THE NEOTIA UNIVERSITY

ज्ञानम् आत्म प्रदीपाय

DEPARTMENT OF MECHANICAL ENGINEERING

Engineering Mechanics and Strength of Materials

LAB MANUAL

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EXPERIMENT NO. : 01

NAME OF THE EXPERIMENT: Verification of Varignon's theorem.

OBJECTIVE:

To verify the law of polygon of forces for a numbers of coplanar forces in equilibrium.

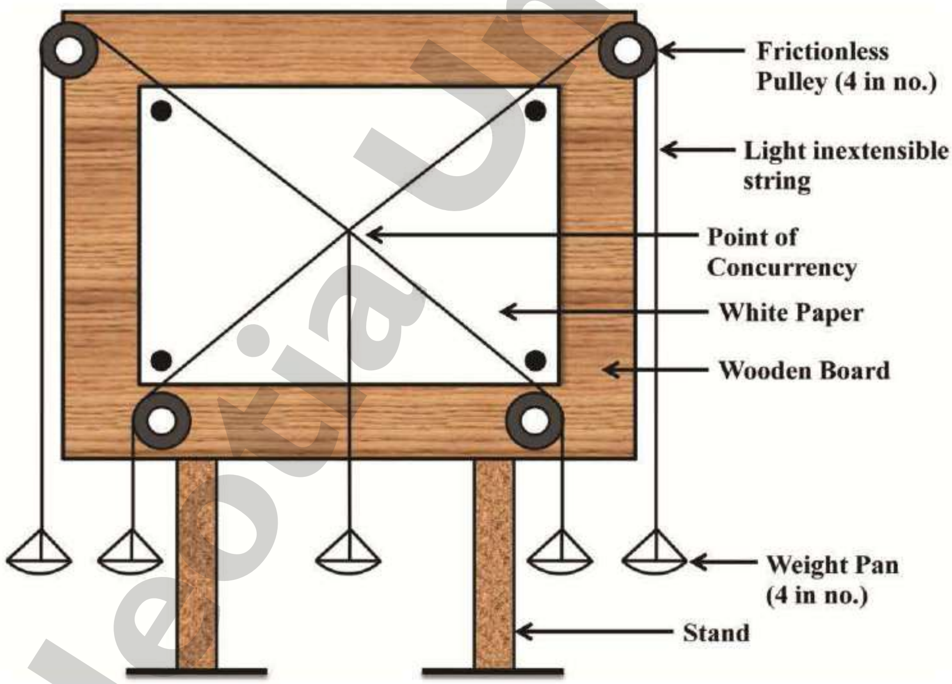

Figure 1.1: Labeled diagram of the apparatus

Theory:

The Law of Polygon of Forces states that – if any number of coplanar concurrent forces can be represented in magnitude and direction by the sides of a polygon taken in order; then their resultant will be represented by the closing side of the polygon taken in opposite order".

Also, if the forces form a closed polygon, then the system is in equilibrium. Fig. 1.2 and 1.3 shows a system of five forces F_1, F_2, F_3, F_3 and F_5. The forces are forming a closed polygon in the first figure, hence they are in equilibrium. In the second figure, the system is not in equilibrium, and the closing side, shown by dotted line, denotes the Resultant R of the force system.

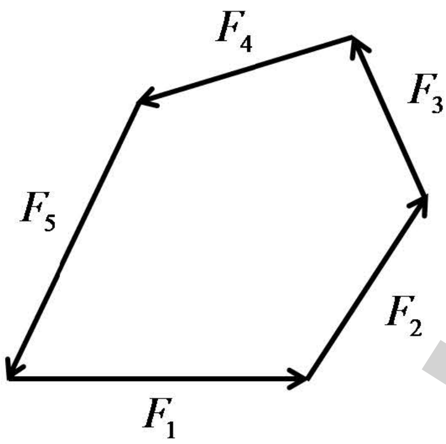

Figure 1.2

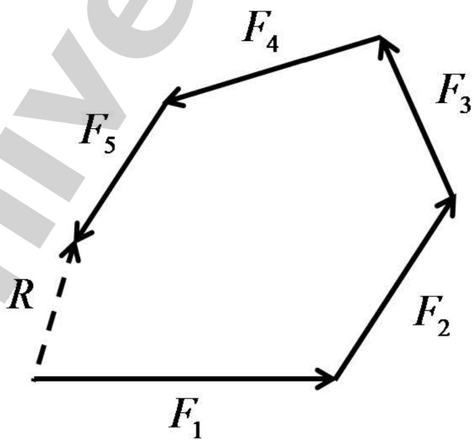

Figure 1.3

PROCEDURE:

1. Set up the apparatus provided after measuring and recording the weights of the pans.
2. Put different weights on the pan (W_1, W_2, W_3, W_4 and W_5) and let the system come to rest and then note their values.
3. Now, fix a sheet of paper on the drawing board and mark the central point (point where the strings meet and the directions of the string with pencil.
4. Remove the paper from the drawing board and draw the lines of actions of the forces.
5. Draw the force polygon by representing W_1, W_2, W_3, W_4 and W_5 in magnitude and direction.
6. The polygon may not be closed. The error (unclosed distance of the polygon) is due to error in experimentation and the friction in various moving parts.
7. Repeat the procedure 4 times and complete the experiment.

DATA PROVIDED:

The weight of the Pan

TABULATION OF RESULTS:

Observation Number	Weights in different pans (gm)				Resultant (Error) (gm)	
	W_1	W_2	W_3	W_4	Analytical Method	Graphical Method
1						
2						
3						
4						

CALCULATIONS:

For each observation, first do the Analytical Calculation, and then find the result using Graphical Method. For graphical method, draw one Space Diagram and one Vector Diagram. Do mention the Scale for the Vector Diagram. Do attach the Sheet of Paper, on which the experiment is performed, with this journal.

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EXPERIMENT NO. : 02

NAME OF THE EXPERIMENT: Experiments on friction: Determination of coefficient of friction.

OBJECTIVE:

Experimental Computation of Co-Efficient of Friction between an Inclined Plane (Glass) and Trolley (Iron).

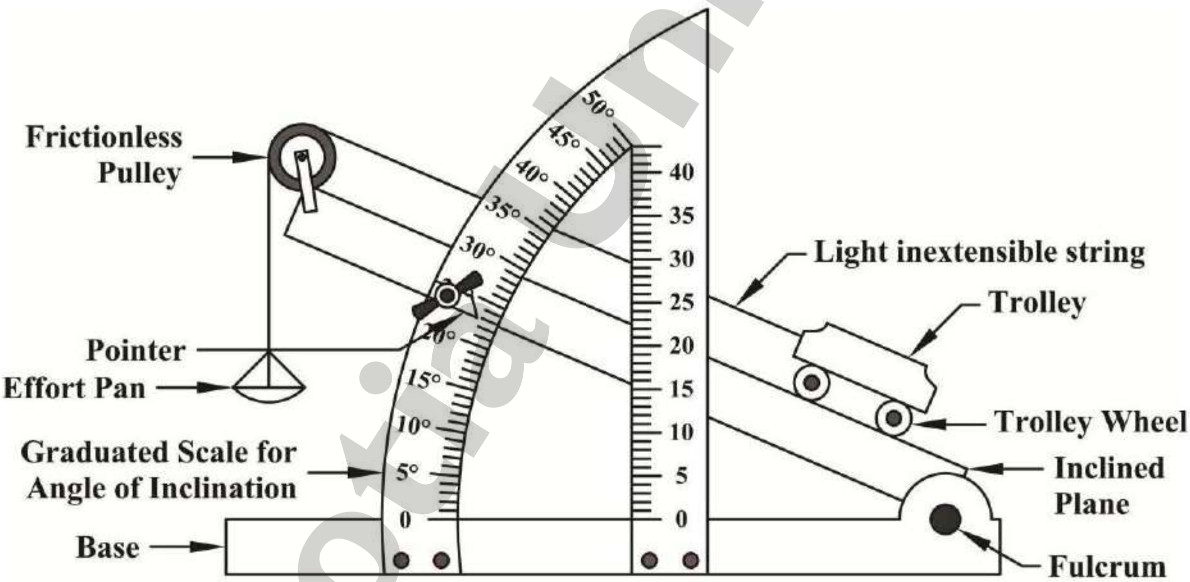
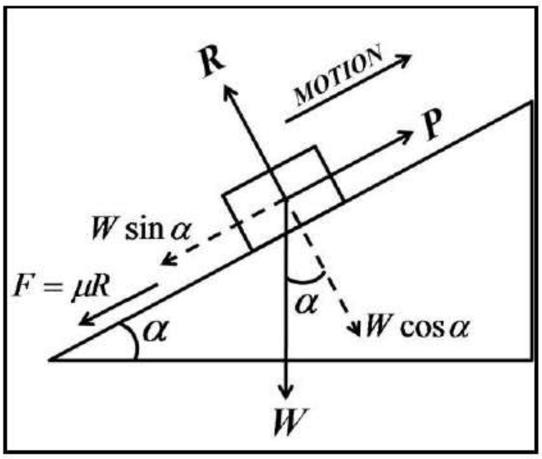


Figure 3.1: Labeled diagram of the apparatus

THEORY:



If, α = Angle of inclination of the plane with the horizontal at which the trolley moves with a minimum uniform speed up the plane.

W = Load on the slider

P = Force which pulls the trolley up with uniform movement

R = Normal Reaction

F = Frictional forces acting against the movement

From the Free Body Diagram, for equilibrium

Resolving along the plane $P = \mu R + W \sin\alpha$ 1

Perpendicular tothe plane $R - W \cos\alpha = 0$ 2

From 1 and 2 , $\mu = P\ W\ \cos\alpha - \tan\alpha$

DESCRIPTION OF APPARATUS:

(1) Inclined plane, (2) Trolley, and (3) Spirit level and Weights.

Figure 3.2: Experimental setup in the lab

PROCEDURE:

(1) Level the plane with a sprit level and set the pointer at zero.

(2) Put suitable load on the pan and adjust the angle of plane so that the trolley moves with uniform speed up the plane.

(3) Note the value of W, P and α.

(4) Repeat the experiment for different value of W, P and α.

(5) Calculate value of μ for each reading.

(6) Find the average of μ.

OBSERVATION TABLE:

Observation number	W (gm)	P (gm)	α (degree)	μ	Average μ
1.(a)					
1.(b)					
2.(a)					
2.(b)					
3.(a)					
3.(b)					

Note: (a) Reading of W without weight on the slider.

(b) Reading of W with weights on the slider.

EXPERIMENT NO. : 03

NAME OF THE EXPERIMENT: Determining spring stiffness under tension and compressive loads; Strain gauge-based strain/ deflection / force measurement of a cantilever beam.

Theory:

To measure the stiffness of a compression spring and compare it with theoretical values.

Apparatus:

- Compression of Spring Apparatus
- Hangers
- Weights

A spring is an object that can be deformed by a force and then return to its original shape after the force is removed. Its sole purpose is to store and utilize the energy. There are broadly two types of deformation: Elastic deformation: When the stress is removed the material returns to the dimension it had before the load was applied. The deformation is reversible, non-permanent. Plastic deformation: This occurs when a large stress is applied to a material. The stress is so large that when removed, the material does not spring back to its previous dimension. There is a permanent, irreversible deformation. The minimum value of the stress which produces plastic deformation is known as the elastic limit for the material. Any spring should be designed so that it only experience upto elastic deformation mostly for efficient working.

Hooke's law: Hooke's law states that the force (F) needed to extend or compress a spring by some distance x is proportional to that distance. That is, $F = kx$ Where F is the force, x is the length of extension/compression and k is a constant of proportionality known as the spring constant which is usually given in N/m. Hooke's law visual representation Material of spring: Steel alloys are the most commonly used spring materials. The most popular alloys include high carbon (such as the music wire used for guitar strings), oil-tempered low-carbon, chrome silicon, chrome vanadium, and stainless steel. Other metals that are sometimes used to make springs are beryllium copper alloy, phosphor bronze, and titanium. Rubber or urethane may be used for cylindrical, non-coil springs. Ceramic material has been developed for coiled springs in very high-temperature environments. One-directional glass fiber composite materials are being tested for possible use in springs. Types of springs according to loading conditions: Springs can be classified depending on how the load force is applied to them: Tension/extension spring The spring is designed to operate with a tension load, so the spring stretches as the load is applied to it.

Derivation of stiffness formula:

A spring may be defined as an elastic member whose primary function is to deflect or distort under the action of applied load; it recovers its original shape when load is released. Springs are energy absorbing units whose function is to store energy and to restore it slowly or rapidly depending on the particular application. In order to derive a necessary formula which governs the behavior of springs, consider a closed coiled spring subjected to an axial load W.

Let, W = axial load D = mean coil diameter d = diameter of spring wire N = number of active coils G = modulus of rigidity Δ = deflection of spring Φ = Angle of twist l = length of spring wire = πDN---(i)

For a helical spring, the partial derivative of the strain energy w.r.t. the applied load gives the deflection in the spring i.e. ∂U / ∂W = deflection.

Consider a helical compression spring made up of a circular wire and subjected to axial load W as shown in the figure above.

Strain Energy is given by: U = ½ T * Φ ----- (ii)

Whereas,

T= ½ W * D ----- (iii)

Φ = T l / JG ----- (iv)

(From Torsion formula) putting the values from eqs. # (i), (iii) & (iv) in eq. # (ii) and simplifying,

we get; T= 4 W2 D^3 N / d^4 G ----- (v)

Now applying the Castiglione' theorem by taking the partial derivative of the strain energy with respect to the applied load ∂U / ∂W = Δ = 8 WD^3 N / d^4 G ----- (vi)

W / Δ = d^4 G / 8 D^3 N Stiffness = K = d^4 G / 8 D^3 N

Experimental Procedure:

(i). Measure the diameter of wire and outer diameter of spring with the help of Vernier caliper.

(ii). Fit the compression spring in the spring support. To fit compression spring, remove the load hanger base by unscrewing the grip knob and base from the rod thread.

(iii). Loosen or remove the grip knob on the marker and pull the load hanger down until the top can be swung out from the slop

(iv). Withdraw the rod upward, insert the new spring and reverse the above procedure to return the apparatus to full working condition.

(v). Load the spring by 5N increments recording the change in length of the spring up to the greatest readable deflection or the max load of25N.

(vi). Record the spring dimensions vii. Repeat the same process for other springs and record the readings.

Observations and Calculations:

Wire diameter (d) = _______ (mm)

Spring O/D = _______ (mm)

Spring Length (l) = _______ (mm)

Number of active turns (N) = _______

Modulus of rigidity (G) = _____ (N/ mm^2)

$Stiffness = W / \Delta = d^4 G / 8N D^3$

Where d = Wire diameter

N = Number of turns

D = mean diameter of spring coil (O/D – d)

G = Modulus of rigidity (77 KN/ mm2 for spring steels)

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EXPERIMENT NO. : 04

NAME OF THE EXPERIMENT: Hardness Tests: Rockwell

Theory:

Rockwell hardness test is one of the static hardness testing methods using indentation depth as a measuring criterion. Basically, two types of indenter are used; one Diamond spheroconical (Brale) indenter with an angle of 120 O and a spherical tip of 0.2mm; second is steel ball indenter with diameters as 1/16, 1/8, 1/4, ½ inches. Rockwell Test works on the principle of major and minor load where we first apply a minor load (10 kg for regular test and 3 kg for superficial tests) to the sample that minimizes the surface preparation and minor defects; then a major load is applied for some dwell time which is removed after the dwell period and a differential depth (incremental depth) is observed. A dial is attached to the testing machine which gives the arbitrary hardness number during the whole process. To cover a different hardness range with varying penetration, the dial has different scales like A, B, C, D etc. on the basis of indenter and load used. The most general dial has Scale C&A for Brale Indenter and load 150 &60 respectively; a B scale for steel ball (1/16 inches diameter) and 100 kg load. The dial also consists of a minor pointer for minor load indications.

The formula applied to find the Rockwell hardness (RH) are:

Regular Rockwell hardness: $HR = 100 - h/0.002$ (For Brale indenter)

$HR = 130 - h/0.002$ (For Steel Ball indenter)

Where h is the incremental depth

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EXPERIMENT NO. : 05

NAME OF THE EXPERIMENT: Hardness Tests: Brinell

Theory:

Brinell test methods are defined in the following standards: ASTM E10 and ISO 6506. It is recommended that operators have a current copy of the relevant standards, which are updated regularly.

The Brinell hardness test consists of applying a constant load or force, usually between 187.5 and 3000Kgf, for a specified time (from 10 - 30 seconds) typically using a 2.5 or 10mm diameter tungsten carbide ball.

Brinell hardness testing is typically used in testing aluminum and copper alloys (at lower forces) and steels and cast irons at the higher force ranges. As the Brinell test uses relatively high loads, and therefore relatively large indent, it is frequently used to determine the hardness in circumstances where the overall material properties are being ascertained and local variations in hardness or surface conditions make other methods un- suitable, such as forgings or castings of large parts. Highly hardened steel or other materials are usually not tested by the Brinell method.

Due to the wide number of ball sizes and loads available, it is possible to test a very wide range of hardness values using the Brinell method. This is constrained by the indenter ball itself, which can become deformed by testing harder materials.

The formula applied to find the Brinell hardness (BHN) are:

$$BHN = 2L / \pi D/2(D - \sqrt{(D2 - d2)})$$

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EXPERIMENT NO. : 06

NAME OF THE EXPERIMENT: Tension test and compression test of ductile and brittle materials: stress-strain diagram, determination of yield strength, ultimate strength, modulus of elasticity, percentage elongation and percentage reduction in areas, observation of fractured surfaces.

Theory:

Tensile tests are used to determine how materials will behave under tension load. In a simple tensile test, a sample is typically pulled to its breaking point to determine the ultimate tensile strength of the material. The amount of force (F) applied to the sample and the elongation (ΔL) of the sample are measured throughout the test. Material properties are often expressed in terms of stress (force per unit area, σ) and strain (percent change in length, ε). To obtain stress, the force measurements are divided by the sample's cross-sectional area ($\sigma = F/A$). Strain measurements are obtained by dividing the change in length by the initial length of the sample ($\varepsilon = \Delta L/L$). These values are then presented on an XY plot called a stress-strain curve. Testing and measuring procedures vary based on the material being tested and its intended application. The idea of a tensile test is to place a sample of a material between two fixtures called 'grips' which clamp the material. The material has known dimensions, like length and cross-sectional area. The tensile testing instrument then begins to apply weight to the material gripped at one end while the other end is fixed. The load is continuously increased, while at the same time, the in-built controller measures the change in length of the sample and simultaneously generates the stress-strain plot.

APPARATUS

- Universal test machine frame
- Load cell
- Controller and/or indicator
- Proper grips
- Rubber bands
- Extensometer
- Specimen samples (dog-bone shaped)

The universal test machine frame provides the structure and rigidity needed to pull the sample apart at the desired rate. Frames are available in both electromechanical and servo-hydraulic configurations with a wide range of capacities. The frame used must be able to withstand the amount of force needed to test the sample. Load cells measure the amount of force being applied to the sample. Depending on the system setup, a controller or an indicator is needed. Controllers, as the name implies, control how the test frame behaves during testing, including test speed and displacement. Indicators capture and display the test data but do not control the machine. There are many types of grips and fixtures available for tension testing. Different materials require different fixturing to properly hold them. For example, a sample made of metal requires different grips than rubber due to how the materials behave as tensile forces are applied. Selecting the correct grips is crucial in achieving accurate results.

PROCEDURE :

Universal Tensile Testing Machine is used for this experiment. A material is gripped at both ends by an apparatus, which slowly pulls lengthwise on the piece until it fractures. The pulling force is called a load, which is plotted against the material length change, or displacement. The load is converted to a stress value and the displacement is converted to a strain value. The gauge width, thickness, and length of each sample was measured with a pair of Vernier calipers before the experiments were performed. The sample is placed at the bottom grip. While still holding it vertically with one hand, the another hand is used to turn its handle in the closing direction as tightly as possible. It is important that the specimens are tightly gripped onto the specimen grips to prevent slipping, which will otherwise result in experimental errors. Also, the specimen must be vertically aligned, if not a torsional force, rather than axial force, will result. An extensometer is attached carefully to monitor strain.A crosshead speed of 1mm/min is maintained. The experiment is then initiated with the help of the software, and the load is gradually applied. Simultaneously, the stress-strain curve appears on the screen. A plot of Force (kN) versus Stroke (mm) will be generated in real-time during the experiment. The experiment stops with failure of the specimen.

Result & Discussion:

Draw a Strain- Strain diagram on available data and show the variation with the theoretical graph.

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EXPERIMENT NO. : 07

NAME OF THE EXPERIMENT: Torsion test

Theory:

Torsion tests twist a material or test component to a specified degree, with a specified force, or until the material fails in torsion. The twisting force of a torsion test is applied to the test sample by anchoring one end so that it cannot move or rotate and applying a moment to the other end so that the sample is rotated about its axis. The rotating moment may also be applied to both ends of the sample but the ends must be rotated in opposite directions. The forces and mechanics found in this test are similar to those found in a piece of string that has one end held in a hand and the other end twisted by the other.

The purpose of a torsion test is to determine the behavior a material or test sample exhibits when twisted or under torsional forces as a result of applied moments that cause shear stress about the axis. Measurable values include: the modulus of elasticity in shear, yield shear strength, torsional fatigue life, ductility, ultimate shear strength, and modulus of rupture in shear. These values are similar but not the same as those measured by a tensile test and are important in manufacturing as they may be used to simulate the service conditions, check the product's quality and design, and ensure that it was manufactured correctly.

TYPES OF TORSION TESTS:
Types of torsion testing vary from product to product but can usually be classified as:

Axial-Torsion: Applying both axial (tension or compression) and torsional forces to the test specimen.
Torsion Only: Applying only torsional loads to the test specimen
Failure Testing: Twisting the product, component, or specimen until failure. Failure can be classified as either a physical break or a kink/defect in the specimen.
Proof Testing: Applying a torsional load and holding this torque load for a fixed amount of time.

Calculation:

Force acts at a radius r then the torque produced is

$$dT = \tau \times 2\pi r^2 dr$$

Since $\frac{G\theta \times r}{L} = \tau$

$$dT = \frac{G\theta \times r}{L} \pi \times 2r^2 dr$$

$$T = \int_0^R 2\pi \frac{G\theta}{L} r^3 \, dr$$

$$T = 2\pi \frac{G\theta}{L} \int_0^R r^3 dr$$

$$T = 2\pi \frac{G\theta}{L} \frac{R^4}{4}$$

Now substituting $R = \frac{d}{2}; \qquad T = \frac{G\theta}{L}\left[\frac{\pi d^4}{32}\right]$

Then,

$$T = \frac{G\theta}{L} J$$

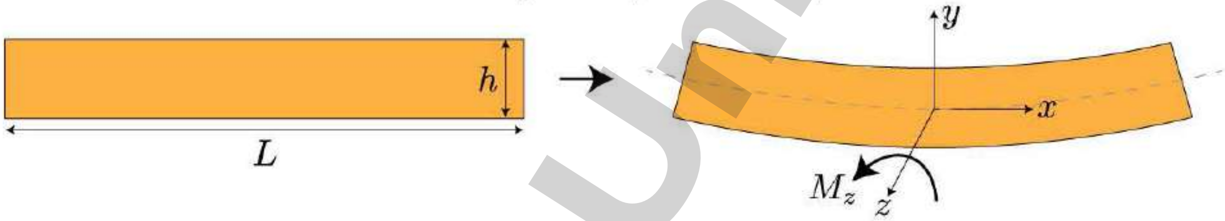
$$\mathbf{\frac{T}{J} = \frac{G\theta}{L} = \frac{\tau}{r}}$$

EXPERIMENT NO. : 08

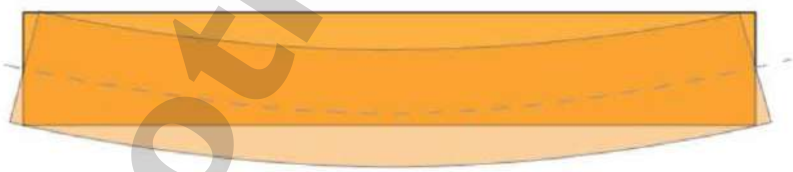
NAME OF THE EXPERIMENT: Determination of Bending stresses

Theory:

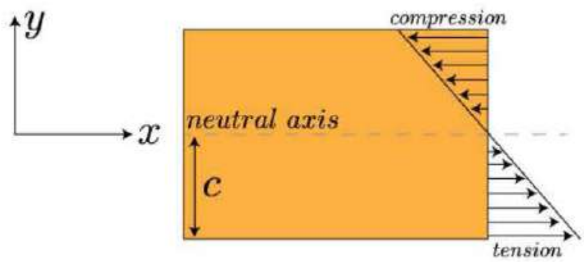
In many ways, bending and torsion are pretty similar. Bending results from a couple, or a **bending moment** *M*, that is applied. Just like torsion, in pure bending there is an axis within the material where the stress and strain are zero. This is referred to as the **neutral axis**. And, just like torsion, the stress is no longer uniform over the cross section of the structure – it varies. Let's start by looking at how a moment about the z-axis bends a structure. In this case, we won't limit ourselves to circular cross sections – in the figure below, we'll consider a prismatic cross section.



Before we delve into the mathematics behind bending, let's try to get a feel for it conceptually. Maybe the be way to see what's happening is to overlay the bent beam on top of the original, straight beam.



What you can notice now is that the bottom surface of the beam got longer in length, while the to surface of the beam got shorter in length. Also, along the center of the beam, the length didn't change at all – corresponding to the neutral axis. To restate this is the language of this class, we can say that the bottom surface is under tension, while the top surface is under compression. Something that is a little more subtle, but can still be observed from the above overlaid image, is that the displacement of the beam varies linearly from the top to the bottom – passing through zero at the neutral axis. Remember, this is exactly what we saw with torsion as well – the stress varied linearly from the center to the center. We can look at this stress distribution through the beam's cross section a bit more explicitly:



Now we can look for a mathematical relation between the applied moment and the stress within the beam. We already mentioned that beam deforms linearly from one edge to the other – this means the strain in the *x*-direction increases linearly with the distance along the *y*-axis (or, along the thickness of the beam). So, the strain will be at a maximum in tension at y = -c (since y=0 is at the neutral axis, in this case, the center of the beam), and will be at a maximum in compression at y=c. We can write that out mathematically like this:

$$\varepsilon_x = -\frac{y}{c}\varepsilon_{\max}$$

Now, this tells us something about the strain, what can we say about the maximum values of the stress? Well, let's start by multiplying both sides of the equation by *E*, Young's elastic modulus. Now our equation looks like:

$$\underbrace{E\varepsilon_x}_{\sigma_x} = -\frac{y}{c}\underbrace{E\varepsilon_{\max}}_{\sigma_{\max}}$$

Using Hooke's law, we can relate those quantities with braces under them to the stress in the *x*-direction and the maximum stress. Which gives us this equation for the stress in the *x*-direction:

$$\sigma_x = -\frac{y}{c}\sigma_{\max}$$

Our final step in this process is to understand how the bending moment relates to the stress. To do that, we recall that a moment is a force times a distance. If we can imagine only looking at a very small element within the beam, a differential element, then we can write that out mathematically as:

$$dM = y dF$$

Since we have differentials in our equation, we can determine the moment *M* acting over the cross-sectional area of the beam by integrating both sides of the equation. And, if we recall our definition of stress as being force per area, we can write:

$$M_z = \int_A y\ dF = \int_A y(\sigma_x dA) = \int_A y\left(\frac{y}{c}\sigma_{\max}\right) dA$$

$$M_z = \frac{\sigma_{\max}}{c}\int_A y^2 dA$$

The final term in the last equation – the integral over *y* squared – represents the second moment of area about the *z*-axis (because of how we have defined our coordinates). In Cartesian coordinates, this second moment of area is denoted by *I* (in cylindrical coordinates, remember, it was denoted by *J*). Now we can finally write out our equation for the maximum stress, and therefore the stress at any point along the *y*-axis, as:

$$\sigma_{\max} = \frac{cM_z}{I_z}$$

$$\sigma_x = -\frac{yM_z}{I_z}$$

It's important to note that the subscripts in this equation and direction along the cross section (here, it is measured along y) all will change depending on the nature of the problem, i.e. the direction of the moment – which axis is the beam bending about? We based our notation on the bent beam show in the first image of this lesson.

Remember at the beginning of the section when I mentioned that bending and torsion were actually quite similar? We actually see this very explicitly in the last equation. In both cases, the stress (normal for bending, and shear for torsion) is equal to a couple/moment (M for bending, and T for torsion) times the location along the cross section, because the stress isn't uniform along the cross section (with Cartesian coordinates for bending, and cylindrical coordinates for torsion), all divided by the second moment of area of the cross section.