Lab #5

Analysis of Weldments Using Beam and Truss Elements

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ME 37100 Computer Aided Design

Section 1EF

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Abstract

In this lab, beams and truss elements were analyzed to compare the stresses and displacements through using ROPS and OUTRIGGERS models. A truss and beam element in the ROPS model were compared by looking at the forces experienced and was found that truss elements did not experience any bending moments. A fixed and immovable boundary conditions was applied for both model but determined that based on the geometry the design and where the boundary conditions are placed, may result in the same results for the two cases.

Introduction

FEA is used as a way to analyze both beam and truss elements to determine the forces experienced through an applied load. The two different structures vary in the load that can be applied. A truss structure is only able to take on axial load and acts as a tension/compression spring. When creating an mesh for the two types of structure, an beam is able to be discretized into their respective elements, but with a truss, the mesh is created over the entire structure as one element.

In the lab, plan carbon steel is used in both models. Each model, ROPS and OUTRIGGERS, a fixed geometry and immovable end point constraint is used. In the OUTRIGGERS model trusses and beams are used to compared the stresses and displacements experienced by the model.

Theoretical Background

Immovable constraints are used to set all translational motion to 0. Such applies to any type of elements (beams, trusses, solids, etc.) while a fixed geometry constraint also constraints the rotational motions. For the purpose of the analysis, end caps are suppressed due to meshing. With end caps included, the structure would be meshed with solid elements. Results can vary based on the constraints and where the load is applied. Changing plains can result in difference in both the overall displacement distribution of the structure and the maximum stress and where such stress concentration occurs.

Graphical Demonstrations of SolidWorks Results

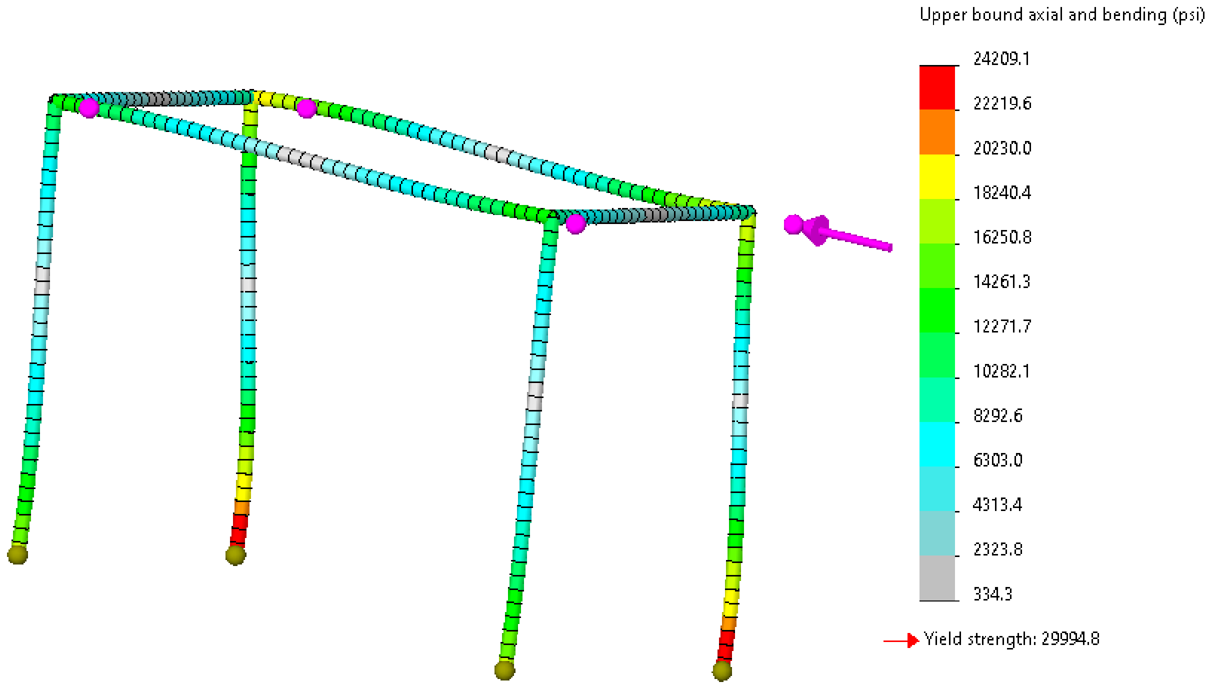

Figure 1A: ROPS model axial and bending diagram with fixed end points and a 2000 lbf force inward at a corner node

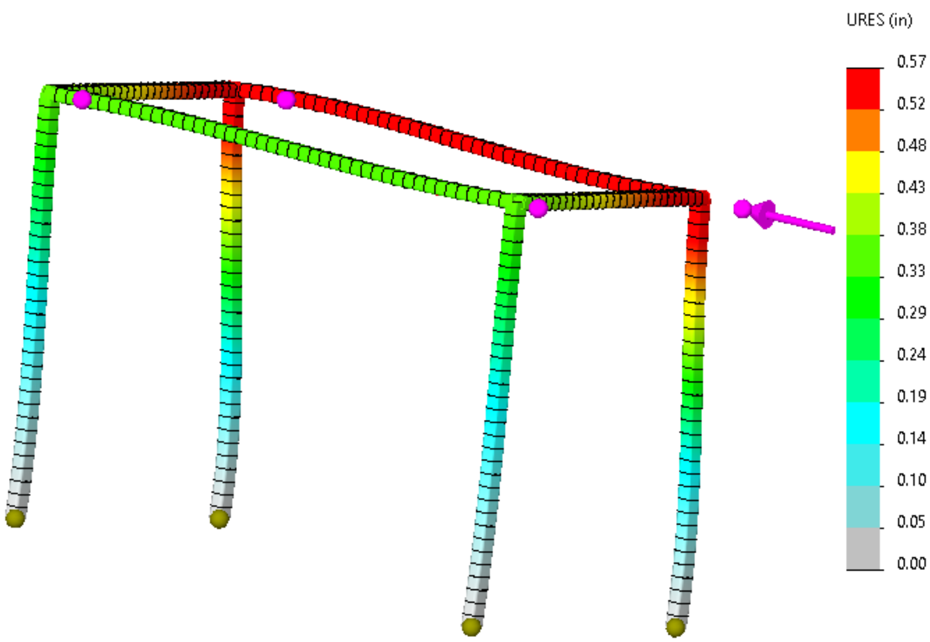

Figure 1B: ROPS model displacement diagram with fixed end points and a 2000 lbf force inward at a corner node

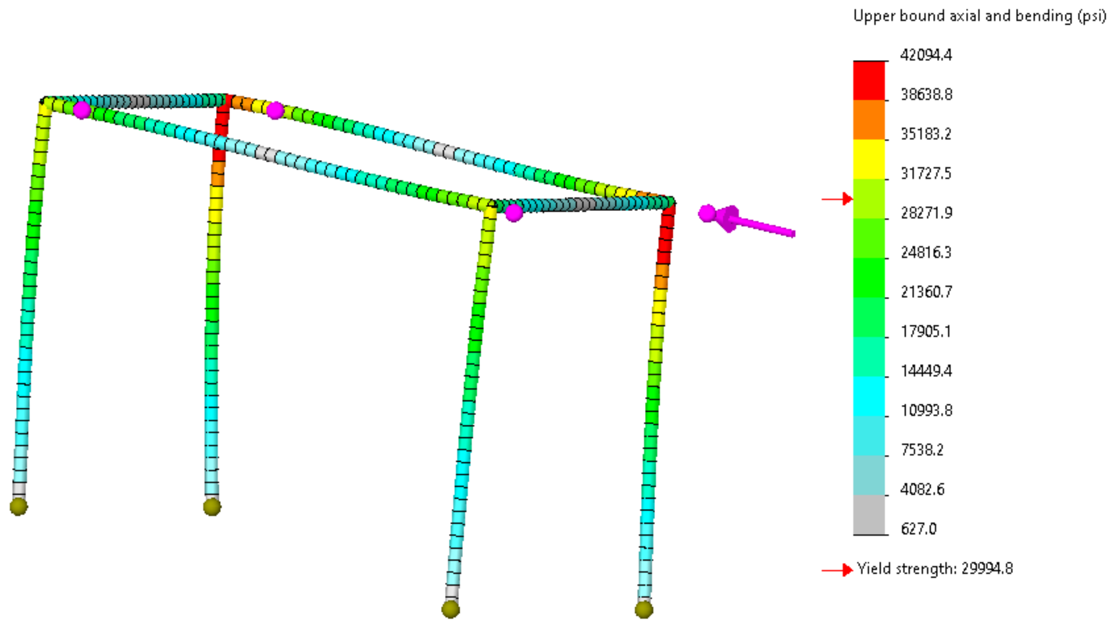

Figure 2A: ROPS model axial and bending diagram with immovable end points and a 2000 lbf force inward at a corner node

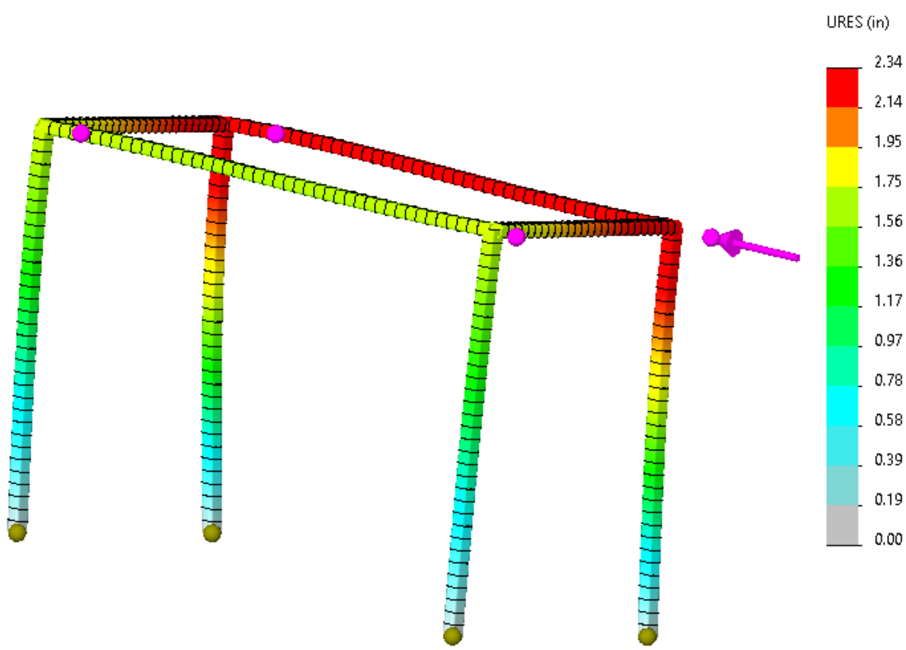

Figure 2B: ROPS model displacement diagram with immovable end points and a 2000 lbf force inward at a corner node

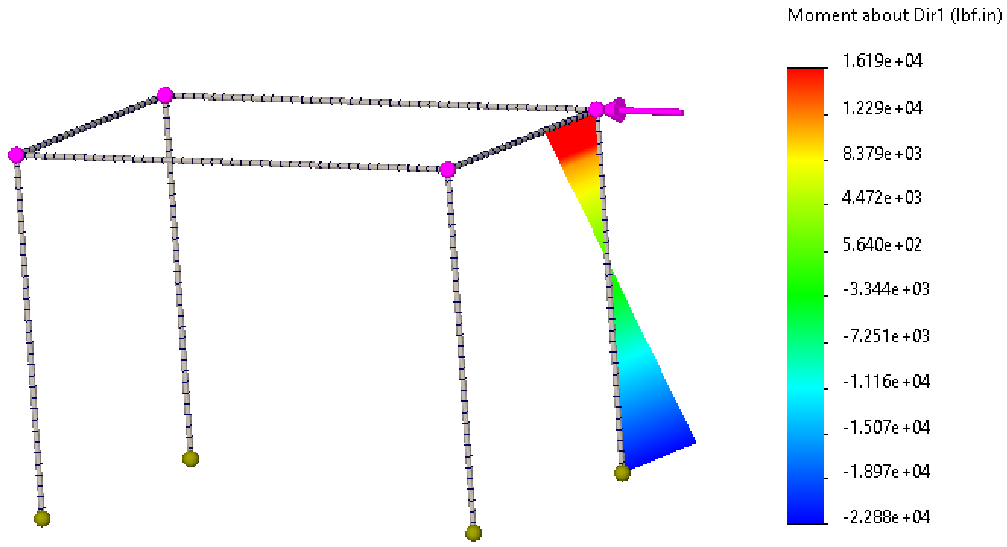

Figure 3A: ROPS model moment diagram with fixed end points and a 2000 lbf force inward at a corner node

Figure 3B: ROPS model moment diagram with immovable end points and a 2000 lbf force inward at a corner node

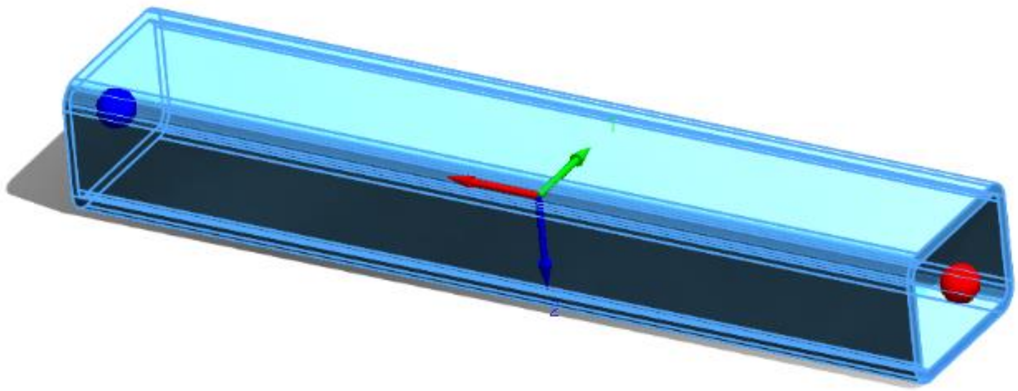

Figure 4A: TUBE model directional diagram

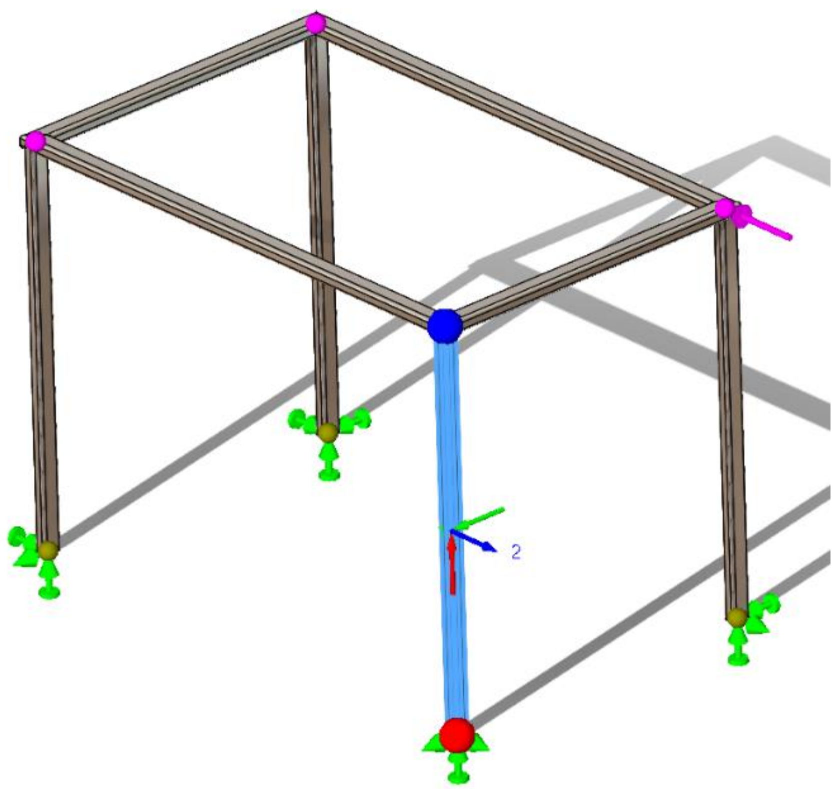

Figure 4B: ROPS model directional diagram of one structural member

Beam Name	Element	End	Axial (lbf)	Shear1 (lbf)	Shear2 (lbf)	Moment 1 (lbf.in)	Moment 2 (lbf.in)	Torque (lbf.in)

Beam-1(Structural Member3[1])	1	1	229.08	-175.03	649.99	-22,832	-6,226.40	-1,727.80
	33	2	-229.08	175.03	-649.99	-16,167	-4,275.40	1,727.80
Beam-2(Structural Member2[2])	34	1	-383.48	175.03	349.27	-12,638	6,226.40	-1,738.20
	66	2	383.48	-175.03	-349.27	-8,318	4,275.40	1,738.20
Beam-3(Structural Member1[1])	67	1	-2.15E-05	348.5	-143.09	3,577.30	8,712.50	1,288.70
	93	2	2.15E-05	-348.5	143.09	3,577.30	8,712.50	-1,288.70
Beam-4(Structural Member1[2])	94	1	0.96138	-175.03	240.39	-9,617.10	-7,017.70	698.11
	137	2	-0.96138	175.03	-240.39	-9,614.20	-6,984.70	-698.11
Beam-5(Structural Member1[3])	138	1	2.15E-05	350.24	143.09	-3,577.30	8,755.90	1,299.10
	164	2	-2.15E-05	-350.24	-143.09	-3,577.30	8,755.90	-1,299.10
Beam-6(Structural Member1[4])	165	1	998.49	-175.03	372.18	-14,896	-7,017.70	698.11
	208	2	-998.49	175.03	-372.18	-14,879	-6,984.70	-698.11
Beam-7(Structural Member3[2])	209	1	-229.08	175.03	651.28	-22,882	6,226.40	-1,738.20
	241	2	229.08	-175.03	-651.28	-16,195	4,275.40	1,738.20
Beam-8(Structural Member2[1])	242	1	383.48	-175.03	349.46	-12,642	-6,226.40	-1,727.80
	274	2	-383.48	175.03	-349.46	-8,325.50	-4,275.40	1,727.80

Table 1A: Shear, axial, moment and torque of the ROPS model at each beam with fixed end points.

Beam Name	Element	End	Axial (lbf)	Shear1 (lbf)	Shear2 (lbf)	Moment 1 (lbf.in)	Moment 2 (lbf.in)	Torque (lbf.in)
Beam-1(Structural Member3[1])	1	1	387.12	-239.41	616.81	-4.35E-09	-8.87E-10	-1.25E-09
	33	2	-387.12	239.41	-616.81	-37,009	-14,364	8.10E-08
Beam-2(Structural Member2[2])	34	1	-1,112.90	239.41	383.02	-2.63E-09	9.06E-10	-1.26E-09
	66	2	1,112.90	-239.41	-383.02	-22,981	14,364	8.07E-08
Beam-3(Structural Member1[1])	67	1	-4.00E-05	382.36	-480.65	12,016	9,558.90	2,302.80
	93	2	4.00E-05	-382.36	480.65	12,016	9,558.90	-2,302.80
Beam-4(Structural Member1[2])	94	1	0.72939	-239.41	632.22	-25,290	-9,593.70	2,348.10
	137	2	-0.72939	239.41	-632.22	-25,288	-9,558.90	-2,348.10
Beam-5(Structural Member1[3])	138	1	4.00E-05	383.75	480.65	-12,016	9,593.70	2,308.90
	164	2	-4.00E-05	-383.75	-480.65	-12,016	9,593.70	-2,308.90
Beam-6(Structural Member1[4])	165	1	999.17	-239.41	867.78	-34,716	-9,593.70	2,348.10
	208	2	-999.17	239.41	-867.78	-34,706	-9,558.90	-2,348.10
Beam-7(Structural Member3[2])	209	1	-387.12	239.41	617.08	-4.53E-09	9.42E-10	-1.27E-09
	241	2	387.12	-239.41	-617.08	-37,025	14,364	8.09E-08
Beam-8(Structural Member2[1])	242	1	1,112.90	-239.41	383.09	-2.87E-09	-9.93E-10	-1.26E-09
	274	2	-1,112.90	239.41	-383.09	-22,985	-14,364	8.10E-08

Table 1B: Shear, axial, moment and torque of the ROPS model at each beam with immovable end points.

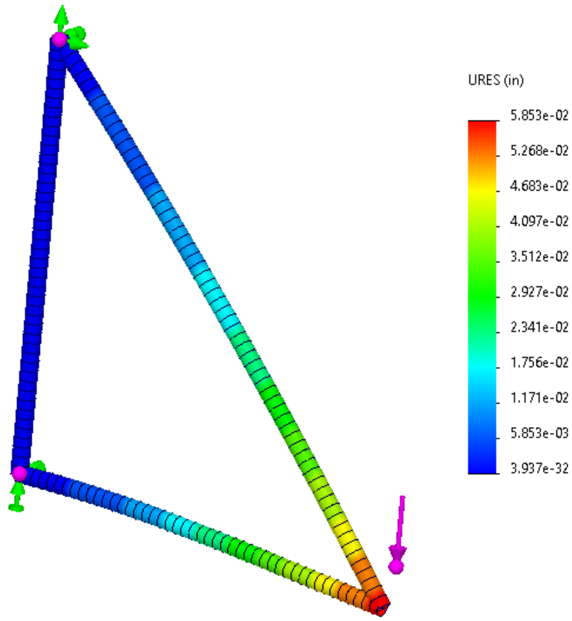

Figure 5A: OUTRIGGERS beam model displacement diagram with fixed end points and a 20000 lbf force inward at a corner node

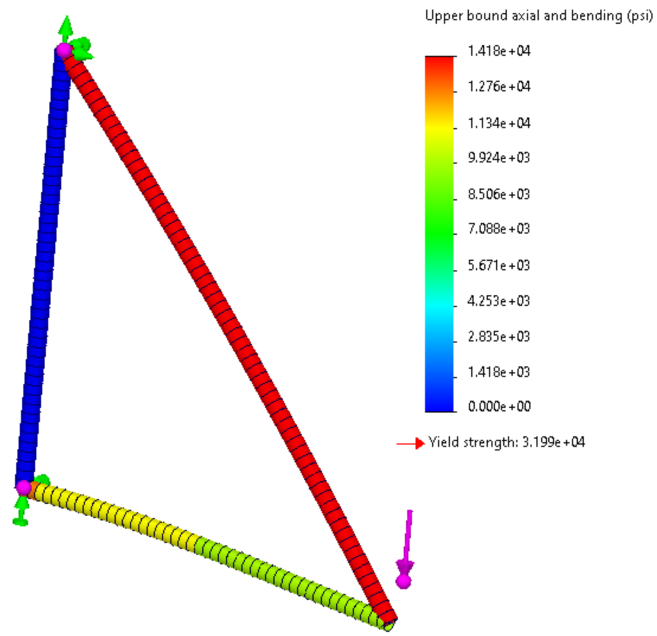

Figure 5B: OUTRIGGERS beam model axial and bending diagram with fixed end points and a 20000 lbf force inward at a corner node

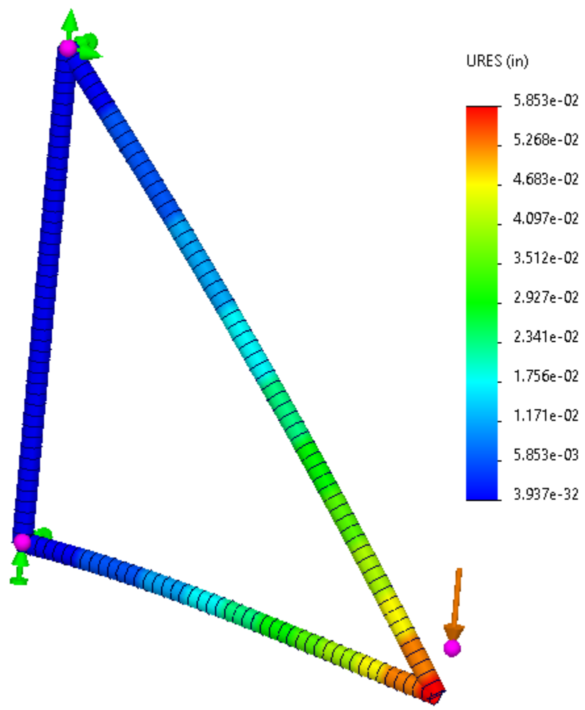

Figure 6A: OUTRIGGERS truss model displacement diagram with fixed end points and a 20000 lbf force inward at a corner node

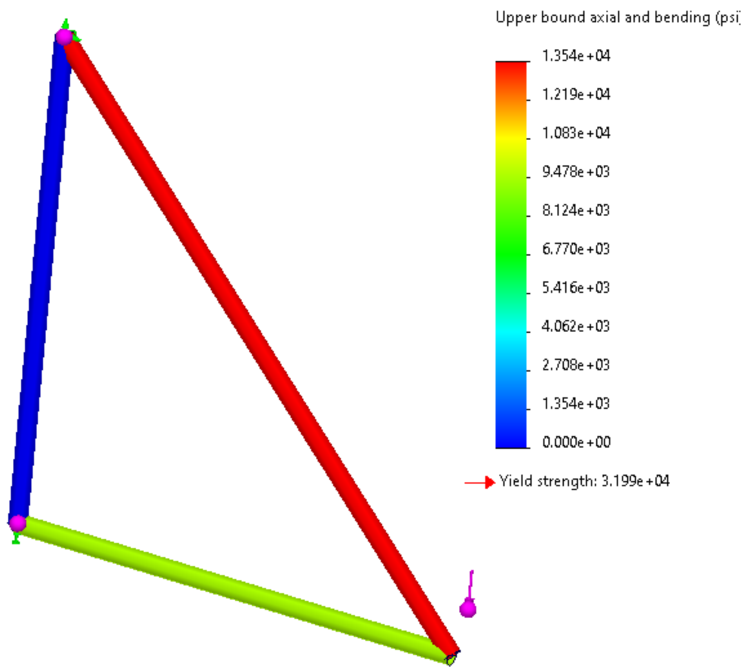

Figure 6B: OUTRIGGERS truss model axial and bending diagram with fixed end points and a 20000 lbf force inward at a corner node

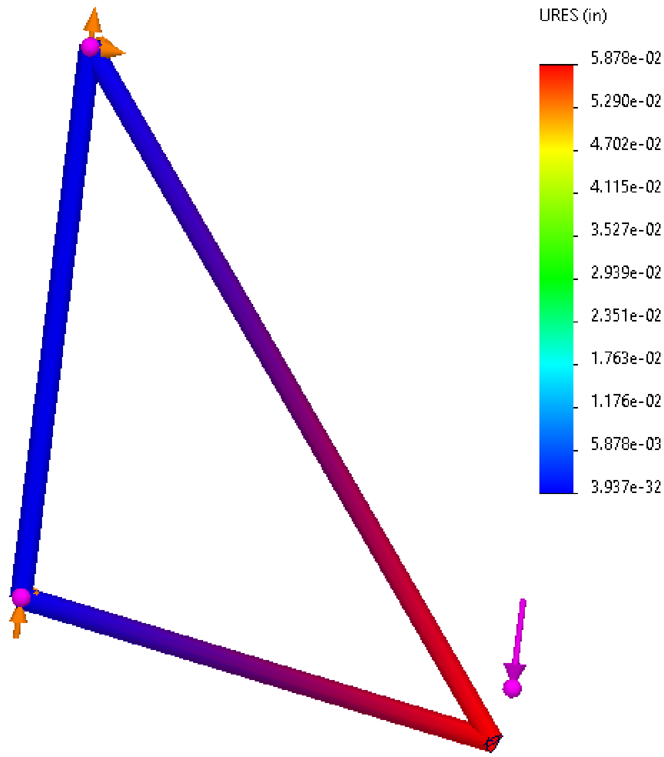

Figure 7A: OUTRIGGERS truss model displacement diagram with immovable end points and a 20000 lbf force inward at a corner node

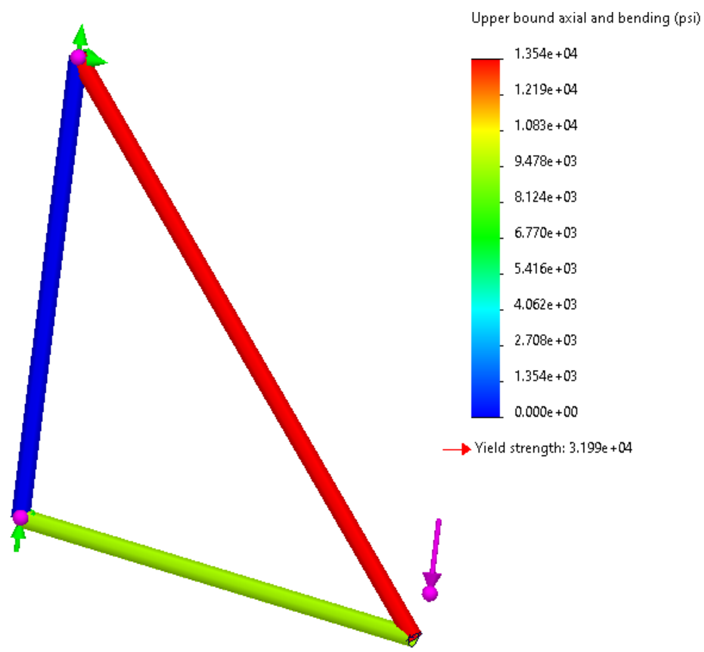

Figure 7A: OUTRIGGERS truss model axial and bending diagram with immovable end points and a 20000 lbf force inward at a corner node

Beam Name	Element	End	Axial (lbf)	Shear1 (lbf)	Shear2 (lbf)	Moment 1 (lbf.in)	Moment 2 (lbf.in)	Torque (lbf.in)
Beam-1(Rectangular tube - configured 3 X 2 X 0.25(1))	1	1	19,919	6.05E-06	81.297	-797.41	1.95E-05	-1.18E-05
	46	2	-19,919	-6.05E-06	-81.297	-3,044.30	0.000267	1.18E-05
Beam-2(Cut-Extrude2)	47	1	-28,169	-6.75E-06	-0.10514	797.41	-0.00528	2.22E-05
	110	2	28,169	6.58E-06	0.077161	-791.31	0.004963	-2.22E-05
Beam-3(Rectangular tube - configured 3 X 2 X 0.25(1))	111	1	0	0	0	0	0	0
	156	2	0	0	0	0	0	0

Table 2A: Shear, axial, moment and torque of the OUTRIGGERS model at each beam with fixed end points.

Beam Name	Element	End	Axial (lbf)	Shear1 (lbf)	Shear2 (lbf)	Moment 1 (lbf.in)	Moment 2 (lbf.in)	Torque (lbf.in)
Beam-1(Rectangular tube - configured 3 X 2 X 0.25(1))	1	1	20,000	0	0	0	0	0
	1	2	-20,000	0	0	0	0	0
Beam-2(Cut-Extrude2)	2	1	-28,284	0	0	0	0	0
	2	2	28,284	0	0	0	0	0
Beam-3(Rectangular tube - configured 3 X 2 X 0.25(1))	3	1	0	0	0	0	0	0
	3	2	0	0	0	0	0	0

Table 2B: Shear, axial, moment and torque of the OUTRIGGERS model at each truss element with immovable end points.

Beam Name	Element	End	Axial (lbf)	Shear1 (lbf)	Shear2 (lbf)	Moment 1 (lbf.in)	Moment 2 (lbf.in)	Torque (lbf.in)
Beam-1(Rectangular tube - configured 3 X 2 X 0.25(1))	1	1	20,000	0	0	0	0	0
	1	2	-20,000	0	0	0	0	0
Beam-2(Cut-Extrude2)	2	1	-28,284	0	0	0	0	0
	2	2	28,284	0	0	0	0	0
Beam-3(Rectangular tube - configured 3 X 2 X 0.25(1))	3	1	0	0	0	0	0	0
	3	2	0	0	0	0	0	0

Table 2C: Shear, axial, moment and torque of the OUTRIGGERS model at each truss element with fixed end points.

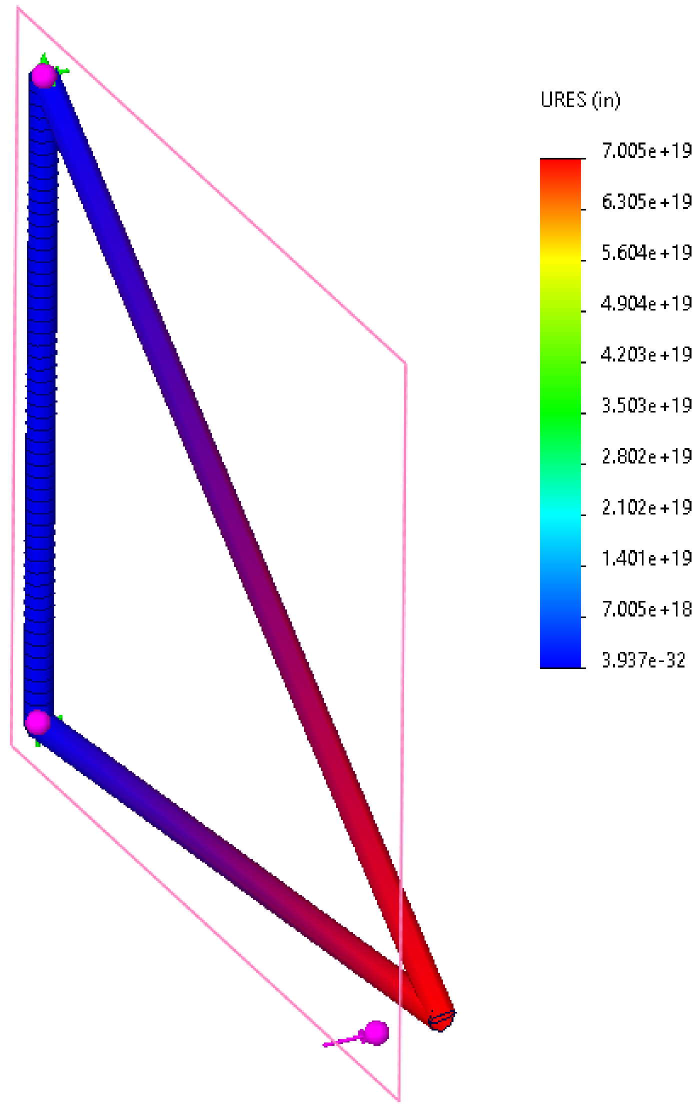

Figure 8A: OUTRIGGERS model displacement plot with an 20,000 lbf at a joint directed at the front plane

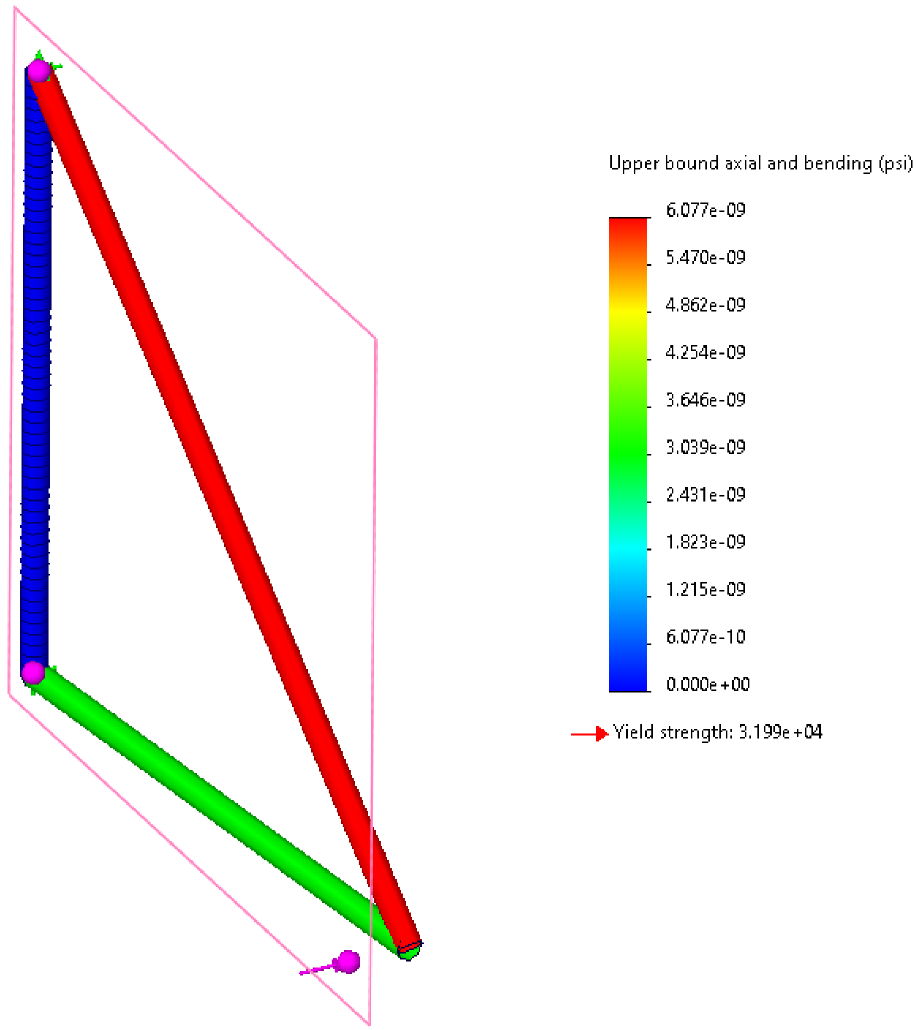

Figure 8B: OUTRIGGERS model axial and bending plot with an 20,000 lbf at a joint directed at the front plane

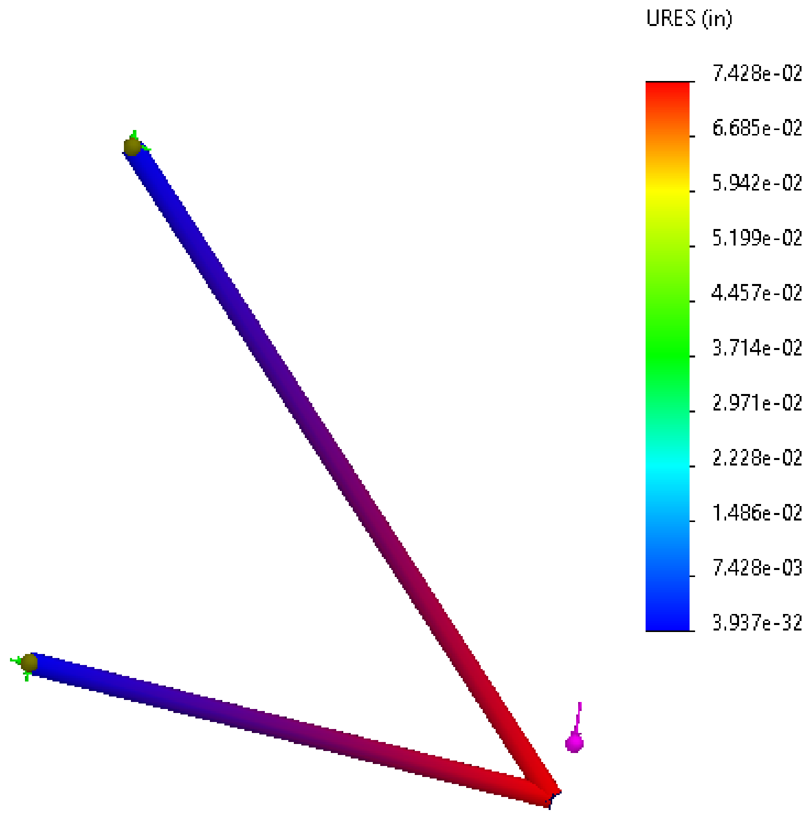

Figure 9A: OUTRIGGERS model displacement plot with an 20,000 lbf at a joint and vertical support removed

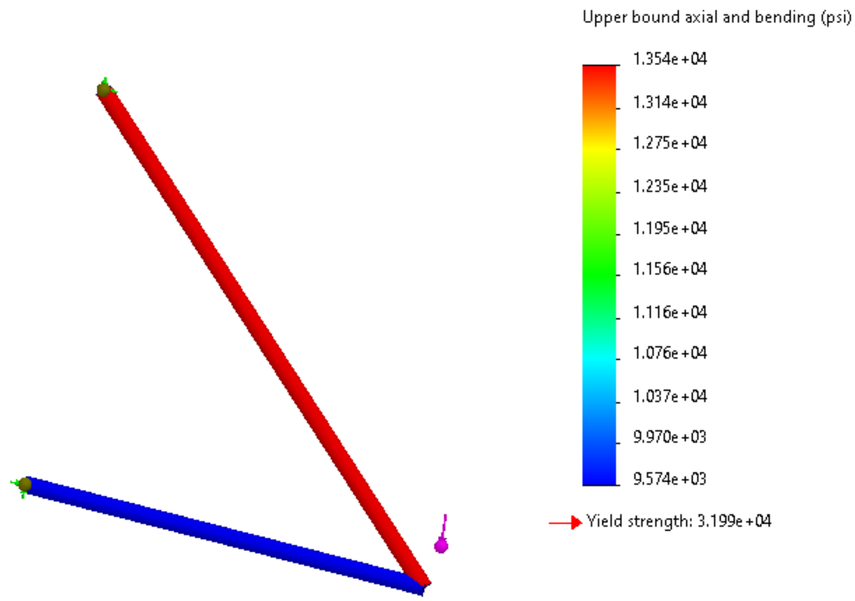

Figure 9A: OUTRIGGERS model axial and bending plot with an 20,000 lbf at a joint and vertical support removed

Discussion and Interpretation of Results

In the first portion of the lab, where two types of boundary condition was applied at the ends of the ROPS model, it was found that with the immovable constraint, the structure failed due to the maximum stress experienced exceeding the yield strength. It can also be seen that the max displacements are higher in the immovable constraints. This difference in results can also be seen in Table 1A and 1B, where each element of the beams in the model is different. The elements also display a different moment distribution seen in Figures 3A and 3B. The differences are due to the nature of the two constraints. Immovable only limited translational motion while a fixed geometry constraints also eliminates the rotational components. By keeping an extra degree pf freedom at the four end points, the applied force has the possibility to cause more displacement and overall force of each element of the model

In the second portion of the lab, both a beam element and truss element is observed. Based on Figures 5-6, where both beam and trusses use a fixed geometry constraint, it can be seen that while the displacements are the same, the truss element experiences less maximum stresses. The two different structures differ from the loads they can carry. While the truss can only carry axial load, the beam is able to carry shear forces and moments as seen in Table 2A and 2B. Compared to the first portion of the lab, the immovable constraint does not change the results of the stresses and load on the truss of the OUTRIGGERS model (Table 2B and 2C). This is also explained in the same manner as earlier in where trusses do not experience moments and therefore immovable restraints basically act as a fixed geometry.

From Figure 8A and 8B, it can be seen that changing the load causes a rotation in the OUTRIGGERS truss. It can be seen that the higher displacements, compared with the downward force as with the other studies, are higher due to the rotational motion occurring as it is not able to carry a moment. From figures 9A and 9B it can be that taking out the vertical support also increased the total max displacement. Without the support, it can be seen from the stress plots have the same maximum value. This result can be seen as with the other plots of the OUTRIGGERS truss where the vertical support is seen to not carry much of the stresses (figures 75A-7A). However, the vertical support is there to provide stability for the truss as can be seen in Figure 8A where the displacement increased due to the removal of the support.

Conclusions

In this lab, beam and truss structures were compared as well as different boundary conditions restraints for ROPS and OUTRIGGERS model. Immovable constraints do not differ from fixed geometry when it comes to truss structure as trusses inherently do not carry moments or shear forces. Trusses are only able to carry axial load which can be validated with the out of plane force in which significant rotations occur. However, in beam elements, by allowing that extra degree of freedom, it can be seen that it may cause more forces and moments experienced by the element of the model as seen in ROPS.

References

[1] Engineering Analysis with SolidWorks Simulation 2024, by Paul Kurowski (2024), ISBN-10: 1630576298.
[2] A First Course in the Finite Element Method, Enhanced Edition, 6th Ed., by Daryl Logan (2022), ISBN-10: 0357884140