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Stress optimization of steel plate under tension force by FEM

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Abstract — steel plate has many applications in steel structural engineering, the tension member is designed to provide adequate cross-sectional area to resist the tensile force applied, Eccentric axial loading is also exposed to steel plate members. The two most basic modes of failure for members subjected to tension are tensile yield on the gross section, tensile rupture on the net section and a block shear failure at the connections. Tensile yielding occurs in gross area, but stresses tensile rupture usually takes place through a row of bolts or holes where the resistance portion is weakest. There are many proses to determine basic mode failures but finite element method (FEM) is the best way of complex structures.

This literature viewpoint is targeted at research and knowledge behavior for steel plate under tension forces and optimization stress produced by FEM. The issue is that the FEM concentrated stress when constructing steel plates of complex structures has many locations such as position forces, holes and changing. cross-section members create concentration stress in FEM. How to optimize and handle this stress? by using the Autodesk inventor software. And what is the methods that used to reduce the stress?

If we have a plate without a hole or any cross-section change under tensile stress, we do not need to optimize (minimize) stress for the selection or design feature by using FEM. many members with tension have similar behavior. The samples and the literatures indicate that the stress on holes is greater three times than the net section but the study of finite elements must not differ to the AISC specification, it has high concentrated stress for the plates that have holes at the edge because it must be minimized.

Keywords*— Steel, tension, plate, hole, optimization and stress*

1.Introduction

Many structures use steel plate as a tension member, such as (truss, tawers, bridges and steel construction). Two primary failures are tensile yield and tensile rupture. The perspective focuses on the behavior of research and knowledge of steel plate under stress forces and optimization stress created by FEM, Concentrated stress is generated by FEM constructing complex structures, place forces, holes and changing cross-section members. Using the Autodesk Inventor program to optimize and control this tension. Professional-grade 3D mechanical modeling, documentation and product simulation tools are developed by Inventor CAD software. Function effectively with a powerful blend of capabilities for parametric, direct, freeform, and rules-based design.

Some samples were taken for this study literature to assess stress in the samples. They were used for specification without factor design, under nominal strength and fracture strength compared to FEM analysis. The Autodesk Inventor was used for FEM. all of them illustrated in the section result and discussion.

We do not need optimization (minimizing) stress for the selection or design function by using FEM if we have a plate without a hole or any cross-section change under tensile stress. But the analysis of finite elements must not differ to the AISC specification because it must be reduced, it has high concentrated stress for the plates that have holes at the edge.

2. Literature Review

When the steel members subjected to tension, the two most failures are tensile yielding on the gross section if the member do not have any change in cross section and tensile rupture at the net section by changing cross section, when it has a hole, it used in various types of structures such as truss members, bracing for buildings and bridges, cables in suspended roof systems, and cables in suspension and cable-stayed bridges (Nursalam, 2016 and Fallis, 2013). In fact, stresses on holes can be as high as three times than the mean stress on the net segment, and they can be more than twice in comparison with the average stress on fillets of rolled shapes(McGuire and Winter, 1968).

A discontinuity in geometry and a disturbance of stress trajectories are caused by the presence of holes in a plate, It is difficult to redistribute the stress concentration in the vicinity of the hole, leading to immediate cracking, resulting in a brittle failure. (Lutfi and Salih, 2010). The bolt nominal forces obtained from the FEM are almost linearly proportional to the bolt number arranged in the connection when the steel achieves the non-linear behavior. In reality, the bolt failure depends partially on the plate thickness that dominates the bending efficiency magnitude(Ju, Fan and Wu, 2004).There will be serious economic and human consequences from the failure of bolted connections, so it is important to gain a better understanding of the structural behavior of bolted connections, the bolted connection calculated from the AISC specification and finite element method are similar(Popov and Takhirov, 2002).

The bearing failure of cold-formed steel bolted connections under shear is studied by using a finite element model with 3D solid parts. they provide the support for studying of finite elements into the structural behavior of cold-formed steel bolted connections(Yang, Murray and Plaut, 2000).

The finite element program can be used as a method to evaluate graphical stress concentration factors for central hole flat plates and to be subjected to axial load, as it can statistically be seen that there are no substantial variations between the theoretical data and simulation data. When the geometric relationship between the hole diameter and the plate width is 0.0044 percent, the maximum measured error between these data is 5.42 percent(Santos, 2013).

Corrosion and cracking are two major causes for failure of plates but it may be changed by thickness of plate, number of pits, crack length and pit depth over thickness of the plate, ultimate strength is detected for thin plates(Ahmadi, Rahbar Ranji and Nowruzi, 2020). In modeling the tension members with bolted end connections, the finite element techniques are used. Not only in predicting the failure capabilities but also in tracing the entire load versus deflection path, the finite element methodology was presented(Barth, Orbison and Nukala, 2002).

Unlike tension plates, compression plates can have buckling-related deformities. For this purpose, compression bolted attachment field tests vary from tension joint studies in which there is a need to ensure thin-walled plate stiffness. Therefore, it is important to test particular profiles to ensure stiffness in order to evaluate the load-bearing ability of a compression-bolted link(Ustimenko and Skachkov, 2020). The tension concentration at the stop-hole wall and edge can be minimized by bolting the crack until the bolt slips are being under tensile and bending conditions. Furthermore, it was also explained that the concentration of stress at the wall and edge of the stop-hole decreased when the location of the bolt was closer to the stop-hole and the number of bolts in the crack increased. The stress concentrations at the stop hole wall and the edge of the bolting stop-hole are obtained from the FE results. they are smaller than those suggested by bolting a crack under tensile and bending conditions(Ishikawa, Kiyokawa and Nakatsuji, 2020).

Tension embers such as the channel section behavior is similar to the angle section behavior(Bharathi Priya *et al.*, 2011). According to the combined effects of relation eccentricity, shear lag and stress concentrations, the stress distribution in the vicinity of connections in a bolted steel angle is non-uniform(Gupta and Gupta, 2005). The specimens' finite element (FE) models were created. The FE predictions, in general, well agreed with the test responses. A typical failure mode of bolted tension members is net section rupture. In particular, the tension angle net section capacity is significantly affected as a result of shear lagging(Yam *et al.*, 2020). With the rise in pit depth and the decrease in pit width, the strength of the steel wire decreased gradually and the stress concentration factor increased. The improvement in pit clearance on the same side did not have an obvious impact on the strength and stress concentration factor of steel wire, but when located on the opposite side, it had a major effect. The concentration factor of strength and stress of steel wire with neighboring pits normally depended on the depth of the larger pits(Li, Miao and Yu, 2020).

With moderate connection eccentricity, the rupture load capacity of the net section was found to be significantly reduced and a net section with an efficiency factor was needed. Net section rupture was seen from the bolt hole to the free edge of the web followed quickly by shear rupture of the immediate bolt line (Orbison, Barth and Bartels, 2002). Comparing FE results and AISC features shows that the current design formula is too conservative to ultimate load the ability of RHS members tied to corners (up to 47 percent of the cases considered)(Abedin *et al.*, 2020).

He provided the findings of the ultra-tension coupon tests.Docol 1400 M high strength sheet steel performed at room (ambient) and elevated temperatures up to 700 °C, including coupons cooled in air or water from temperatures as high as 1000 C. The American and European codes were found to greatly underestimate the degree of tensile strength deterioration at elevated temperatures, whereas the elastic modulus degradation was well expected. The elastic modulus was less than 20 percent of the initial value at 700 °C, and just about 5 percent of the initial strength was tensile strength(Cho *et al.*, 2020).

3. Materials and Methods:

A. Literatures’ Method and Materials.

The significant strain concentration can be clearly observed at the edge of the bolt hole as well as the significant necking at the critical net section(Lutfi and Salih, 2010). Stress distribution for a plate subjected to tensile load in figure 2(Spotts and Shoup, 1999). comparisons between test results and FE predictions in figure 3(Yam et al., 2020).

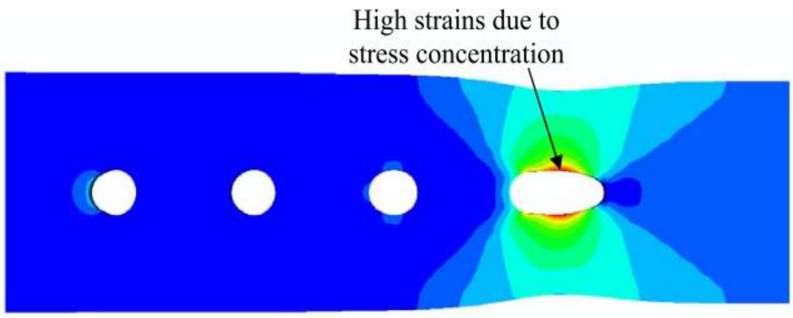


Figure 1 Typical FE model failing in net rupture from the parametric studies (Lutfi and Salih, 2010)

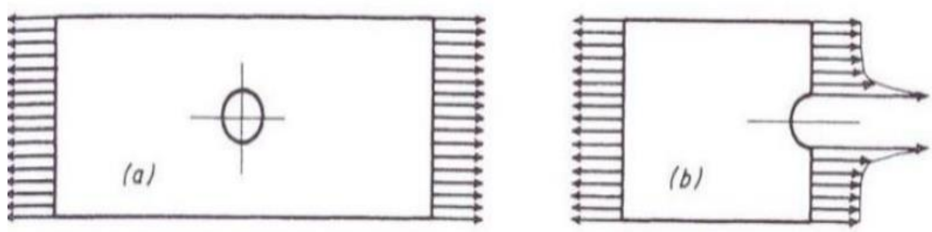


Figure 2 Stress distribution for a plate subjected to tensile load (a) away from the hole; (b) the section of the central hole (Spotts and Shoup, 1999).

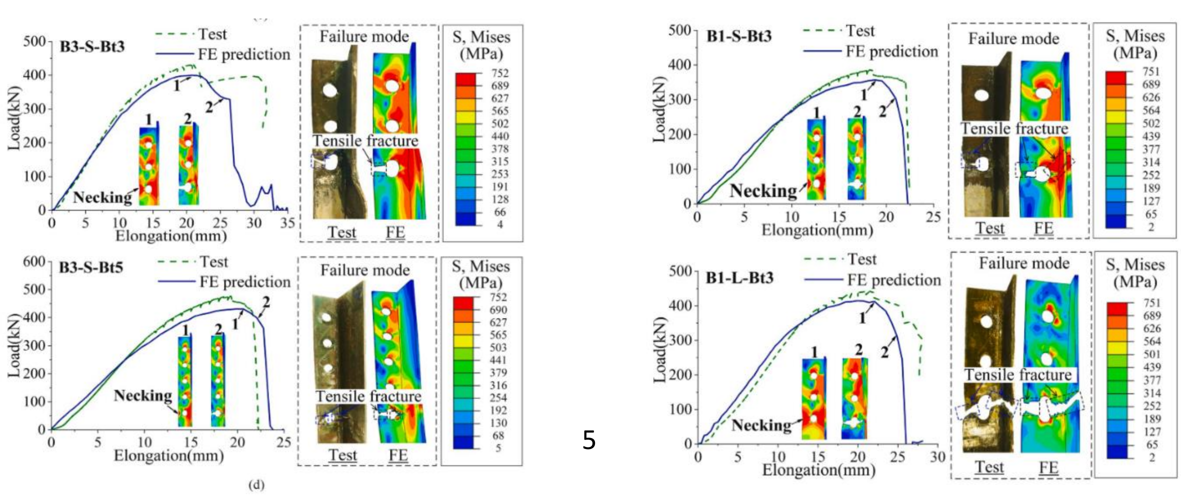


Figure 3 elongation and load test with FEM (Yam *et al.*, 2020)

B. Topic's Material and method.

Test samples under ASD and LRFD by AISC (Committee and others, 2010) specification without factor design, under nominal strength and fracture strength. For FEM used Autodesk Inventor.

Pn = Fy Ag (Segui, 2012)
Pn = Fe Ae (Segui, 2012)

Pn = nominal strength, Fy = Yield stress, Ag = gross section.
Fe = fracture stress, Ae = net Area

All sample information as seen in the section's result and discussion.
Sample 1. Tension Member Example 3.1 (Segui, 2012)
Sample 2. W12 Steel A992 section(Jack C. McCormac and Stephen f. Csernak, 2012).
Sample 3. S-shape example 3.9 (Segui, 2012).
Sample 4. plate with different size and shape hole.

4.Results and Discussions

The finite element program can be used as a method to evaluate graphical stress concentration. However, among these results, the maximum calculated error was 5.42 that he used the ANSYS software(Santos, 2013).

For multi-bolt connections of tension components, the forces on the line perpendicular to the force direction applied are concentrated in the region of the first row of the bolts and the concentration of forces in the region of the first bolt would still have a multi-bolt compression relation, but the key difference is the lack of breaking forces which are substituted by crushing forces as shown in figure 3(Ustimenko and Skachkov, 2020).

As well as the deformations occur at the end of the steel element with a cross-section of an equal or unequal single-angle is proved to affect the shape of the stress distribution. their ratios, experimental and FE-modelled load capacities and final elongations. The mean load capacity ratio of the FEM/load experimental load is 1.015, and in the final elongation is 1.006. These values illustrate that the simulation of steel components and FE analysis have a high accuracy(Sayed, 2020).

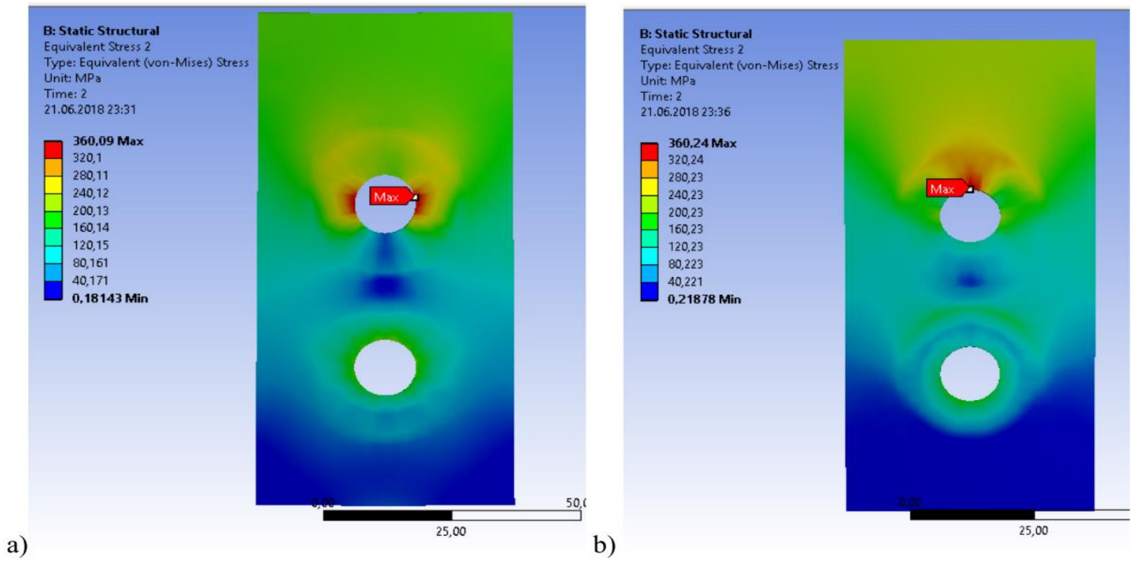


Figure 4 Diagram of bolted connection stresses: a – in tension element, b – in compression elements. (Ustimenko and Skachkov, 2020)

Some samples have been taken to find the stress and the concentrated of the stress by FEM compared with the numerical method.

Sample 1:

A plate of A36 steel is used as a tension member. It is connected to a gusset plate with four 5/8-inch-diameter bolts as shown in the below figure.

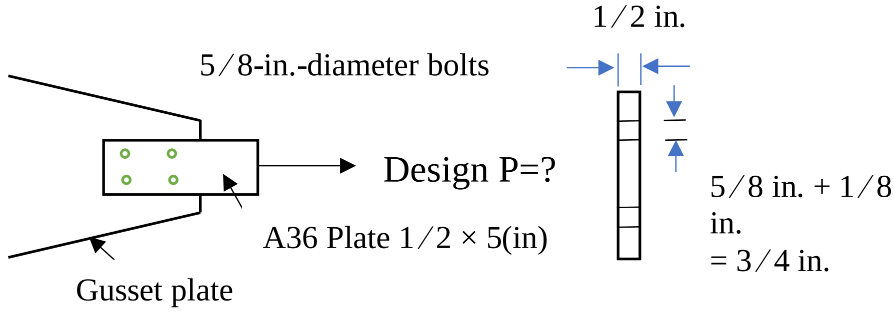
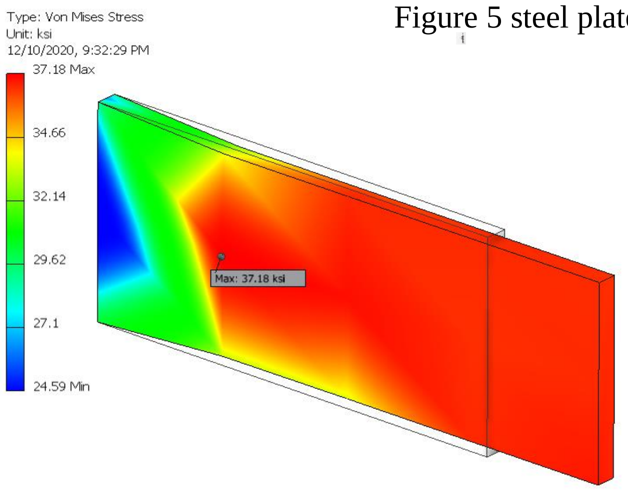


Figure 5 steel plate (Segui, 2012)



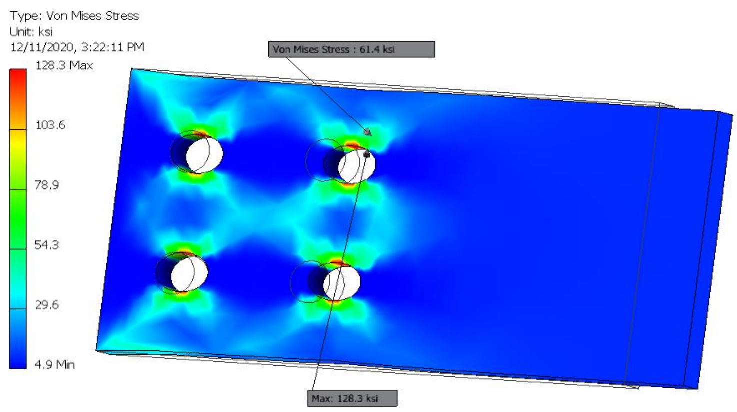


Figure 6 Sample one EFM stress is resulted by Autodesk Inventor with holes and without hole.

Sample 2:

W12 section A992 Steel the member is to have two lines of bolts each in flange for 7/8 in bolts, distance between bolts are 4 in (Jack C. McCormac and Stephen f. Csernak, 2012).

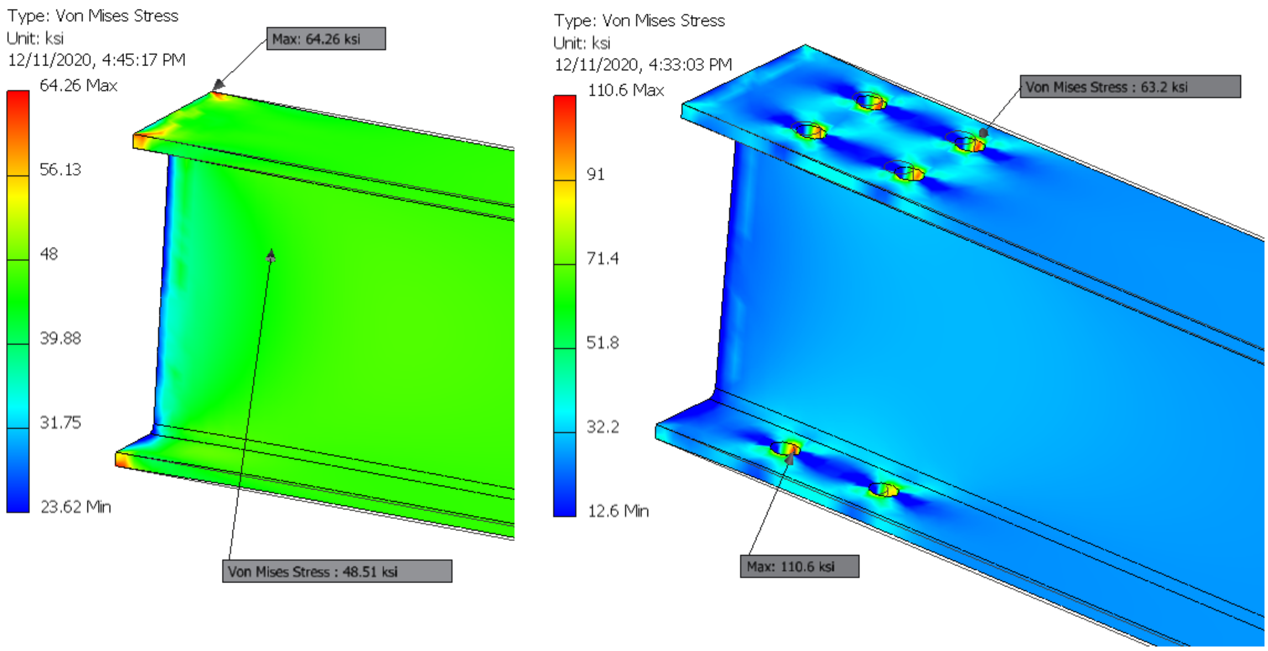


Figure 7 Sample two EFM stress is resulted by Autodesk Inventor with holes and without hole

Sample 3:

The S-shape(S15*50) is shown in the below figure. The holes are 3⁄4- for inch-diameter bolts. Use A36 steel, in this section bolt holes are staggered. center to center bolts (3.5) in.

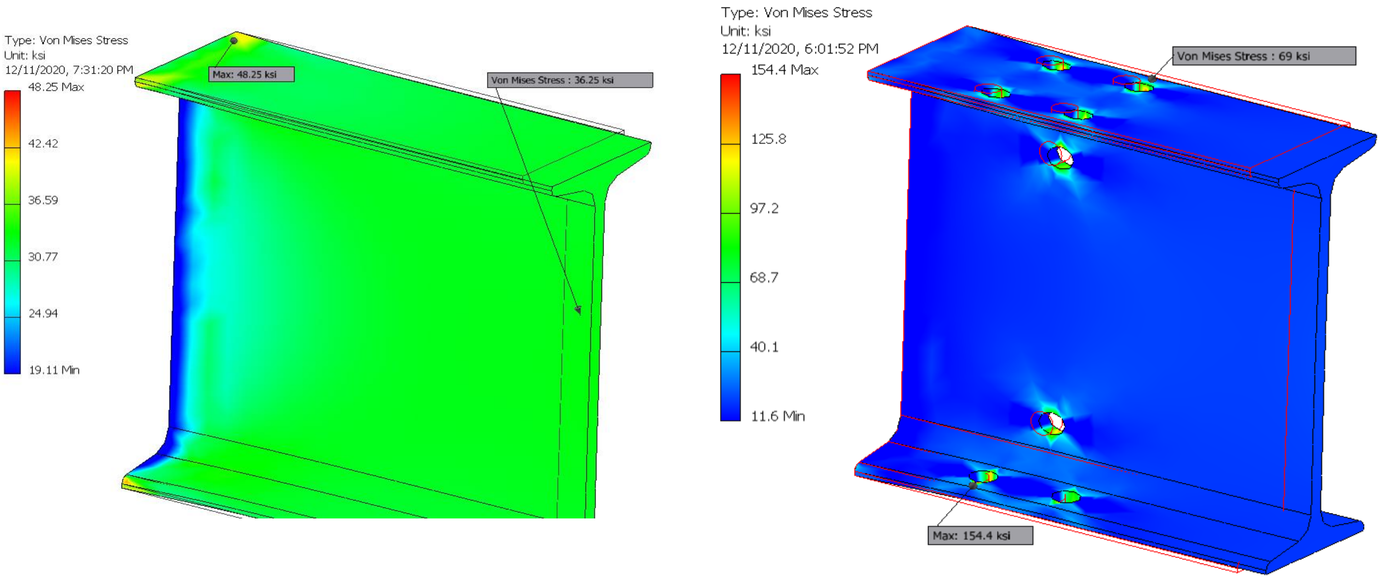
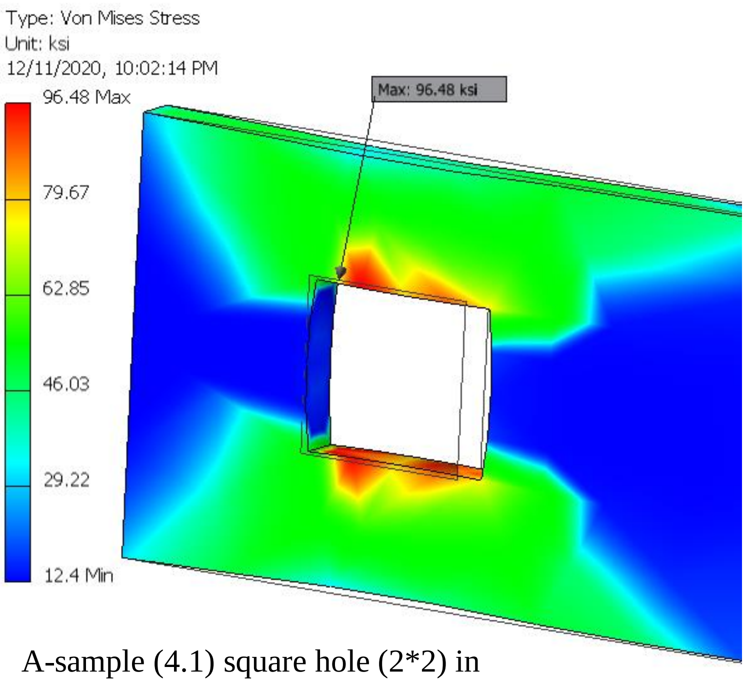


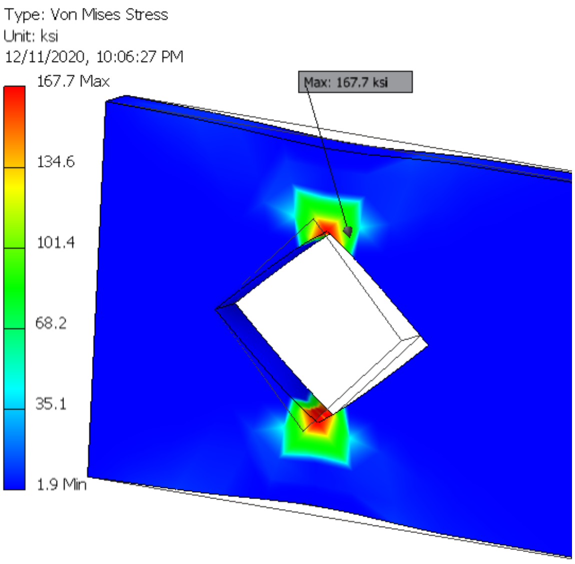
Figure 8 sample three EFM stress is resulted by Autodesk Inventor with holes and without holes

Sample 4:

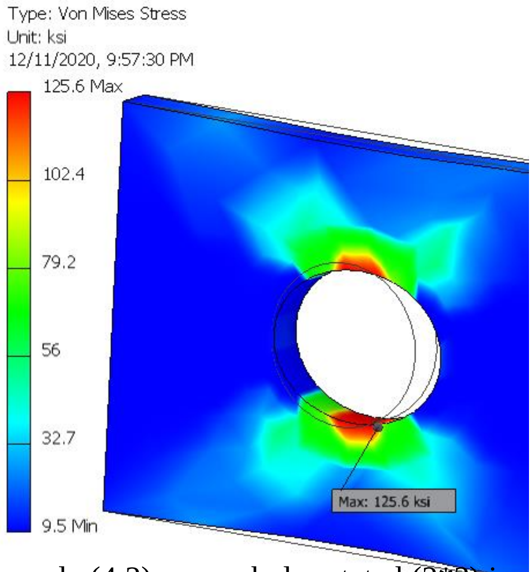
A plate (0.5 in) of A36 steel is used as a tension member. It is connected to a gusset plate with square hole (2*2) in, a square hole rotated and circle hole 2 in Diameter as shown in the below figures.



A-sample (4.1) square hole (2*2) in



B-sample (4.2) square hole rotated (2*2) in



C-sample (4.2) square hole rotated (2*2) in

Figure 9 stress in plate under tension with different hole shape and size

Table 1 Difference stress results numerically from FEM with fracture and yield stress.

Sample	yielding of the gross section(kips)	Yield stress (kips)	fracture of the net section (kips)	Fracture Stress(kips)	Stress FEM without Hole(kips)	Difference	Stress FEM with Hole(kips)	Difference
1	90	36	101.5	58	37.18	3.27 %	128.3	121.2 %
2	515	50	454.2	65	48.51	-3 %	110.6	70.15 %
3	529.2	36	680.3	58	36.25	0.7 %	154.4	166 %
4.1	90	36	87	58	37.18	3.27 %	96.48	66.34 %
4.2	90	36	63	58	37.18	3.27 %	167.6	189 %
4.3	90	36	87	58	37.18	3.27 %	125.6	116.5 %

The gross section yield and the net section fracture are forces that will take the members to the stress of yield and fracture under the equation illustrated in the material and method section. In the result sample forms table (1) the largest difference between Stress FEM without hole to yield stress is 3.27 %, if we have a plate without hole or a change in cross section under tensile stress, by using FEM, we do not need to optimize (minimize) the stress to select or design element. And the literature difference between the Stress FEM and the cross section under tensile stress was %4(Abedin *et al.*, 2020). And we see high value in plate without hole. Hence, they are considered supportive more than concentration stress.

The result sample forms table (1) has largest difference between the stress FEM with hole to fracture stress by 189 %, but these numbers change from one to another sample because the size hole and the shape hole, especially for the holes near the edge of the plate, as shown in the S-shape the small flange causes the holes near the edge and there is a rotated in the sample square hole. The large stress near the holes that concentrated by the holes should not be different with AISC, cause must be optimized to select them. In the place of the support and in the connection welding support with gusset plate, a high force will be created if current design formula is too conservative to ultimate load the ability.

The programs have a special way to control the concentrated stress and some of them use increased stiffness in the regions or more meshing in the region to reduce strength. and Autodesk inventor is the best optimization and design method specifically for steel components and mechanical components using FEM and controlled by restraints.

5.Conclusion

1. Literatures show that the stress on holes more than the net segment by three times or two times in average, tension plate has two failures which are: tensile yielding and tensile rupture.
2. It is difficult to optimize the stress concentration in the around of the hole. Changing the distance of holes from the edge of the plate is more than the changing of hole dimeter on the increase stress concentration.
3. Finite element analysis must not be different with AISC specification.
4. Increasing a plate's thickness results in a decrease in the ultimate strength of the cracked-pitted plate. Compared to the thick plate. pitting corrosion has less effect on the ultimate strength reduction of thin plates.
5. Depending on the number and position of bolts, the compression stresses are 13-32 percent lower than those produced by tension, the difference between loads is 9-35% depending on the number and position of bolts when the tension and compression yield stresses are achieved.
6. By bolting the crack until the bolt slips under tensile and bending conditions, the stress concentration on the stop-hole wall and edge can be minimized.
7. The behavior of the channel section in tension is similar to the behavior of the angle section.
8. For angle section, the distribution and concentration of stresses of Von Mises indicate that in a two-bolt connection, block shear failure may occur and net section failure may occur in the connection of three and four bolts.
9. The specimen's finite element (FE) models were created. In general, the FE predictions well agreed with the test responses.
10. We do not need optimization (minimization) stress for the selection or design function by using FEM if we have a plate without a hole or any cross-section change under tensile stress.
11. High concentrated stress has been discovered for the plates that have hole at the edge because it must be minimized, finite elements must not differ to the AISC specification.
12. At 1 ~ 2 (height/width), the stress concentration factor for the cable pit reached the maximum, which most seriously affected the stress

concentration factor. Although the pit height to width was greater than 2, the concentration factor for stress concentration appeared to be stable and converged to around 2.7

13. In the place of the support and in the connection welding support with gusset plate, a high force will be created if current design formula is too conservative to ultimate load the ability.