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Mohrs circle is a geometric representation of plane (2D) stress transformation and allows us to quickly visualize how the normal () and shear () stress components change as their plane changes orientation.German civil engineer Otto Mohrdeveloped this method from the good ol stress transformation equations. Recall:If we remove by squaring both sides of each equation and then add the two equations together, we get:After defining avg and R, we can modify Equation 3 to get Equation 4, which is the equation for a circle with center (avg,0) and radius R.Sign ConventionThe sign convention for normal stress () isthattension is positiveandcompression is negative. Shear stress ()is illustrated below. Geotechnical engineers may use the opposite sign conventions, because they mostly deal with compressive stress.Mohrs circle is drawn with normal stress () plotted on the abscissa (horizontal axis) and shear stress () plotted on the ordinate (vertical axis). Normal stress () is positive to the right, and shear stress () is positive downward.Pole MethodMost mechanics of materials textbooks prefer using the Double Angle Methodto draw Mohrs circles. The general idea of this approach is that angles between radial lines in the Mohrs circle are twice the actual angles between the real planes. In other words, a 40 rotation on the plane corresponds to an 80 rotation on the circlein the same direction.We prefer thePole Method, which is based on a unique point on the Mohrs circle known as thepole. This pole is unique, because any straight line drawn through the pole intersects the Mohrs circleat a point representing the state of stress on a plane with the same orientation as the line. As shown in the figure above, a line drawn through the pole and some stress point (,) on the circle isexactly parallel to the plane with corresponding and , making this approach very intuitive! Let us illustrate how the pole method works.To draw a Mohrs circle, we need to know the plane state of stresses for an element. Consider this:1. Plot the StressesImmediately, we know the two points that form the diameter of the circle,(x,xy) = (80,40) and(y,yx) = (20,-40). (If you are asking why yxis -40, remember the sign convention for shear stress!) The center of the circle is the halfway point between xand y, or avg.2. Locate the PoleDraw a straight line from one of the known stress points on the circle (,) in the direction of the plane on which (,) acts. Starting at point (80,40), a line is drawn parallel to the plane on which (80,40) acts. This is represented by the vertical dotted green line in the figure below. Starting at point (20,-40), a second line is drawn parallel to the plane on which (20,-40) acts. This is represented by the horizontal dotted pink line in the same figure below. The pole is at the intersection of these dotted lines on the circle. Note that there is only ONE pole!3. Find Transformed Stresses (e.g. 30 CCW Rotation)To find other states of stresses, we start drawing the lines from the pole instead of a known stress point (,). This is the general procedure:Draw a line from the pole in the direction of orientation of the transformed plane.The point where this line intersects the circle represents the state of stress acting on that plane.Let us assume a 30 counterclockwise (CCW) rotation of the element. Starting at the pole, to find the transformed counterpart of (20,-40), we draw a new line that is30 CCW from the existing dotted pink line. The transformed stresses on this plane is where the new pink line intersects the circle. Similarly,to find the transformed counterpart of (80,40), we draw a new line from the pole that is30 CCW from the existing dotted green line.The transformed stresses on this plane is where the new green line intersects the circle. Staying consistent with the rules, the new lines are parallel to their corresponding planes. The transformed stresses are:To get these transformed stress values by hand, we would need a protractor to measure the angle and a ruler to connect the pole to the point of intersection on the circle. This can seem like an elaborate process, and it goes to show that hand-calculating plane stress transformations via Mohrs circle is only an approximate method. To get the exact transformed stress values, we can use thegood ol stress transformation equations.4. Check with Analytical MethodUsing the the stress transformation equations (Equations 1 and 2):Because the center of the circle, or avg, is the same (the circle does NOT move!), we can find y.5. Principal StressesPrincipal stresses act on planes where = 0. The larger principal stress is called themajor principal stress, and the smaller principal stress is called theminor principal stress.Similar to finding transformed stresses, we draw lines from the pole to where = 0, or the two x-intercepts on the circle. The major and minor principal stresses are 100MPa and 0MPa, respectively. The angle, or the rotation required to reach zero shear stress on the plane, is measured between either pair of the original (dotted) line and the new line connecting the pole to the x-intercept.Square vs. TriangleSome textbooks show stress elements as squares (like in this article), while others show them as triangles. They are two different representations of the same element, because the triangles are just corner cutouts from the square, as shown below by the two a-a and b-b sections.The advantage of the triangular representation is that we can visually identify the transformed stresses on the hypotenuse. However, since we are dealing with two transformed normal stresses (x and y), we still need two triangles to give complete representation of plane stresses. In the figure below, A is the sectioned area (length of hypotenuse depth of 3D stress block).TL;DRStresses change as the plane on which they act changes orientation. Mohrs circle maps these changes.Keeping a consistent sign convention is important.In Pole Method, things are determined in this order:(,) pole(,).To determine anytransformed plane state of stress (,), we ALWAYS start at the pole and draw a line parallel to the plane. The point of intersection on the circle is(,). Mohrs circle is the graphical method for finding the stresses at different oblique planes and this method requires less time and calculations than the analytical method to find stresses at different oblique planes.In this article, were going to discuss:What is mohrs circle?Mohrs circle uses and significances:Sign conventions for mohrs circle:How to draw mohrs circle?What are the principal stresses on a mohrs circle?Maximum shear stress from mohrs circle:Stresses at the oblique plane by using mohrs circle:Mohrs circle for different cases:8.1. Case I: Mohrs circle for pure shear stresses:-8.2. Case II: Mohrs circle for only normal stresses:-8.3. Case III: Mohrs circle for zero shear stresses and same normal stresses:-Mohrs circle example:Mohrs circle represents the graphical form of the transformation law. The mohrs circle is the easiest method for finding the principal stresses and normal stresses at various planes.Each point on the circumference of mohrs circle represents a certain plane which gives the value of normal stress and shear stress at that plane.Therefore the value of normal stress along with the shear stress indicates the particular plane of the object.The mohrs circle can be drawn for the biaxial stresses and also for the triaxial stresses.The mohrs circle method has the following uses and significances:-1] By drawing a single mohrs circle, we can easily find normal and shear stresses at various inclined oblique planes which is difficult by using the analytical method.2] By using mohrs circle, it is easy to calculate principal stresses, maximum shear stress, resultant stress, principal plane angle, etc.3] The method of mohrs circle is a simple and faster method than the analytical method.For normal stress:-Tensile stress is considered as +ve and compressive stress is considered as -ve.For shear stress:-1] If shear stresses are of clockwise nature then it is considered as positive.2] If shear stress is anticlockwise in nature then it is considered as negative.For oblique angle:-1] If the angle is measured in a clockwise direction from the reference plane then it is considered as positive.2] If the angle is measured in an anticlockwise direction from the reference plane then it is considered as negative.How to identify the reference plane?The plane which has maximum axial stress is considered as a reference plane.If `\sigma_{x}` > `\sigma_{y}` then vertical plane is considered as reference plane.If `\sigma_{y}` > `\sigma_{x}` then horizontal plane is considered as reference plane.Consider an example with stresses as shown below with `\sigma_{x}` > `\sigma_{y}`.The plane A shown by red color is the reference plane (as `\sigma_{x}` > `\sigma_{y}`) at 0. The plane B shown by green color is the horizontal plane at 90 clockwise.The steps to draw the Mohrs circle from the normal and shear stresses are as follows:-Step 1] Draw, the vertical and horizontal axis with normal stress (`\sigma_{n}`) as abscissa and shear stress (`\tau`) as ordinate with the suitable scale.Step 2] Locate plane A on `\sigma_{n}` `\tau` plot.First locate `\sigma_{x}` on `\sigma_{n}` axis. If the `\sigma_{x}` is tensile then locate it on positive `\sigma_{n}` axis from origin. And if the `\sigma_{x}` is compressive then locate it on negative `\sigma_{n}` axis from origin.From the endpoint of the `\sigma_{x}`, draw `\tau_{xy}` in the vertical direction. If the nature of `\tau_{xy}` is clockwise then draw it in positive `\tau` direction and if the nature of `\tau_{xy}` is anticlockwise then draw it in negative `\tau` direction.For the given example, plane A is located as A (+ `\sigma_{x}`, + `\tau_{xy}`), as shown in the below figure.Step 3] Locate plane B on `\sigma_{n}` `\tau` plot.Similarly, plot the plane B on `\sigma_{n}` `\tau` plot.For the given example, plane B is located as B(`\sigma_{y}`, -`\tau_{yx}`).Step 4] Join points A and B.Step 5] Draw a circle with radius AC or BC with C as the center of the circle.In this figure, point A indicates plane A while point B indicates plane B.The principal stresses are the normal stresses when the value of shear stress (`\tau`) is zero. On the mohrs circle, there are two points that are F and G.Therefore the major principal stress is,`\mathbf{\sigma_{1}}` = Distance OFAnd the minor principal stress is,`\mathbf{\sigma_{2}}` = Distance OGThe magnitude of maximum shear stress (`\tau_{max}`) is equal to the radius of mohrs circle in the verticle direction.To find maximum shear stress from mohrs circle, follow the steps given below:-1] Draw a perpendicular line to the `\sigma_{n}` axis from the center C of mohrs circle.2] Find the value of shear stress at the point where the perpendicular line cuts the mohrs circle.Or by using principal stresses, the maximum shear stress can be calculated as,`\tau_{\text{max}}` = `\frac{\sigma_{1}-\sigma_{2}}{2}`In the mohrs circle, the angle of the oblique plane is double of actual angle.In the stress diagram, if the angle of the oblique plane () is measured anticlockwise from the reference plane then in mohrs circle diagram the oblique plane should be drawn with an angle (2) measured anticlockwise from a reference plane.In the stress diagram, if the angle of an oblique plane () is measured clockwise from the reference plane then in mohrs diagram, the oblique plane should be drawn with angle (2) measured clockwise from a reference line.The example of the oblique plane at a clockwise angle () is shown below.Now after drawing the oblique plane on mohrs circle, draw perpendicular lines on the `\sigma_{n}` and `\tau` axis to get the values of normal stress and shear stress at this oblique angle.Here `\sigma_{o}` and `\tau_{o}` are normal stress and shear stress for the oblique plane at angle .Following are the different special cases of the mohrs circle:-For the object subjected to only shear stresses (pure shear), the stress diagram is drawn below,For zero normal stresses, plane A and plane B has the following coordinates on Mohrs circleA = (0, `\tau_{xy}`)B = (0, -`\tau_{yx}`)The point A and B can be plotted on `\sigma_{n}` graph as follows,The line AB intersects the `\sigma_{n}` axis at point C. Thus draw a circle with a radius of AC and C as the center of the circle.In this case, the relation between principal stresses is given by,`\mathbf{\sigma_{1} = -\sigma_{2}}`Case II: Mohrs circle for only normal stresses:-For the object subjected to only normal stresses and zero shear stresses (`\tau_{xy} = \tau_{yx}` = 0), the stress diagram is drawn below,For zero shear stresses, plane A and plane B has the following coordinates on Mohrs circleA = (`\sigma_{x}`, 0)B = (`\sigma_{y}`,0)The point A and B can be plotted on `\sigma_{n}` graph as follows,Divide the line AB and find the center of Mohrs circle. Draw a circle with C as the center and AC as the radius of Mohrs circle.In this case, the maximum shear stress is given by,`\mathbf{\tau_{max} = frac{\sigma_{x}-\sigma_{y}}{2}}`Case III: Mohrs circle for zero shear stresses and same normal stresses:-If the normal stresses `\sigma_{x}` and `\sigma_{y}` are equal (`\sigma_{x} = \sigma_{y}`) and there is no shear force is acting on the object, (`\tau_{xy}` = `\tau_{yx}` = 0) then in this situation both plane A and B lies on same location.Therefore the diameter of mohrs circle becomes zero and in this situation, the mohrs circle becomes a point.1] For the given stress condition, find the principal stresses by using mohrs circle method.Given:`\sigma_{x}` = 100 Mpa`\sigma_{y}` = 40 MPa`\tau_{xy}` = 20 MPa (Clockwise)`\tau_{yx}` = -20 MPa (Anticlockwise) Mohrs circle is a graphical representation of the stress state at a point within a body, which is used to visualize and analyze the state of stress at that point. It is named after the German engineer Johann Mohr, who developed the concept in the early 1800s. To construct a Mohrs circle, the normal and shear stresses at a point in a body are plotted on a graph, with the normal stress plotted on the horizontal axis and the shear stress plotted on the vertical axis. The stresses are plotted at different angles, with the angle between the stress and the horizontal axis representing the direction of the stress. The intersection of the plotted stresses forms a circle, which represents the state of stress at that point. Mohrs circle can be used to determine the maximum and minimum principal stresses at a point in a body, as well as the orientation of those stresses. It is a useful tool for understanding the behavior of materials under different loading conditions, and is widely used in mechanical engineering, civil engineering, and materials science. The formula for the Mohr circle is used to represent the stress at a point in a two-dimensional plane. It is defined as follows: For plane stress: x = (sigma_x + sigma_y)/2 y = (sigma_x sigma_y)/2 r = sqrt(x^2 + y^2) theta = atan(y/x) Where sigma_x and sigma_y are the normal stresses in the x and y directions, x and y are the coordinates of the point on the Mohr circle, r is the radius of the circle, and theta is the angle of the point with respect to the x-axis. There are several equations that are used in the construction of Mohrs circle. Here are a few of the most common ones: The equation for the radius of the circle is: r = ((s1^2 s2^2)/2 + s3^2) The equation for the center of the circle is: x = (s1 + s2)/2, y = s3/2 The equation for the angle of the principal stress is: tan(2) = 2s3/(s1 s2) The equation for the maximum shear stress is: tmax = r y The equation for the minimum shear stress is: tmin = r + y Note: In these equations, s1, s2, and s3 are the principal stresses and r, x, y, and are the parameters of the Mohrs circle. To construct a Mohrs circle for plane stress, the following steps can be followed: Determine the normal stress components (x and y) and shear stress (xy) at the point of interest. Plot the normal stress components on the x and y axes, and the shear stress on the z axis. Draw a circle with the shear stress as the radius and the normal stress components as the center. Plot the stress states at different loading conditions as points on the circle. Analyze the stress states by examining the position and orientation of the points on the circle. The Mohrs circle is a useful tool for understanding and analyzing the stress states in two-dimensional systems, and it can be used to predict the behavior of materials under various loading conditions. Mohrs circle is a graphical method for representing the state of stress at a point in a material. It is a tool that is commonly used in mechanics of materials to analyze and understand the behavior of materials under load. Mohrs circle is based on the concept of stress transformation, which is the idea that the stress state at a point in a material can be represented by a combination of normal stresses (tensile or compressive stresses) and shear stresses. The normal stresses are represented by the x-axis and y-axis of the circle, and the shear stresses are represented by the radius of the circle. To construct a Mohrs circle, the normal and shear stresses at a point in a material are plotted on a graph, and the resulting points are connected to form a circle. The center of the circle is located at the point where the normal stresses are equal, and the radius of the circle is equal to the maximum shear stress. Mohrs circle is a useful tool for analyzing the behavior of materials under different types of loading and for understanding the effect of stress on the strength and reliability of materials. It is commonly used in engineering design to predict the stress and strain distributions within a material and to optimize the performance and reliability of structures and components. Mohrs circle is a graphical tool used in mechanics of materials to represent the state of stress at a point within a body. It is used to determine the normal and shear stress at a point on the surface of a body under a given set of stresses. The circle is constructed by plotting the normal stress at a point on the x-axis and the shear stress on the y-axis. The radius of the circle represents the magnitude of the maximum shear stress at the point, and the center of the circle represents the mean normal stress. Mohrs circle is commonly used in the analysis of stress in beams, columns, and other structural elements, as well as in the design of machine components such as gears, bearings, and shafts. Tags: Mohrs circle, Principle of Mohrs circle, Mohrs circle formula, Mohrs circle applications Internal stresses develop within any body in response to externally applied loads. At any given point within the body, these internal stresses have components acting in both the normal and the shear directions.The normal and shear stress components are shown in the image below acting on a 3D stress element that represents a single point within the body. They can also be written in a matrix form, which is called the stress tensor. A tensor is a mathematical object, in this case a 33 matrix, that has special properties and is used to represent certain physical quantities, like the stress state at a given point in a body.The stress element (left) and the stress tensor (right) describe the stress state at a single point within a bodyFor plane stress conditions the stress tensor is simplified to a 22 matrix because the stresses in one of the three directions are close to zero. This is usually a valid assumption for thin objects that are only loaded in the plane of the material.The stress element and stress tensor for two-dimensional plane stress conditionsThe magnitude of the normal and shear stress components will change depending on how the stress element is oriented. This is illustrated below for a bar under plane stress conditions subjected to uniaxial tension.If the stress element is oriented as shown in the top part of the image, where it is aligned with the direction of the applied load, then there is only one stress component, a normal stress σ_x acting in the x direction the σ_y and τ_{xy} components are equal to zero. If the stress element is rotated by an angle θ, as shown in the bottom part of the image, the components denoted as σ_{x}, σ_{y} and τ_{xy} are now non-zero.The normal and shear stress components change as the stress element is rotated (i.e. as the coordinate system used to observe the stresses changes)Its important to understand that the overall stress state at the point of interest isnt changing as the stress element is rotating. The only thing that is changing is the coordinate system used to observe the stresses.The equations shown below can be used to compute the stress components for any orientation of the stress element, where θ is the angle through which the stress element is rotated. The process of determining the normal and shear stress components for different orientations of the stress element is called stress transformation, and as such these are called the stress transformation equations. Stress Transformation Equations $$\sigma_{x} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$$$\sigma_{y} = \frac{\sigma_x + \sigma_y}{2} \frac{\sigma_x \sigma_y}{2} \cos 2\theta \tau_{xy} \sin 2\theta$$$$\tau_{xy} = -\frac{\sigma_x \sigma_y}{2} \sin 2\theta + \tau_{xy} \cos 2\theta$$The purpose of stress transformation is to obtain the normal and shear stress components acting on a particular plane. There are quite a few different scenarios where you might need to do this. Here are a few examples:You might need to determine the normal forces acting on a weld.You might be interested in the shear stresses acting on an adhesive joint.You might need to determine the largest normal stress for any orientation of the stress element, to predict how and when the material will fail.Mohrs circle is a powerful graphical method used to visualise and analyze the stress state at a single point within a body. It allows you to determine the normal and shear stress components for different orientations of the stress element graphically, instead of using the stress transformation equations.Mohrs circle is a circle drawn on a graph that has normal stress on the horizontal axis and shear stress on the vertical axis. An example for a plane stress case (i.e. two-dimensional stress) is shown below. Each point on the circle defines the normal and shear stress components for a certain orientation of the stress element. The image shows the stress elements for three different points on Mohrs circle, corresponding to three different orientations of the stress element.Each point on Mohrs circle provides the normal and shear stresses for a certain orientation of the stress elementMohrs circle can be used to, for example:Easily determine the maximum shear and normal stresses at a single point.Determine the principal stresses and the orientation of the principal plane at a single point (more about principal stresses later).Develop a more intuitive and complete understanding of the stress state at a single point.An important thing to note is that angles on Mohrs circle are doubled compared to the angle the stress element is rotated by. For example there is a 90 degree angle between the stresses on the X and Y faces of the stress element. However on Mohrs circle there is a 180 degree angle between these stresses.When angles are shown on Mohrs circle they are often denoted as 2θ. θ is the angle the stress element is rotated by, and 2θ is the corresponding angle on Mohrs circle. In the image above rotating the stress element by an angle of $\theta = 80^\text{o}$ corresponds to an angle of $2 \theta = 160^\text{o}$ on Mohrs circle.Stresses are usually considered to be positive or negative based on the following sign convention:Shear stresses are positive if they tend to rotate the stress element counter-clockwise, and are negative if they tend to rotate it clockwise.Normal stresses are positive if they are tensile and negative if they are compressive.Sign convention for Mohrs circleOn Mohrs circle the normal stress component is shown on the horizontal axis and the shear stress component is shown on the vertical axis. The most common convention for the vertical axis is to plot positive shear stresses (i.e. shear stresses that tend to rotate the stress element counter-clockwise) in the downwards direction.The Efficient Engineer Summary SheetsThe Efficient Engineer summary sheets are designed to present all of the key information you need to know about a particular topic on a single page. It doesnt get more efficient than that!Get The Summary Sheets!The video below covers stress transformation and how to construct Mohrs circle in detail. construct Mohrs circle all you need to know is the normal and shear stresses for one orientation of the stress element. Here are the steps:Step 1 | Plot Stress State on X FacePlot a point (Point 1) corresponding to the stress conditions on the X face of the stress element, by plotting a point with coordinates (σ_x, τ_{xy}).Step 2 | Plot Stress State on Y FaceDo the same for the stress conditions on the Y face of the stress element (Point 2), by plotting a point with coordinates $(\sigma_y, -\tau_{xy})$.Step 3 | Draw the DiameterDraw a straight line between Point 1 and Point 2 this is the diameter of Mohrs circle.Use the diameter to draw Mohrs circle.A lot of useful information can be determined from Mohrs circle, like the maximum shear stress τ_{max}, which is equal to the radius of the circle, or the principal stresses σ_1 and σ_2.For certain orientations of the stress element the shear stresses will be zero, and the normal stresses will be at their maximum and minimum values. These maximum and minimum normal stresses are called the principal stresses, and they are denoted as σ_1 and σ_2 respectively. If the normal stress is at its maximum value on the X face of the element, it will be at its minimum value on the Y face of the element, and vice-versa.It is easy to identify the principal stresses on Mohrs circle they occur where the shear stress component is zero, i.e. where the circle crosses the horizontal axis.The normal stresses are at their maximum value on the X-face of the element and at their minimum value on the Y-face of the element for the orientation of the stress element where the shear stresses are zeroThe planes (i.e. the orientations of the stress element) where the principal stresses occur are called the principal planes.Being able to determine the principal stresses is often an important first step in predicting failure of a material.Determine the maximum shear stress for the stress state defined by the Mohr's circle shown below.The maximum shear stress is the lowest point on the vertical axis (postive shear stresses have been plotted in the downwards direction). As can be seen from the image below, this corresponds to 90.1 MPa.More quiz questionsSo far weve only discussed Mohrs circle for plane stress conditions, where the stress state is two dimensional. But Mohrs circle can also be drawn for a more generic three-dimensional stress state, where it is made up of three different circles, as shown below. All possible combinations of normal and shear stresses for the 3D stress element lie on the boundary of, or within, the shaded area.Mohrs circle for a three-dimensional stress-state is made up of three circlesFor a three-dimensional stress state there are three principal stresses, which by convention are numbered as follows: $\sigma_3 < \sigma_2 < \sigma_1$.Mohrs circle can also be applied to strains instead of stresses. It works in exactly the same way, except the normal stresses σ and shear stresses τ are replaced by normal strains ε and shear strains γ. Stress and strain are fundamental concepts that relate to the internal forces and deformations within a body in response to applied loads.Learn more A component is said to be in a condition of plane stress when all of the stresses acting on it are in the same plane.Learn more Explore Mohrs Circle in this insightful article, covering stress, strain, and material equilibrium theory in engineering and physics.Mohrs Circle: Understanding Stress and Strain in MaterialsMohrs Circle is a graphical representation used in engineering and physics to understand and analyze the states of stress and strain at a point in a material. Developed by the German engineer Otto Mohr in 1882, this tool has become essential in the field of material science and structural engineering. It aids in visualizing the transformation of stress components and understanding the concepts of principal stresses and maximum shear stress.Stress and Strain BasicsBefore delving into Mohrs Circle, its important to understand the basics of stress and strain. Stress is a measure of the internal forces within a material, usually resulting from external loads. Its defined as force per unit area, often represented in units of Pascals (Pa) or Newtons per square meter (N/m2). Strain, on the other hand, is the deformation or displacement of material that occurs when it is subjected to stress. Its a dimensionless measure of deformation.Equilibrium in MaterialsWhen discussing stress and strain, the concept of equilibrium is crucial. A material is in equilibrium when the sum of forces and moments acting on it is zero. This principle ensures that the material does not undergo uncontrolled deformation or failure under applied loads.Understanding Mohrs CircleMohrs Circle is constructed by plotting the normal stress () on the x-axis and the shear stress () on the y-axis. This circle helps in determining the principal stresses (1 and 2), maximum shear stress (max), and the orientations of these stresses. The principal stresses are the maximum and minimum normal stresses experienced by the material, and they occur on planes where shear stress is zero.Using Mohrs Circle, engineers can transform stresses from one plane to another and analyze the materials behavior under complex loading conditions. Its particularly useful in predicting failure modes in materials, understanding stress concentrations, and designing safe and efficient structures.In the following sections, we will explore how to construct Mohrs Circle step-by-step and its applications in practical scenarios.Constructing Mohrs CircleTo construct Mohrs Circle, the following steps are typically followed:Determine the normal () and shear () stresses on the plane of interest.Plot these stresses on a Cartesian plane, with on the x-axis and on the y-axis. This point is known as the stress point.Using the center of the circle (average of the normal stresses) and radius (sqrt[(/2)2 + 2]), draw the circle. Here, is the difference between the normal stresses on the x and y planes.The intersections of the circle with the x-axis represent the principal stresses, and the maximum value on the y-axis is the maximum shear stress.Applications of Mohrs CircleMohrs Circle is not just a theoretical concept but has numerous practical applications. It is used extensively in:Material Failure Analysis: By understanding the stress states, engineers can predict where and how a material might fail under certain loading conditions.Geotechnical Engineering: It helps in analyzing soil mechanics and rock stability.Structural Engineering: It aids in designing structures that can withstand various stress conditions without failure.ConclusionMohrs Circle is a powerful tool in the field of engineering and materials science. It provides a visual and analytical method to understand and analyze stress states in materials. By allowing the determination of principal stresses and the maximum shear stress, it assists engineers in predicting material behavior and designing safer, more efficient structures. The universality and simplicity of Mohrs Circle make it an indispensable part of any engineering curriculum and a fundamental tool in professional practice. With advancements in computational methods, the principles of Mohrs Circle continue to be relevant in modern engineering analyses and simulations, ensuring its enduring legacy in the world of engineering and science.Internal stresses develop within any body in response to externally applied loads. At any given point within the body, these internal stresses have components acting in both the normal and the shear directions.The normal and shear stress components are shown in the image below acting on a 3D stress element that represents a single point within the body. They can also be written in a matrix form, which is called the stress tensor. 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Stress and strain are fundamental concepts that relate to the internal forces and deformations within a body in response to applied loads.Learn more A component is said to be in a condition of plane stress when all of the stresses acting on it are in the same plane.Learn more Mapping based Best Questions (Indian Geography)Starting Soon Mohrs circle is a geometric representation of plane (2D) stress transformation and allows us to quickly visualize how the normal () and shear () stress components change as their plane changes orientation.German civil engineer Otto Mohrdeveloped this method from the good ol stress transformation equations. Recall:If we remove by squaring both sides of each equation and then add the two equations together, we get:After defining avg and R, we can modify Equation 3 to get Equation 4, which is the equation for a circle with center (avg,0) and radius R.Sign ConventionThe sign convention for normal stress () isthattension is positiveandcompression is negative. Shear stress ()is illustrated below. Geotechnical engineers may use the opposite sign conventions, because they mostly deal with compressive stress.Mohrs circle is drawn with normal stress () plotted on the abscissa (horizontal axis) and shear stress () plotted on the ordinate (vertical axis). Normal stress () is positive to the right, and shear stress () is positive downward.Pole MethodMost mechanics of materials textbooks prefer using the Double Angle Methodto draw Mohrs circles. The general idea of this approach is that angles between radial lines in the Mohrs circle are twice the actual angles between the real planes. In other words, a 40 rotation on the plane corresponds to an 80 rotation on the circlein the same direction.We prefer thePole Method, which is based on a unique point on the Mohrs circle known as thepole. This pole is unique, because any straight line drawn through the pole intersects the Mohrs circleat a point representing the state of stress on a plane with the same orientation as the line. As shown in the figure above, a line drawn through the pole and some stress point (,) on the circle isexactly parallel to the plane with corresponding and , making this approach very intuitive! Let us illustrate how the pole method works.To draw a Mohrs circle, we need to know the plane state of stresses for an element. Consider this:1. Plot the StressesImmediately, we know the two points that form the diameter of the circle,(x,xy) = (80,40) and(y,yx) = (20,-40). (If you are asking why yxis -40, remember the sign convention for shear stress!) The center of the circle is the halfway point between xand y, or avg.2. Locate the PoleDraw a straight line from one of the known stress points on the circle (,) in the direction of the plane on which (,) acts. Starting at point (80,40), a line is drawn parallel to the plane on which (80,40) acts. This is represented by the vertical dotted green line in the figure below. Starting at point (20,-40), a second line is drawn parallel to the plane on which (20,-40) acts. This is represented by the horizontal dotted pink line in the same figure below. The pole is at the intersection of these dotted lines on the circle. Note that there is only ONE pole!3. Find Transformed Stresses (e.g. 30 CCW Rotation)To find other states of stresses, we start drawing the lines from the pole instead of a known stress point (,). This is the general procedure:Draw a line from the pole in the direction of orientation of the transformed plane.The point where this line intersects the circle represents the state of stress acting on that plane.Let us assume a 30 counterclockwise (CCW) rotation of the element. Starting at the pole, to find the transformed counterpart of (20,-40), we draw a new line that is30 CCW from the existing dotted pink line. The transformed stresses on this plane is where the new pink line intersects the circle. Similarly,to find the transformed counterpart of (80,40), we draw a new line from the pole that is30 CCW from the existing dotted green line.The transformed stresses on this plane is where the new green line intersects the circle. Staying consistent with the rules, the new lines are parallel to their corresponding planes. The transformed stresses are:To get these transformed stress values by hand, we would need a protractor to measure the angle and a ruler to connect the pole to the point of intersection on the circle. This can seem like an elaborate process, and it goes to show that hand-calculating plane stress transformations via Mohrs circle is only an approximate method. To get the exact transformed stress values, we can use thegood ol stress transformation equations.4. Check with Analytical MethodUsing the the stress transformation equations (Equations 1 and 2):Because the center of the circle, or avg, is the same (the circle does NOT move!), we can find y.5. Principal StressesPrincipal stresses act on planes where = 0. The larger principal stress is called themajor principal stress, and the smaller principal stress is called theminor principal stress.Similar to finding transformed stresses, we draw lines from the pole to where = 0, or the two x-intercepts on the circle. The major and minor principal stresses are 100MPa and 0MPa, respectively. The angle, or the rotation required to reach zero shear stress on the plane, is measured between either pair of the original (dotted) line and the new line connecting the pole to the x-intercept.Square vs. TriangleSome textbooks show stress elements as squares (like in this article), while others show them as triangles. They are two different representations of the same element, because the triangles are just corner cutouts from the square, as shown below by the two a-a and b-b sections.The advantage of the triangular representation is that we can visually identify the transformed stresses on the hypotenuse. However, since we are dealing with two transformed normal stresses (x and y), we still need two triangles to give complete representation of plane stresses. In the figure below, A is the sectioned area (length of hypotenuse depth of 3D stress block).TL;DRStresses change as the plane on which they act changes orientation. Mohrs circle maps these changes.Keeping a consistent sign convention is important.In Pole Method, things are determined in this order:(,) pole(,).To determine anytransformed plane state of stress (,), we ALWAYS start at the pole and draw a line parallel to the plane. The point of intersection on the circle is(,). Internal stresses develop within any body in response to externally applied loads. At any given point within the body, these internal stresses have components acting in both the normal and the shear directions.The normal and shear stress components are shown in the image below acting on a 3D stress element that represents a single point within the body. They can also be written in a matrix form, which is called the stress tensor. 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The center of the circle is the average of the normal stresses, and the diameter is equal to the difference between the maximum and minimum normal stresses. The circles radius, which is also equal to the maximum shear stress, is drawn from the center of the circle to the point on the circle that corresponds to a 45-degree line that crosses the x-axis. The stress state at any angle can be represented by a line passing through the center of the circle.Interpretation of Mohrs CircleIn Mohrs Circle, the point of intersection between the line representing the stress state of a material and the circle represents the normal and shear stresses at that point. The angle between the line and the x-axis gives the direction of the principal stresses, while the angle between the line and the 45-degree line gives the direction of the maximum shear stress. The size of the circle represents the difference between the maximum and minimum normal stresses, while the radius represents the maximum shear stress.Example Applications of Mohrs CircleMohrs Circle is used in many engineering applications, including soil mechanics, geotechnical engineering, and structural analysis. In soil mechanics, Mohrs Circle is used to analyze the failure of soil under different loading conditions. In geotechnical engineering, Mohrs Circle is used to determine the shear strength of soil and rock. In structural analysis, Mohrs Circle is used to analyze the stresses in beams and columns, and to design reinforced concrete structures. Overall, Mohrs Circle provides a powerful graphical tool for understanding and analyzing complex stress states in different materials. Mohrs circle is explained below with a brief explanation of each terminology for a better understanding of the concept. Here you will learn about the basics of Mohrs circle, how to plot it, its uses, and its importance in advanced engineering. Lets get started! Mohrs Circle Definition Mohrs circle is a two-dimensional graphical representation of transformation equations for plane stress. This graphical representation enables us to visualize the relationship between the normal and shear stresses that acts on various inclined planes at a point in a stressed body. It can also be used to calculate principal stresses, maximum shear stresses, and stresses on inclined planes. This representation has been created by Otto Mohr and based on his name, the circle is named as Mohrs circle. Lets see the practical approach and correlation between the physical object and the cycle. In this process, a small square is considered for derivations, applications, etc. Now, what is this small square? Fig. 1 Mohrs circle stress strain basics Considerations are as follows, A small square is a very small portion of the main object. Take a cylindrical iron rod and image a very small portion as shown in Fig. 1 Now, if force, F is applied along the length, the entire object, as well as the small sections, will also be subjected to that force. So, tensile stress () will be acted on the small object. if the iron rod is subjected to a torque, T, then a small object will also be subjected to that torque, and shear stress () will be acted as shown in Fig. 1 Terminology Used for Mohrs Circle Explanation To understand it in the simplest way, Principal Plane means a plane on which stress value normal to the plane that is normal stress value is maximum. It is the stress value perpendicular to a plane. The normal stress value in the principal plane is maximum, this stress is called principal stress. The stress acted along the plane or perpendicular to the normal stress. A branch of mechanics that deals with the mechanical behavior of materials is considered as a continuous mass. It is used for determining stress analysis caused by small deformations in the material bodies. Fig. 2 2D stress representation diagram Mohrs circle According to Cauchy stress tensor, the stress at any point in an object assumed as a continuum can be completely defined by nine stress components. Cauchy stress tensor stress components The stress distribution is determined using the coordinate system represented by (x, y) we need to calculate the stress component at point O at the new position achieved by the displacement of the object due to stress represented by (x, y). To find the normal stress and the shear stress acting on a particular point, tensor transformation is performed. Mohrs circle is the graphical representation of the transformation law for Cauchy stress tensor. In a two-dimensional state, three stress components namely Normal stresses x and y and Shear stress xy give the stress tensor at any given point O. Fig. 3 Mohrs circle for 2D stress The Cauchy stress tensor can be written in a two-by-two symmetric matrix: Cauchy stress tensor stress components two Our aim is to find the stress components involved using the Mohrs circle on a rotated coordinate system i.e. (x, y). The rotated plane makes an angle with the original plane (x, y). Consider a two-dimensional material element around point O with a certain unit area. Using the equilibrium forces on the given element, the magnitude of the normal stress n and the shear stress n can be determined by: n = 1/2 (x + y) + 1/2 (x y) cos2 + xy sin2 n = 1/2 (x y) sin2 + xy cos2 These equations are obtained by applying the tensor transformation law on the Cauchy stress tensor. Lets derive the equation and find out how we get the above equations: Stress tensor transformation law is stated as, = AAT Stress tensor transformation law Expanding the right-hand side, As x= n and xy= n, We get, n = 1/2 (x +y) + 1/2 (x y) cos2 + xy sin2 n = (x y) sin cos + xy (cos2 sin2) Where, [cos2 sin2 = cos2, sin2 = 2sin cos] The above two equations are the parametric equation of Mohrs circle. 2 = Parameter n & n = Coordinates The points on the Mohrs circle can be found by choosing the coordinates with n and n and giving the values to the parameter . To get the non-parametric equation of Mohrs circle, we eliminate the parameter 2, n = 1/2 (x +y) + 1/2 (x y) + xy and n = 1/2 (x y) + xy The above equations can be rearranged into one by taking n and n in an equation and then squaring it:- [n 1/2 (x +y)]2 + n2 = [1/2 (x y)]2 + xy2 (n avg)2 + n2 = R2 Hence, R =[(n avg)2 + n2] R =[{n (x +y)/2 }2 + n2] Where, avg = (x +y)/2 The equation of the Mohrs circle can be given by (x a)2 + (y b)2 = r2 r = R (radius of the circle) (a,b) = (avg, 0) Coordinates in the (n, n) coordinate system. Now, after deriving the equation for Mohrs circle lets learn how to Draw/Plot it! To take an example we take an elastic element where the signs of the Normal stresses x & y are positive (Tension and stress going out of the surface) and Shear stress xy is negative (stress coming in on the surface) as shown in the figure. Fig. 4 Stressed elements Mohrs circle Steps needed to be followed for the construction of Mohrs circle are given below:- Step#1 Draw the horizontal and vertical axis (x, y). Step#2 Measure the values of x & y along the horizontal (y) axis based on their sign convention and mark them as shown in Fig. 5. Fig. 5 How to draw Mohrs circle measure normal stresses Step#3 Draw a vertical line of xy at point C and name it as shown in Fig. 6. (Project the line up if it is positive and down if it is negative). Fig. 6 Draw vertical lines for shear stress Step#4 Find the midpoint between points A and B as shown in Fig. 7. Draw the diagonal CD passing through the midpoint M. Fig. 7 Draw diagonal line through midpoint Step#5 Draw the circle with its centre M and passing through the points C and D as shown in Fig. 8 with its radius MC and MD. Fig. 8 Draw circle which is Mohrs circle Step#6 Mohrs circle is ready to get the principal stress 1 measure OE (the maximum value) To get the principal stress 2 measure OF (the minimum value) as shown in Fig. 9. max value can be found by measuring the radius of the circle. Fig. 9 Measure principal stress Step#7 The value of angle 2 is shown in the Fig. 10 below. Fig. 10 Value of angle Step#8 The triangle DBM have the following elements as shown in Fig. 11: Fig. 11 Mohrs circle radius Now that you have learned how to draw Mohrs circle and get the values from it. Lets take an example to understand it better. For the below given elastic element draw Mohr circle of stress and find the maximum and minimum stress values. Fig. 12 Mohrs circle example From the diagram given above we get: x = 10 N/mm2 y = -20 N/mm2 xy = -8 N/mm2 Now draw the Mohrs circle based on the values given above:- Fig. 13 Mohrs circle calculation 1 = 12 N/mm2 2 = -22 N/mm2 Lets check the results using the principal stress equation: 1,2 = [10 + (-20)]/2 [{((10 (-10))/2}2 + (-8)2] 1,2 = 5 [(15)2 + (-8)2] 1,2 = 5 17 1 = 12 N/mm2 2 = -22 N/mm2 Thus, we can see that we got the same results as we got through Mohr circle method. Lets see few applications, With advanced mechanics and the development of high-end design and analysis software, the use of Mohrs circle to find stress at a given point has been decreasing. Mohrs circle finds its use in the Structural Geology for the determination of elastic states for lithospheric stress. It helps to indicate the strength of different kinds of materials. To calculate the strength of soil, structural members, etc.Any circle becomes a point when its radius becomes zero. In case of Mohr circle the radius becomes zero when the principal stresses acting on the element are same and alike. Both the normal stress should be either tensile or compressive having the same value. The value of shear stress should also be zero to turn Mohrs circle in to a point. Fig. 14 Mohrs circle becomes point We have learned all about Mohr circle in the above article, this knowledge can be used for the construction of Mohr circle with the values given and finding the principal stresses acting on it. Mohrs circle is an easy method of finding the stress acting on a point on an elastic element with minimal calculations. Refer to a nice book on Mohr Circles, Stress Paths and Geotechnics for detail learnings. Refer to our few most interesting articles, Most mechanical engineers in their studies will learn Mohrs Circle. Its an important concept that, unfortunately, isnt appreciated much outside the university curriculum. But what is it and can we apply it to our understanding of FEA results? Read further to find out! A Quick Background Mohrs circle is named after its creator, Christian Otto Mohr, who developed the method in the late 1800s. It built off the previous concepts of the Cauchy stress tensor and Karl Kulmanns method of graphically visualizing stresses. Mohrs circle is a way to visualize the transformation equations for plane stress. For a more detailed explanation on what plane stress is, refer to this awesome blog post. Essentially, plane stress assumes that the three stress tensor components related to the z-direction are 0. This assumption is mainly used for plate surfaces and very thin parts. Any engineer performing FEA should know Mohrs circle because it is essential to understanding how normal, shear, and principal stresses interact and determining the plane in which they act. The principles used in generating Mohrs circle are the same principles FEA softwares use. Knowing how the software works is essential; otherwise, youre just blindly trusting the outputs and thats never a good idea! Making The Circle Because of the plane stress assumption, there are three non-zero values within the stress tensor involved in making Mohrs Circle: x, y, and xy. These equations would give two points in a coordinate system where x is and y is : (x, xy) and (y, -xy). With two points forming the diameter, only one unique circle can be made to connect them. The idea behind Mohrs circle is that any point on the circle is a valid stress state of the element depending on its orientation, . Below are the equations used to determinate the center point and radius of the circle. The center point is represented by the point (avg,0). Then, the radius value can be used around the center point to draw Mohrs circle. We will illustrate this using an example. Say we have a stress element where x = 40 MPa, y = 30 MPa, and xy = 15 MPa. By using the above equations, we find that avg = 35 MPa and R = 15.8 MPa. We will draw the Mohrs circle below: How To Use It In Mohrs circle, the x-axis is and the y-axis is . In order to keep the standard angle convention of counterclockwise being positive, the y-axis is reversed. The minimum and maximum principal stresses as well as the maximum shear stress can be determined from initial inspection of Mohrs circle. As shown in gray, the maximum and minimum principal stresses are determined using avg R. The maximum shear stress, shown in yellow, is determined by R. The initial stress state is shown in orange. These points are loaded at a certain orientation that can be determined by the following equations: We can calculate these orientations using our example to be P = 35.8 and S = -9.2. This means if you rotate the original stress element 35.8 degrees, then you will achieve the maximum principal stress. If you rotate the original stress element -9.2 degrees, then you will achieve the maximum shear stress. Additionally, you can determine the principal and shear stresses at any angle by the following equations: Note that the angle is measured from the initial stress state and NOT from the x or y axis. So, if you had 0 as the angle, x1 would be 40 MPa and x1y1 would be 15 MPa, which is the untransformed stress state. Does It Work In 3 Dimensions? Yes it does you just have to make more circles (more circles = Mohr circles, lololol)! Essentially, you would have six possible non-zero values in the stress tensor and would make three Mohrs circles one in the xy plane, one in the xz plane, and one in the yz plane. In order to do this, the principal stresses must first be calculated by solving for the roots of the below polynomial: where Once the three roots are found (which we will call 1, 2, and 3), then the centers and radii of the three Mohrs circles can be found using the below equations where 1 2 3: The final result should be two circles inscribed within a third circle, corresponding to the plane stress states of the three principal stresses, and you can do stress transformations along the principal axes for any of the three circles. Any stress within the shaded region in the 3D Mohrs circle is a valid combination of normal and shear stresses in the stress element. There are ways to determine the normal and shear stresses on a certain plane within the 3D stress element as well as deriving the plane from a certain combination of normal and shear stresses, but they dont need to involve the Mohrs circle, so we will stop here for now and end with an example of drawing the 3D Mohrs circle. For our example, lets use the stress tensor We can calculate the polynomial and the principal stresses to be Now we can calculate C and R for each circle and draw the 3D Mohrs circle: All values outside of the yellow and blue circles but within the orange circle are valid combinations of normal and shear stresses. Final Thoughts Mohrs circle is a great tool for visualizing stress transformations in plane stress elements. It can also be applied to strains and moments using the same methodology. Our engineering team loves spending their free time drawing Mohrs Circle and wed be happy to help you with any mechanics related project, whether that be FEA or CFD. Reach out to us today! A powerful graphical tool used to visualize and analyze the state of stress in a material, determining principal stresses and maximum shear stress.Mohrs Circle is an essential concept in engineering mechanics that provides a visual method for stress transformation. By representing the stress components on a two-dimensional plot, it simplifies the determination of the principal stresses and the maximum shear stress acting on a material. This method is invaluable for analyzing complex stress states in structures and mechanical components.The main elements of Mohrs Circle include:Center: Represents the average normal stress (_avg = (+) / 2).Radius: Determined by the equation R = sqrt[(( )/2) +], which is equal to the maximum shear stress.Principal Stresses: The points where the circle intersects the horizontal axis, indicating the maximum and minimum normal stresses.Shear Stresses: The vertical distances from the horizontal axis to any point on the circle, representing the shear stress on planes at various orientations.Understanding these components allows for a comprehensive analysis of the stress state in a material.To construct Mohrs Circle, start with the stress components on a given element:_avg = (+) / 2R = sqrt[(( ) / 2) +]Plot the circle on a graph where the horizontal axis represents the normal stress () and the vertical axis represents the shear stress (). The circles center is at (_avg, 0), and its radius is R. The intersections with the horizontal axis provide the principal stresses, while the distance R gives the maximum shear stress.Follow these steps to analyze a stress state using Mohrs Circle:Determine the Stress Components: Identify the normal stresses (and) and the shear stress () acting on the material.Calculate the Center and Radius: Compute _avg and R using the formulas provided.Plot the Circle: Draw the circle on a - graph with the calculated center and radius.Identify Critical Stresses: Locate the points where the circle intersects the horizontal axis to find the principal stresses, and use the radius to determine the maximum shear stress.Problem: Given a stress state with x = 80 MPa, y = 20 MPa, and xy = 30 MPa, calculate the principal stresses and maximum shear stress._avg = (80 MPa + 20 MPa) / 2 = 50 MPaR = sqrt[((80 MPa 20 MPa) / 2) + (30 MPa)] 42.43 MPa = 50 MPa + 42.43 MPa 92.43 MPa = 50 MPa 42.43 MPa 7.57 MPaExplanation: The principal stresses are found at the intersections of Mohrs Circle with the horizontal axis, while the circles radius represents the maximum shear stress.Example 2: Pure Shear ConditionProblem: For a pure shear condition where x = 0, y = 0, and xy = 50 MPa, determine the principal stresses._avg = (0 + 0) / 2 = 0 MPaR = sqrt[((0 0) / 2) + (50 MPa)] = 50 MPa = 0 MPa + 50 MPa = 50 MPa = 0 MPa 50 MPa = -50 MPaExplanation: In a pure shear state, the principal stresses are equal in magnitude but opposite in sign, with the maximum shear stress equal to the applied shear stress.Example 3: Combined Compressive and Tensile StressesProblem: Given a plane stress state with x = -100 MPa, y = 40 MPa, and xy = 20 MPa, determine the principal stresses._avg = (-100 MPa + 40 MPa) / 2 = -30 MPaR = sqrt[((-100 MPa 40 MPa) / 2) + (20 MPa)] 72.80 MPa = -30 MPa + 72.80 MPa 42.80 MPa = -30 MPa 72.80 MPa -102.80 MPaExplanation: This example demonstrates the application of Mohrs Circle to a mixed stress state, revealing both tensile and compressive principal stresses.Mohrs Circle is used across various engineering disciplines for:Structural Engineering: Analyzing stress distributions in beams, columns, and other load-bearing elements.Mechanical Engineering: Assessing stress concentrations in machine components to prevent failure.Geotechnical Engineering: Evaluating soil and rock stress conditions for safe foundation design.Materials Science: Investigating how materials respond to complex loading and predicting failure modes.Beyond the basic construction and interpretation, Mohrs Circle can be applied to more advanced stress analysis scenarios:Stress Transformation: It offers a graphical method to determine the stress components on rotated planes.Plane Strain Conditions: Adaptations of Mohrs Circle are used when one dimension is constrained, as in plane strain problems.Failure Criteria: Combined with theories like von Mises or Tresca, it aids in predicting material failure under complex loading.Experimental Analysis: It is also used to interpret experimental data from strain gauges and photoelasticity studies.Mohrs Circle is a graphical tool that represents the state of stress at a point, helping engineers easily determine the principal and shear stresses.By calculating the average normal stress and the radius from the stress components, then plotting the circle on a - graph, you can visualize the stress transformation.It reveals the principal stresses, the maximum shear stress, and the orientation of the planes on which these stresses act.It is extensively used in structural, mechanical, and civil engineering, as well as in materials science, to analyze and predict material behavior under various loading conditions.Mohrs Circle is more than just a diagramit is a fundamental tool for stress analysis that enables engineers to quickly and accurately determine the critical stress values within a material. Mastery of Mohrs Circle leads to better insights into material behavior, safer designs, and more efficient engineering solutions. Understanding stress and strain is essential in designing safe and efficient structures. Mohrs Circle is a graphical tool that simplifies the process of analyzing stress and strain for two-dimensional transformations. In this article, we will discuss the concept of Mohrs Circle, its equations for plane stress and plane strain, and how it can be used in analyzing and designing structures subjected to complex loading conditions. To design safe and efficient structures, it is important to understand stress and strain. Stress refers to the internal force experienced by a material, while strain refers to the deformation or change in shape caused by that force. In solid mechanics, the general state of stress at a point is characterized by six independent normal and shear stress components that act on the faces of an element of material located at that point. Similarly, the general state of strain can be represented by the same number of normal and shear strain components that tend to deform each face of an element of the material. In both cases, the normal and shear components at a point can vary depending on the orientation of the element. Therefore, it is important to understand how the magnitudes of these components change when the element is oriented differently. This process of determining the stress and strain components at different orientations is called stress and strain transformation. Advance in Excel with engineering-focused training that equips you with the skills to streamline projects and accelerate your career. Stress and strain transformation can generally be done using mathematical equations. However, there is a graphical tool that simplifies the process for two-dimensional transformations this is called the Mohrs Circle. Mohrs circle is a graphical representation used to determine the state of stress or strain at a point in a material. The circle is used to visualize the relationship between the normal and shear components acting on a material element at different orientations. It is named after Christian Otto Mohr, who first introduced the concept in 1882. The circle is drawn by plotting the normal component on the x-axis and the shear component on the y-axis. The center of the circle is located at the average normal component, and the radius of the circle is equal to the maximum shear component. The circle is especially helpful in determining the maximum and minimum normal and shear components, as well as the orientation of the element at which they occur. Mohrs Circle is used to analyze and design structures subjected to complex loading conditions, such as bridges, buildings, and machine components. Additionally, it can assist in predicting material failure, allowing engineers to make informed decisions on material selection and safety factors. Suppose we have an initial state of stress within a material defined by the normal stresses x and y, as well as the shear stress xy. The goal is to find the transformed stresses x and y, and the transformed shear stress xy on any inclined plane with an angle with respect to the original coordinate system. The first step in constructing Mohrs Circle is to determine the center of the circle, called point C, which represents the average normal stress. This can be computed using the following formula: Where: C = center of the circle, corresponding to the average normal stress [Pa] x = initial normal stress along the x axis [Pa] y = initial normal stress along the y axis [Pa] Next, the radius of the circle, R, which represents the maximum shear stress, can be found using the stress values: Where: R = radius of the circle, corresponding to the maximum shear stress [Pa] xy = initial shear stress [Pa] Now, we can plot the circle on a - plane, with the center C and radius R, as shown in the diagram below. The horizontal axis represents normal stresses, while the vertical axis represents shear stresses. After constructing the circle, the initial reference point, P, can be plotted having coordinates P(x, xy). This point represents the initial shear stress and normal stress along x axis, which also represents = 0. Each point on the Mohrs circle represents two stress components acting on a side of the element defined by the axis, when the axis is in a specific direction with respect to the reference point. However, note that a rotation on the Mohrs circle will correspond to only half of the rotation on the actual element in the same direction. Similar to plane stress, Mohrs Circle can be used the same way for plane strain. Suppose we have an initial state of strain defined by the normal strains x and y, as well as the shear strain xy. The goal is to find the transformed strains x and y, and xy on an inclined plane with an angle relative to the reference plane. The center of the circle, C, represents the average normal strain, which can be computed using the following formula: Where: C = center of the circle, corresponding to the average normal strain [unitless] x = initial normal strain along the x axis [unitless] y = initial normal strain along the y axis [unitless] Then, the radius of the circle, R, can be found using the following formula: Where: R = radius of the circle [unitless] xy = initial shear strain [unitless] Now, we can plot the circle on a plane, with the center C and radius R, as shown in the diagram below. The horizontal axis represents normal strain, while the vertical axis represents half of the shear strain. The initial reference point is located at A(x, xy/2), representing the initial normal strain and half of the shear strain. This is designated as = 0. The Mohrs circle for strain can be utilized in a similar manner as the Mohrs circle for stress. Truss members can have zero internal forces depending on how the loads are applied on the truss. Therefore, identifying these zero force members and eliminating them can simplify truss analysis. There are three main cases where zero force members exist. Case 1: Pin-Pin When members are attached to pin supports AND no applied force is []Read More Zero Force Members When all the forces in a structure can be determined directly from equilibrium equations, the structure is considered statically determinate. In contrast,when all the forces in a structure cannot be determined directly from equilibrium equations, the structure is considered statically indeterminate. In the latter case, there are more unknown forces than available equilibrium equations, and []Read More Static Determinacy Intro and Derivation Mohrs circle is a geometric representation of plane (2D) stress transformation and allows us to quickly visualize how the normal () and shear () stress components change as their plane changes orientation.German civil engineer Otto Mohrdeveloped this method from the good ol stress transformation equations. Recall:If we remove by squaring both []Read More Mohrs Circle Axial, shear, and bending moment diagrams (AFD, SFD, and BMD)show the internalforces and moments along a structural member. They help determine the material, size, and type of a member given a set of loads it can support without structural failure. Keeping a consistent sign convention is extremely important! We are going to define the positive []Read More Axial, Shear & MomentDiagrams Definitions Stress is defined asforce per unit cross-sectional area. Some common measurements of stress include Pa(pascal) and psi(pounds per square inch).There are two types of stress: normal and shear. Normal stress includes tensile and compressive stress, because they act normal, or perpendicular, to the stress area. Tensile stress tends to stretch or lengthen the material, []Read More Stress & Strain Share copy and redistribute the material in any medium or format for any purpose, even commercially. Adapt remix, transform, and build upon the material for any purpose, even commercially. The licensor cannot revoke these freedoms as long as you follow the license terms. Attribution You must give appropriate credit , provide a link to the license, and indicate if changes were made . You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use. ShareAlike If you remix, transform, or build upon the material, you must distribute your contributions under the same license as the original. No additional restrictions You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits. You do not have to comply with the license for elements of the material in the public domain or where your use is permitted by an applicable exception or limitation . No warranties are given. The license may not give you all of the permissions necessary for your intended use. For example, other rights such as publicity, privacy, or moral rights may limit how you use the material. 10 MPa16 MPa8 MPa11.7 MPaInternal stresses develop within any body in response to externally applied loads. At any given point within the body, these internal stresses have components acting in both the normal and the shear directions.The normal and shear stress components are shown in the image below acting on a 3D stress element that represents a single point within the body. They can also be written in a matrix form, which is called the stress tensor. A tensor is a mathematical object, in this case a 33 matrix, that has special properties and is used to represent certain physical quantities, like the stress state at a given point in a body.The stress element (left) and the stress tensor (right) describe the stress state at a single point within a bodyFor plane stress conditions the stress tensor is simplified to a 22 matrix because the stresses in one of the three directions are close to zero. This is usually a valid assumption for thin objects that are only loaded in the plane of the material.The stress element and stress tensor for two-dimensional plane stress conditionsThe magnitude of the normal and shear stress components will change depending on how the stress element is oriented. This is illustrated below for a bar under plane stress conditions subjected to uniaxial tension.If the stress element is oriented as shown in the top part of the image, where it is aligned with the direction of the applied load, then there is only one stress component, a normal stress σ_x acting in the x direction the σ_y and τ_{xy} components are equal to zero. If the stress element is rotated by an angle θ, as shown in the bottom part of the image, the components denoted as σ_{x}, σ_{y} and τ_{xy} are now non-zero.The normal and shear stress components change as the stress element is rotated (i.e. as the coordinate system used to observe the stresses changes)Its important to understand that the overall stress state at the point of interest isnt changing as the stress element is rotating. The only thing that is changing is the coordinate system used to observe the stresses.The equations shown below can be used to compute the stress components for any orientation of the stress element, where θ is the angle through which the stress element is rotated. The process of determining the normal and shear stress components for different orientations of the stress element is called stress transformation, and as such these are called the stress transformation equations. Stress Transformation Equations $$\sigma_{x} = \frac{\sigma_x + \sigma_y}{2} + \frac{\sigma_x \sigma_y}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$ $$\sigma_{y} = \frac{\sigma_x + \sigma_y}{2} \frac{\sigma_x \sigma_y}{2} \cos 2\theta \tau_{xy} \sin 2\theta$$ $$\tau_{xy} = -\frac{\sigma_x \sigma_y}{2} \sin 2\theta + \tau_{xy} \cos 2\theta$$The purpose of stress transformation is to obtain the normal and shear stress components acting on a particular plane. There are quite a few different scenarios where you might need to do this. Here are a few examples:You might need to determine the normal forces acting on a weld.You might be interested in the shear stresses acting on an adhesive joint.You might need to determine the largest normal stress for any orientation of the stress element, to predict how and when the material will fail.Mohrs circle is a powerful graphical method used to visualise and analyze the stress state at a single point within a body. It allows you to determine the normal and shear stress components for different orientations of the stress element graphically, instead of using the stress transformation equations.Mohrs circle is a circle drawn on a graph that has normal stress on the horizontal axis and shear stress on the vertical axis. An example for a plane stress case (i.e. two-dimensional stress) is shown below. Each point on the circle defines the normal and shear stress components for a certain orientation of the stress element. The image shows the stress elements for three different points on Mohrs circle, corresponding to three different orientations of the stress element.Each point on Mohrs circle provides the normal and shear stresses for a certain orientation of the stress elementMohrs circle can be used to, for example:Easily determine the maximum shear and normal stresses at a single point.Determine the principal stresses and the orientation of the principal plane at a single point (more about principal stresses later).Develop a more intuitive and complete understanding of the stress state at a single point.An important thing to note is that angles on Mohrs circle are doubled compared to the angle the stress element is rotated by. For example there is a 90 degree angle between the stresses on the X and Y faces of the stress element. However on Mohrs circle there is a 180 degree angle between these stresses.When angles are shown on Mohrs circle they are often denoted as 2θ. θ is the angle the stress element is rotated by, and 2θ is the corresponding angle on Mohrs circle. In the image above rotating the stress element by an angle of $\theta = 80^\text{o}$ corresponds to an angle of $2 \theta = 160^\text{o}$ on Mohrs circle.Stresses are usually considered to be positive or negative based on the following sign convention:Shear stresses are positive if they tend to rotate the stress element counter-clockwise, and are negative if they tend to rotate it clockwise.Normal stresses are positive if they are tensile and negative if they are compressive.Sign convention for Mohrs circleOn Mohrs circle the normal stress component is shown on the horizontal axis and the shear stress component is shown on the vertical axis. The most common convention for the vertical axis is to plot positive shear stresses (i.e. shear stresses that tend to rotate the stress element counter-clockwise) in the downwards direction.The Efficient Engineer Summary SheetsThe Efficient Engineer summary sheets are designed to present all of the key information you need to know about a particular topic on a single page. It doesnt get more efficient than that!Get The Summary Sheets!The video below covers stress transformation and how to construct Mohrs circle in detail. construct Mohrs circle all you need to know is the normal and shear stresses for one orientation of the stress element. Here are the steps:Step 1 | Plot Stress State on X FacePlot a point (Point 1) corresponding to the stress conditions on the X face of the stress element, by plotting a point with coordinates (σ_x, τ_{xy}).Step 2 | Plot Stress State on Y FaceDo the same for the stress conditions on the Y face of the stress element (Point 2), by plotting a point with coordinates $(\sigma_y, -\tau_{xy})$.Step 3 | Draw the DiameterDraw a straight line between Point 1 and Point 2 this is the diameter of Mohrs circle.Use the diameter to draw Mohrs circle.A lot of useful information can be determined from Mohrs circle, like the maximum shear stress τ_{max}, which is equal to the radius of the circle, or the principal stresses σ_1 and σ_2.For certain orientations of the stress element the shear stresses will be zero, and the normal stresses will be at their maximum and minimum values. These maximum and minimum normal stresses are called the principal stresses, and they are denoted as σ_1 and σ_2 respectively. If the normal stress is at its maximum value on the X face of the element, it will be at its minimum value on the Y face of the element, and vice-versa.It is easy to identify the principal stresses on Mohrs circle they occur where the shear stress component is zero, i.e. where the circle crosses the horizontal axis.The normal stresses are at their maximum value on the X-face of the element and at their minimum value on the Y-face of the element for the orientation of the stress element where the shear stresses are zeroThe planes (i.e. the orientations of the stress element) where the principal stresses occur are called the principal planes.Being able to determine the principal stresses is often an important first step in predicting failure of a material.Determine the maximum shear stress for the stress state defined by the Mohr's circle shown below.The maximum shear stress is the lowest point on the vertical axis (postive shear stresses have been plotted in the downwards direction). As can be seen from the image below, this corresponds to 90.1 MPa.More quiz questionsSo far weve only discussed Mohrs circle for plane stress conditions, where the stress state is two dimensional. But Mohrs circle can also be drawn for a more generic three-dimensional stress state, where it is made up of three different circles, as shown below. All possible combinations of normal and shear stresses for the 3D stress element lie on the boundary of, or within, the shaded area.Mohrs circle for a three-dimensional stress-state is made up of three circlesFor a three-dimensional stress state there are three principal stresses, which by convention are numbered as follows: $\sigma_3 < \sigma_2 < \sigma_1$.Mohrs circle can also be applied to strains instead of stresses. It works in exactly the same way, except the normal stresses σ and shear stresses τ are replaced by normal strains ε and shear strains γ. Stress and strain are fundamental concepts that relate to the internal forces and deformations within a body in response to applied loads.Learn more A component is said to be in a condition of plane stress when all of the stresses acting on it are in the same plane.Learn more

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