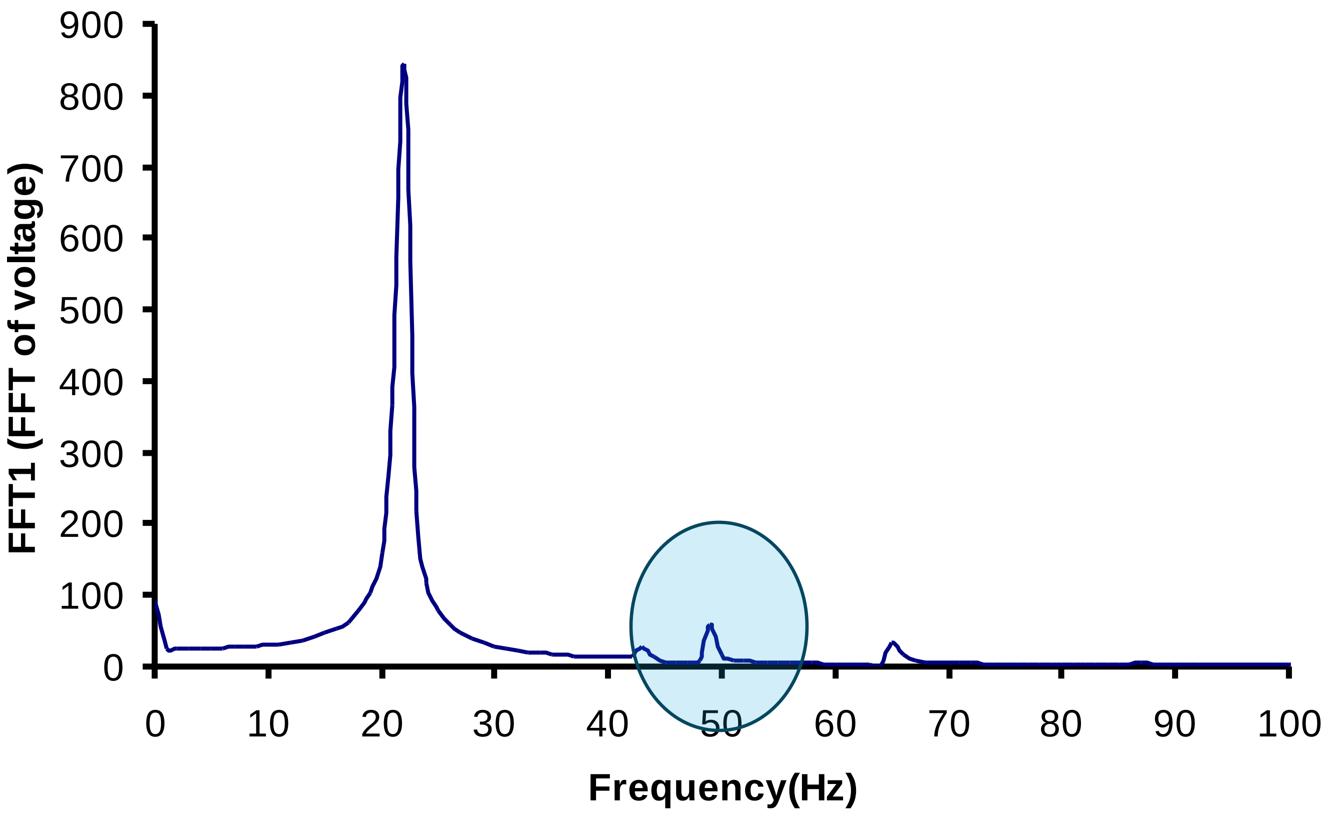


What are observations related to signal to noise ratio (SNR) ??

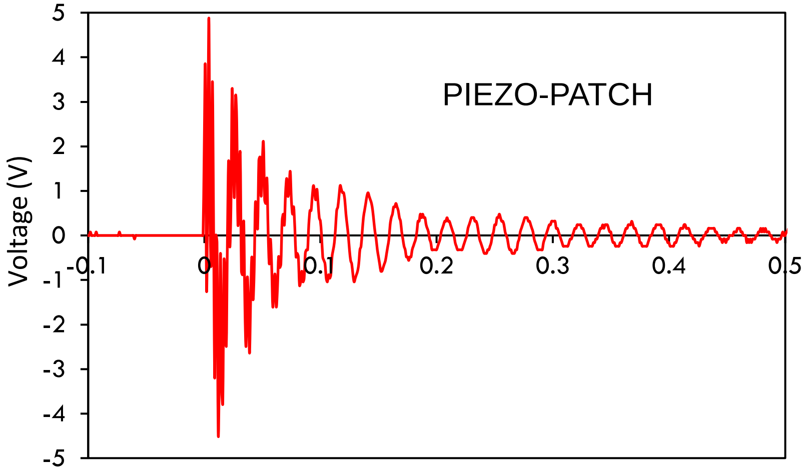
RESPONSE USING PZT PATCH (TIME DOMAIN)

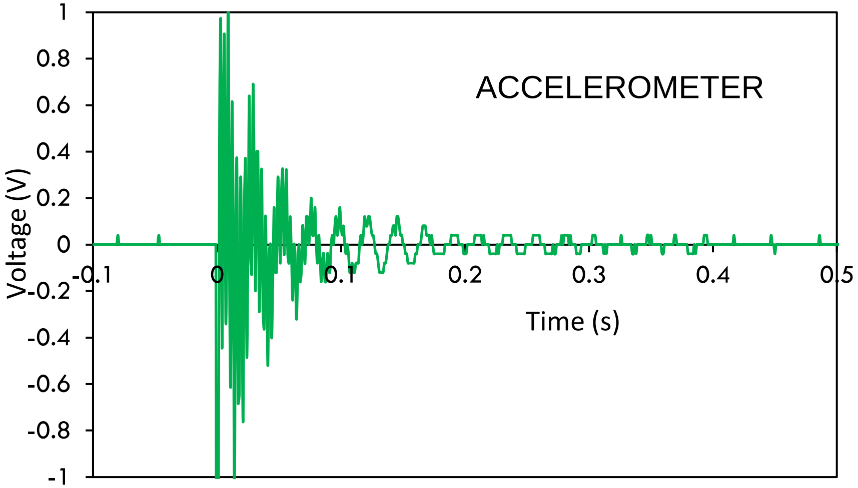


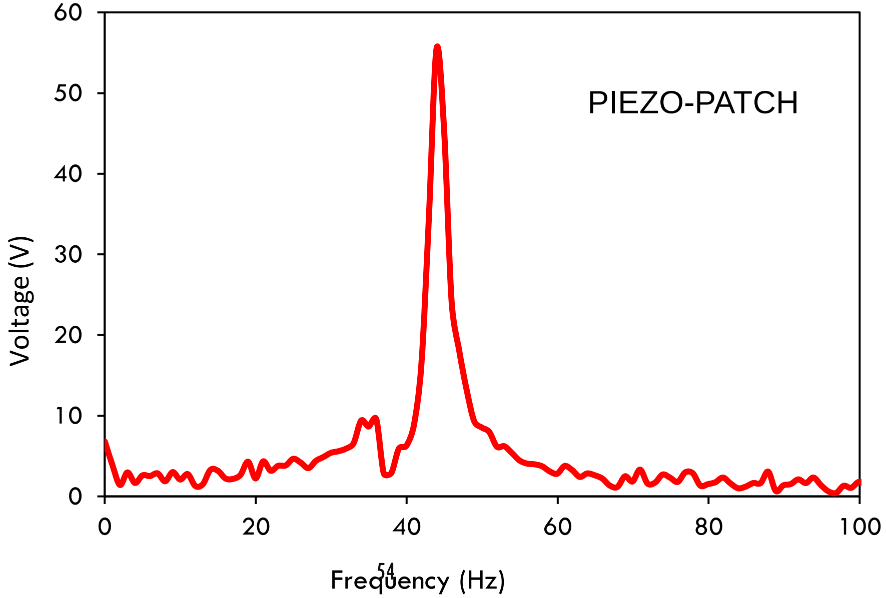
RESPONSE USING PZT PATCH (FREQUENCY DOMAIN)

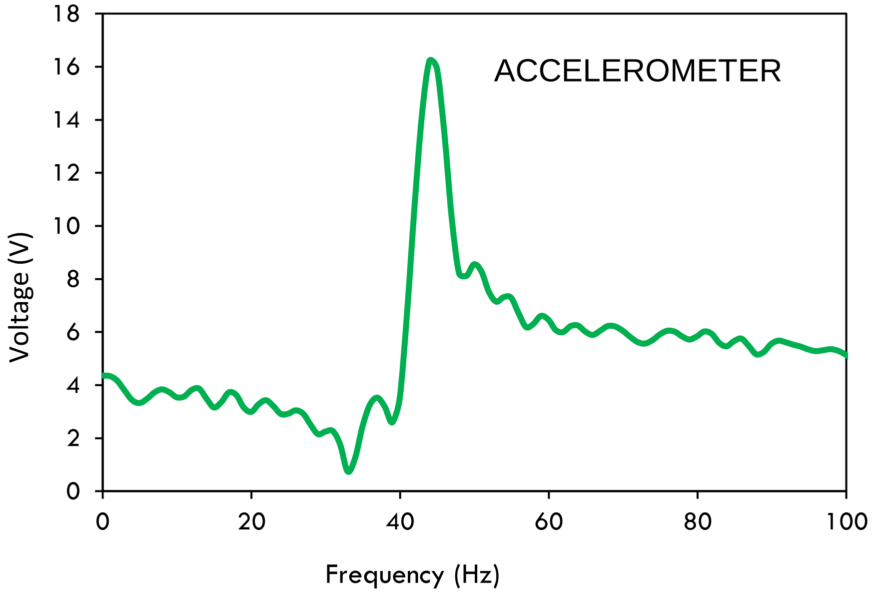



Digital multimeter
(Agilent 34411A)
Personal computer
Hammer
Sensors
Test specimen


PIEZO-PATCH
Voltage (V)
5
4
3
2
1
0
-1
-2
-3
-4
-5
-0.1
0
0.1
0.2
0.3
0.4
0.5


ACCELEROMETER
Voltage (V)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.1
0
0.1
0.2
0.3
0.4
0.5
Time (s)


PIEZO-PATCH
Voltage (V)
60
50
40
30
20
10
0
0
20
40
60
80
100
Frequency (Hz)


ACCELEROMETER
Voltage (V)
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Frequency (Hz)

IMPORTANT OBSERVATIONS

- WORST RESPONSE IN CASE OF ESG

  TYPICAL COST: $1.5 (Rs 100)

- BEST RESPONSE IN CASE OF ACCELEROMETER

  TYPICAL COST: $500 (Rs 35, 000 and above)

  (Also bulky, bandwidth limitation)

- PZT PATCH: RESPONSE QUALITY ALMOST COMPARABLE TO ACCELEROMETER

  TYPICAL COST: $1-10 (Rs 70-700)

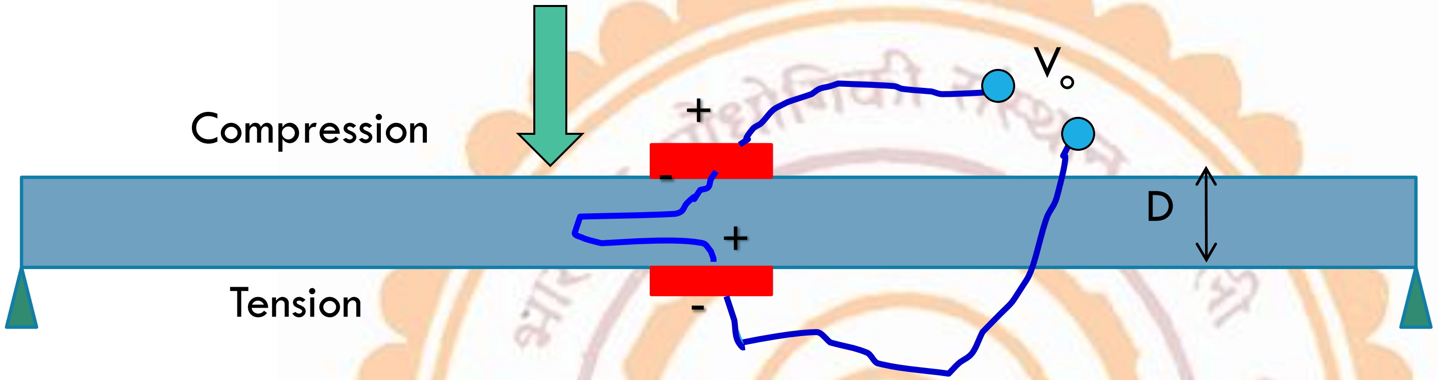
SHM BY PZT PATCHES

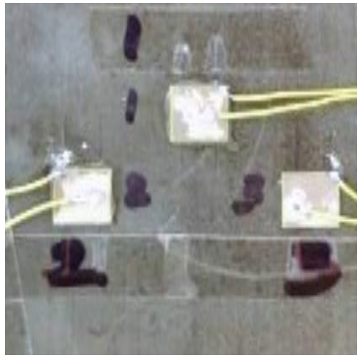
Two modes

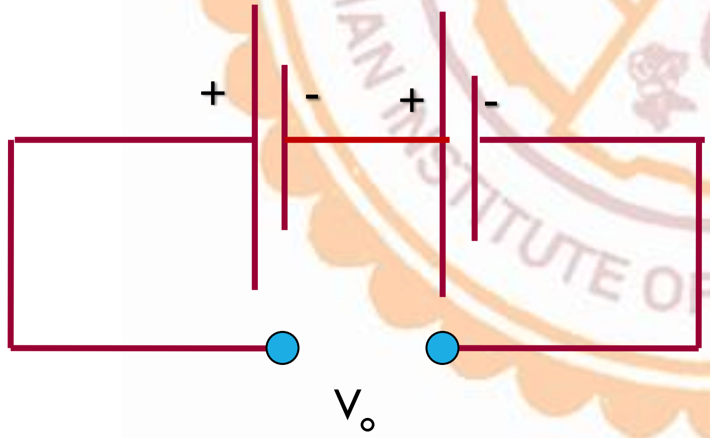
(a) Dynamic strain sensor
Direct effect, low-frequency

(b) Electro-mechanical impedance (EMI) sensor
Direct+ converse effect, high-frequency

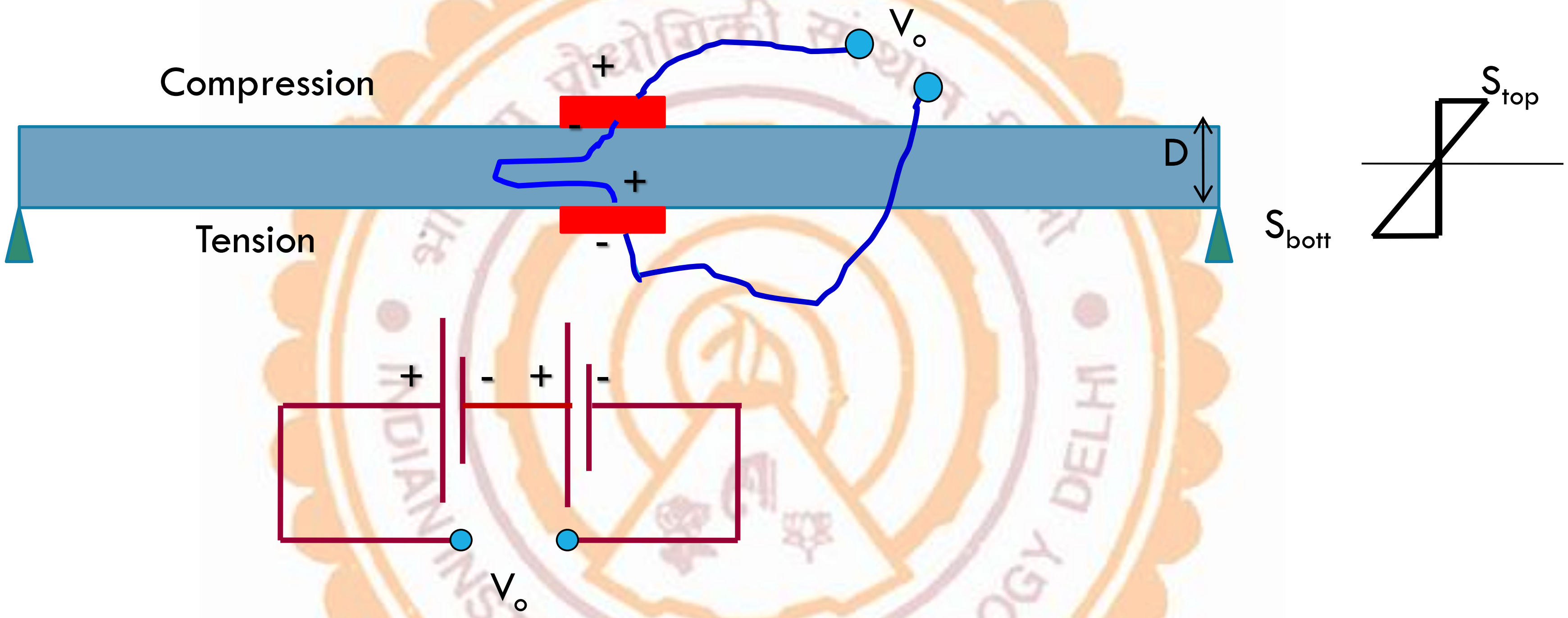
SENSING OF FLEXURE







SENSING OF FLEXURE



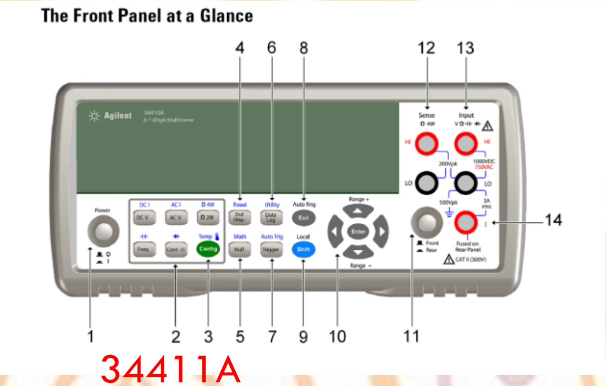
$$V_o = k(S_{top} + S_{bott})$$

$$\phi = \frac{S_{top} + S_{bott}}{D}$$

Curvature $$\phi = \frac{S_{top}+S_{bott}}{D} = \frac{V_o}{kD}$$ Voltage α Curvature

TDS 2004B
Tecktronix oscilloscope

Four channel, real-time, low on resolution IMPORTED



34411A
Agilent digital multimeter

Single channel, near real-time, high on resolution IMPORTED

QDA 1000
Quazar Technologies
http://ww.quazartech.com

Eight channel, real-time, high on resolution, INDIGENOUS

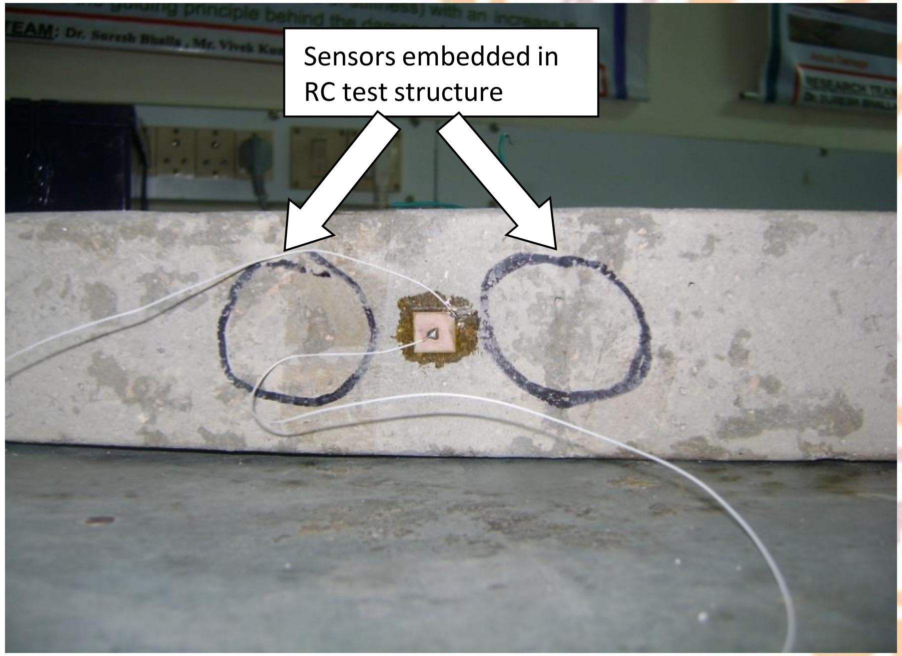
U2331
USB Modular Multifunction Data Acquisition
Agilent Technologies

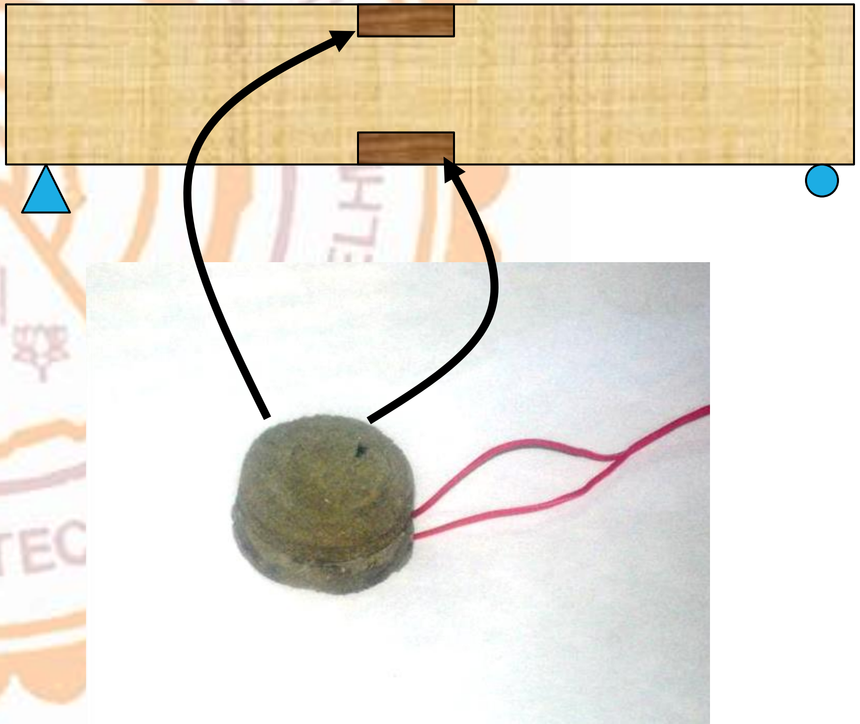
64 channels, 3Mega samples per second per channel IMPORTED

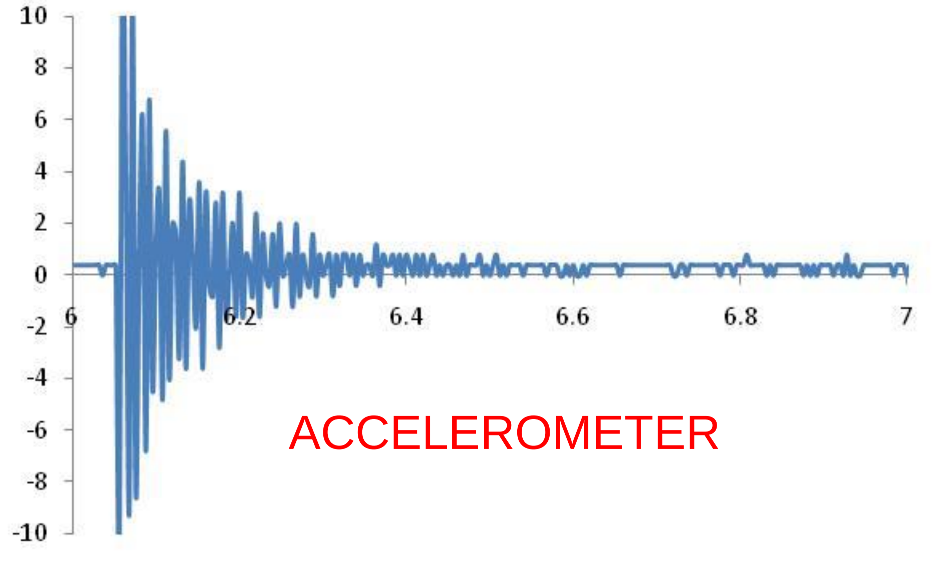
FOR STUDENTS OF CVL 864 IIT DELHI

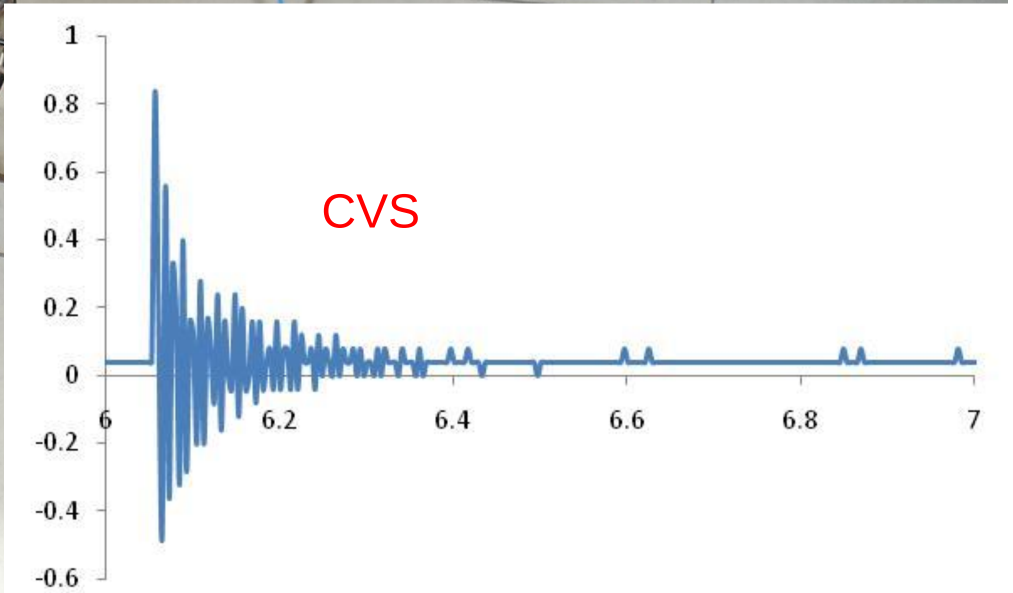
CONCRETE VIBRATION SENSOR (CVS)

CVS is a ready to use packaged sensor for dynamic response measurement developed especially for reinforced concrete (RC) structures such as buildings and bridges.






10
8
6
4
2
0
-2
-4
-6
-8
-10
6
6.2
6.4
6.6
6.8
7
ACCELEROMETER


1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
6
6.2
6.4
6.6
6.8
7
CVS

KEY STRONG POINTS OF CVS

- Excellent signal to noise ratio
- Special encapsulation of the sensing element to prevent damage during casting.
- Higher longevity, negligible decay of the sensing element.
- Low cost (~ one-tenth of the cost of accelerometer)
- Miniature size
- No frequency bandwidth limitation

SYNOPSIS OF COURSE COVERAGE

ANSWERS EXPECTED FROM SHM

Has any damage occurred in the structure after its construction?

If yes, what is damage location?

If damage has occurred, how severe is it?

If damage has occurred, can the structure be still used? What is its remaining life?

GLOBAL SHM TECHNIQUES

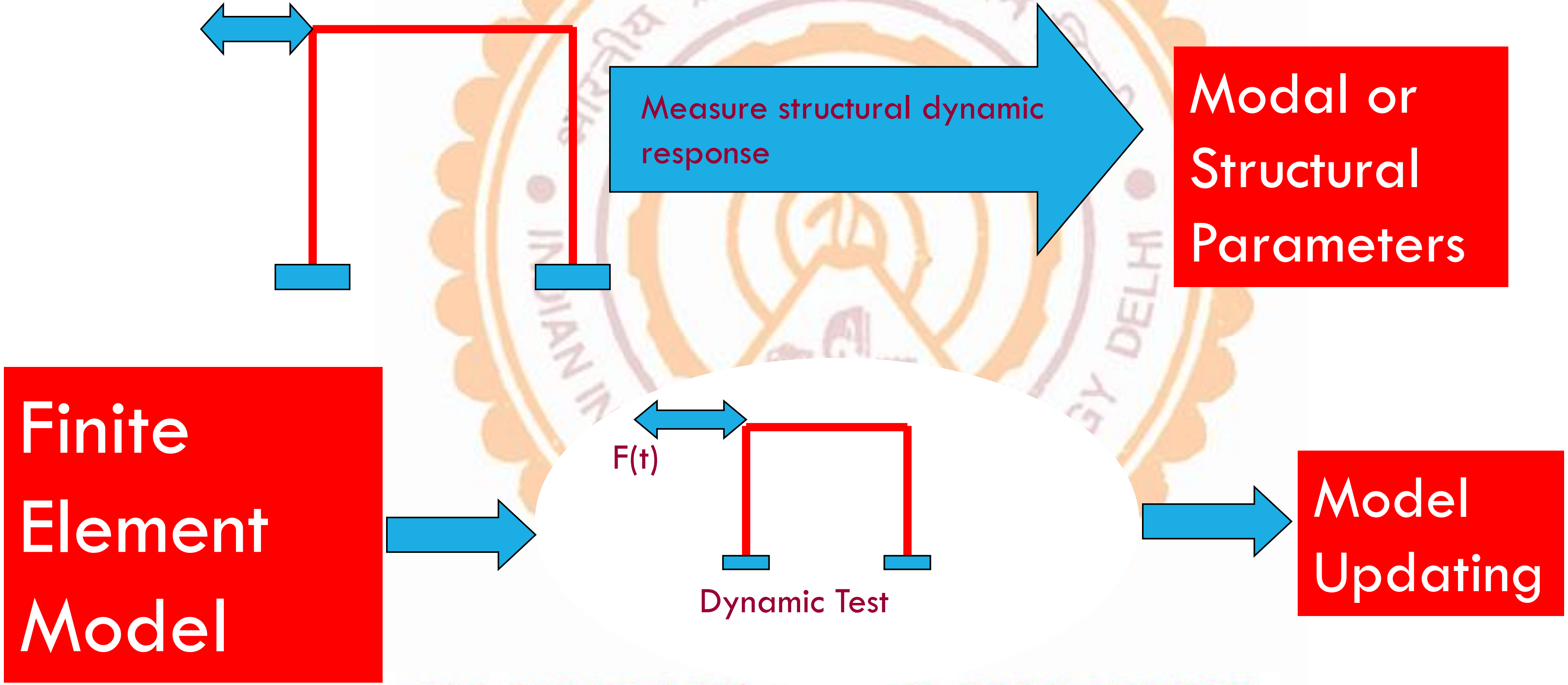
(1) *Static Response Based Techniques*

- Static Displacement Response (Banan & Hjelmstad, 1994)
- Static Strain Response (Sanayei & Saletnik, 1996)

Time consuming => Cannot Enable Quick Assessment of Health.

GLOBAL SHM TECHNIQUES

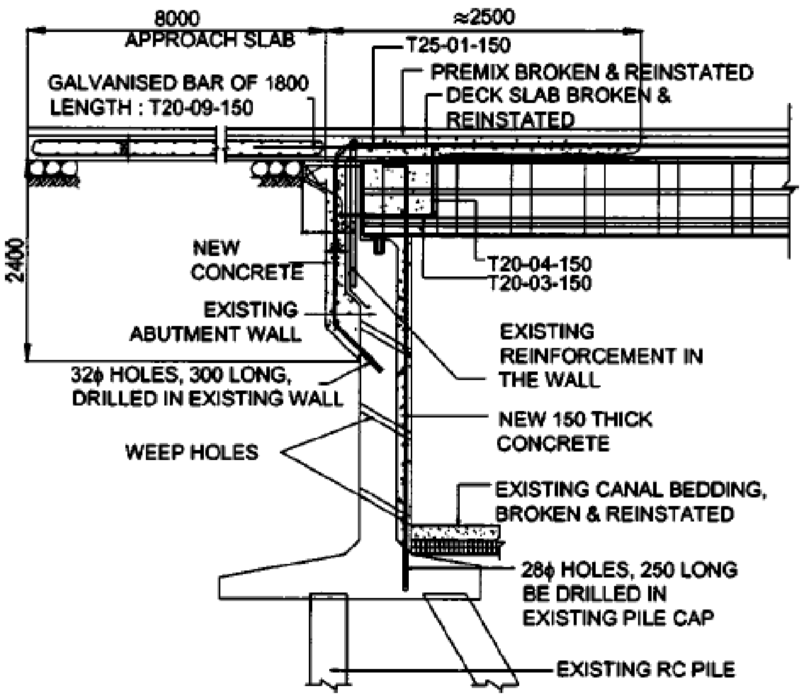
(2) *Dynamic Response Based Techniques*



PIONEER BRIDGE- SINGAPORE

BROWNJOHN ET AL. (2003)

RETROFITTING was carried out to convert the simply supported system into a continuous deck monolithic with supports



How to make sure that retrofitting works were successful???

ANSWER:

MODEL UPDATING OF PIONEER BRIDGE

Model updating was conducted for the bridge before and after upgrading based on experimental modal analysis of pre- and post-upgrade dynamic response. The bridge was modelled using 3D beam elements.

MAJOR OBSERVATIONS

- To reflect the structural change in the upgrading, the abutment restraints were modelled as rotational springs of finite stiffness. The rotational stiffness at the abutments was found to be about 108N.m/rad after upgrading.

- These investigations showed that bridge stiffness considerably increased due to the upgrading. This is evident from the increase of first natural frequency from about 6Hz to approximately 8 Hz.

GLOBAL SHM TECHNIQUES

Some features.........

- Practical, capable of quick assessment of health for simple structures.
- However, rely on first few modes only- Global modes.
- Hence, insensitive to local or incipient damages.

NDE TECHNIQUES (LOCAL)

Best when damage location be known a-priori

May render the structure unavailable during interrogation

Suitable for specific applications

SHM BY PZT PATCHES

Two modes

(a) Dynamic strain sensor
Direct effect, low-frequency

(b) Electro-mechanical impedance (EMI) sensor
Direct+ converse effect, high-frequency

ELECTRO-MECHANICAL IMPEDANCE (EMI) TECHNIQUE

Interface between global dynamic techniques and local NDE techniques

Principle = Similar to global vibration techniques

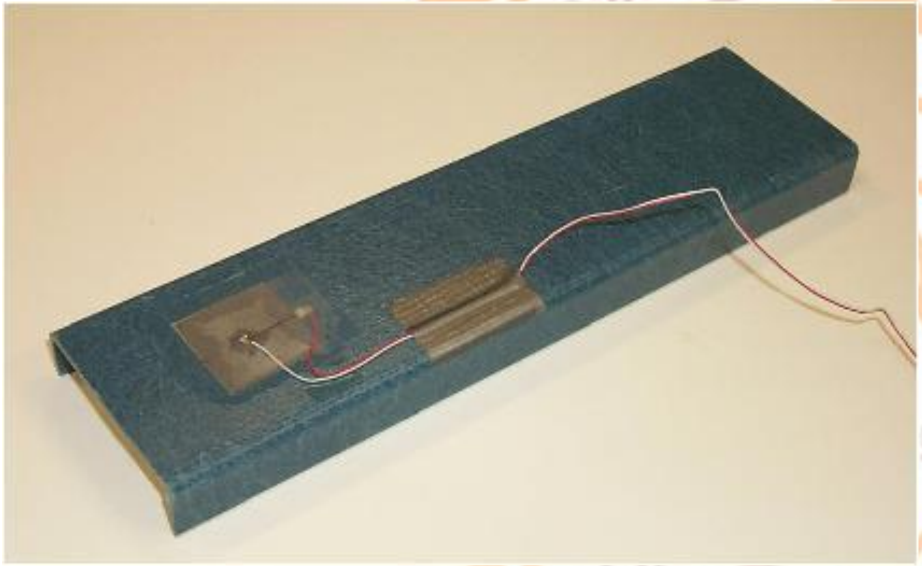
(Frequency employed: 30-400 kHz)

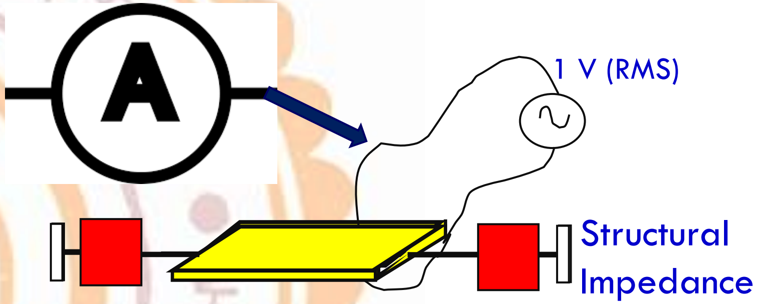
Sensitivity = As high as local ultrasonic (NDE) technique

Piezoelectric materials are the key elements of EMI technique

ELECTRO-MECHANICAL MPEDANCE (EMI) TECHNIQUE

A PZT patch is surface bonded on a structure using high strength adhesive and excited at high frequency (30-400 kHz) by an LCR meter or impedance analyzer (in sweep mode).





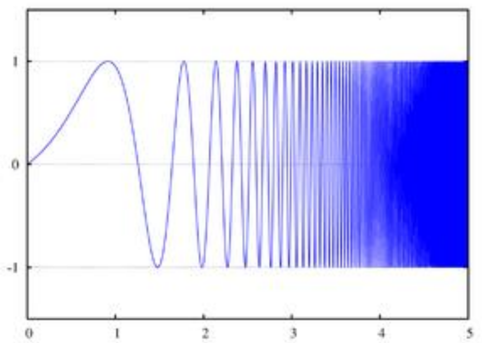
A simple physical model of system (Liang et. al, 1994)

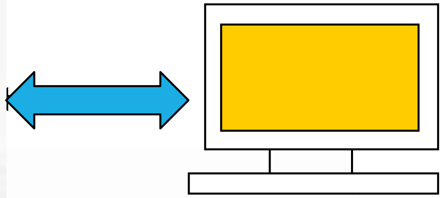
$$\bar{Y} = \frac{I_o e^{j(\omega t - \emptyset)}}{V_o e^{j\omega t}} = I_o e^{-j\emptyset} \qquad = G + Bj$$

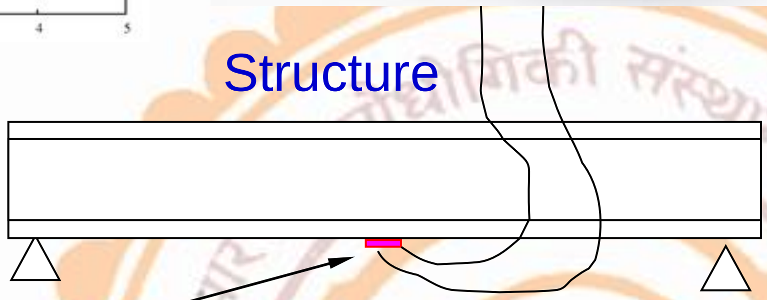
G: Conductance, B: Susceptance

PZT PATCH ACTS AS <u>SENSOR</u> AND <u>ACTUATOR</u> SIMULTANEOUSLY.

The technique was originally developed for aerospace structures.

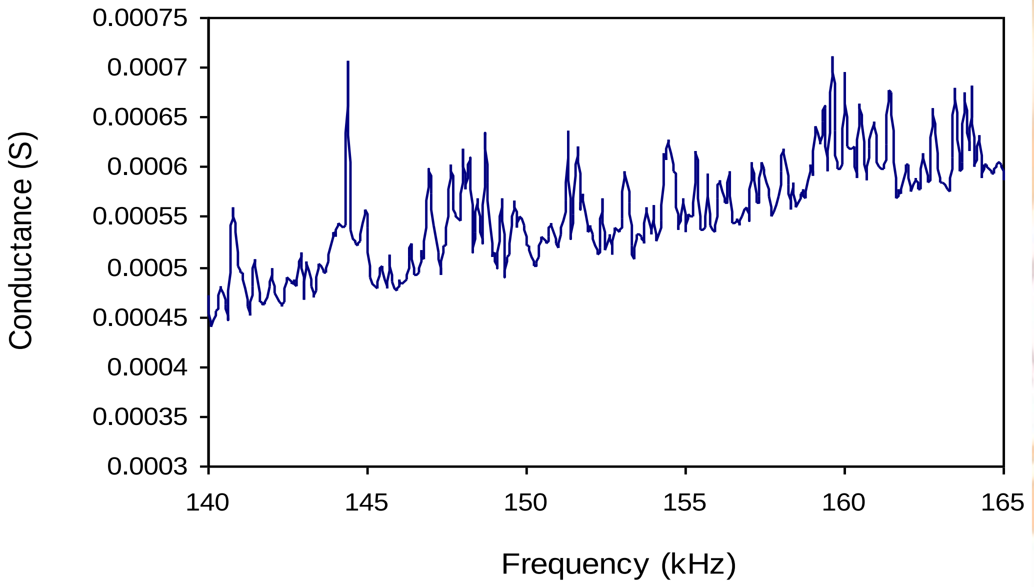


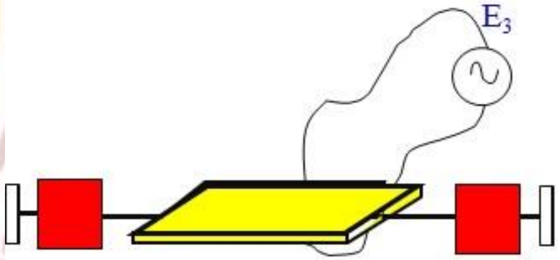




Admittance measurements at multiple frequencies form “signature”

PZT patch

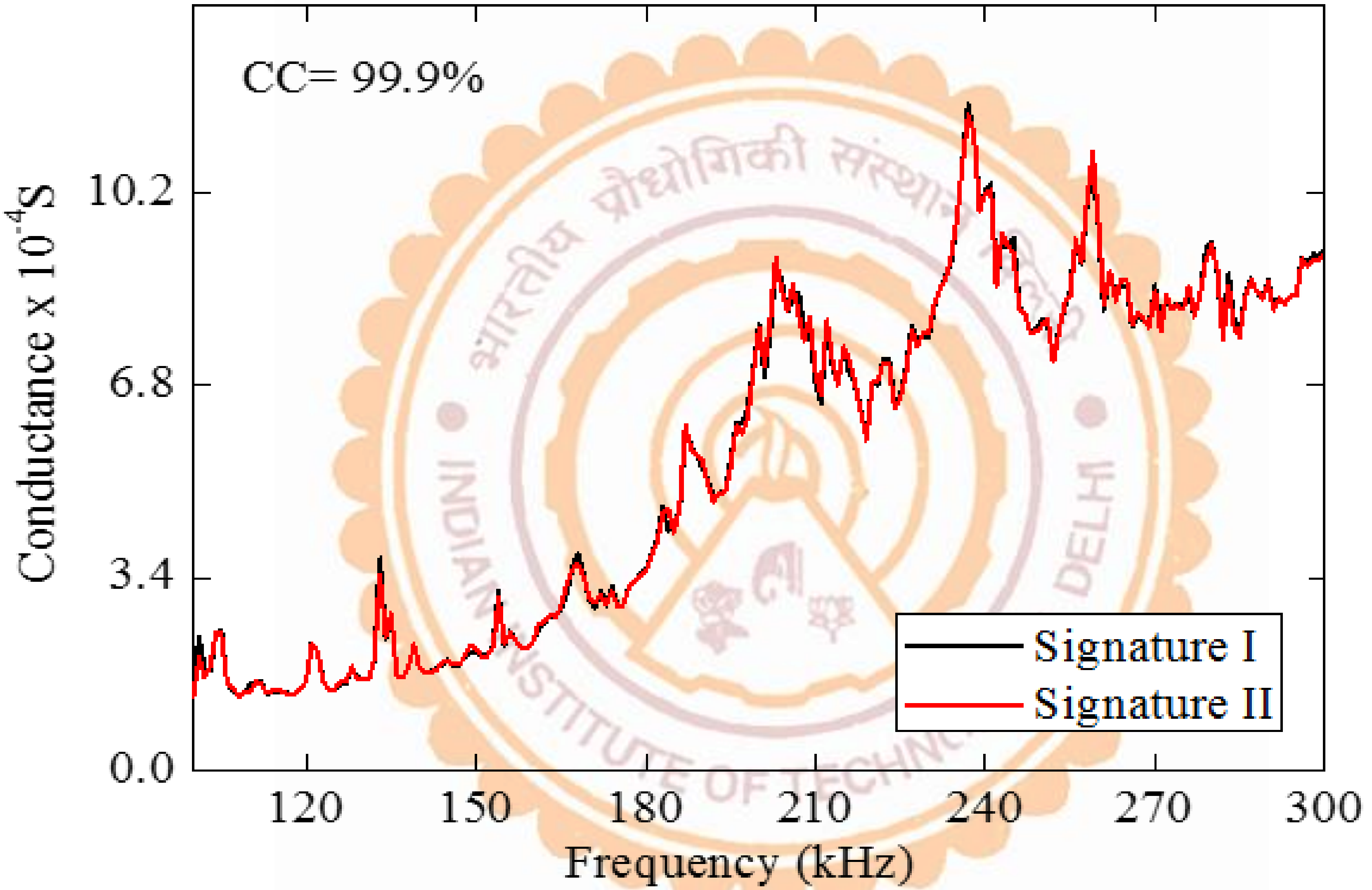


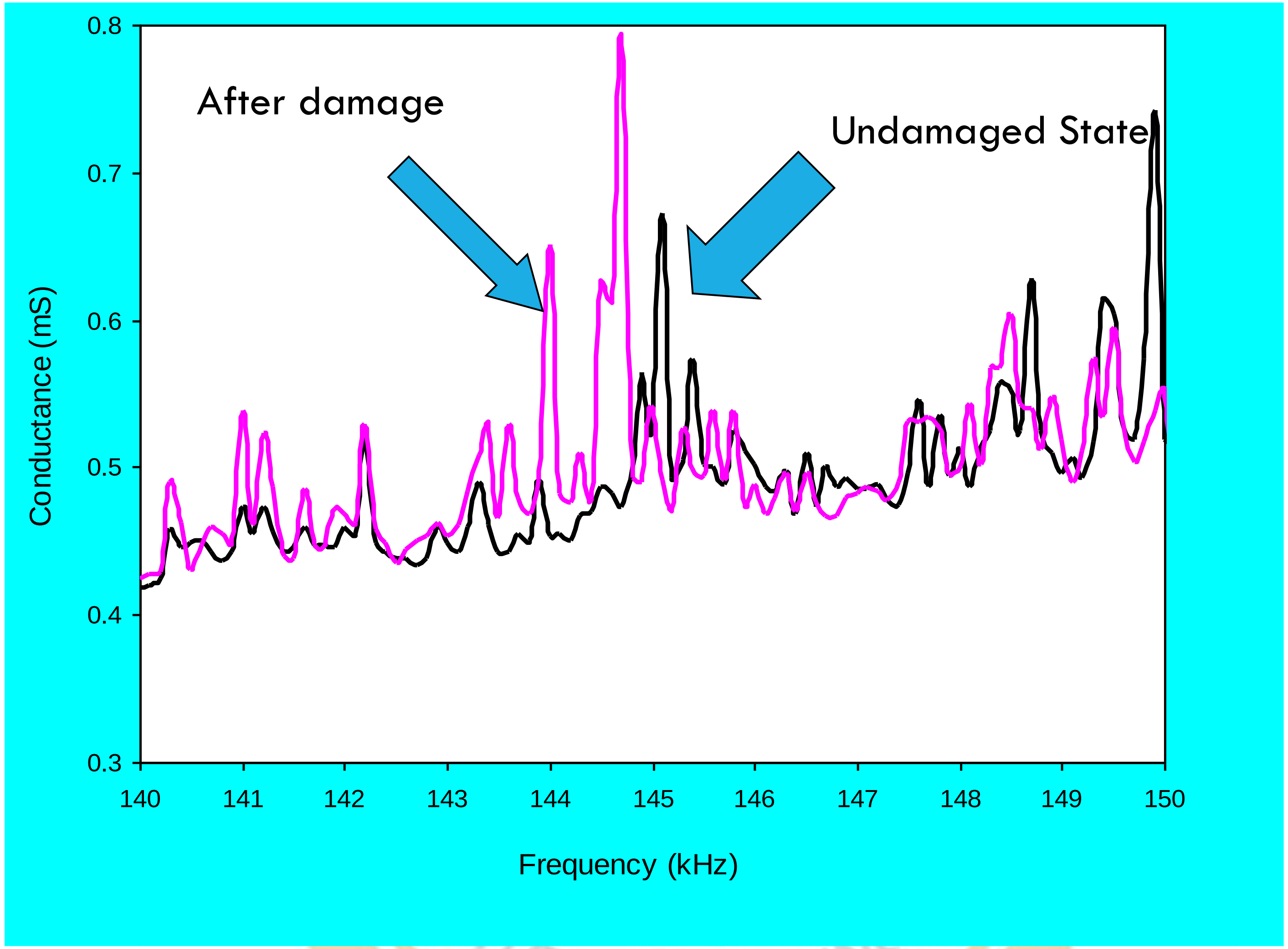


Structural Impedance

NO CHANGE IN SIGNATURE IMPLIES……..

NO OCCURRENCE OF DAMAGE IN THE STRUCTURE




After damage
Undamaged State
Conductance (mS)
0.8
0.7
0.6
0.5
0.4
0.3
140
141
142
143
144
145
146
147
148
149
150
Frequency (kHz)

ADVANTAGES OF PIEZO-IMPEDANCE TRANSDUCERS

* LOW COST

* Fast dynamic response, long term durability, competitive performance, negligible ageing

* High sensitivity (comparable to ultrasonic techniques)

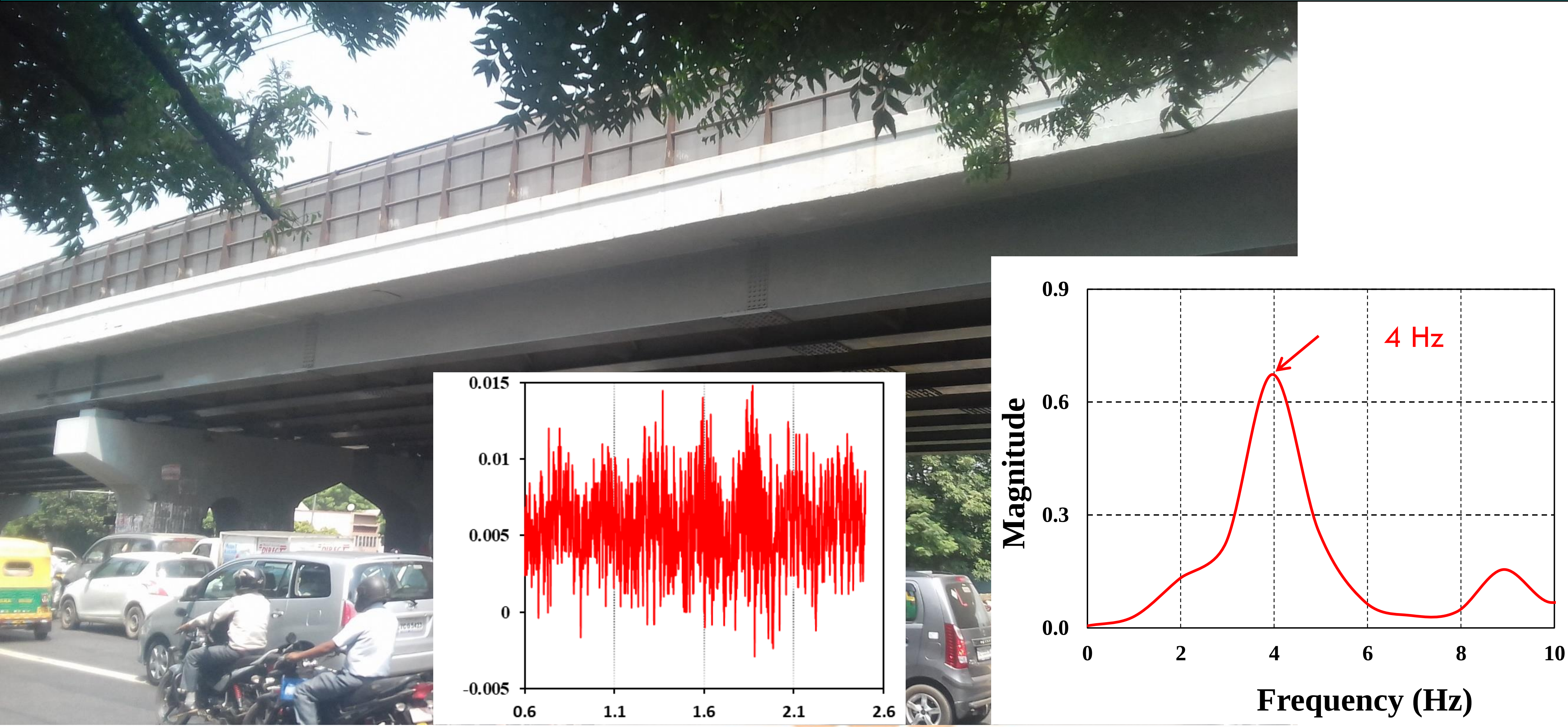
* Same PZT patch can also be used to measure dynamic strain……No frequency limitation (0.5Hz to few MHz).

* Immunity to ambient noise (EMI Technique)….Why?

ENERGY HARVESTING

IDTECHEX (2009)

REAL-LIFE APPLICATION




Piezo patch
Cantilever

THANK YOU

SUGGESTED READING:
BHALLA ET AL. (2005)
(TUNNELLING & UNDERGROUND SPACE TECHNOLOGY)