

Module 3

Smart Materials

- **Definition**
- **Principles of Piezo-electricity**
- **Materials (Polymers and ceramics)**
- **Sensors (Piezo-electric sensor, Strain gauge sensor, Shear sensor, inplane and out-plane sensor, accelerometers)**
- **Smart composites**

Smart Materials: Smart materials are materials that are manipulated to respond in a controllable and reversible way, modifying some of their properties as a result of external stimuli such as certain mechanical stress or a certain temperature, among others.

Why smart materials are used?

- Smart materials and systems are able to sense and respond to the environment around them.
- They have the potential to improve existing technology and add new functionality to products.
- They have applications in a wide variety of areas and could have an important role in waste reduction.

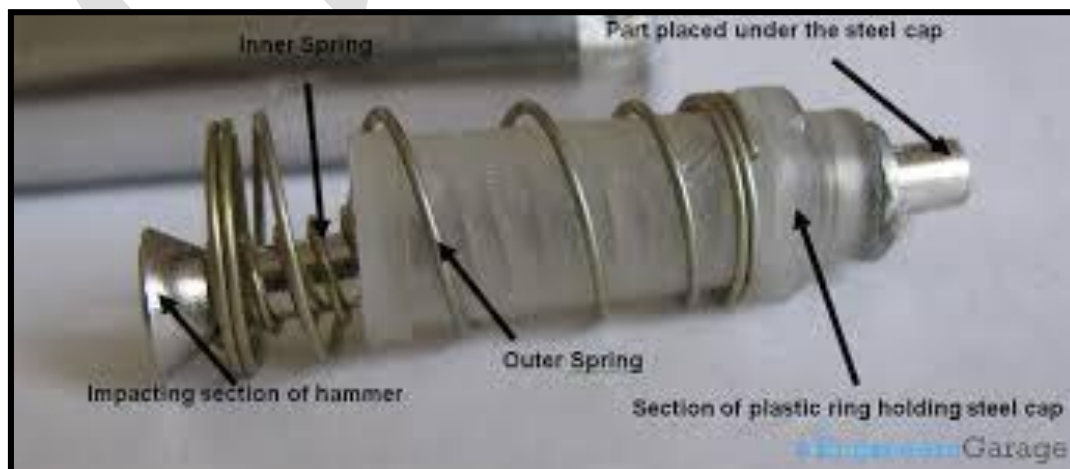
Piezo-electricity

Piezoelectricity, also called the piezoelectric effect, is the ability of certain materials to generate an AC (alternating current) voltage when subjected to mechanical stress or vibration, or to vibrate when subjected to an AC voltage, or both.

Piezoelectric materials or piezoelectric are the materials that can produce electric energy upon application of mechanical stress. A commonly known piezoelectric material is quartz. The mechanism involves development of electric charge due to movement of electron upon application of stress

General example of application of Piezo-electricity

It is used in gas igniters. (It consists of a small, spring-loaded hammer which, when a button is pressed, hits a crystal of PZT. This sudden forceful deformation produces a high voltage and subsequent electrical discharge, which ignites the gas.



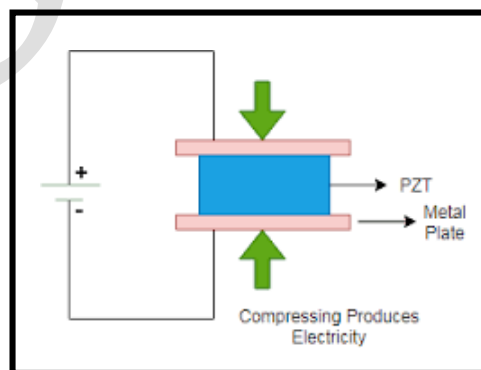
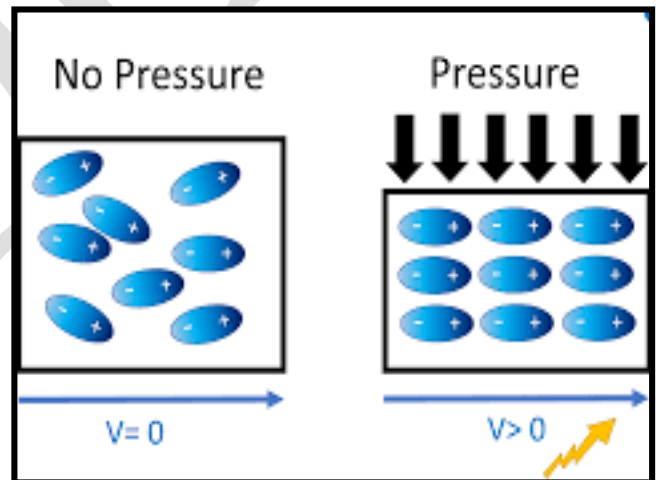
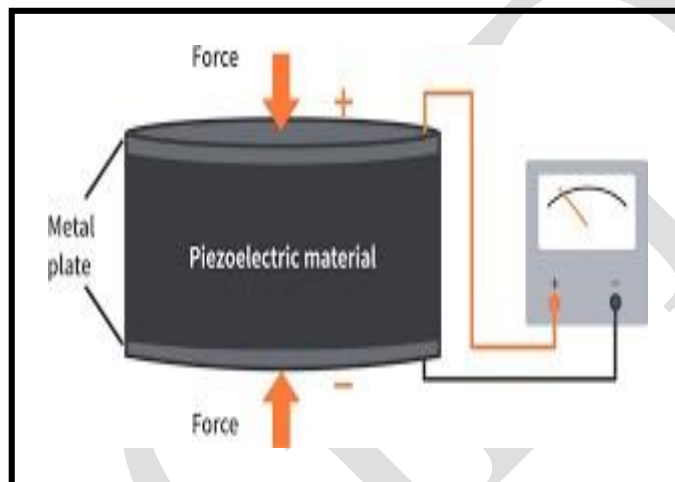
History: The word Piezo is derived from Greek word for pressure. Piezoelectric effect was discovered by Jacques and Pierre Curie in 1880. They found electricity is produced when mechanical stress is applied.

Forms of Piezoelectric Material

- Quartz (SiO_2)
- Lithium Niobate (LiNbO_3)
- Lead Zirconate Titanate PZT

Principle of piezo-electricity

Piezoelectricity is linear interaction between mechanical and electrical systems in non-centric crystals or similar structures



<https://youtu.be/4nbBAG-848c>

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Role of Piezoelectric material in Civil Infrastructure

- Determination of structural damage that is presented in structure in the RCC structure
- Determination of location of damage
- Quantification of severity of the damage
- Prediction of the remaining service life of the structure

Properties of Piezoelectric material

- Size : 10*10*0.2 mm
- Thickness : 0.1 to 0.3 mm
- Width : 5 to 10 mm wide
- Frequency range : 20-400 KHZ
- Sensing Zone : 0.4 to 2m

Piezo-electric materials (Polymers and Ceramics)

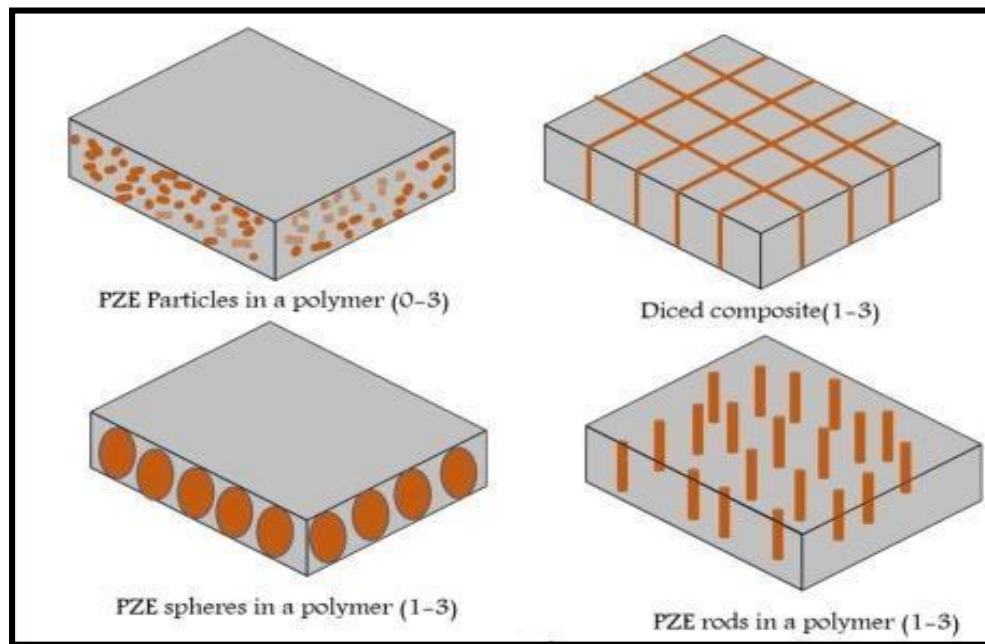
Piezoelectric materials can be classified in three categories:

- Piezoelectric polymers
- Piezoelectric ceramics
- Piezoelectric composites

A. Piezoelectric polymers

Piezoelectric polymers are polymers that can generate electric charges on the surface under pressure/strain thus convert mechanical energy into electrical energy. The most commonly explored piezoelectric polymers are poly (vinylidene fluoride) (PVDF) or its copolymer poly (vinylidene fluoride-co-trifluoroethylene) (PVDF-TrFE).

A. Piezoelectric polymers



B. Piezoelectric Ceramics

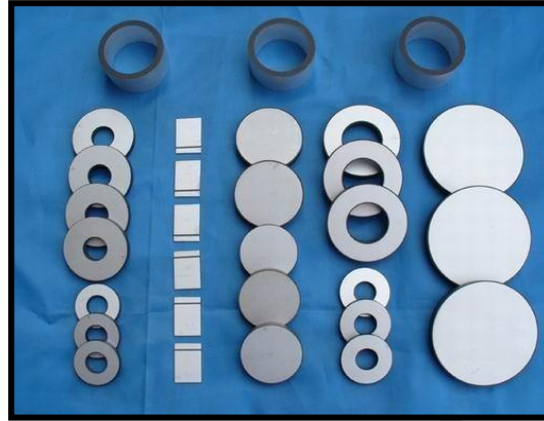
A piezoelectric ceramic is a smart material that converts a mechanical effect (such as pressure, movement, or vibration) into an electrical signal and vice versa.

These are commonly used in mechatronic devices and smart systems. They can be used to sense changes in pressure and strain in the environment and can generate electrical responses.

The most commonly produced piezoelectric ceramics are lead zirconate titanate (PZT), barium titanate, and lead titanate.

To prepare a piezoelectric ceramic, fine PZT (lead zirconate titanate) powders of the component metal oxides are mixed in specific proportions, then heated to form a uniform powder. The piezo powder is mixed with an organic binder (water, oil, sodium silicate, bentonite and corn starch) and is formed into structural elements having the desired shape (discs, rods, plates, etc.).

Piezoelectric Ceramics



Piezoelectric composites

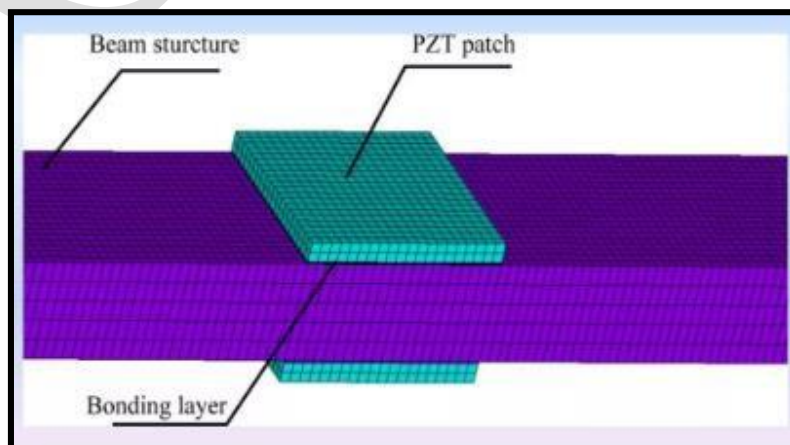
Piezoelectric composites are materials that combine the piezoelectric properties of certain ceramics or polymers with other materials to create enhanced, multifunctional materials. Piezoelectricity refers to the ability of certain materials to generate an electric charge in response to mechanical stress. This effect is reversible, meaning that applying an electric field can also induce mechanical deformation.

Installation of Piezoelectric material in concrete structure

For the assessment of active response of the structure the piezoelectric material can be installed in two ways

Surface Bonded

- Bonded to the surface of concrete through a high strength epoxy adhesive.
- Drawback material rapidly deteriorates with respect to atmospheric weather Condition.



Embedded piezoelectric material

- Install at the time of construction structure
- Safe against the aggressive environmental condition
- More effective as compare to the surface bonded material.



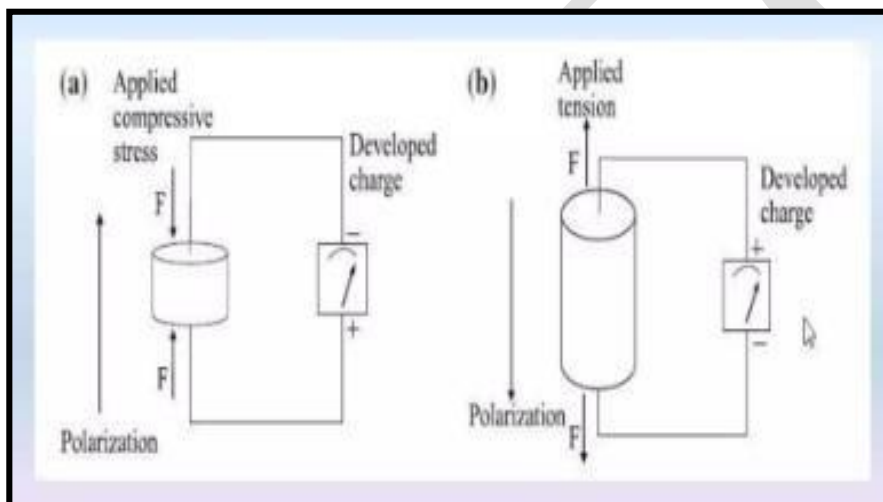
Piezoelectric Sensor

- A piezoelectric sensor is a device that uses the [piezoelectric effect](#) to measure changes in [pressure](#), [acceleration](#), [temperature](#), [strain](#), or [force](#) by converting them to an [electrical charge](#).
- Piezoelectric sensor is capable of transforming mechanical strain and vibration energy into electrical energy. This property allows opportunities for implementing renewable and sustainable energy through power harvesting and self-sustained smart sensing in buildings.

How they are made ?

- Both Natural and Manmade.
- When DC electric field is applied, all molecules are aligned in one direction.
- Exhibit electric behavior at a particular temperature or Curie temperature.

Piezoelectric sensor is also a kind of smart material which possesses both sensor and actuator (An **actuator** is a component of a machine that is responsible for moving and controlling a mechanism) characteristics used in concrete structure for the structural health monitoring of concrete structure.



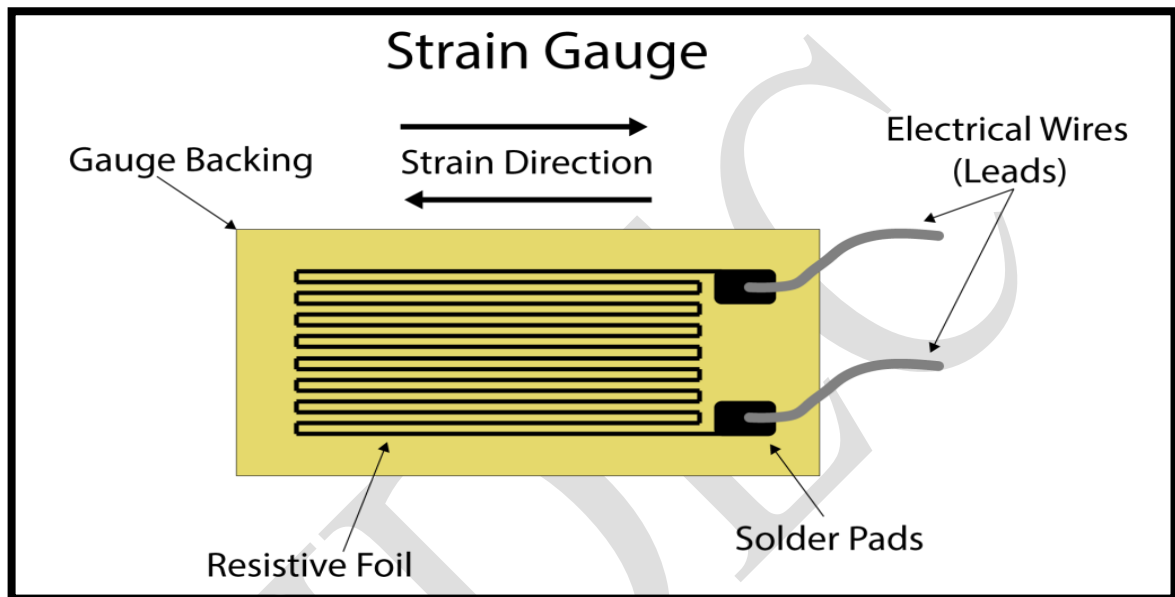
Advantages of Piezoelectric Sensor

- Favorable for structure health monitoring.
- Broad frequency range.
- Cost effective.
- Small size and negligible weight.
- Implemented at any time.
- Example: Installed after an earthquake to monitor the growing cracks.
- Easy installation makes it easily suitable for existing as well as to be built structure.
- Involve less manpower.

Strain Gauge Sensor

A strain gauge is a sensor that converts mechanical displacement into electrical signals that can be measured.

A strain gauge is a thin, wafer-like device that can be attached to a variety of materials to measure applied strain.



Strain Gauge Sensor

A strain gauge is an electrical sensor; they are used to measure and monitor strain. It is one of the significant sensors used in the geotechnical field **to measure the amount of strain on any structure** (Dams, Buildings, Nuclear Plants, Tunnels, etc.). The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc.

What is strain in building construction?

Strain is **the deformation of a material from stress**. It is simply a ratio of the change in length to the original length. Deformations that are applied perpendicular to the cross section are normal strains, while deformations applied parallel to the cross section are shear strains.

Types of Strain Gauge

1. Mechanical Strain gauge
2. Electrical Strain gauge
3. Piezoelectric Strain gauge
4. Bonded Strain gauge
5. Unbonded Strain gauge
6. Foil Strain gauge
7. Semiconductor Strain gauge
8. Photoelectric Strain gauge

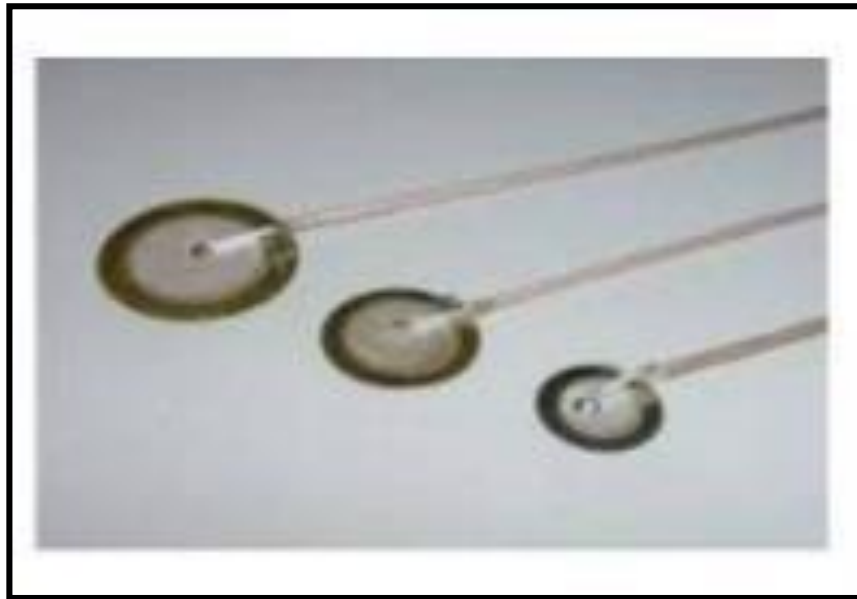
1. Mechanical Strain gauge

It is made up of two separate plastic layers. The bottom layer has a ruled scale on it and the top layer has a red arrow or pointer. One layer is glued to one side of the crack and one layer to the other. As the cracks opens, the layers slide very slowly past one another and the pointer moves over the scale. The red crosshairs move on the scale as the cracks.



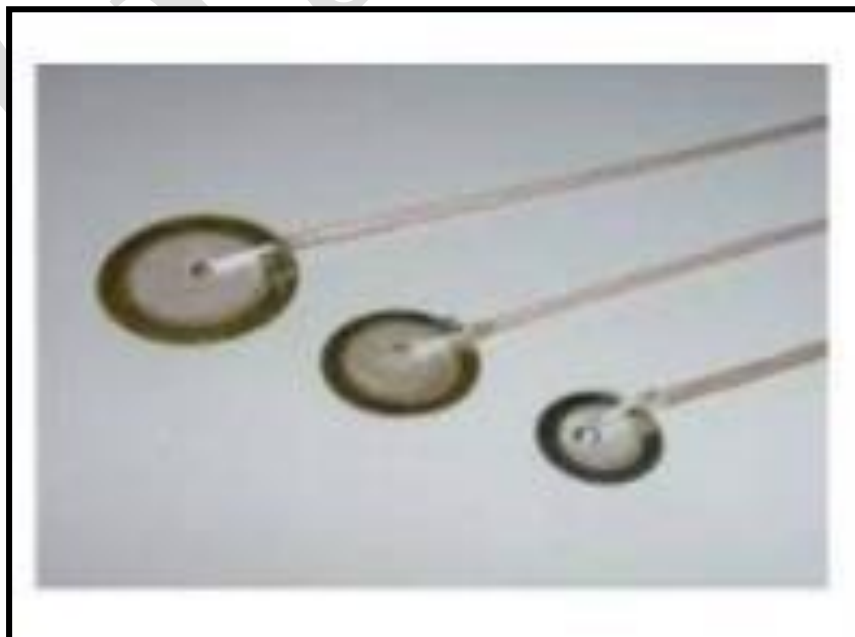
2. Electrical Strain gauge

When an electrical wire is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increases its electrical resistance end to end. Strain can be inferred by measuring change in resistance.



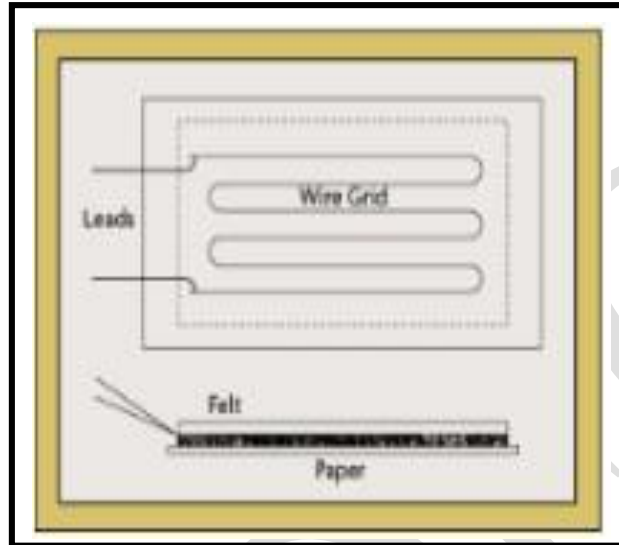
3. Piezoelectric Strain gauge

Piezoelectric generate electric voltage when strain is applied over it. Strain can be calculated from voltage. Piezoelectric strain gauges are the most sensitive and reliable devices.



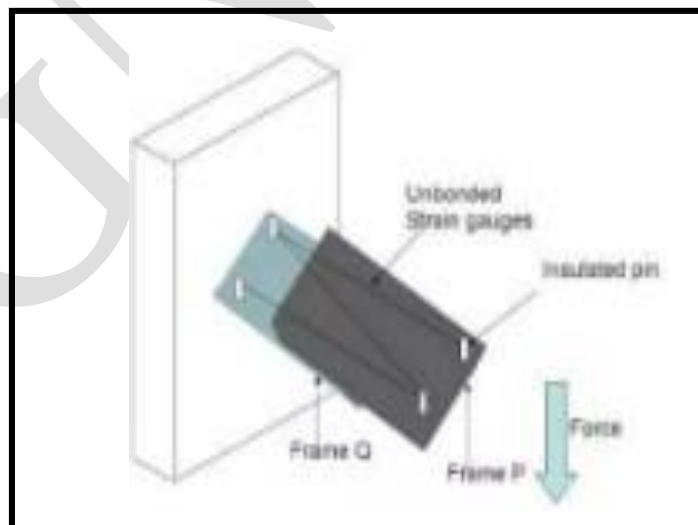
4. Bonded Strain gauge

A bonded strain gauge element, consisting of a metallic wire, detached foil, vacuum deposited film, or semiconductor bar, is cemented to the strained surface.



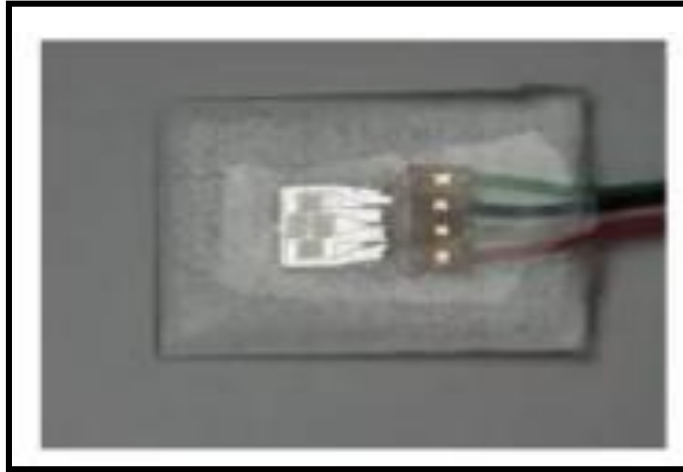
5. Unbonded Strain gauge

The unbonded strain gauge consists of a wire stretched between two points in an insulating medium such as air. One end of the wire is fixed and the other end is attached to a movable element.



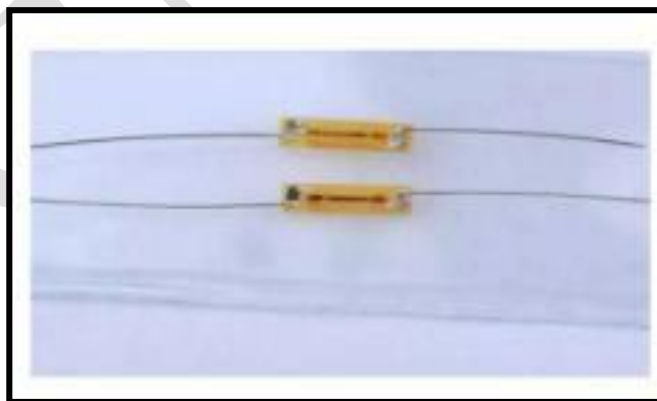
6. Foil Strain gauge

The foil strain gauge has metal foil photo - etched in a grid pattern on the electric insulator of the thin resin and gauge leads attached



7. Semiconductor Strain gauge

For measurement of small strain, semiconductor strain gauges, so called piezoresistors, are often preferred over foil gauges. Semiconductor strain gauges depend on the piezoresistive effects of silicon or germanium and measure the change in resistance with stress as opposed to strain.



8. Photoelectric Strain gauge The photoelectric gauge uses a light beam, two fine gratings, and a photocell detector to generate an electrical current that is proportional to strain. The gauge length of these devices can be as short as 1/16 inch, but they are costly and delicate.



Application of Strain Gauge Sensor in building

- Measurement of residual stress (stresses are usual in processes such as welding, machining, grinding, and wire drawing).
- Vibration measurement.
- Torque measurement.
- Bending and deflection measurement.
- Compression and tension measurement.
- Strain measurement.

Advantages of Strain Gauge Sensor in building

- Simple in construction.
- Strain gauges can be calibrated in terms of quantities, such as, force, displacement, pressure and acceleration.
- Very sensitive.

- They provide good output for indicating and recording purposes.
- Inexpensive and reliable.

Disadvantages of Strain Gauge Sensor in building

- It is non-linear.
- It needs to be calibrated.

Accelerometers

An accelerometer is an electro mechanical device that measures proper acceleration forces. These forces may be static like the constant force of gravity pulling at your feet, or they could be dynamic- caused by moving and vibrating the accelerometer. Accelerometer sensors detect vibration, tilting and acceleration in a structure.

Principle of accelerometers

The working principle of accelerometers is based on piezoelectric effect (due to accelerative forces) and on the displacement sensing (Based on displacement mass).

Accelerometers

There are basically 2 types of accelerometer used for measurement of acceleration

- Piezoelectric accelerators.
- Displacement sensing or Seismic type accelerometers.

Piezoelectric accelerators: It employs the piezoelectric effect of certain materials to measure dynamic changes. It converts one form of energy into another and provide electrical signal of measured amount.

Advantages of Piezoelectric Accelerometers

- Rugged (Rocky, Uneven) and Inexpensive.
- High Impedance (Effective resistance of electric circuit).
- High Sensitive
- High frequency respond

Disadvantages of Piezoelectric Accelerometers

- Sensitive to temperature.
- Hysteresis (Lagging) error.
- Less longevity (Duration of life).
- Decreased efficiency with time.

Displacement sensing or Seismic type accelerometers: In displacement sensing accelerometer the displacement of the mass resulting from is measured and correlated to the acceleration.

Working principle: The working principle of this is based on mass spring damper combination and similarly acceleration calculation from displacement.

Advantages of Displacement sensing or Seismic type accelerometers

- Easy calculation
- Simple and Reliable
- Durable and Efficient

Disadvantages of Displacement sensing or Seismic type accelerometers

- Spring system is not always accurate.
- Fluctuation in mass leads to wrong calculation

Smart Composites

Smart composites are defined as the systematic composition of smart materials to provide enhanced dynamic sensing, communicating, and interacting capabilities via interactive connected smart materials (ICS materials).

Smart composites can be explained simply as there are designed materials, where smart materials are embedded in polymer, metal or concrete etc to sense, control, communicate etc.

Smart materials are also called intelligent or responsive materials the materials which have the ability to change their physical properties in response to specific stimulus input or environmental changes. These stimulus could be pressure, temperature, electric, magnetic field, chemical, mechanical stress, radiation etc.

Some of the smart materials types

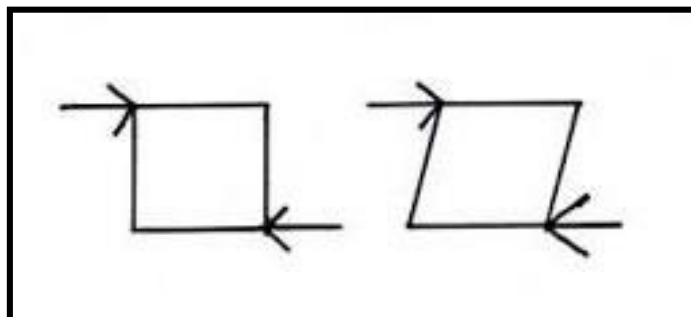
- Piezo Electric Materials - Materials that produce a voltage when stress is applied.
- Photovoltaic or Opto electronics materials- Converts Light to electrical current.
- Shape memory materials Induce deformation due to temperature, stress change.
- PH Sensitive polymers- Material which changes in volume when PH of surrounding medium changes.
- Halochromic materials - change their color as a result of changing acidity.
- Temperature response polymers - Materials which undergo changes upon temperature.
- Thermo electric materials - convert temperature difference to electricity & Vice versa.
- Di Electric elastomers-produce large strains (up to 500%) under the influence of an
- Electric field.

Shear Sensor

What is Shear force in building?

A shear force is a force applied along the surface, in opposition to an offset force acting in the opposite direction. This results in a shear strain. In simple terms, one part of the surface is pushed in one direction, while another part of the surface is pushed in the opposite direction.

The basic technique of shear force measurement and its application for measurements of shear force in the structural components is done by using shear force sensor.



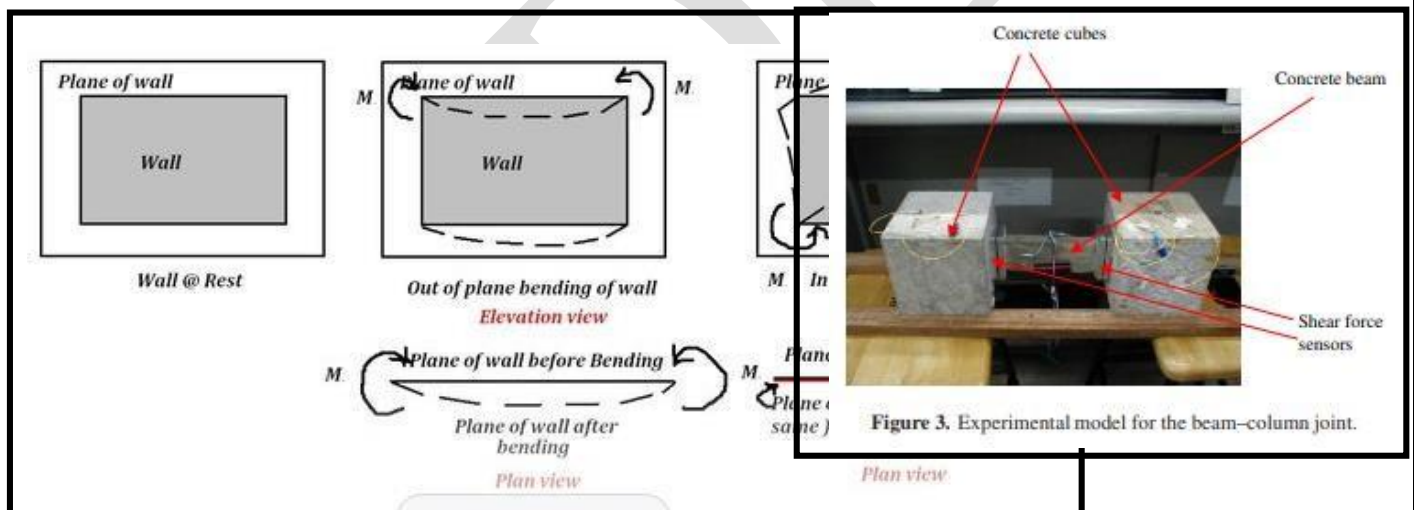
Shear Sensor

Advantages of Shear sensor:

- Small size and easy integration into a wide variety of systems.
- Electrically immune, hence no conduction of electric current.
- Long term stability
- Miniature size
- Ease and cost of installation
- Fatigue durability
- Tolerant to harsh environment

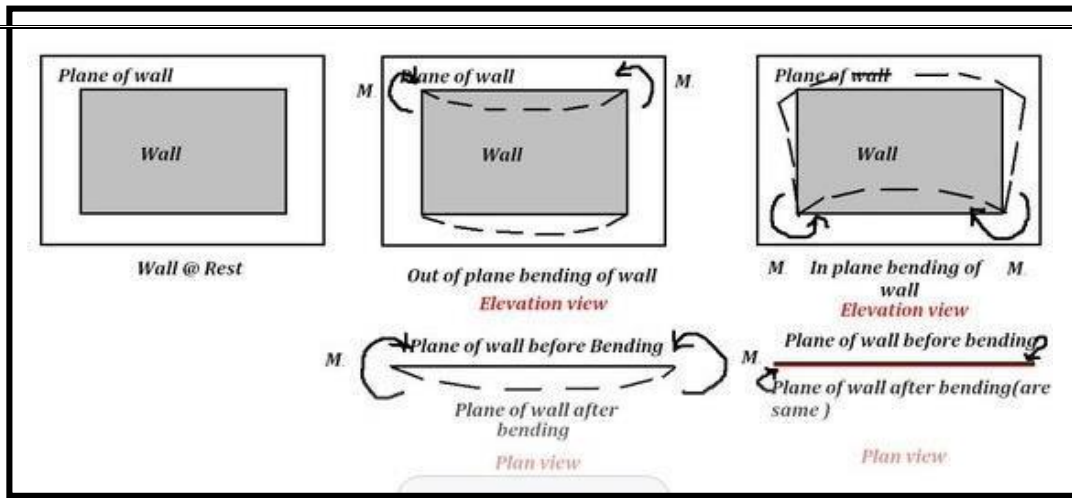
Disadvantages of Shear sensor:

- It is thermal sensitive
- It is expensive to build and maintain
- It is difficult to demodulate (extract) wavelength shift



In-plane and Out – plane Sensor

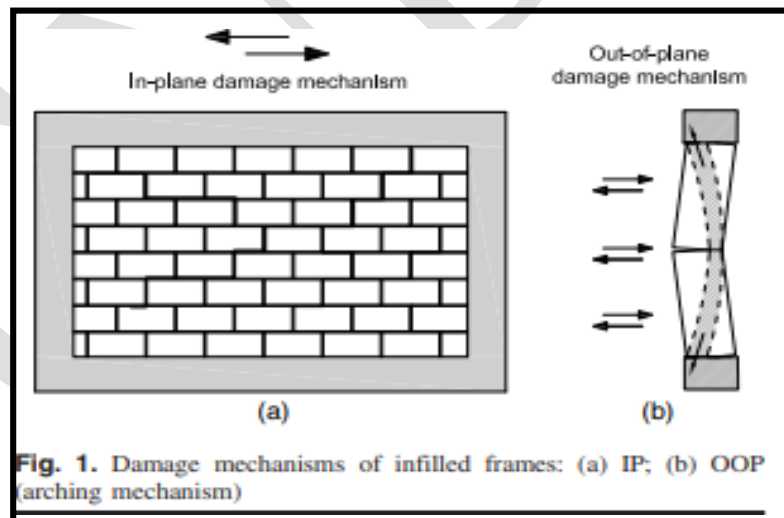
In the in-plane panels load is applied parallel to the surface, whereas in out-plane panels, the load is applied perpendicular to the surface of the panels. If the member is bending in its own plane it is called in plane bending and if it is bending out of its plane it is called out of plane bending. Out-of-plane failures occur due to various reasons such as quality of construction materials, large span of wall without cross support, and large openings.



In-plane and Out – plane Sensor

During an earthquake, a brick wall, similar to any structural system, undergoes a global acceleration field in which it is subjected to both in-plane and out-of-plane loads. Infilling steel and RC frames with unreinforced masonry walls for architectural purposes are a common construction practice in many regions of the world. Frame –infill interactions under in-plane (IP) and out-of-plane (OOP) seismic loads have been investigated.

In the recent past, the extensive use of nonlinear static and dynamic analyses for the assessment of the seismic performance of structural systems has created a pressing need for reliable macroelement models based on beam-column elements that can deliver the required accuracy as well as computational efficiency.



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