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Load Estimation Methods on Welded Joints Using Finite Element Analysis

Tae Kyo Kang [a*], Sung Jun Kim [a], Hyun Min Kim [a], Taek Sang Choi [a]
[a] *KEPCO E&C, 150 Deokjin-dong, Yuseong-gu, Daejon, 305-353, Korea*
[*] *Corresponding author: skylove@kepco-enc.com*

1. Introduction

Finite Element Analysis (FEA) is effective for predicting loads on weldments fabricated from plates, shells, structural shapes and tubes. Although the loads through the joints can be calculated by FEA, they are not readily presentable to determine throat size in most common FEA programs. The nodal loads and stresses from the analysis results should be converted to weld loads suitable to weld evaluation. Therefore, accurate load estimation depends on the model of the weld.

This paper provides various methods to model the welded joints and to develop the weld loads from the FEA results. Additionally, using a specific tube model, weld throat sizes are calculated by various methods.

2. Methods and Results

2.1 Stress Traction

The stress traction method presented by Weaver [1] develops weld loads from element nodal stresses at welded connections. This method extracts the stress tractions through the weld for both element faces of top and bottom by multiplying the joint normal unit vector by the shell element top and bottom stress tensors. The stress traction vector is expressed by [2]

$$T = [\sigma]u_j \, , \tag{1}$$

where, T is stress traction vector, σ is stress tensor, and u_j is joint unit normal vector. If we assume the joint normal only affects weld strength and aligns to z-axis, Eq.(1) is in expanded notation,

$$\begin{Bmatrix} T_x \\ T_y \\ T_z \end{Bmatrix} = \begin{bmatrix} \sigma_{xx} & \sigma_{xx} & \sigma_{xx} \\ \sigma_{xx} & \sigma_{xx} & \sigma_{xx} \\ \sigma_{xx} & \sigma_{xx} & \sigma_{xx} \end{bmatrix} \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix} = \begin{Bmatrix} \sigma_{xz} \\ \sigma_{yz} \\ \sigma_{zz} \end{Bmatrix} , \tag{2}$$

The stress components of Eq.(2) are nodal stresses at the top and bottom of shell elements along welded joints. From the stress tractions for element top and bottom, and member thickness, weld loads are solved for the normal loads, bending loads and shear loads per unit length of weld. Then weld properties [3] are determined by weld geometries and use them for calculating weld stress. Finally required size of weld throat is determined from the weld loads and thickness of member.

2.2 Maximum Nodal Load

This method uses maximum loads, forces, and moments at the nodes in the welded joints as weld loads. The nodes are shared in interfacing elements between connected parts. Although nodal loads are varied along the weld, the maximum among the loads at the shared nodes on the attached part can be used for weld loads.

Basically the nodal loads in nodal coordinate system shall be transformed to global coordinate to select the maximum. Then weld loads for whole welded line are obtained from multiplying maximum nodal loads by the number of nodes. Weld loads of forces and moments per unit length calculated by dividing them by the weld properties, area, moment of inertia and twisting moment of inertia as line, respectively. The moment components are transformed into applicable force terms and combined with forces in each direction. Size of weld throat is determined from dividing it by allowable stress of electrode material.

In general, welded joints are modeled by sharing nodes in the elements of connected parts. It implies that efficiency of the welded joints is completed like a full penetration weld. The stress traction method only uses weld normal stress components at shared nodes whereas maximum nodal load employs all components of forces and moments acting on the weld in the same weld model.

2.3 Spring Element Modeling

The welded joints are classified into full penetration weld and partial weld like two side weld and one side weld. In practice, fillet or groove weld with one or two side is a more common design than the full penetration weld, which is applicable to limited areas and conditions.

Spring element modeling method allows to simulate the welded joints as rigid spring connection members with six way degree of freedoms (DOFs) or three way DOFs to represent full penetration or partial welds. The connected parts are separately modeled and nodes on each part are connected by spring elements which represent weld. Separating nodes of each part, a coordinate of weld connection loads is easily transformed, and one side welds can be readily simulated by three way spring elements. One side weld modeling with three way springs may cause completely different weld loads as well as stresses and behaviors of parts from the results of shared node model or six way spring connection model.

From the FEA, design maximum nodal forces are obtained out of the rigid spring connection member. Since the nodal forces from the analysis are at one node, they are changed to total forces on the weld line by multiplying the number of nodes. Then equations are set up based on the sectional properties of weld pattern, and equivalent weld forces with three force components are converted from three member forces and three member moments. The weld forces in the same direction are summed and three member forces are combined for determining the resultant weld loads per unit length. By dividing resultant weld loads by allowable stress of electrode, size of weld throat is decided.

2.4 Analysis Example and Results

Fig.1 depicts one side welded tube on flange loaded in horizontal and vertical forces and twisted moment. The tube is 20 inches long and 1.0" thick. Fig. 1 also shows FEA model with shell elements. ANSYS 10 program is used for the example analysis. The loadings are applied at nodes of tube top, where P is 3000 lbs, V_1 is 1500 lbs, V_2 is 1000 lbs, and T is 2000 in-lbs.

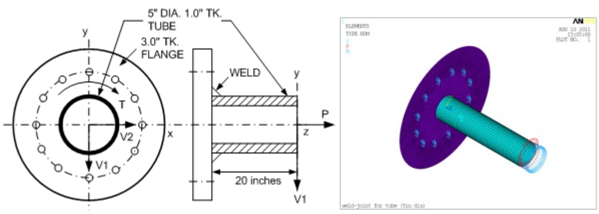

Fig.1 Tube geometry and loadings and FEA model

FEA model for methods of stress traction and maximum nodal load are identical and share nodes between interfaces at tube and flange. Spring element modeling method uses spring elements to simulate welded joints, and nodes of tube and flange are modeled separately. The welded joints are modeled by six way springs or three way springs. 1.0E7 lbs/in of the spring stiffness for all directions is applied for the spring elements.

Table 1 shows weld throat sizes as well as maximum stress intensities and displacements for the tube. Weld throat sizes are calculated by applying the methods of stress traction, maximum nodal loads and spring element modeling described above. Shear allowable is 13,200 psi of EX60xx of weld electrode material [3]. For comparison, the tube joint is analyzed using classical method provided in Blodgett [3].

Table 1 Weld throat sizes, maximum stress and displacement of tube for various methods

Methods (Notes)	Minimum Weld Throat (inch)	Max. Stress Intensity of Tube (ksi)	Max. Disp. of Tube (inch)
(1)	0.208	-	-
(2)	0.330	5,593	0.006297
(3)	0.631	5,593	0.006297
(4)	0.628	5,394	0.006902
(5)	0.155	2,083	0.007835

Notes ;
(1) Classical Method [3]
(2) Stress Traction Method [1]
(3) Maximum Nodal Load Method
(4) Spring Element Modeling Method with 6 way DOFs
(5) Spring Element Modeling Method with 3 way DOFs

In the classical method, size of weld throat is the smaller of the other methods because the weld loads are assumed to be evenly distributed on the welded joint. However FEA can provide uneven distribution of loads or stresses along the welded joints to determine weld throat sizes.

The size of weld throat by maximum nodal load method is double of that by stress traction method but the stresses and displacements of tube are same in both methods. The difference between the two methods is whether it includes loads or stresses acting on weld surface and weld axis direction. The fracture of weld may start when stresses in weld normal direction reaches allowable shear stress so that stress traction method provides reasonable results.

Spring element modeling method with six way springs provides similar results, weld throat size, stress and displacement, with maximum nodal load method, which shares nodes in the model. Although the spring elements have specific stiffness, it makes identical stiffness effect with node shared model. In order to simulate one side weld, three way spring elements are modeled connecting tube and flange for the analysis. By ignoring rotational stiffness of weld, this model produces the smallest weld throat size and stress and the biggest deflection of tube.

3. Conclusions

Some methods to develop weld loads from the FEA are presented, and weld throat sizes as well as stresses and displacements are calculated and compared depending on the methods.

Stress traction method gives the most reliable results by using weld normal stresses, whereas methods of maximum nodal load and rigid spring element provide very conservative weld throat because of developing methods of weld loads and rigid connection modeling. Spring element modeling with three ways is useful method where to model one side fillet or groove weld but it shall be carefully applied because it may produce totally different results for weld throat and parts from the others. It affects the behaviors of structures.

Further studies for the various weld patterns to verify the methods and to determine spring element stiffness of weld are required. Therefore spring element modeling method shall be studied with respect to the behaviors of overall structures as well as weld loads.

REFERENCES

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