Modeling Method of the L-Type Co-Use of Weld and Bolts Joint Interface

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Keywords: Weld and bolts joint interface structure, virtual gradient material, dynamic characteristic, modeling mothed.

Abstract In order to analyze the dynamic characteristic of a co-use of weld and bolts joint structure, this paper, based on the virtual gradient material model and two welded joint interface modeling methods, proposed a modeling method of the L - type co-use of weld and bolts joint interface. The natural frequency and vibration mode of the co-use of weld and bolts joint structure were studied according to simulation and experimental researches. The natural frequency of two kinds of joint surface modeling methods are respectively obtained. Modal test analysis was then carried out to verify what kind of modeling method is more effective and feasible. The results shows that the 45°weld rigid connection model is consistent with the first six-order vibration mode shapes of the experimental mode. The relative errors of corresponding natural frequencies between the model and the experiment are less than 5%, which have higher modeling accuracy.

1 INTRODUCTION

In order to meet the requirements of functions, performance and transportation, machineries and equipments are composed of parts according to some certain requirements. During the mechanical dynamic design, reasonable dynamic parameters of the joint surface and the dynamic mechanism of the bounding surface itself play an important role in establishing an accurate dynamic model (S. T. Wang et al., 2008). Therefore, research on the dynamic characteristics of the interface is of great significance.

At present, there has been great progress in the study of the stress performance of co-use of weld and bolts joint structure at home and abroad. Some scholars have conducted experimental and finite element analysis. Sun Lei et al. (2007) through the finite element analysis, proved that co-use of side weld and bolts joint structure worked well in together through the finite element analysis. Wang Yongzhe et al. (2011) proved that the high strength bolt could reduce the stress of the weld joint, restrained the crack propagation, improved the stiffness of the structure and prolonged the fatigue life of the structure effectively. The determination of the connection area is based on experience in most studies, without considering the influence of the surface pressure and distribution of the bolt on the joint surface, therefore, it is not suitable for simulating preload in linear modal analysis (Jeong Kim, 2007).

In this paper, finite element analysis and performance experiments,for the L-type co-use of weld and bolts joint structure were carried out. The advantages and disadvantages of two different modeling forms are discussed.

2 MODELING METHOD

2.1 Bolt Joint Interface Modeling

In the virtual gradient material method, the bolted joint is equivalent to a kind of local virtual gradient material. The contact pressure distribution of the bolt joint surface is obtained by finite element method. Finite element analysis software ANSYS is used to analyze the pre-tightening force of the bolted joints, as shown in Fig.1. Two-dimensional axisymmetric finite element model of M6 bolt

Xin, Y., Zhang, J., Liao, J. and Wang, Y.
Modeling Method of the L-Type Co-Use of Weld and Bolts Joint Interface.
In *3rd International Conference on Electromechanical Control Technology and Transportation (ICECTT 2018)*, pages 400-404
ISBN: 978-989-758-312-4

connection was established. The material was Q345, the thickness was h_1=h_2=10mm, and the preload was 6666.7N. Filtering the contact line and extracting the initial nodal contact forces, interpolating them could improve the characterization accuracy. The curve was scaled down so that total force was equal to the bolt preload after correction. The interpolation and correction of the nodal contact forces curve was shown in Fig.2.

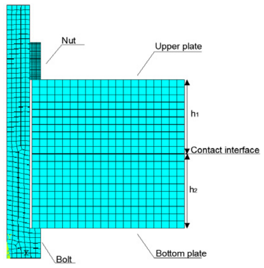


Figure 1: finite element model of the single bolted joint.

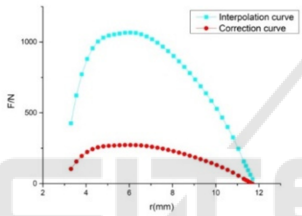


Figure 2: Contact pressure distribution curve.

After obtaining the pressure distribution curve, fourth degree polynomial was used to fit the pressure distribution curve of the bolt joint surface. Under 95% confidence bounds, linear least squares regression technique was used to the contact pressure data to estimate the relevant parameters. In order to make the pressure at the maximum contact radius of the fitting curve equal to zero and the total pressure equal to the pre-tightening force of the bolt, subtracting a constant was subtracted from the fitting curve and the fitting curve was scaled down (L. Wang et al., 2013). The normal contact pressure can then be expressed by

$$P(r) = -0.061r^4 + 2.022r^3 - 24.3r^2 + 120.2r - 173.57 \quad (1)$$

where r is the radius from the center of the bolt hole. The pre-tightening force F_i(i=1,2,3)can obtain with diffident r .

The properties of the virtual gradient material are Z-direction's elastic modulus E_Z, equivalent elastic modulus E' , XY plane's shear modulus G_{xy}, equivalent shear modulus G', poisson's ratio μ and density ρ(J.P. Liao et al., 2016).The key parameters for them are calculated by

$$K_{ni} = \frac{E^* D \psi^{1-0.5D} (a_L)^{0.5D}}{\sqrt{2\pi}(0.5-0.5D)} \times [(a_L)^{0.5-0.5D} - (a_C)^{0.5-0.5D}] \quad (2)$$

$$K_{\tau i} = \frac{2\sqrt{2}G}{\sqrt{\pi}(1-D)(2-\mu)} D \psi^{1-0.5D} \times (a_L)^{0.5D} [(a_L)^{0.5-0.5D} - (a_c)^{0.5-0.5D}] \quad (3)$$

$$F_i = \begin{cases} 0.25 K \sigma_y D \psi^{1-0.5D} (a_L)^{0.5D} \dfrac{(a_c)^{1-0.5D}}{1-0.5D} \\ + \dfrac{2E^*}{3\sqrt{2}} G^{D-1} D \psi^{1-0.5D} (a_L)^{0.5D} \\ \dfrac{(a_L)^{1.5-D} - (a_c)^{1-0.5D}}{1.5-D} \quad D \neq 1.5 \\ 1.5 K \sigma_y (a_L)^{0.75D} (2.0007 a_c)^{0.25} \\ + \dfrac{E^*}{\sqrt{2\pi}} G^{0.5} (2.0007)^{0.25} (a_L)^{0.75} In \dfrac{a_L}{a_c} \\ D = 1.5 \end{cases} \quad (4)$$

Where D is fractal dimension, ψ is parameters determined by the fractal dimension D, G is fractal feature length scale, a_L is the maximum contact area of the micro convex body, a_c is the critical contact area of the micro convex body, $K=H/\sigma_y$, where H is the hardness of the softer material, σ_y is the yield strength of the softer material.

The above mentioned virtual gradient material method is used to simulate a bolt-connected plate on the L-type co-use of weld and bolts joint structure. The size of the two plates are (150 × 150 × 10) mm. The two plates are connected by 4×M6 bolts. The parameters of the plates are listed in Table 1.

Table 1: Q345 material parameters.

parameter	Value
Elastic Modulus（GPa）	210
Poisson's ratio	0.3
density（kg/m^3）	7800
hardness（MPa）	500
Yield Strength（MPa）	345

For the model of virtual gradient material, the more the layers are used the closer the solution to the theoretical value. However, considering the computational efficiency, the material is evenly divided into three layers as shown in Fig.3. The parameters for each sub-layer of the virtual gradient material were shown in Table 2.

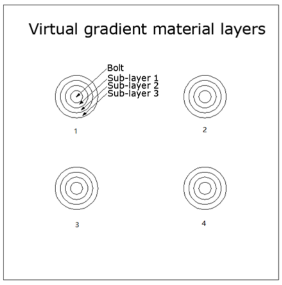


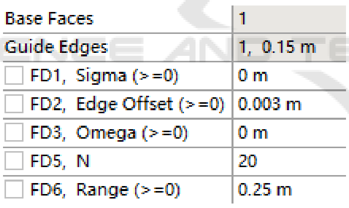
Figure 3: Virtual gradient material finite element mode.

Table 2: Property parameters of each sub-layer.

Sublayer	1	2	3
Contact force F(N)	2659	2604	1404
E_Z(GPa)	11.4	5.1	1.7
G_{XY}(GPa)	9.4	4.3	1.4

2.2 Weld joint interface modeling

There are two methods to build the finite element model of welded joint interface. One is to create some rigid connection points by creating point in ANSYS workbench instead of the solder joints for simulation. The parameters are set up and the model is established as shown in Fig.4 and Fig.5.



Base Faces	1
Guide Edges	1, 0.15 m
FD1, Sigma (>=0)	0 m
FD2, Edge Offset (>=0)	0.003 m
FD3, Omega (>=0)	0 m
FD5, N	20
FD6, Range (>=0)	0.25 m

Figure 4: Create the solder joints parameter setting.

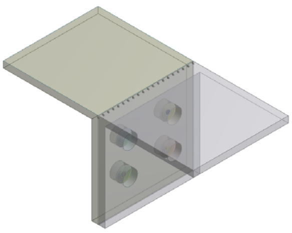


Figure 5: Solder joint finite element model.

Another way is to set the weld material, taking into account the groove size. The electrode using E5015 electrode whose material parameters were shown in Table 3. 45 ° weld angle was adopted to establish the model, as shown in Fig.6.

Table 3: E5015 electrode parameters

Specimen material	Elastic Modulus /GPa	Poisson's ratio	Yield Strength /MPa
E5015 electrode	1500	0.3	400

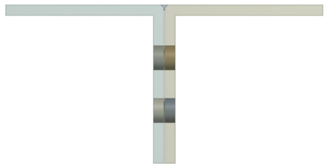


Figure 6: 45 ° weld rigid connection model.

3 EXPERIMENTAL VERIFICATION

In order to verify the effectiveness of the proposed modeling method in this paper, a test piece which is consistent with the simulation model, modal experiments were carried out. The modal test system is shown in Fig.7. The test piece consists of two L-shaped steel plates which joined together by bolting and welding. The dimensions of the joint are 150 mm × 150 mm.

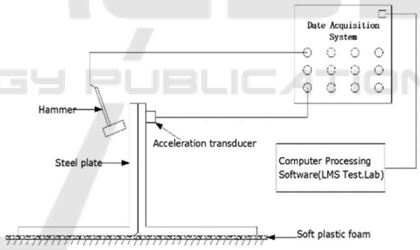


Figure 7: Test modal of the L-shaped structure.

The specimen was placed on the soft plastic foam to simulate a free boundary. A piezoelectric accelerometer (PCB 356A15) was used to record the vibration response of PCB 086C03 impact hammer. The LMS SCADAS III multichannel data acquisition system was used to acquire and process dynamic testing data. The specimen modalities were measured by the hammer, as shown in Fig.8.

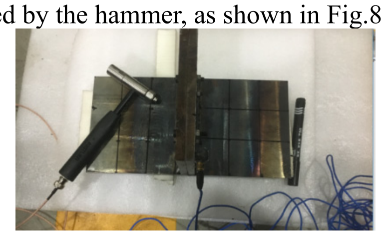


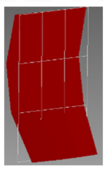
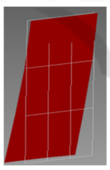
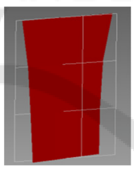
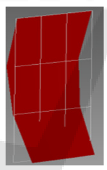
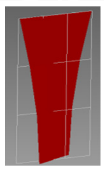
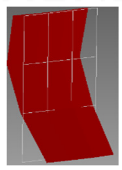
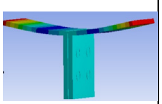
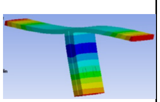
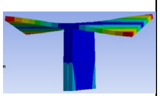
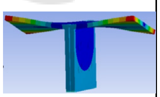
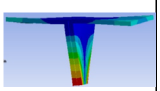
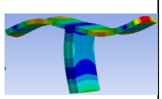
Figure 8: Experimental test.

A 16-node specimen test model was established on one side of the joint and then knocked them one by one. Through the LMS Test. Lab mechanical vibration test system, the natural frequencies under each pre-tightening torque can be obtained. The experimental and simulation results were compared in Table 5. The simulation errors of the two models are less than 8% which are less than no weld model. The experimental results show good agreement with 45 ° rigid connection model. The comparison of first six-order mode shapes for the 45 ° rigid connection model and experiments is illustrated in Table 5. The results indicates that the 45 ° rigid connection model mode shapes show good agreement with the experimental shapes.

Table 4: Comparisons of the first six-order vibration mode.

Natural frequency/Hz	No Weld model	Spot spacing 7.5mm	Spot spacing 5mm	Spot spacing 2mm	Spot spacing 1.7mm	45° Rigid contact	Experimental results	Error of no Weld model	Error of spacing 7.5mm/%	Error of spacing 5mm(%)	Error of spacing 2mm(%)	Error of spacing 1.7mm(%)	Error of 45° Rigid contact(%)
f_1	317.9	475.7	477.0	482.5	480.6	467.7	448.5	-41	6.08	6.36	7.6	7.17	4.29
f_2	498.7	587.3	587.4	588.9	588.0	582.4	579.9	-16.2	1.27	1.3	1.55	1.4	0.43
f_3	669	888.1	887.8	891.1	890.5	881.8	874.1	-30.7	1.61	1.58	1.96	1.89	0.89
f_4	808.7	1021	1023	1028	1027	1012	1013	-25.3	0.84	0.99	1.53	1.42	-0.11
f_5	1133	1337	1338	1342	1340	1329	1379	-21.6	-3	-2.99	-2.67	-2.79	-3.61
f_6	1152	2136	2137	2140	2139	2126	2124	-84.4	0.55	0.58	0.74	0.68	0.06

Table 5: Comparison of 3 kinds of theoretical and experimental mode shapes.

order	1	2	3	4	5	6
Experimental mode shape						
45° Rigid contact weld mode shape						

4 CONCLUSION

(1) Considering the influence of the bolt distribution on the joint surface, the model of the bolt joint interface was established by a virtual gradient material method. In order to obtain a more accurate modeling method of the weld joint interface, the create solder joints method and rigid connection method was analyzed.

(2) The experimental modal and the simulation analysis modal were compared. The first six-order vibration mode shape of the simulation was corresponding to the experimental results. The relative error of the first six-order vibration mode natural frequencies of 45° rigid connection model were within 5%. It showed that this method was more effective to simulate the weld join.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support for this research from the National Natural Science Foundation of China (Grant No. 51575301).

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