Study on Deformation Behavior of Multi-pass Weld Joints for I-girder Bridge*

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In recent years, steel I-girder bridges with fewer main girders have been widely adopted in Japan. In this design, the weight of the bridge can be reduced, and the thickness of the main girder flange plate is increased. The main girder blocks are welded and assembled onsite instead of being friction joined using high-strength bolts. Since achieving dimensional accuracy is important, accurate prediction is required for predicting the deformations that occur during the welding process. Therefore, in the present study, the idealized explicit finite element method is adopted to accurately predict such deformations. Through the comparison between computational and experimental results, the mechanism of the deformation, which occurs in I-girder bridges, is examined.

Key Words: I-girder Bridge, Multi-pass Weld Joints, Welding Deformation, Idealized Explicit FEM

1. Introduction

In recent years, steel I-girder bridges with fewer main girders have been widely adopted in Japan. Due to the smaller number of main girders compared to conventional bridges, in the new design, the weight of the bridge can be reduced, and the thickness of the main girder flange plate is increased. Because of these structural modifications, the main girder blocks are welded and assembled onsite instead of high-strength friction bolts. Figure 1 shows a comparison of the appearance of conventional and new I-girder bridges.

However, it is a problem about such bridges is that there is very little experimental or empirical data regarding shrinkage or angular distortion during multi-pass welding when the thickness of plate is more than 50 mm. Collecting such data for plates of different thicknesses would be a very costly process. Therefore, it is difficult to predict accurately the welding deformation caused by various joint constraints before construction.

In the present study, a new type of finite element method, Idealized explicit FEM, is used to predict the deformation during multi-pass welding of thick plates, and the results are compared to those of experimental measurements. This approach can be used to improve the accuracy of large-scale bridge onsite construction.

2. Idealized explicit FEM

The dynamic explicit FEM can be used to analyze dynamic problems such as those related to impacts. Its main advantage is that it does not require a large amount of computer memory because it solves only scalar equations. Therefore, unlike the implicit FEM, the dynamic explicit FEM can analyze large-scale structural problems.

In the present study, a new dynamic explicit FEM is adopted. This method is referred as Idealized explicit finite element method (IEFEM)^2\(^3\). Using this method, it is easily to solve long-time problem such as welding in spite of using the dynamic explicit FEM. The proposed method neglects mass and damping effects and treats welding phenomena using a static equilibrium approach. A comparison is executed between the computing time and memory required by the IEFEM and the static implicit FEM. In the previous study, it was found that for a model with approximately 240,000 degrees of freedom, the IEFEM was shown to be almost 12 times faster than the static implicit FEM.
3. Experimental study of welding deformation

Figure 2 shows a schematic illustration of the specimen of an I-girder to be analyzed. The start tab, end tab and restraint plates are already welded. The web joint is welded in a vertical direction as during actual field welding. For the girders used in actual bridges, the web length is generally about 2-2.5 m, the specimen to be analyzed is 1/2 scale model which is shown in Fig. 2. The widths and thicknesses of the flanges are the same as in I-girders used in actual bridges.

Figure 3 shows the sequence of welding passes. The total number of welding passes is 95. The thickness of both flanges is 70 mm, and the web thickness is 24 mm. One-sided welding with back bead formation was carried out. When welding of the lower flange or web joint had been completed, the angular distortion and shrinkage were evaluated.

4. Experimental and computational results

In this section, the experimental results and those computed using IEFEM are compared. As shown in Fig. 4, three different constrains were considered for the flange and web joint in the numerical analysis. Case a) corresponds to one-sided fillet welding at the web plate (1 element), case b) represents two-sided fillet welding (2 elements), and case c) shows full penetration welding (6 elements).

4.1 Angular distortion

4.1.1 Upper flange joint

Figure 5 shows the relation between the angular distortion of the upper flange and the number of welding passes. The red solid marks represent experimental results, and the other symbols represents the results obtained using the IEFEM. Positive values of angular distortion correspond to upward displacement. During the welding process for the upper flange, the distortion is seen to gradually increase and then saturate. This is in agreement with the behavior observed during multi-pass welding. In contrast, during welding of the lower flange, almost no angular distortion of the upper flange is observed. Finally, during the web welding stage, the angular distortion rapidly decreases. It can be seen that the experimental results are in good agreement with the value simulated using 2 elements.
As seen from Fig. 5, it is also clear that constraint strongly influences the angular distortion. In the case with 6 elements constraint, the angular distortion becomes large during web welding. This is because that the longitudinal shrinkage along the welding line of web, the upper flange is pulled.

4.1.2 Lower flange joint

Figure 6 shows the angular distortion of the lower flange. Different behavior is observed during welding of the lower flange joint (beginning at pass 42). In the initial stage of the welding of lower flange, angular distortion occurs in the negative direction. And then, it gradually increases similar to the welding stage of the upper flange. The direction of angular distortion is determined by the relation between welding position and neutral axis of plate on the transverse cross section. In present case, the negative values of angular distortion are generated due to deposition of welding metal. The bending moment gives rise to an angular distortion due to initial weld shrinkage, because the center of rotation is on the upper surface of the lower flange plate. This phenomenon is not observed when the upper flange is welded. This is because during the initial stages of upper flange welding, the other joints have not yet been welded, in short, there is no constraint. Although the predicted deformation behavior of the upper flange has been observed experimentally, very little data is available regarding deformation of the lower flange during welding of the upper flange. From Fig. 6, it can be seen the angular distortion of the lower flange increases rapidly during the web welding stage, the largest distortion increases when 2 or 6 elements for flange and web joints are used.

4.2 Transverse shrinkage

4.2.1 Upper flange joint

Figure 8 shows the relation between transverse shrinkage and the number of welding passes. The shrinkage shows that on transverse cross section at the center of welding line. From this figure, it is seen that the transverse shrinkage gradually increase (become more negative) and then saturate during the upper flange welding stage. The final values are close to the experimentally measured value. There are no significant differences between the results obtained using different numbers of elements.

4.2.2 Lower flange joint

Figure 9 shows the relation between transverse shrinkage of the lower flange and the number of weld passes. During the lower flange welding stage, it gradually increases and then
saturates. The final values are close to the experimentally results, and there is no significant dependence when the constraint elements are changed.

4.2.3 Web joint

![Graph showing transverse shrinkage of lower flange and number of welding passes.](image)

**Fig. 9 Relation between transverse shrinkage of lower flange and the number of welding passes.**

![Graph showing transverse shrinkage of web and number of welding passes.](image)

**Fig. 10 Relation between transverse shrinkage of web and the number of welding passes.**

Figure 10 shows the relation between transverse shrinkage of lower flange and the number of welding passes. From this figure, it is found that the transverse shrinkage of web shrinkage associated with the previous welding of both flanges. The transverse shrinkage decreases to about 1.5 mm (2 elements) before the web itself is welded. And then, it increases rapidly during the web welding stage.

5. Conclusion

1) IEFEM was used to predict deformation occurring during multi-pass welding of a mock specimen that was representative of an I-girder used in bridge construction. In general, there was good agreement between the analysis and experimental results.

2) The analysis results indicated that the angular distortion and transverse shrinkage increase as the welding process proceeds, which is consistent with empirical data.

3) Different values for deformation were obtained by using different constraints which model the types of fillet welding.

Reference


