AC 2012-3232: APPLICATIONS OF SOLIDWORKS IN TEACHING COURSES OF STATICS AND STRENGTH OF MATERIALS

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Application of SolidWorks in teaching courses of Statics and Strength of Materials

Abstract

Statics and Strength of Materials are two core technical courses for any mechanical program. In Statics, vector operations: the parallelogram law, the triangle rule and the polygon rule are introduced and explained in the first two weeks. Many students, especially in the mechanical engineering technology program have difficulty using vector operations to obtain a resultant magnitude or its direction by the trigonometry approach because some students have forgotten the laws of sine and cosine. In the case of Strength of Materials, many students have a hard time understanding the stress concentration phenomena and some assumptions for stress formulas under different loadings. Some students are puzzled about the purpose and the approach of the Mohr's circle so they only sketch the Mohr's circle for visualization purposes but still use stress transformations to calculate the stresses at different orientations. Since 2010 we have introduced the idea of using the sketch tools in SolidWorks to run vector operations for statics and to draw Mohr's circle for determining the stresses at a given orientation. We also have used SolidWorks Simulation as a virtual lab and an alternative approach to visualize the stress distributions to facilitate student's understanding of stress concentration phenomena, and the assumptions of stress formulas under shear, bending and torsion loadings. The application of SolidWorks in Statics and Strength of Materials courses since 2010 will be summarized, presented and discussed in this paper. Results of student surveys conducted in the fall of 2011using the application of SolidWorks in these two courses will also be presented in this paper. According to the survey, students favored the application of SolidWorks in these two courses and would like to see more integration of SolidWorks in Statics and Strength of Materials courses.

1. Introduction

For the course Statics [1, 2], the definition of a vector and vector operations: the parallelogram law, the triangle rule and the polygon rule are introduced and explained in the first two weeks at Wentworth Institute of Technology (WIT). These vector operations are graphically described and stated, but they are not implemented using graphical tools. Therefore, vector operations are solved by a trigonometric approach. Many students have difficulty performing vector operations to solve for the resultant magnitude or direction. Some students have forgotten key trigonometry equations, such as the laws of sine and cosine. In some cases, students tried a graphical approach with hand sketches however, this approach lacks accuracy. Since 2010, we have developed and implemented a graphical approach using SolidWorks to perform vector operations. The implementation of SolidWorks' graphical approach in this course will be summarized, presented and discussed in this paper.

For the Strength of Materials course, there are common issues for many students. Students have difficulty understanding the stress concentration phenomena. They need a visualization tool to see the stress values in the stress concentrations. Another common issue is that many students have difficulty conceptualizing the assumptions used in the derivation of stress formulas. An example of this is the linearity assumption in bending and torsion. The last concept for Strength of Materials addressed in this paper is Mohr's circle [3,4]. Most textbooks only discuss the working principle of Mohr's circle, without providing a practical, graphical approach to obtain accurate results. Therefore, some students question why we sketch Mohr's circle for visualization purposes but use stress transformation equations to calculate the actual stresses at different orientations. The application of SolidWorks has been used to solve the above three issues. Implementation of SolidWorks Simulation and graphical approach in the Strength of Materials course since 2010 will be summarized, presented and discussed in this paper.

In the fall 2011 semester, we conducted student surveys on the application of SolidWorks in Statics and Strength of Materials courses. The survey results and discussion will be presented. According to the survey, students favored the application of SolidWorks in these two courses and would like to see more integration of this tool for a greater understanding of the concepts in Statics and Strength of Materials.

2. Program Description

Wentworth Institute of Technology remains committed to academic excellence by providing a hands-on, practical education to the future leaders in the disciplines of engineering, technology, design, and management. The Baccalaureate programs of Mechanical Engineering and Mechanical Engineering Technology in the Department of Mechanical Engineering and Technology at Wentworth Institute of Technology is a cooperative education and projected-based program in which there are 2 required and 1 optional semester of industry experience in the form of co-ops. Every incoming freshman at Wentworth is issued a laptop, which is replaced with a new laptop their junior year. All necessary software applications are available for students.

For the mechanical engineering technology program, Statics and Strength of Materials are scheduled in the sophomore year. Students have learned how to use AutoCAD in the course Engineering Graphics in their freshman year. In the fall semester of their sophomore year, they are introduced to SolidWorks in the Mechanical CAD Applications I course, and take the Statics course. The Strength of Materials course follows in the spring of their sophomore year.

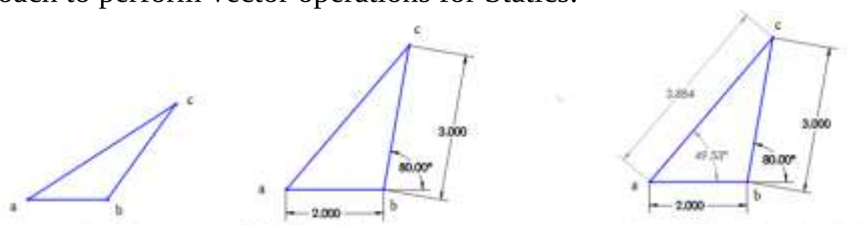
For the mechanical engineering program, Engineering Statics and Mechanics of Materials are scheduled in the sophomore year. In their freshman year, these students have been introduced to SolidWorks as a design tool for creating parts, assembly and drawing in Engineering Graphics.

3. Application of SolidWorks in Statics and Strength of Materials

3.1 Introduction to SolidWorks

SolidWorks is a parametric feature-based 3D software program in which geometries can be modified and changed by dimensioning and creating geometrical relations between or among geometrical items [5,6]. "Parameters" refer to constraints whose values determine the shape or geometry of the model or assembly. Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can be associated with each other through the use of relations, which allow them to capture design intent.

An example, shown in figure 1, is used to explain the "Parameters" in 2D sketcher of SolidWorks. In figure 1-a, a generic triangle is sketched in SolidWorks 2D sketcher. In figure 1-b, the side $\overline{ab}$ is then specified as the length of 2" and a horizontal line. The $\overline{bc}$ side is specified as the length of 3" and the angle 80^0 with respect to horizontal line. It is noted that when the "parameters" of the side $\overline{ab}$ and $\overline{bc}$ are changed, the geometric shape of the triangle abc changes accordingly. For the fully specified triangle shown in figure 1-b, the "parameters" of the side $\overline{ac}$, that is, the length and its angle are also fully determined. These "parameters" are called the "driven parameters", which can be directly measured in SolidWorks 2D sketcher. The length and angle of side $\overline{ac}$ are measured as 3.884" and 49.53^0 as shown in figure 1-c. When a scale or ratio of the force to length is assigned to the sketched geometry, any line can be used to represent a force vector. From this example, it can be seen that SolidWorks can be used as a graphical approach to perform vector operations for Statics.



a) A generic triangle

b) A fully defined triangle side ab is horizontal with length 2" side bc has a 80 angle with respection to horizontal line and with a length 3"

c) The length 0f side bc and its angle with the horizontal line are fully defined and can be directly measured.

Figure 1: Explanation of "parameters" in the 2D sketcher of SolidWorks

SolidWorks is also a platform for numerical simulation to show and calculate stress/strain of components [7,8]. There is a module of SolidWorks called SolidWorks Simulation, which can perform several different types of engineering analyses including linear static problems. This is an ideal tool for demonstrating and visualizing the stress/strain distribution under different loading conditions in a Strength of Materials course.

3.2 Applications of SolidWorks in Statics

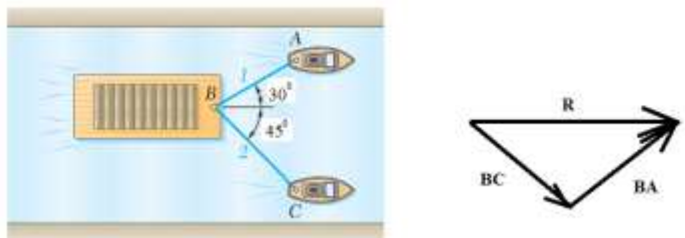
The Statics courses at WIT have 3 hours of lecture and 2 hours of lab per week. The lab is used to solve statics problems. Our approach to teaching Statics is similar to other institutions with the exception of adding SolidWorks as an alternative graphic and visualization tool. In the following, we will explain how we implement this approach with examples in teaching Statics.

A: Vector operations on statics of a particle

The traditional approach of using vector operations to solve for the unknown using free-hand sketching and trigonometry are explained and demonstrated in detail first. We then introduce the graphic approach using SolidWorks. The SolidWorks' graphical approach is only a tool by which students solve Statics problems. We use SolidWorks to solve and demonstrate the same examples which have been solved by the trigonometric approach.

The basic concept for the SolidWorks' graphical approach is explained in section 3.1. The procedure is simple and straightforward and is shown in the following example.

Example 1[1]: a barge is pulled by two tugboats as shown in figure 2 a). If the resultant of the forces exerted by the tugboats is a 5000-lb forced directed along the axis of the barge, determine the tension in each of the ropes.



a) A barge towed by two tugboats   b) the free-hand sketch of the vector operation

Figure 2: Example 1 [1]

The procedure for the SolidWorks' graphical approach

Step 1: fully understand the question and draw the free-hand sketch on paper as a reference. For example 1, there are three force vectors. The given parameters are: the magnitude and direction of the resultant force and the angles of force vectors **BC** and **BA.** The unknown parameters for this example are the magnitudes of force vectors **BC** and **BA**. Based on the understanding of example 1, the free-hand sketch of the vector operation for is shown in figure 2-b.

Step 2: Choose a scale or a ratio representing the force per unit length in SolidWorks. In SolidWorks' sketcher, a line is used to represent a vector. The orientation of the line represents the line of action of the vector. The length in SolidWorks is in units of inch or mm. One inch or 1 mm can be used to represent 100 lb or 1000 lb. Therefore, using a scale of 1 inch equals 1000 lb., the length of the resultant force in the SolidWorks' graphical approach will be 5 inches.

Step 3: Activate SolidWorks and enter part mode and select "new", "part" and "ok" as shown in figure 3. Then enter sketch mode by clicking "Sketch" and selecting any one of the existing sketch planes, such as "Front plane" as shown in figure 4.

Step 4: Draw one vertical and one horizontal construction line as shown in figure 5 These will be the reference lines used for determining the angle of the line of action of the vectors.

Step 5: Draw the geometric profile by using the line toolbar as shown in figure 6-a. The geometric profile has a similar geometry as the free-hand sketch shown in figure 6-a. Then, use the "smart dimension" tool to specify the length and/or angle of the given parameters of vectors as shown in figure 6-b. After all parameters are totally specified in the SolidWorks' sketcher, the geometry is fully defined.

Step 6: Select Measure from the Tools menu to measure the length and/or angle of the fully specified geometry to get the answers for the statics problems.

In example 1, the unknown parameters are the magnitudes of force vectors **BC** and **BA**. We can directly measure the length of force vectors BC and BA for the fully defined geometry in the SolidWorks' sketcher. According to figure 7, the magnitude of the force vector BC and BA are 2588 and 3660 lb., respectively, which match the answers obtained from the trigonometric approach.

Figure 3: Entering the SolidWorks' part mode

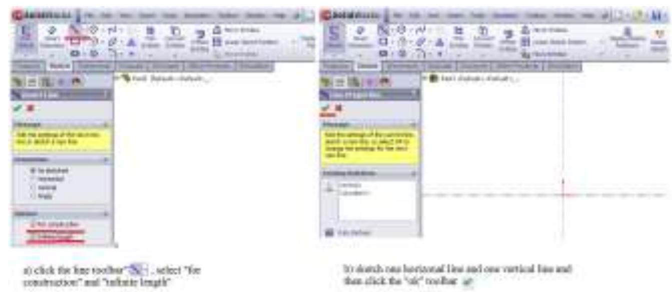


Figure 5: Sketch two reference lines

Figure 4: Entering the SolidWorks' sketching mode

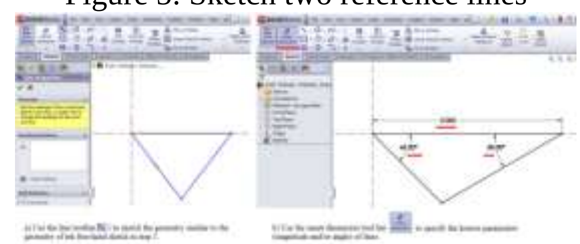


Figure 6: Sketch and then specify the geometry with the given parameters

The SolidWorks' graphical approach is especially effective for dealing with vector operations of several vectors. This approach is then used to solve 2D equilibrium of particles, 2D equilibrium of three-force body, and 2D friction problems without consideration of tipping after the analytical approach. That is, $\sum F_x = 0$ and $\sum F_y = 0$, is used to solve concurrent statics' problems.

The following is an example of particle equilibrium:

Example 2: Two cables are tied together at C and are loaded as shown in figure 8-a. The measured tension in cable AC is 870 lb. Determine the tension and the angle α of cable CB.

Following the procedure described above, the free-hand sketch of the vector operation for this problem is shown in figure 8-b. Using a scale of 1000 lb/unit length, the tension and the angle α of the cable CB are 726 lb and 32.03 degrees, respectively.

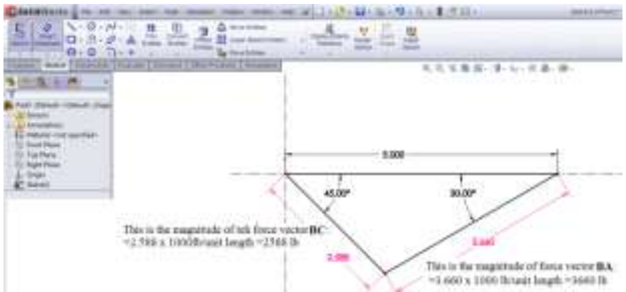


Figure 7: Direct measurement for obtaining answers for the statics problem

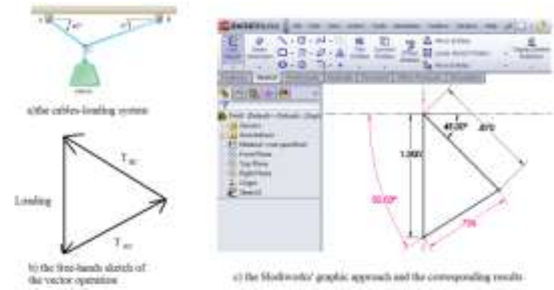


Figure 8: Examples 2 –equilibrium of a particle

B: Truss analysis by SolidWorks simulation

The main objective in Statics is to determine the reaction and internal forces of objects or components. Most exercise problems are an abstraction of real-world applications. After the methods of joints and sections are fully explained and used to determine the internal forces of each member for simple trusses, most students are eager to know how to deal with truss analysis in real-world designs. SolidWorks Simulation is one of many tools used in real-world engineering design [5,6,7,8,13]. SolidWorks is the simulation tool chosen for, and implemented in our mechanical engineering and technology programs [9, 10, 11, 12].

After the methods of joints and sections are fully explained and used to determine the internal forces of each member of simple trusses, we use one 2-hour lab to demonstrate how to use SolidWorks Simulation to determine the internal forces for each truss member. The primary purpose of this approach is not to teach students how to perform the Finite Element Analysis (FEA), but to expose them to numerical simulation and demonstrate that it can provide professionally accepted results, that can be verified by theoretical analysis discussed in the lecture.

During the lab, students follow the faculty in a step by step solution of a simple three-member truss problem as shown in figure 9-a. The truss members are made from 3”x2”x0.25” rectangular tubes with a length of 6 feet each. The 1000 lb force is applied at joint B. The model and the boundary conditions in SolidWorks Simulation are shown in figure 9-b. The procedure for performing truss analysis is shown in detail in reference [13]. The internal force for each member is shown in figure 10.

The internal forces and the relative error of each truss member by the method of joints and SolidWorks Simulation are listed in table one. The maximum relative error is 1.8%. This numerical simulation example shows students that the results of the analytical approach and the numerical simulation are not the same, but can be accepted due to the small relative error.

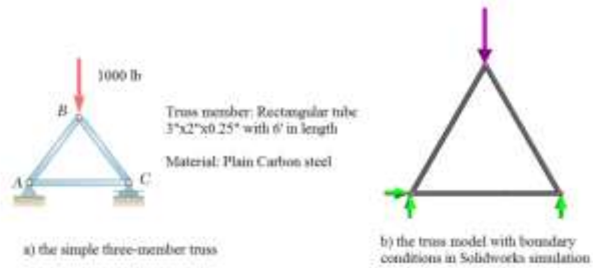


Figure 9: Simple three-member truss and its model in SolidWorks Simulation

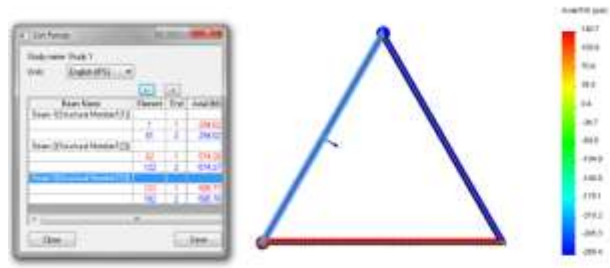


Figure 10: Internal force of each member of the truss by the SolidWorks Simulation

Table 1: Comparison of analytical results and numerical simulation results

Truss member	$T_{AB-theory}$	$T_{AB-simulation}$	The relative error: $abs\left(\frac{T_{AB-theory} - T_{AB-simulation}}{T_{AB-theory}}\right)\%$
AB	-577.4	-585.8	1.5%
BC	-577.4	-574.3	0.5%
AC	288.7	294.0	1.8%

Students are then asked to perform the SolidWorks simulation of a Warren bridge truss as shown in figure 11. The truss members are made from 3"x2"x0.25" plain carbon steel rectangular tubes. Students are asked to run the SolidWorks Simulation and as well as calculate the internal force of the truss member BD by the method of sections. Students were pleased and excited to find that the internal force of member BD by numerical simulation and method of sections were 8995.2, and 9000 respectively.. The relative error was only 0.05%.

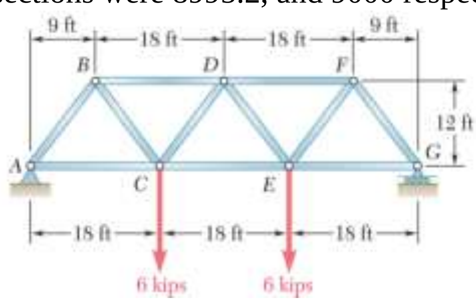


Figure 11: Warren bridge truss [1]

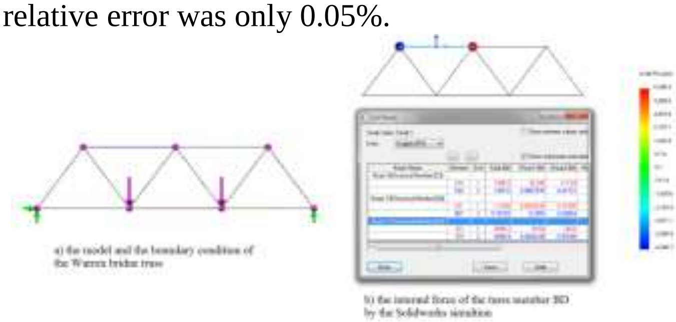


Figure 12: SolidWorks Simulation on the Warren bridge truss

C: Discussion

The SolidWorks' graphical approach for statics of a particle is an alternative approach for solving statics problems. This approach is simple and straight forward. It provides technology students an alternative to overcome difficulties in the first few weeks of class in performing and visualizing vector operations. Many students used this approach to solve the exercise problems involving statics of particles. Some engineering students used this approach to verify their analytical solutions.

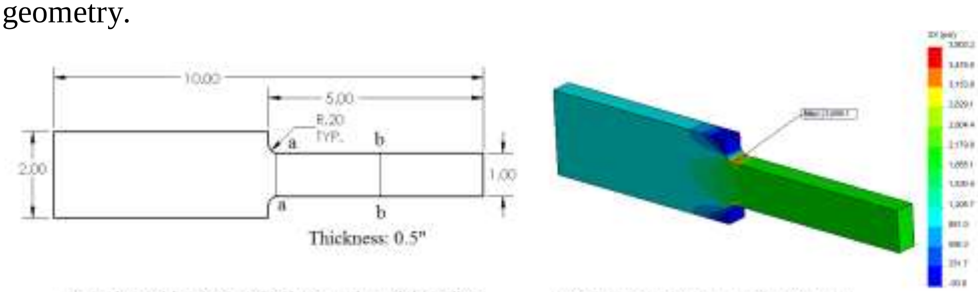
SolidWorks Simulation of a truss is only one demonstration exercise in the Statics course. The primary purpose of this demonstration exercise is to expose students to numerical simulation by using an industry accepted design tool, namely SolidWorks Simulation, and to bridge the gaps between the analytical approaches taught in class and the design - analysis approach used in industry.

3.3 Application of SolidWorks in Strength of Materials

Strength of Materials has 3 hours of lecture and 2 hours of lab per week. The 10 physical experiments and two virtual labs of numerical simulation are conducted during lab periods. Faculty derive typical stress equations, teach students how to calculate stress and strain under different loading conditions and then discuss and demonstrate how to compare the component stress with the material properties through design theory to conduct component design. However, we also use SolidWorks Simulation as a demonstration and visualization tool to show the stress distribution of components under different loading scenarios. SolidWorks' graphical approach is also used to draw Mohr's circle and to directly measure the shear and normal stress at any orientation.

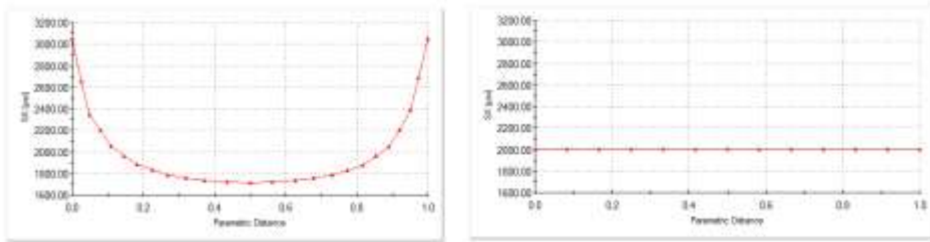
A: The stress concentration

A geometric discontinuity can cause an object to experience a local increase in the intensity of stress field. There are many ways to explain the stress concentration phenomenon, including photo-elasticity, physical, and virtual experimentation. SolidWorks Simulation is a practical tool for our pedagogy because every student is issued a laptop with SolidWorks installed. We use a lecture to demonstrate numerical simulation on a component under a 1000-lb axial loading as shown in figure 13-a. The purpose of using SolidWorks Simulation in Strength of Materials is not to teach students FEA, but to use this tool in virtual experiments for visualizing the stress distribution, and facilitating their understanding of concepts taught in lecture. Students follow the faculty in the numerical simulation step by step. The axial stress distribution of a component under axial loading is shown in figure 13-b, which shows the stress concentration phenomena. The distribution of axial stress along section b-b, in figure 14-b, shows that the stress is uniformly distributed. The axial normal stress from SolidWorks simulation is almost equal to the values obtained by the theoretical calculation. The axial normal stress along section a-a shown in figure 14-a, also clearly shows the stress concentration due to change in geometry.



a) A plate with a geometric chane under axial loading b) the axial normal stress distribution

Figure 13 Axial stress distribution of a plate under axial loading



a) the axial normal stress along the line a-a

b) the aixal normal stress along the line b-b

Figure 14 Comparison of axial normal stresses along the sections a-a and b-b

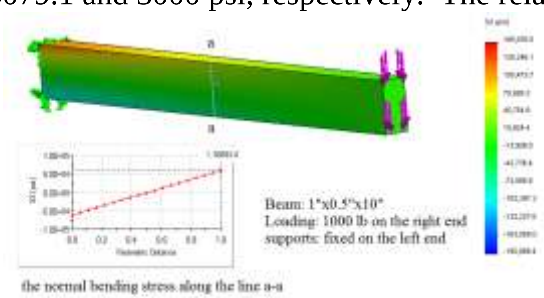
B: Demonstration of stress distributions of bending, torsion and shearing

After stress equations under bending, shear and torsion are fully derived and discussed, SolidWorks Simulation is usedfor virtual labs, comparing the numerical simulation with the derived results. Students follow the faculty step by step, through each demonstration which takes approximately 20 minutes.

Example 3: A beam with 1” x 0.5” cross-section and length 10” is fixed at the left end and subjected to 1000-lb transverse load on the right end. Display normal and shear stresses along section a-a and compare the numerical with theoretical results.

The bending stress distribution of the beam and the bending stress along a-a are shown in figure 15. Figure15 shows that the bending stress along line a-a is linear and the maximum and minimum bending stress are on the outermost fibers. This verifies the linear distribution of stress as per the bending stress formula. The maximum stress at section a-a obtained from the numerical simulation and the theoretical calculation are 60,693.8 and 60,000 psi, respectively. The relative error is 1.1%.

The shear stress distribution along section a-a is shown in figure 16. The maximum shear stress from numerical simulation and the theoretical calculation by the shear stress formula are 3079.1 and 3000 psi, respectively. The relative error is 2.6%.



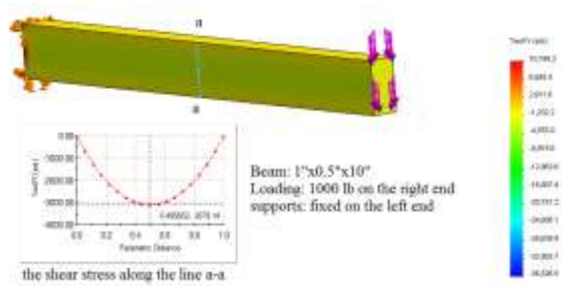


Figure 15:Normal bending stress distribution and the stress along the line a-a

Figure 16:Shear stress distribution along the line a-a

Example 4: A shaft with diameter 1” and length 4” is fixed at the left end and is subjected to 1000-lb.in torque on the right end. Display the shear stress along a diametral line and compare the numerical with the theoretical results.

The simulation results in figure 17 show that shear stress distribution along the diametral line a-a is linear, which is one main assumption for deriving the torsion formula. The maximum shear stress along a-a from numerical simulation and theoretical analysis using the torsion formula are 5096.8 and 5093.0, psi; respectively. The relative error is 0.07%.

C: Constructing Mohr's circle using SolidWorks' graphical approach

Mohr's circle is a two-dimensional graphical representation of the state of stress at a point. The stress transformation equations and Mohr's circle are two different approaches for solving for normal and shear stresses at any orientation. According to the discussion in section 3.1 above, SolidWorks' sketcher can effectively be used to construct the Mohr's circle. The following describes the approach for the construction of Mohr's circle.

Example 5: The stress element of a point is shown in figure 18. Use the Mohr's circle to determine the normal and shear stresses on the surface along line a-a

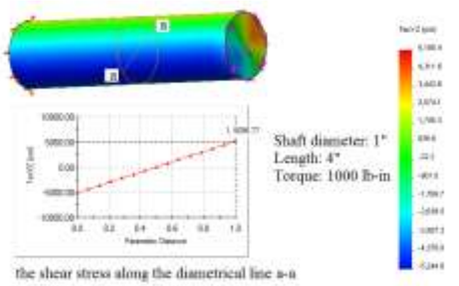


Figure 17: Shear stress distribution along the diametral line under torsion

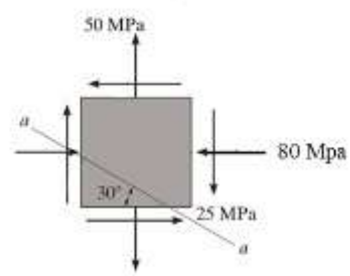


Figure 18: 2D stress element

Procedure for constructing the Mohr's circle using SolidWorks

Step 1: Activate SolidWorks and enter part mode by clicking "new", "part" and "ok" as shown in figure 3. Then enter the sketch mode by clicking "Sketch" and select any one of existing sketch planes such as "Front plane" as shown in figure 4.

Step 2: Draw the vertical and horizontal axes to form a 2D coordinate system as shown in figure 19. The horizontal axis represents the normal stress and the vertical axis represents the shear stress. The sign conventions for the Mohr's circle are: (1) Tensile stresses (positive) are to the right; (2) Compressive stresses (negative) are to the left; (3) Clockwise shear stresses (positive) are plotted upward and (4) Counterclockwise shear (negative) stresses are plotted downward.

Step 3: Choose a scale or a ratio representing the stress per unit length to be used in SolidWorks. In the 2D coordinate system sketched in step 2, the coordinate values with respect to the horizontal and the vertical axes are in length unit, but they represent stresses. For example 5 we can use the scale 10 Mpa/unit length. According to the sign convention specified in step 2, the stress element (σ_x, τ_{xy}) and (σ_y, τ_{yx}) will be represented by the coordinate values $(-8, 2.5)$ and, $(5, 2.5)$ respectively.

Step 4: Draw the line in SolidWorks' sketcher and then use the "smart dimension" toolbar to dimension both ends as shown in figure 19.

Step 5: Use the "circle" to draw a circle centered at the midpoint of the line and through both ends of the line specified in step 4. This is the Mohr's circle in the SolidWorks' sketcher.

Step 6: Any point on the Mohr's circle represents the normal and shear stress at a corresponding orientation (angle). Draw a radial line from the center of the Mohr's circle to the Mohr's circle and then dimension the counterclockwise angle from the point (σ_x, τ_{xy}) to the radial line as 2θ.The angle θ is specified as the angle between the outer normal of the interested surface for normal stress and shear stress and the positive x axis (the horizontal axis). The coordinate values of the specified point on the Mohr's circle will represent the normal and shear stresses as shown in figure 21. For this example, the angle θ is 60 degrees which measure 120 derees on the Mohr's circle (2θ). From figure 21, the normal stress and shear stress will be:

$$\sigma_\theta = 0.415 \times 10\text{Mpa/unit length} = 4.15\ \text{Mpa(Compression)}$$

$$\tau_\theta = 6.879 \times 10\text{Mpa/unit length} = 68.79\ \text{Mpa(CCW)}$$

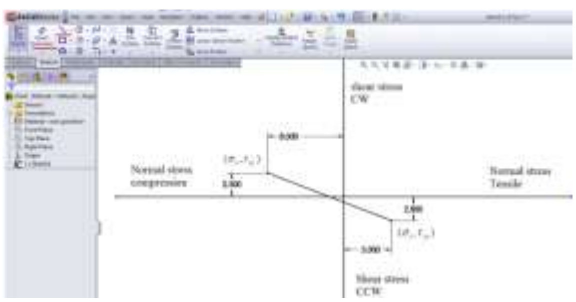


Figure 19: 2D coordinate and two end points of the (σ_x, τ_{xy}) and (σ_y, τ_{yx})

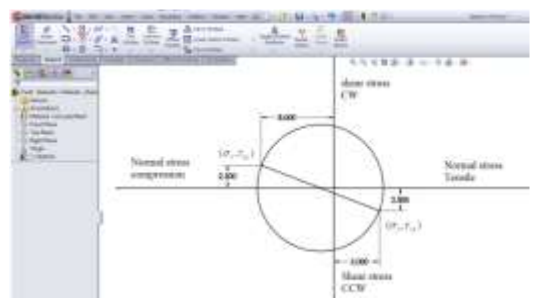


Figure 20: Mohr's circle in the Solidworks' sketcher

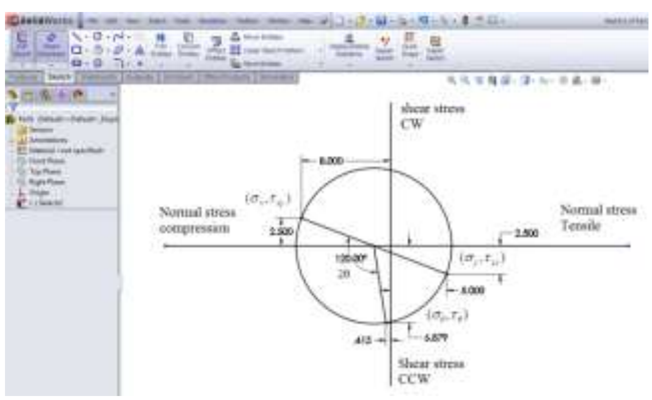


Figure 21: Normal and shear stress at the given orientation

C: Discussion

The Strength of Materials course is a core technical course and a foundation of mechanical design. The in-depth derivations, discussions and calculations of stress equations under different loading conditions are a must. Numerical simulation is a tool of choice in industry. Therefore, it is good pedagogy to use this tool as a virtual lab for visualizing the stress distribution of components under different loading. Comparing results using equations derived in lectures with numerical simulation results in students' understanding of concepts taught in lecture.

The SolidWork's graphical approach for Mohr's circle is simple and straightforward for determining the normal and shear stress of a point at a given orientation. It makes the Mohr's circle graphic approach a real alternative for determining the stress status at a desired point and orientation.

4. Survey data and analysis

In fall semester of 2011, we implemented the application of SolidWorks in MECH343-Statcis and MECH302-Stength of materials. At the end of the semester, we conducted a survey on two section of MECH343-statics and two sections of MECH302-Strength of materials.

The survey results for MECH343-Statics are shown in table 2. From the table 2, the 88% of students favored the application of the SolidWorks' graphic approach for vector operations on statics of particles and stated that the SolidWorks' graphic approach facilitated their understanding of vector operations. 82% of students stated that the numerical simulation demo on the truss analysis helped them have better understanding of structure analysis. The 78 % of students expressed that they would like to see more simulation in the course Statics.

The survey results for MECH302 –Strength of materials are shown in table 3. From table 3, 92% of students stated that the numerical simulation for visualizing stress distribution on the stress concentration area helped them to have better understanding of the stress concentration phenomena. The 81% of students agreed that the graphical approach of the Mohr's circle by SolidWorks is much simpler and more convenient for solving stress transformation problem. The 96 % of students expressed that they would like to see more numerical simulation in the course Strength of Materials.

Table 2 the survey results about the application of Solidworks in the course Statics

Question 1: The graphic approach for vector operations by SolidWorks facilitated and reinforced your understanding of the parallelogram law in solving vector operations on a particle.				
Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
20	23	5	1	0
Question 2: Application of the numerical simulation by SolidWorks in truss analysis helped you understand the analysis of structures.				
Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
18	22	7	2	0
Question 3: Additional simulation if possible should be added to the Statics course.				
Add a lot more	Add a little more	Leave alone	Remove a little	Remove Entirely
12	26	11	6	0

Table 3 the survey results about the application of Solidworks in "Strength of Materials"

question 1:The numerical simulation on stress concentration by Solidworks facilitated and reinforced your understanding of the stress concentration phenomena				
Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
10	14	2	0	
Question 2:The graphical approach of the Mohr's circle by Solidworks is much simpler and more convenient for solving stress transformation problem.				
Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
7	14	4	1	0
Question 3: Additional simulation if possible should be added to the Strength of Materials course.				
Add a lot more	Add a little more	Leave alone	Remove a little	Remove Entirely
10	15	1	0	0

Some of the comments made by the students for Statics classes were: "SolidWorks makes it easier to understand certain statics concepts and applications."; "It was great to apply SW to have a better understanding and another method to find forces."; "It really helped in solving problems."; and "Getting a basic understanding of the work is good then SW makes it go faster."

Some of the comments made by the students for Strength of Materials classes were: "Simple and easy to understand. Made the equations make more sense."; "Would like to see it implemented more."; "Extremely helpful, a method to double-check work."; and "Helps visualize the theories with greater ease."

5. Discussions and Conclusions

Statics and Strength of Materials are two basic core technical courses for mechanical engineering and mechanical engineering technology programs. During these two courses, we discussed every concept, derived every important equation and demonstrated how to apply the concepts and equations to solve exercise problems.

The vector operations: the parallelogram law, the triangle rule and the polygon rule are graphically described and stated for explaining and conducting force vector operations. But most Statics textbooks do not provide an effective executable tool to make their graphics approach practical. The SolidWorks' graphic approach described in this paper can be used as an effective executable tool to run the vector operations. This SolidWorks' graphic approach is an effective alternative to the analytical approach of the vector operations. Since its implementation in our courses at Wentworth, it has helped many students, who were not strong in trigonometry, to overcome their obstacles during the first few weeks of Statics course. This approach is simple, straightforward, and easy to use and provides accurate results. It helped students to have a better understanding of the vector operations.

The Mohr's circle with the SolidWorks' graphic approach described in this paper becomes a real graphic approach for determining accurate stresses at given orientation. It becomes an alternative to the stress transformation approach. The SolidWorks' graphic approach is simple and straightforward and is easy to use. After this approach is fully understood, students remember it as an alternative to the stress transformation equations.

The numerical simulation is a design tool of choice used in industry. Statics and the Strength of Materials are two core technical foundation courses for engineering design. SolidWorks Simulation was successfully used as a virtual lab and demonstration tool in truss analysis, and to determine stress distribution of components under different loadings. The visualization of stress distribution and the verification of the numerical simulation results by theoretical calculation facilitated students understanding of the concepts and contents discussed in lecture.

According to our survey, students have shown a greater understanding of the concepts due to the approaches we implemented in Statics and Strength of Materials. Majority of students would like to see more application of numerical simulation in these two courses.

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