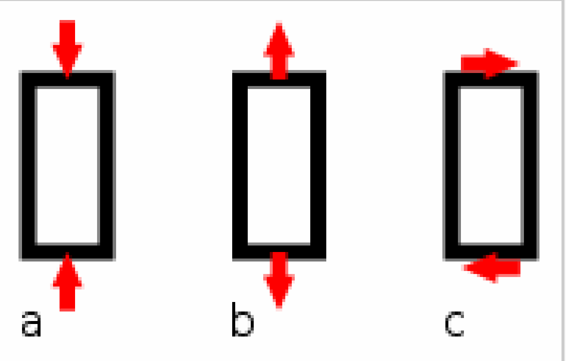
Strain Gauges

Before discussing strain gauges

we must first briefly explain the concepts of

- √ Stress
- √ Strain
- √ Elastic modulus
- √ Poisson's ratio

Stress = F/A



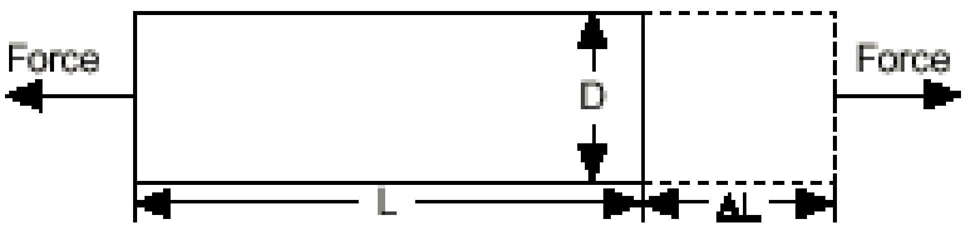
A material being loaded in a) compression, b) tension, c) shear.

where *F* is the force [N] acting on an area *A* [m2].

- *Compressive stress* (or compression)
- *Tensile stress*
- *Shear stress* is the stress state caused by a pair of opposing forces acting along parallel lines of action through the material, in other words the stress caused by *sliding* faces of the material relative to one another.

What Is Strain?

Strain is the amount of deformation of a body due to an applied force. More specifically, strain (e) is defined as the fractional change in length, as shown in Figure below.



$$\varepsilon = \frac{\Delta L}{L}$$

Strain can be positive (tensile strain) or negative (compressive strain).

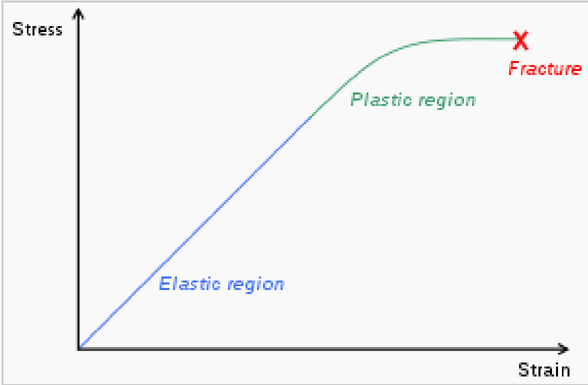
- Positive sign indicates a tensile stress which tends to *increase* the length of the body.

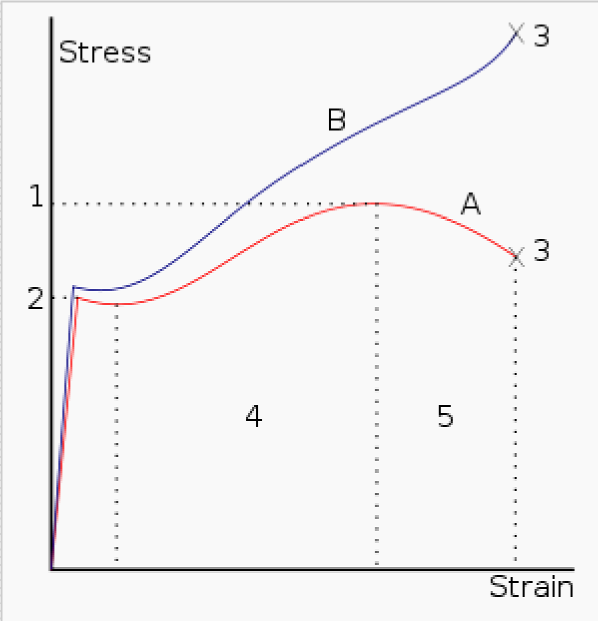
$$e = +\Delta l / l$$

- Negative sign indicates a compressive stress which tends to *reduce* the length of the body.

$$e = -\Delta l / l$$

- Metals including steel have a linear stress-strain relationship up to the yield point, as shown in the figure.
- Below the yield strength all deformation is recoverable, and the material will return to its initial shape when the load is removed. This recoverable deformation is known as elastic deformation.
- For stresses above the yield point the deformation is not recoverable, and the material will not return to its initial shape. This unrecoverable deformation is known as plastic deformation.





Stress vs. Strain curve typical of structural steel
1. Ultimate Strength
2. Yield strength
3. Rupture
4. Strain hardening region
5. Necking region.
A: Apparent (engineering) stress (F/A_0)
B: Actual (true) stress (F/A)

Elastic Modulus =stress/ strain

- An **elastic modulus**, or **modulus of elasticity**, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress-strain curve in the elastic deformation region.

$$\lambda \stackrel{\text{def}}{=} \frac{\text{stress}}{\text{strain}}$$

where λ (lambda) is the elastic modulus; *stress* is the force causing the deformation divided by the area to which the force is applied; and *strain* is the ratio of the change caused by the stress to the original state of the object.

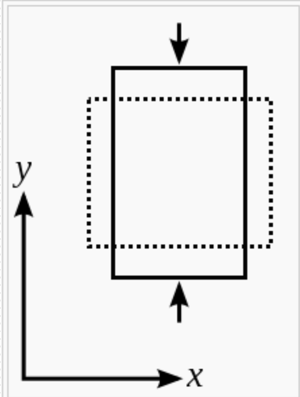
If stress is measured in pascals, since strain is a unitless ratio, then the units of λ are pascals as well.

- *Young's modulus* (Є) describes tensile elasticity, or the tendency of an object to deform along an axis when opposing forces are applied along that axis; it is defined as the ratio of tensile stress to tensile strain. It is often referred to simply as the *elastic modulus*.

Poisson's Ratio

- **Poisson's ratio** (***v***), named after Siméon Poisson, is the ratio, when a sample object is stretched, of the contraction or transverse strain (perpendicular to the applied load), to the extension or axial strain (in the direction of the applied load).

- When a sample cube of a material is stretched in one direction, it tends to contract (or occasionally, expand) in the other two directions perpendicular to the direction of stretch. Conversely, when a sample of material is compressed in one direction, it tends to expand (or rarely, contract) in the other two directions. This phenomenon is called the **Poisson effect**. Poisson's ratio *v* (nu) is a measure of the Poisson effect.



Assuming that the material is compressed along the axial direction:

$$\nu = -\frac{\varepsilon_{\mathrm{trans}}}{\varepsilon_{\mathrm{axial}}} = -\frac{\varepsilon_{\mathrm{x}}}{\varepsilon_{\mathrm{y}}}$$

where

ν is the resulting Poisson's ratio,

$\varepsilon_{\mathrm{trans}}$ is transverse strain (negative for axial tension, positive for axial compression)

$\varepsilon_{\mathrm{axial}}$ is axial strain (positive for axial tension, negative for axial compression).

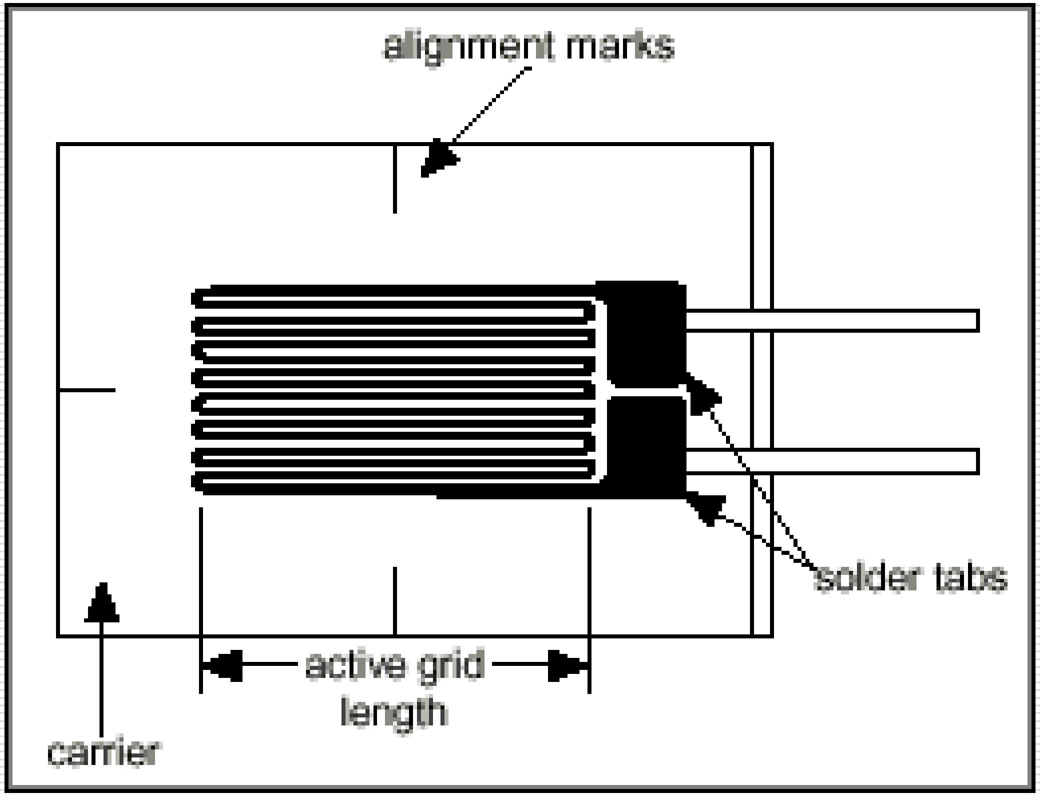
The Poisson's Ratio ν of a material is defined as the negative ratio of the strain in the transverse direction (perpendicular to the force) to the strain in the axial direction (parallel to the force), or ν **=** $\mathbf{e_T / e_L}$.

Where Poisson's Ratio which has a value between 0.25 and 0.4 for most materials.

for steel, for example, ranges from 0.25 to 0.3.

Bonded Metallic Strain Gauge

A strain gauge is a metal or a semiconductor element whose resistance changes under strain.



The Strain Gauge

- The metallic strain gauge consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern.
- The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction.
- The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson Strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance.
- Strain gauges are available commercially with nominal resistance values from 30 to 3000 Ω, with 120, 350, and 1000 Ω being the most common values.

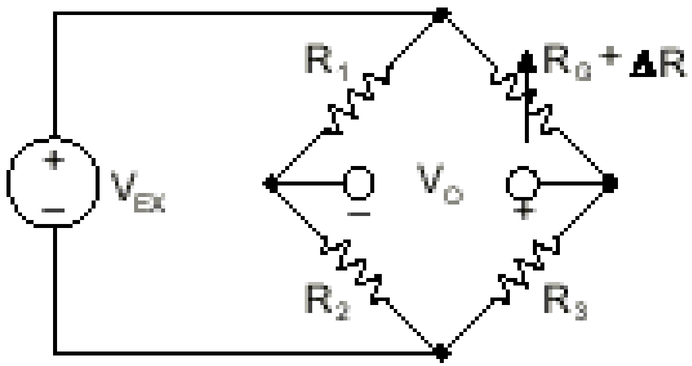
$$GF = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

- A fundamental parameter of the strain gauge is its sensitivity to strain, expressed quantitatively as the ***gauge factor*** (G).
- Gauge factor is defined as the ratio of fractional change in electrical resistance to the fractional change in length (strain):

Strain Gauge Measurement

- To measure such small changes in resistance, strain gauges are almost always used in a bridge configuration with a voltage excitation source. The general Wheatstone bridge, illustrated below, consists of four resistive arms with an excitation voltage, V_{EX}, that is applied across the bridge.

Wheatstone Bridge



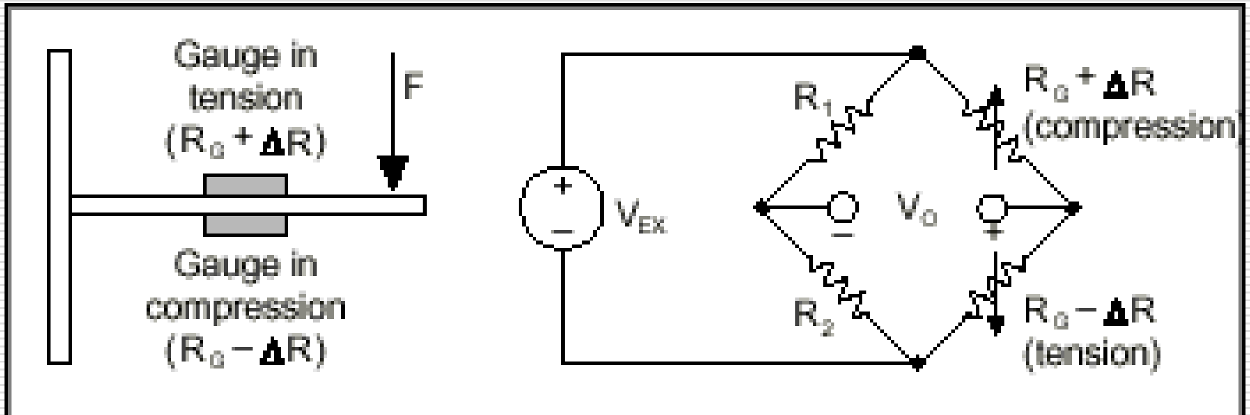
$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{4}\left(\frac{1}{1 + GF \bullet \frac{\varepsilon}{2}}\right)$$

$$V_O = \left[\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2}\right] \bullet V_{EX}$$

Quarter-Bridge Circuit

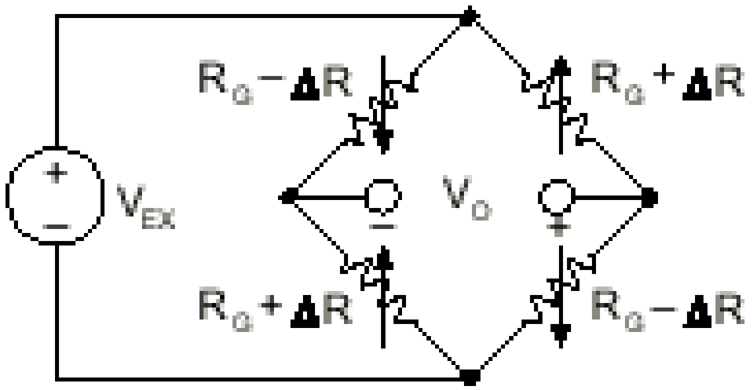
Half Bridge

- Below circuit yields an output voltage that is linear and approximately doubles the output of the quarter-bridge circuit.



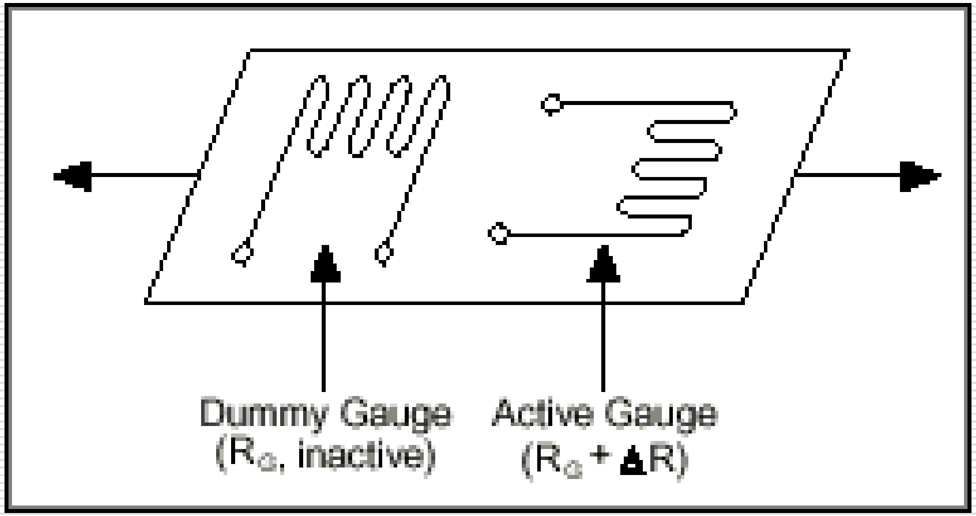
$$\frac{V_O}{V_{EX}} = -\frac{GF \bullet \varepsilon}{2}$$

Full-Bridge Circuit



$$\frac{V_O}{V_{EX}} = -GF \bullet \varepsilon$$

Use of Dummy Gauge to Eliminate Temperature Effects



What is a Load Cell?

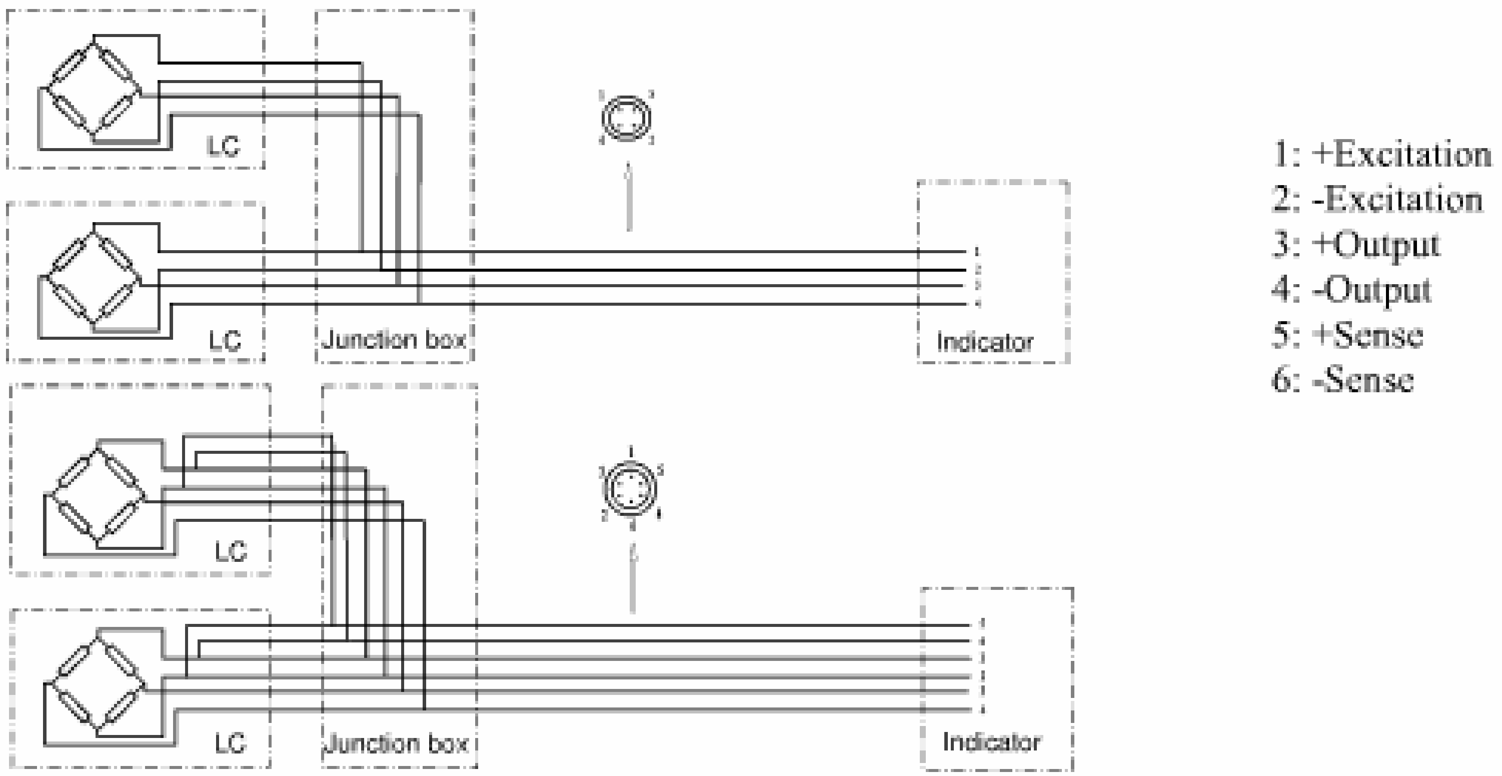
- A load cell is a transducer which converts force into a measurable electrical output. Although there are many varieties of load cells, strain gage based load cells are the most commonly used type.

Force into electrical signal conversion

- This conversion is *indirect and happens in two stages:* Through a mechanical arrangement, the force being sensed deforms a strain gauge. The strain gauge converts the deformation (strain) to electrical signals. A load cell usually consists of four strain gauges in a Wheatstone bridge configuration. Load cells of one or two strain gauges are also available. The electrical signal output is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used.

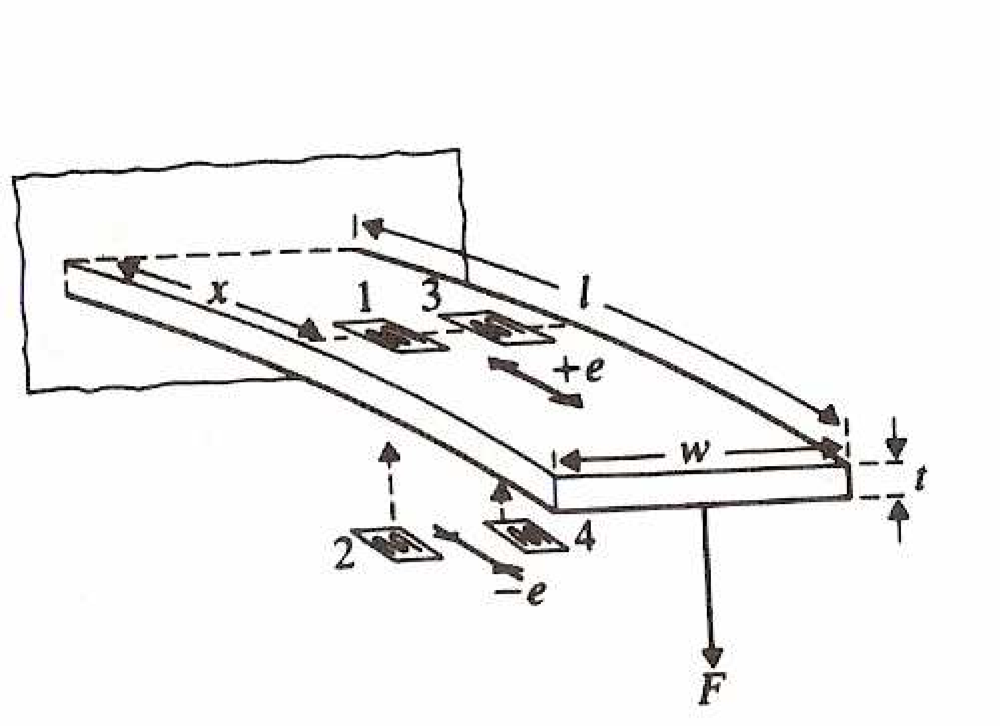
- Although strain gauge load cells are the most common, there are other types of load cells as well. In industrial applications, hydraulic (or hydrostatic) is probably the second most common, and these are utilized to eliminate some problems with strain gauge load cell devices. As an example, a hydraulic load cell is immune to transient voltages (lightning) so might be a more effective device in outdoor environments.
- Other types include piezo-electric load cells (useful for dynamic measurements of force), and load cells, which are useful in applications due to low amounts of drift

Loadcell Cabling



The above figures represent the two basic configurations, using four- or six-wire (sense) load cells.

Cantilever Loadcell



- Applied force F causes the cantilever to bend so that the top surface experiences a tensile strain (+e) and the bottom surface an equal compressive strain (-e).

The magnitude of strain e is given

$$e = \frac{6(l - x)}{wt^2 E} F$$

$$e = \frac{6(l - x)}{wt^2 E} F$$

Where

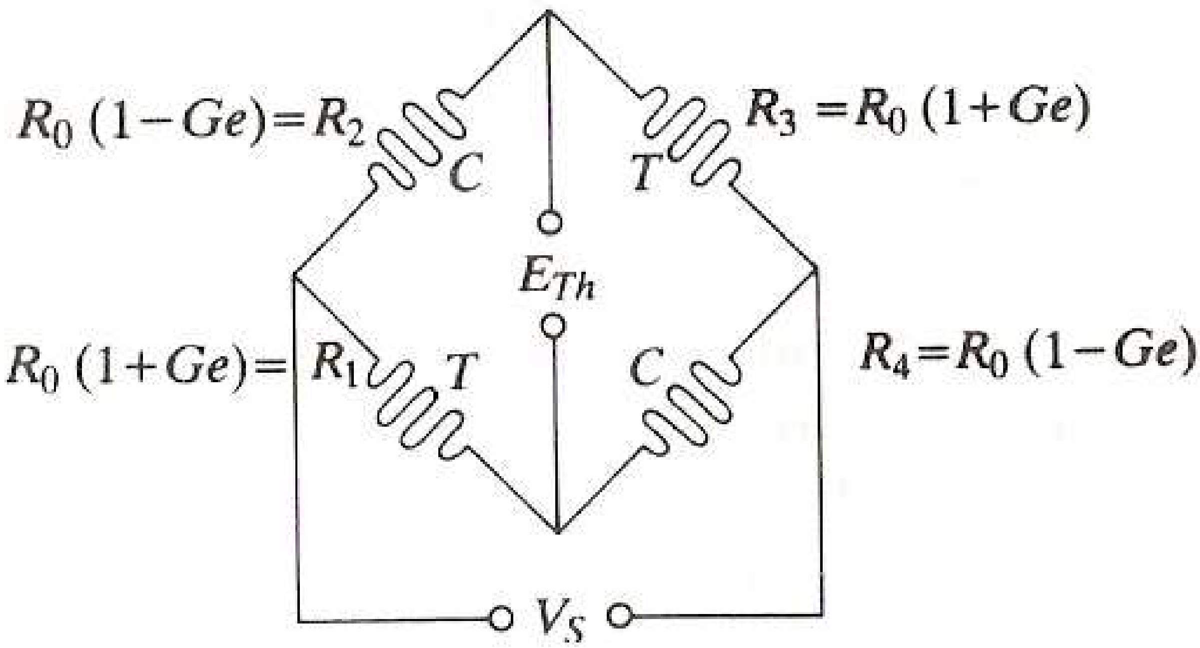
- E is Young's modulus for the cantilever material.
- The other quantities *(l, w, t, x)* are defined in the figure.

- Strain gauges 1 and 3 sense a tensile strain +e so that their resistance increases by ΔR.
- Gauges 2 and 4 sense a compressive strain −e so that their resistance decreases by an equal amount.

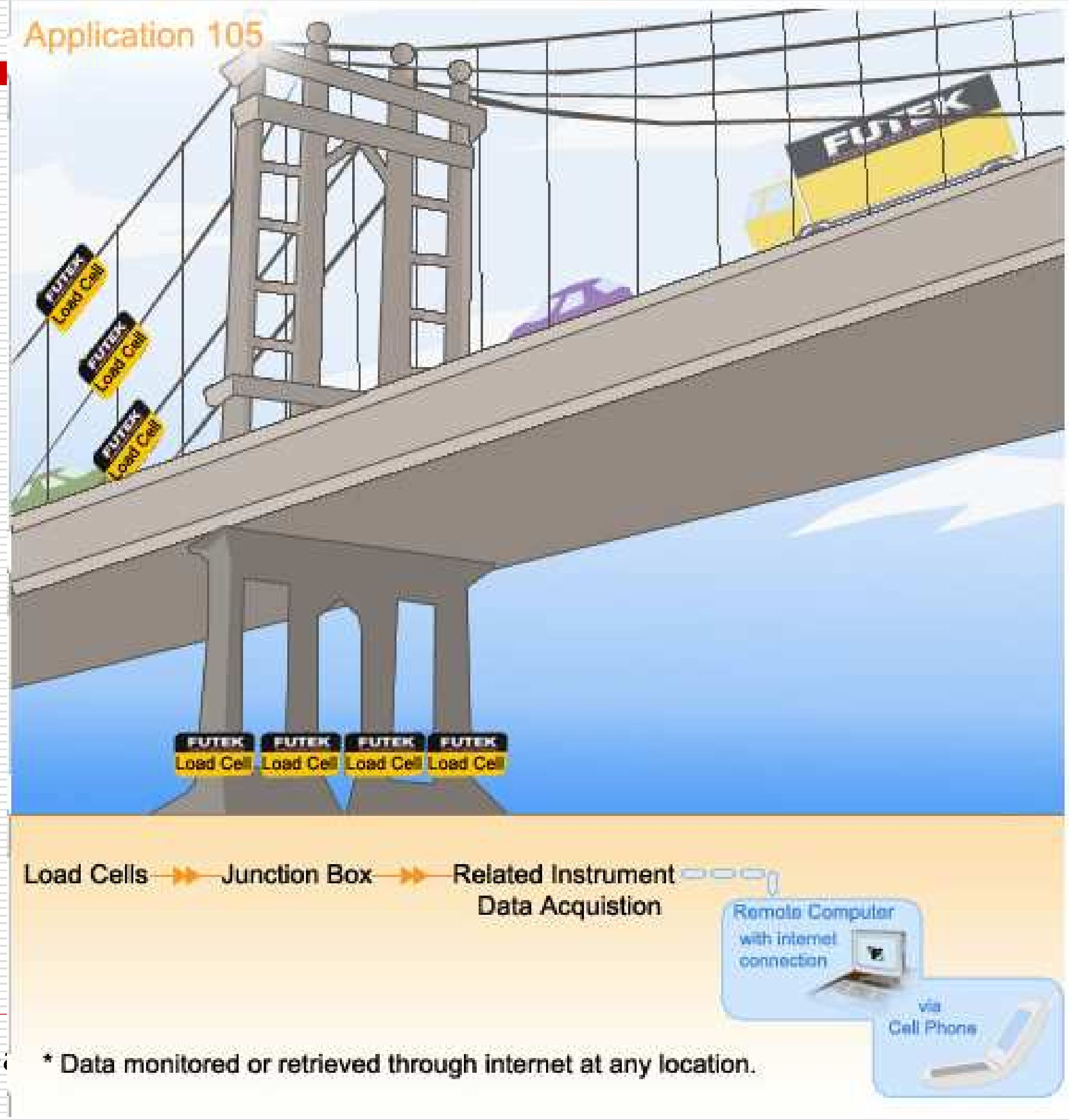
$$\Delta R = GR_0e$$

Where G is the gauge factor and R_0 the unstrained resistance of the gauges.

Four-element strain gauge Bridge



A Load Cell Application - Suspension Bridge



Reference:
http://www.futek.com/apps_105.aspx

FUTEK load cell and instruments can be used in suspension bridges.

Load cells can be installed on the cables to measure the tension and stress applied to the cables under various traffic conditions.

They can also be installed under the post of the bridge to measure the compression the bridge experiences under various conditions.

Data acquired will be sent to a data logger or data acquisition system using FUTEK Junction Box and related instrument. Remote management of data via internet or cell phones can be achieved.