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Influence of welding sequence on residual stress and deformation of deck-rib welding details

Wen Zhong[1], *You-liang Ding[2] and Bao-ya Cao[3]

[1), 2), 3)] *Key Laboratory of C&PC Structures of the Ministry of Education, Southeast University, Nanjing 210096, China*
[2)] *civilding@163.com*

ABSTRACT

In this study, the influences of welding sequence on residual stress and deformation in the deck-rib of the orthotropic steel bridge are investigated. In order to analyze the distribution of transverse and longitudinal residual stress, the welding details of the deck-rib are simulated by using the element birth and death technology and the thermal elastic-plastic finite element. The analysis results show that the influence of welding sequence on the longitudinal residual stress and deformation is small and its effect on the transverse residual stress is significant. Moreover, the welding deformation is flexure deformation and the amount of deformation increases from both ends toward the middle. The maximum of deformation is 2.2mm. In addition, the symmetrical welding method not only cannot reduce the welding residual stress and deformation, can induce transverse residual stress to increase further instead. An adoption of sequential welding process in the welding of deck-rib of the orthotropic steel bridge was still recommended.

1. INTRODUCTION

Orthotropic steel decks (OSDs) are widely used in large-span and medium-span bridges because of their high load-carrying capacity, light weight, and short installation time. Complicated welding residual stress exists in the deck-rib welding details. It may reduce fatigue strength and stability ultimate bearing capacity of structure. Therefore, it is essential to know the distribution rule of welding residual stress of the deck-rib welding details to investigate their stability bearing capacity and fatigue life. At present, large numbers of domestic and foreign scholars adopted the numerical simulation method to research welding residual stress (Lee 2014 and Teng 2011). However, limited work had been done on describing the influences of the welding sequence on residual stress and deformation in the deck-rib. In the literature (Masahito and Makoto

[1)] Ph.D. Student
[2)] Professor
[3)] Ph.D. Student

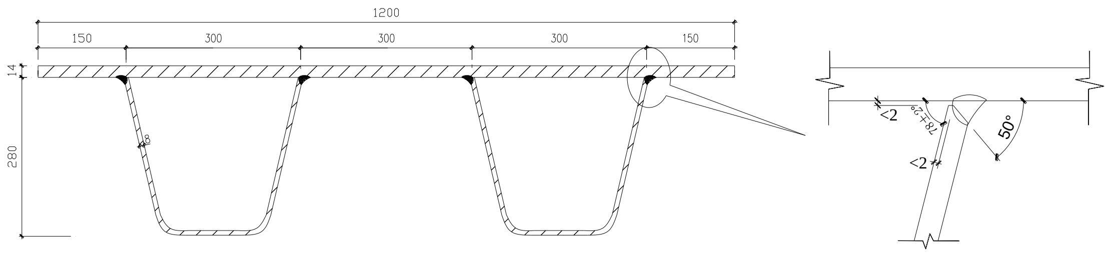
2000), the researchers adopted the analytical evaluation methods that combined inherent strain analysis and thermal elastic-plastic analysis, and investigated distributions of through-thickness residual stress in a pipe butt-welded joint and a pipe socket-welded joint. (JIA 2013) has established a finite element model of the 12 mm thick multi-layer and butt-welding by finite element software to simulated the residual stress and deformation under two welding sequence.

In this paper, on basis of the element birth and death technology and the thermal elastic-plastic finite element, three-dimensional dynamic simulation using ANSYS is done for the welding temperature and stress fields of the welding details of the deck-rib firstly. Secondly, the distribution of transverse and longitudinal residual stress are analyzed based on the finite element model. Finally, the influence factors of plate thickness, weld number and welding sequence on the residual stress and deformation in the deck-rib of the orthotropic steel bridge are investigated. It can provide reference for research and design of welding residual stress.

2. Numerical simulation of residual stress in of deck-rib welding details

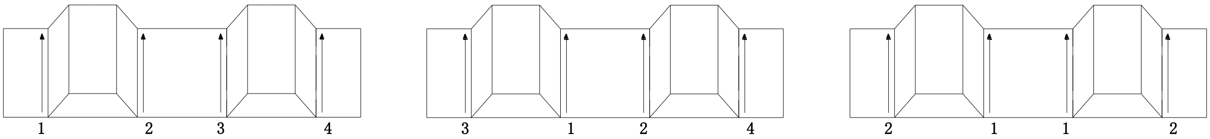
2.1 Finite element model

Fig. 1(a) shows the cross section of weldment. Fig. 1(b) shows the geometric sizes of welding details and the gap between the deck and the rib must be less than 2mm according to Eurocode3 (CEN, 2005). This model adopted 3 type of welding sequence as illustrated in Fig. 2. The first and second welding methods are the sequential welding, which means only one weld was welded at a time. The last type of welding sequence is symmetrical welding method that is two welds were welded at the same time. It will take 30 second to complete a weld. The cooling time between the two welds is 300s. The weldment cannot cool down to room temperature until 3424 second.



(a)The cross section of weldment (b) deck-rib welding details

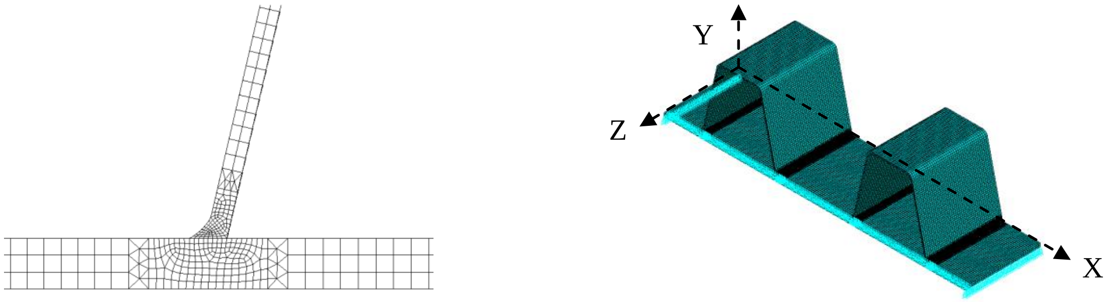
Fig. 1 The cross section of deck-rib (mm)



(a)Welding sequence1 (b)Welding sequence2 (c)Welding sequence3

Fig. 2 Three type of welding sequence

The finite element model of the deck-rib is shown in Fig.3. The length of the model is 1.2 m, and the width is 0.3 m. The model contains 2 U-ribs and 4 welds with 300mm. The 8-node linear transfer brick element (DC3D8) has been employed for 3-D thermal analysis and the 3-D 8-node bi-quadratic stress/displacement quadrilateral with reduced integration (C3D8R) has been used in the structural analysis. A relatively dense mesh has been adopted close to the weld line to represent the temperature and strain gradients accurately; further away, the size of elements are longer. The complete model contains approximately 152 548 elements and 163 955 nodes. The smallest element size is 0.5mm approximately obtained based on mesh density analysis.



(a) Meshing of deck-rib welding details (b) Displacement boundary condition

Fig. 3 Finite element model of deck-rib

2.2 Displacement boundary condition

Boundary conditions only limited the model from rigid body motions. Applying Y constraint on the left and right sides of deck. Applying Z constraint on the one side of cross section of deck as shown in Fig. 3(b).

2.3 Thermodynamics of Materials and mechanical parameters

The temperature-dependent thermal–physical properties such as specific heat, conductivity, density, and temperature dependent thermal–mechanical properties, such as Young's modulus, Poisson's ratio and thermal expansion coefficient and yield strength can be found in Cao (2016) for thermal and mechanical analysis. In this work, the mechanical properties of the weld metal are considered to be the same as the parent metal. In this model, the material of deck-rib welding details is Q345, Electrode selection of Chinese national standard E50 model.

2.4 Thermal field simulation

In this paper, the initial temperature of component is 20℃. The Solid 70 element has been employed for thermal field stimulation. The model has adopted the technique of element birth and death to simulate weld filler material. The heat generation rate is applied on the reactivate element. The function time of thermal load is equal to the actual time of welding. In the literature (Zhao 2012), the heat generation rate can be expressed as

$$HGEN = Q/(A \times V) = \eta UI/(V \times A) \quad (1)$$

Where Q= the effective power of welding; U= voltage; I=current; η= thermal coefficient ; A=the sectional area of welds; V= welding speed. In this model, U=29V; I=320A; η=0.65; V=10mm/s. Fig. 4 shows the temperature variation during welding heat process. The temperature variation relatively large at the beginning of welding, then tend to be stable after a time. Finally, the stable temperature of weld is 2849℃.

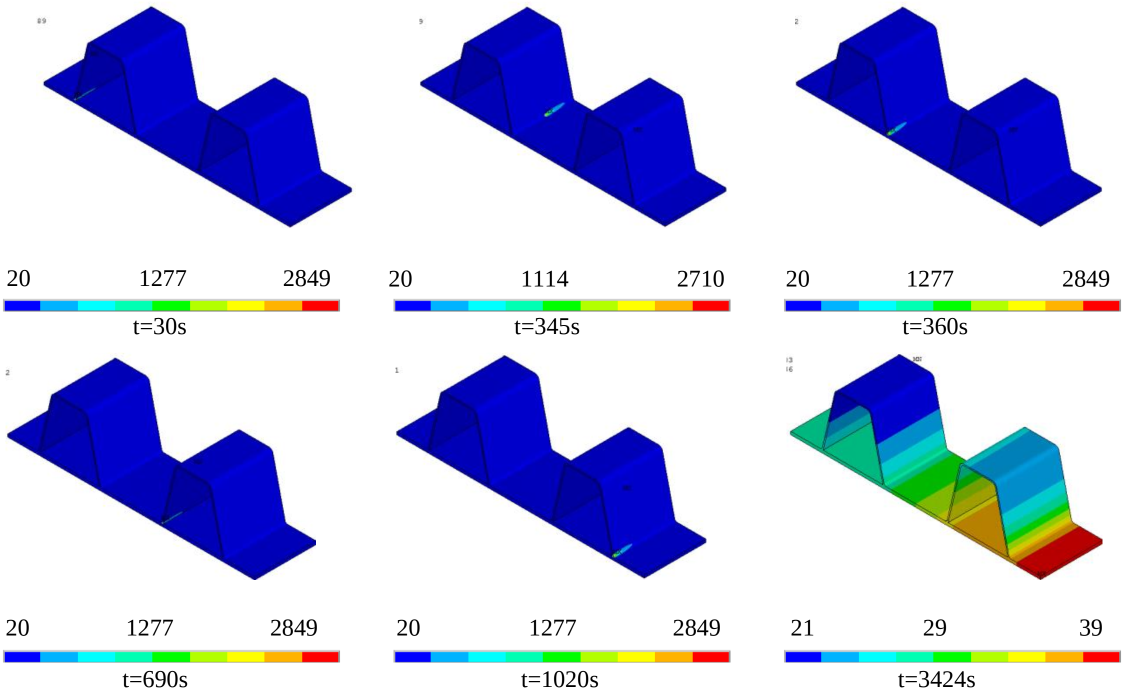
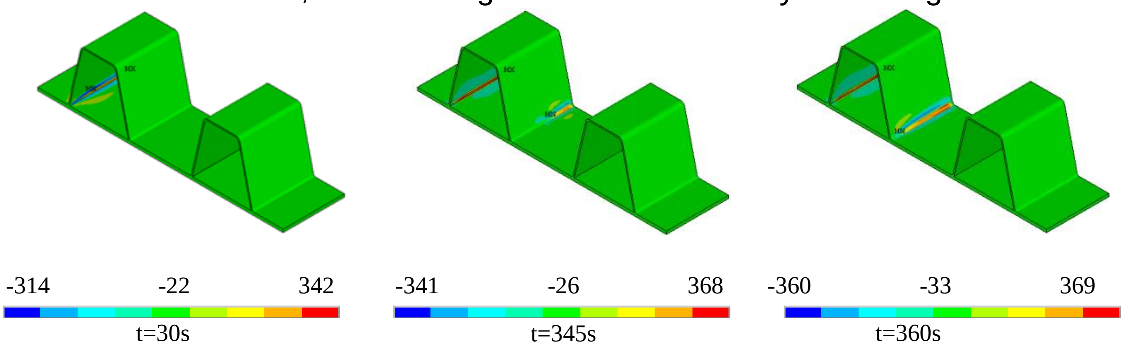


Fig. 4 The temperature field results of the first welding sequence (℃)

2.5 Stress field stimulation

A sequentially coupled thermal-stress analysis was conducted by assuming that the stress solutions are dependent on the temperature fields while there is no inverse dependency. Sequentially coupled thermal-stress analysis was performed by first solving the non-linear transient heat transfer problem. The time-dependent temperature data were then fed into the stress analysis model as a predefined field. During the thermal analysis, it was assumed that the stress generated in welding has negligible influence on the temperature field. Furthermore, the heat convection and radiation effects were both considered in the modeling. In this paper, the Solid 185 element has been employed for stress field stimulation. Taking the longitudinal residual stress as an example, Fig. 5 shows the stress field variation to time. The maximum longitudinal residual stress is 382MPa, which is larger than the material yield strength.



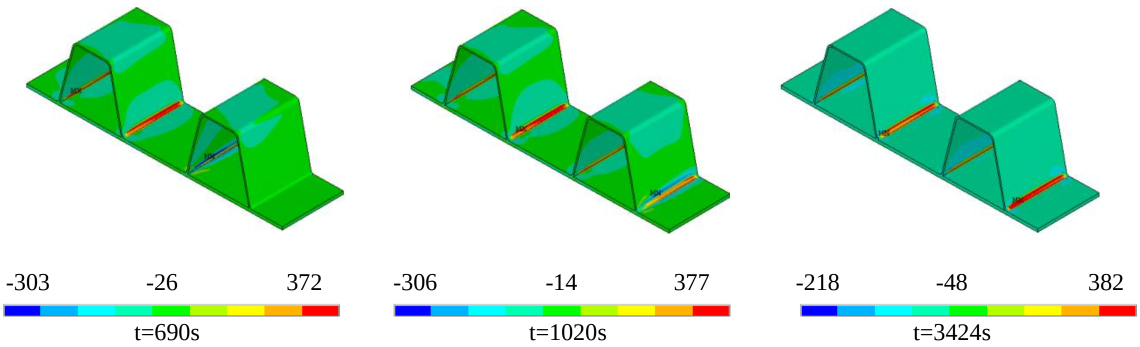


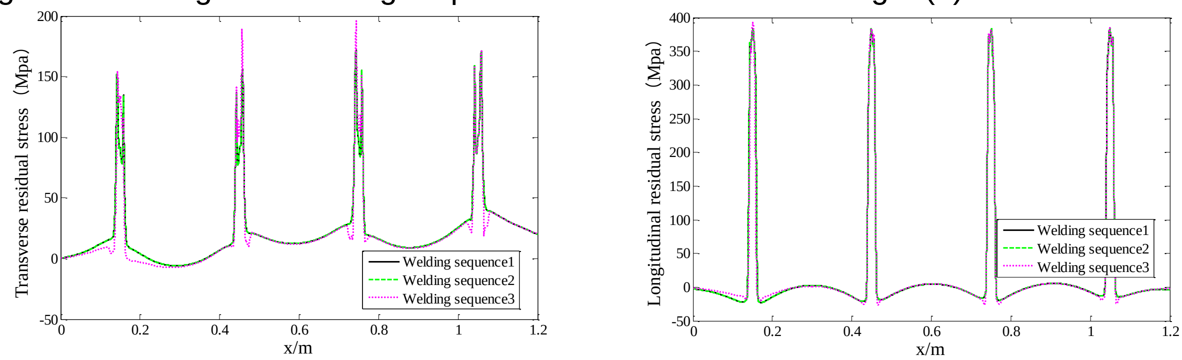
Fig. 5 The stress field results of the first welding sequence (MPa)

3. The influence rule of welding sequence variation on the residual stress

According the previous study, the residual stress in the surface of top plate at the weld side and the external surface of rib is relatively high (Cao 2016). Therefore，this section only analysis the most unfavorable stress. In order to ignore the influence of boundary conditions at the weldment ends, the residual stress on cross-section was analyzed only at Z=0.15m.

3.1 Residual stress distribution in the transverse direction

Fig. 6 shows the distribution curve of welding sequence variation on residual stress in the transverse direction. There are 4 main stress peaks represents the residual stress of 4 welds respectively. In Fig. 6(a), the transverse residual stress near the welds is bigger than that of other places. Each main stress peak has two small peaks represent the left weld toe and the right weld roof. The transverse residual stress of welding sequence1 and 2 have the same varying trend; the maximum value high to 145Mpa.The transverse residual stress of welding sequence3 is larger than the other two, the maximum value high to 195Mpa. The longitudinal residual stress has no significant changes in welding sequence variation as show in Fig. 6(b).

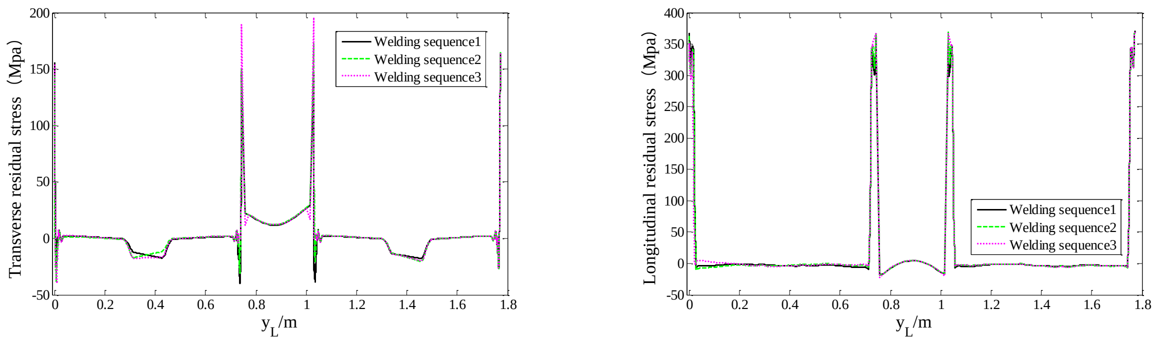


(a) Transverse residual stress (b) Longitudinal residual stress

Fig. 6 The distribution curve of welding sequence variation on residual stress in the transverse direction

3.2 Residual stress distribution in the rib height direction

Fig. 7 shows the distribution curve of welding sequence variation on residual stress in the rib height direction. In Fig. 7(a), the maximum transverse residual stress presents near the weld 2 and 3 in the rib of welding sequence3; the value is 198Mpa. The transverse residual stress of welding sequence1 and 2 have the same varying trend; the maximum value high to 140Mpa.The results reveal that the symmetrical welding method not only cannot reduce the welding residual stress, can induce transverse residual stress to increase further instead. The longitudinal residual stress has no significant changes in welding sequence variation as show in Fig. 7(b).

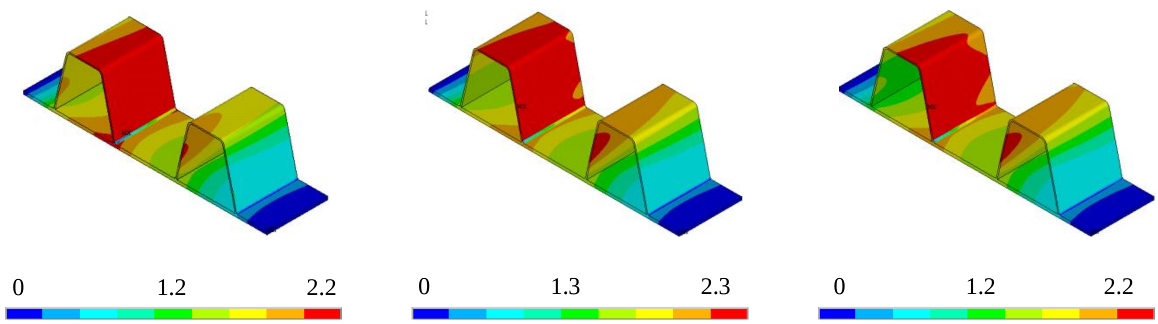


(a) Transverse residual stress (b) Longitudinal residual stress

Fig. 7 The distribution curve of welding sequence variation on residual stress in the rib height direction

3.3 The results of residual deformation distribution

Fig. 8 presents welding deformation results of varying welding sequence. The deformation results have no significant changes in 3 kinds of welding sequence. The maximum deformation is 2.2m, appears on the right side of first U-rib. The results reveal that the welding sequence has no significant influence on the welding residual deformation.



(a) Welding sequence1 (b) Welding sequence2 (c) Welding sequence3

Fig. 8 The welding deformation results of varying welding sequence (m)

4. CONCLUSIONS

In this paper, in order to investigate the influences of welding sequence on residual stress and deformation in the deck-rib of the orthotropic steel bridge, the element birth and death technology in the finite element software ANSYS and the thermal-structure coupling analysis method are used to simulate the welding details of the deck-rib，and the distribution of the welding residual stress and deformation of 3 welding sequence are obtained. According to the analysis results, the following general conclusion can be drawn. The influence of welding sequence on the longitudinal residual stress and deformation is small and its effect on the transverse residual stress is significant. The transverse residual stress increases 35 percent when welding sequence varied from No.1 to No.3. Moreover, the welding deformation is flexure deformation which is symmetrical, the amount of deformation increases from both ends toward the middle. The maximum of deformation is 2.2mm. In addition, the symmetrical welding method not only cannot reduce the welding residual stress and deformation, can induce transverse residual stress to increase further instead. An adoption of sequential welding process in the welding of deck-rib of the orthotropic steel bridge was still recommended. The results can provide reference for research and design of welding residual stress.

REFERENCES

Lee, C.K., Chiew, S.P. and Jiang, J. (2014), “Residual stress of high strength steel box T-joints part 2: Numerical stud*y,” J. Constr Steel Res.*, *ASCE,*98,73-87.

Masahito, M., Makoto, H. and Toshio, H. (2000), “Numerical analysis of welding residual stress and its verification using neutron diffraction measurement”, *J. Eng Mater-T.,* 122, 98-103.

Teng, T.L., Fung, C.P. and Chang, P.H. (2001), “Analysis of Residual Stresses and Distorions in T-Joint Fillet Welds,” *Int. J. Pres. Ves. Pip.,* 78(8), 523-538.

Jia, H.L. (2013), “Numerical Simulation on Effects of Welding Sequence on Residual Stress and Deformation of Multi-pass Welding”, *J. Fou. Tech.*,34(7),898-901.

European Committee for Standardization. Eurocode3: Design of steel structures, part1-9: Fatigue. BS EN1993-1-9:2005.

Cao, B.Y. and Ding, Y.L. (2016), “Influence analysis of plate thickness on welding residual stress of steel deck deck-rib”, *J. SEU.*,46(3),565-571.

Zhao, Q. and Wu,C. (2012), “Numerical analysis of welding residual stress of U-rib stiffened plate ”, *J. Eng. Mech.*,29(8),262-267.