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Use of MDSolids to Learn the Mechanical Behavior of Materials

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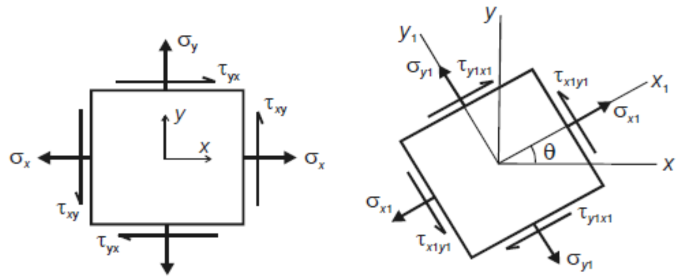
Abstract: Teaching abstract concepts in Physics through Mathematics requires innovative techniques. The concept of stress in two dimensions is difficult to grasp especially because the state of stress at a point in a material in two dimensional state of stress is governed by stress transformation equations which are difficult to visualize. MDSolids is a freeware which helps the student to visualize the concept of "State of Stress" by calculating the stress values and also displaying the results graphically using Mohr's Circle. In this paper, the use of MDSolids for teaching concepts in state of stress in 2-dimensions are presented and discussed.

Index Terms: Stress, State of Stress and Mohr's Circle.

1. Introduction

Students at the undergraduate level would have no difficulty in understanding simple stress – tensile or compressive on simple shapes like rods or bars. When an object is subject to two dimensional state of stress, the three values - normal stresses, σ_x, σ_y, along the X and Y directions and the shear stress τ_{xy} in the XY plane describe the state of stress completely. However, the values depend on the orientation of the chosen axes. A rotation of the axes causes changes in the values of σ_x, σ_y, and τ_{xy} though the state of stress remains unaltered. Thus an infinite set of the three values exist which specify the same state of stress for different orientations of the axes.

The transformation of the values of σ_x, σ_y, and τ_{xy} to the new set of axes x_1 and y_1 namely σ_{x1}, σ_{y1}, and τ_{x1y1}which are inclined at an angle of θ to the original axes, are governed by the well known rules of tensor transformation and these equations of transformation are given below:

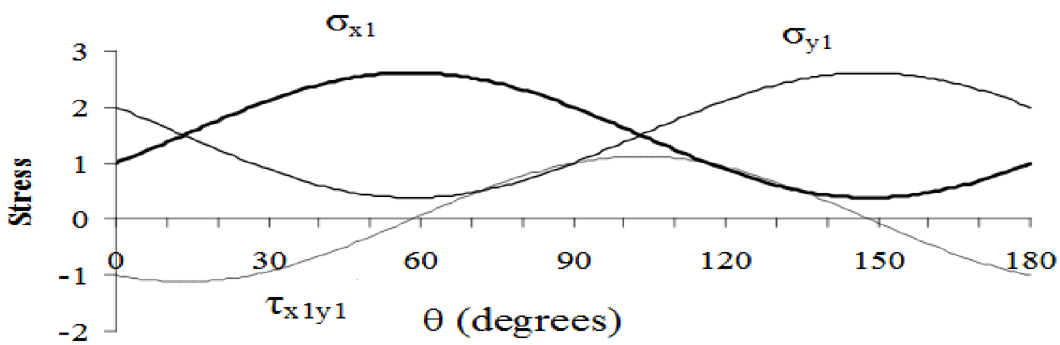


$$\sigma_{x1} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x - \sigma_y}{2}\cos 2\theta + \tau_{xy}\sin 2\theta \quad (1)$$

$$\tau_{x1y1} = -\frac{(\sigma_x - \sigma_y)}{2}\sin 2\theta + \tau_{xy}\cos 2\theta \quad (2)$$

These equations 1 and 2 can be used to calculate a new set of values σ_{x1}, σ_{y1}, and τ_{x1y1} for any new position of the axes for various values of θ ranging from 0° to 180°. The values are repeated from 180° to 360° due to the symmetry of the equations. Equations involve the expression 2θ which implies that the values are repeated every 180°.

The variation of σ_{x1}, σ_{y1}, and τ_{x1y1} with θ is plotted in the figure below assuming typical values.
For any given value of θ the set of values of σ_{x1}, σ_{y1}, and τ_{x1y1} can be determined and they all represent the same state of stress. The following graph can be summarized using the well known Construction, known as Mohr's circle.



The above equations 1 and 2 can be rewritten in the following way.

$$\sigma_{x1} - \frac{\sigma_x + \sigma_y}{2} = \frac{\sigma_x - \sigma_y}{2} Cos2\theta + \tau_{xy} Sin2\theta \quad (3)$$

$$\tau_{x1y1} = -\frac{(\sigma_x - \sigma_y)}{2} Sin2\theta + \tau_{xy} Cos2\theta \quad (4)$$

Eliminating θ from the above equations 3 and 4 we get

$$\left(\sigma_{x1} - \frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{x1y1}{}^2 = \left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}{}^2$$

The Right Hand Side of the above equation is a fixed positive quantity and can be replaced by the term R^2 thus yielding

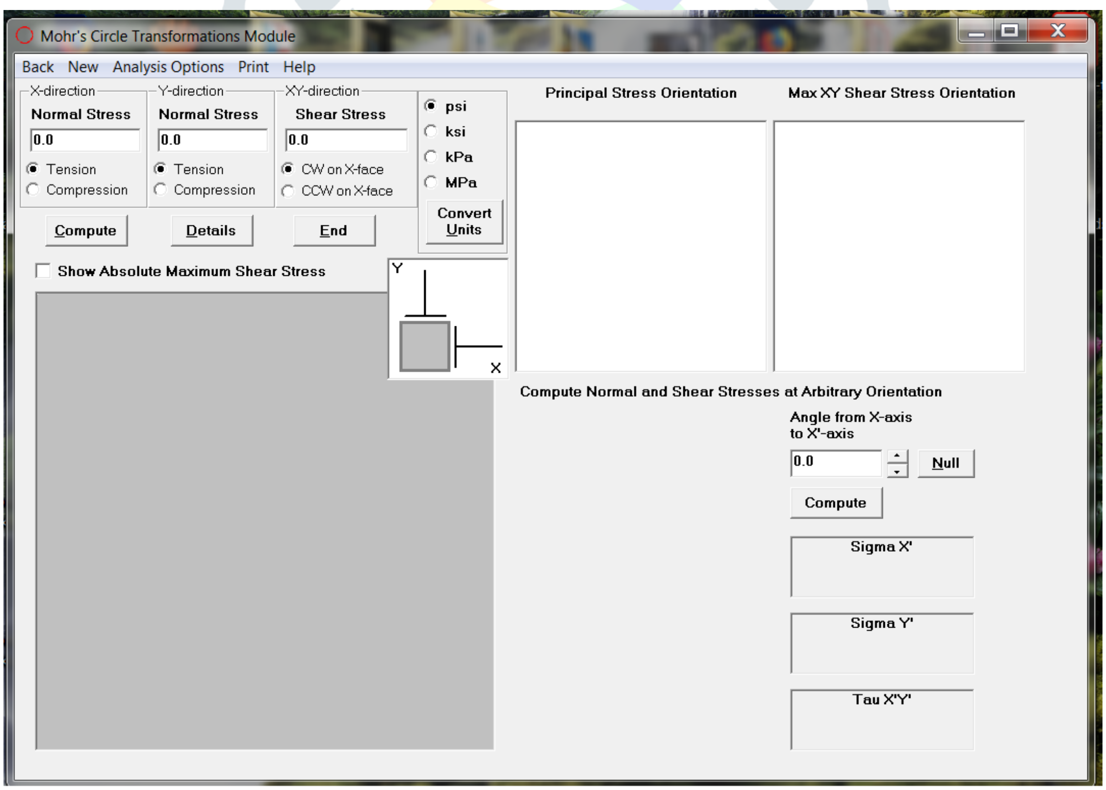
$$\left(\sigma_{x1} - \frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{x1y1}{}^2 = R^2 \qquad (5)$$

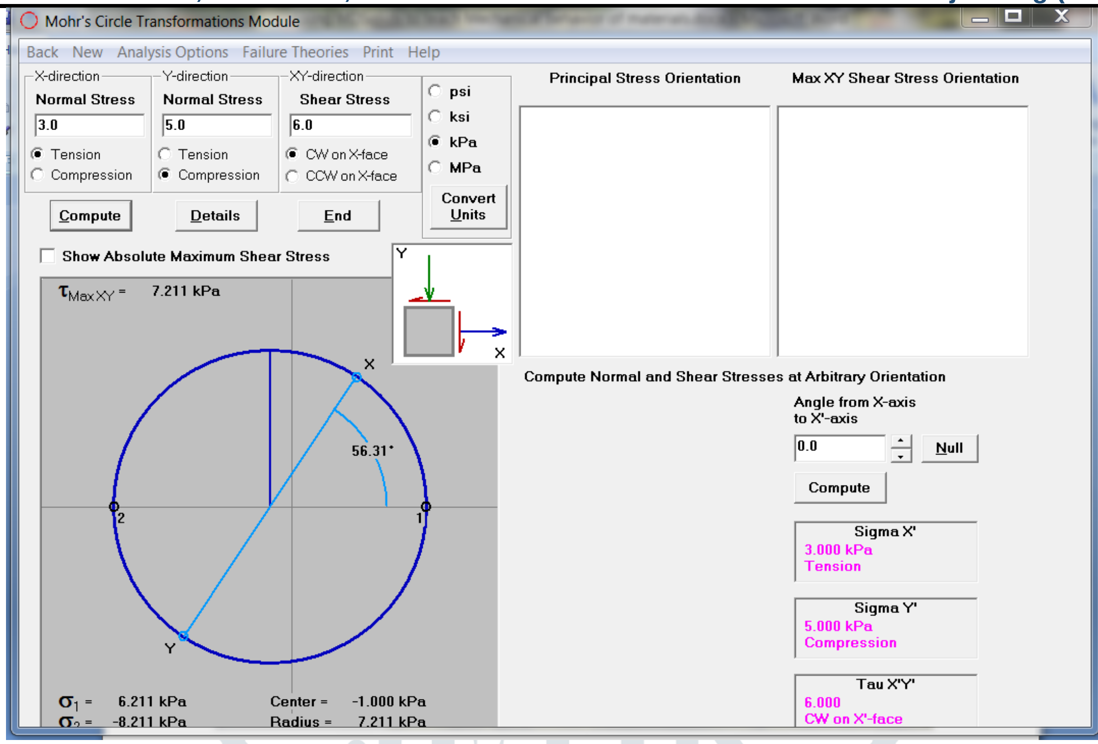
The above equation 5 represents a circle and can be drawn using standard rules which are found in standard text books of mechanics of materials.

2. MDSolids

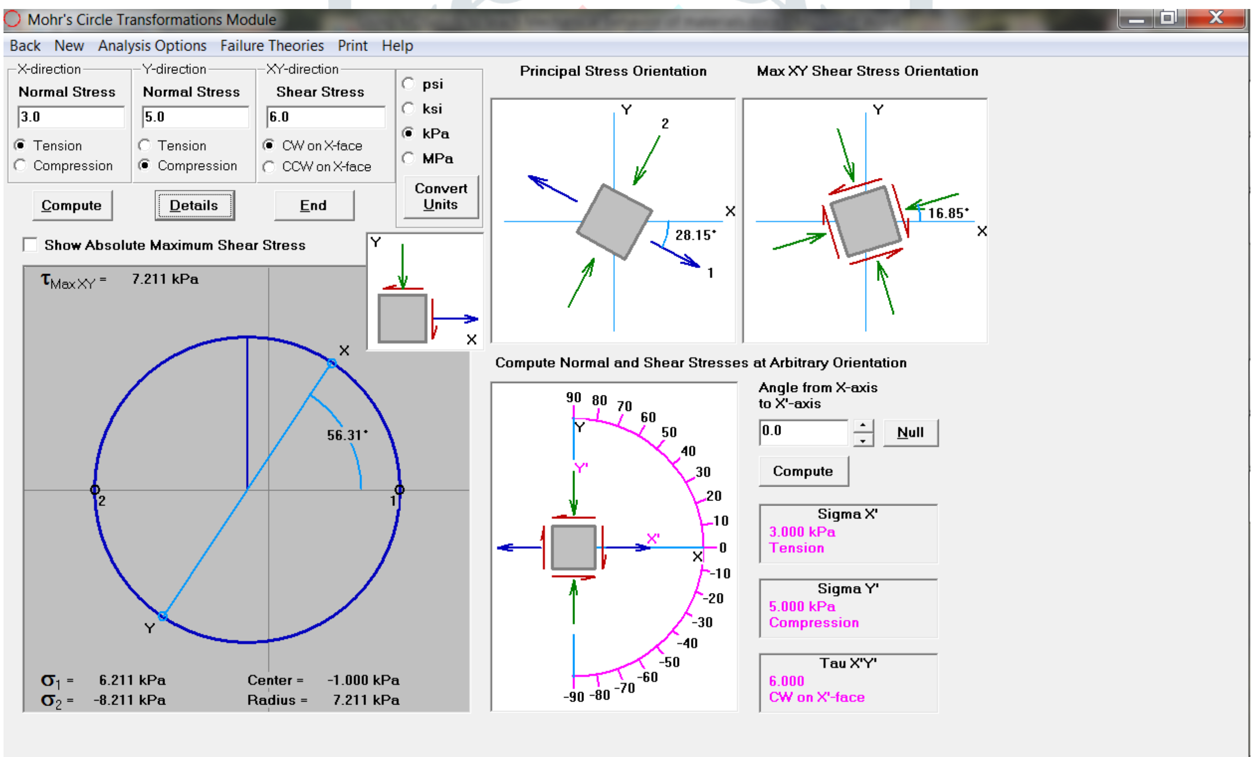
MDSolids is a freeware which was downloaded from the internet. The earlier version used here is capable of analyzing a variety of problems in stress analysis. In this paper the method of using Mohr's Circle is discussed.

The initial screen is given below. Inserting known values of σ_x, σ_y, and τ_{xy} in the space provided and pressing the 'compute' button gives the Mohr's Circle for the given state of stress.





Pressing the "Details" button gives the following screen which presents details pertaining to principal stresses, maximum shear stress and their inclinations.



3. Conclusions:

We found the above software very helpful for understanding Mohr's Circle. The variation of Mohr's circle with different values of stresses helps us to understand the mechanical behavior of materials and this can be coupled with failure criteria to predict the failure of the material.

References:

1. http://web.mst.edu/~mdsolids/download.htm
2. Mechanics of materials , 4 thEdision by Dimothy A. Philpot John Wiley, 2017.