Prediction Method of Welding Deformation for Large Steel Structures

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Summary

In order to accomplish an effective production system in large steel structure, it is important to keep the accuracy of blocks that are welded together. When they are welded, welding distortion is inevitable. So it is necessary to establish a prediction system of welding distortion with high accuracy. We surveyed studies of welding distortion prediction method that had been conducted in the past, and we conducted some fundamental experiments on simple weld joints. We established the database for welding deformation based on the relationship between the welding deformation and the weld heat input. Once we obtain the relationship, we can apply the formula to the welded structures. Then we can estimate the welding deformation of the structures. In order to confirm the validity and accuracy of the estimation method, we had produced an experimental block that had few curved members, and the deformations were measured very carefully. The estimated values of the welding deformation by the developed methods were found to be in good agreement with the actual use. The developed welding deformation prediction system is applied to the shipbuilding and the bridge manufacturing.

Introduction

In order to manufacture a large steel structure, there are various thermal processes, such as cutting, welding, and straightening. These thermal processes cause the shrinkage, and distortion in the structure. The welding is the major cause of distortion in these processes.

We had usually estimated the deformation by formulae based on the experiences in yards. However, when the structures are different or the welding methods are changed, the deformation could not be estimated by such formulae.

Welding deformation is mainly classified into transverse shrinkage, angular distortion and longitudinal shrinkage. The welding joints in a large steel structure are mostly butt joints or fillet joints, and the welding lengths are exceeding 20m in some cases. Although some studies have been carried out about welding deformation of structures in which welding lengths are short and geometry of joints are comparatively simple [1], there is little study about welding deformation of large structure.

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In this research, we developed the prediction system of welding deformation with high accuracy for a large steel structure, and applied the system to the VLCC square body block with a few curved parts and bridge manufacturing. Consequently we reduce the correcting work, and achieve the cost reduction in production.

Formulation of Welding Deformation

Generally welding deformation is governed by weld heat input. In order to estimate the weld heat input, it is necessary to know the heat efficiency corresponding to each welding method [2]. Since the weld heat input is calculated by formula (1), it is important to know the heat efficiency for each welding method.

We surveyed the past studies about heat efficiency and conducted some fundamental experiments [3]. We established the database of heat efficiency for each welding method.

$$Q_{net}= Q \hspace{4cm} (1)$$

$$Q=I_W E_A/v \hspace{4cm} (2)$$

Q : Heat input [J/mm] Q_{net} : True heat input [J/mm]   : heat efficiency
I_W : Welding current [A] E_A : Arc voltage [V]   v : Welding velocity [mm/sec]

The submerged arc welding method with 3 or 4 electrodes is used for butt welding in production of a large steel structure such as ship and bridge. In this case the material melts to bottom side, so angular distortion hardly occurs but transverse shrinkage and longitudinal shrinkage occurs.

In the case of butt welding, transverse shrinkage can be predicted by the formula shown in Table1 from the concept that thermal expansion of the base material becomes transverse shrinkage [1].

Generally longitudinal shrinkage can be expressed by the formula using tendon force F_T.

Since there was no formula about tendon force for the submerged arc welding with multi electrodes, tendon force was measured by experiment. Consequently, the formula of tendon force was derived as shown in Table1.

In many cases of fillet welding, the deformation of the flange part becomes a problem. The weld heat input of the flange part in fillet welding can be calculated by the following formula considering the ratio of cross-section area of heat conduction, when the plate thickness of the web and the flange are different from each other [4].

$$Q_{net} = Q_{Total}(2\,h_F\,/(2h_F + h_W)) \tag{3}$$

h_F : Plate thickness of flange [mm] h_W : Plate thickness of web [mm]

Q_{Total}: Heat input to flange and web [J/mm]

Table1 Formulation of welding deformation

Butt welding	Submerged arc welding	Transverse shrinkage	$S=2.85\times 10^{-3}Q_{net}/h$	
		Longitudinal shrinkage	$L= F_T \quad E\times A \times L$	
			Tendon Force	F_T=0.20 Q_{net} One electrode
				F_T=0.12 Q_{net} 3 or4 electrode
Fillet welding		Transverse shrinkage	$Q_{net}\quad h^2\quad 6.27$	
			$S_{200}\quad 1.16\times 10^{-3}\times Q_{net}\quad h$	
			$6.27\quad Q_{net}\quad h^2\quad 20$	
			$S_{200}\quad [1.44\times 10^{-4}\times (Q_{net}\quad h^2)^2 \quad Q_{net}\quad h^2\quad 0.0025]h$	
			$Q_{net}\quad h^2\quad 20$	
			$S_{200}\quad 2.85\times 10^{-3}\times Q_{net}\quad h$	
			$S_L\quad \mathbf{a}\ S_{200}$	
			a=[4Tan^{-1}(L/200)+(L/100)log(1+40000/L^2)]/3.74	
		Angular distortion	(Q_{net} / h^2<=6.27)	
			$_{200}$=1.44 x 10^{-3} x Q_{net} / h^2	
			(6.27< Q_{net} / h^2)	
			$_{200}$=0.1061 x Q_{net} /h2/{(Q_{net} /h^2-6.16)2+73.6}	
			$_L$=b $_{200}$	
			b=[8Tan-1(L/120)+(1+n)L/60 log(1+14400/L^2)]/8.82	
		Longitudinal shrinkage	$L = F_T \quad E\times A \times L$	
			Tendon Force	F_T=0.2 Q_{net}

S: Transverse shrinkage [mm] h: Plate thickness [mm]   L: Longitudinal shrinkage [mm]
L: Welding length [mm]   E: Young's modulus [MPa]   A: Cross section area [mm^2]
F_T: Tendon force [kN] S_{200} : Transverse shrinkage for L=200 [mm] S_L : Transverse shrinkage
for L [mm] $_{200}$: Angular distortion for L=200 [radian] $_L$: Angular distortion for L [radian]

The transverse shrinkage and angular distortion in welding are expressed by using a heat input parameter Q_{net}/h^2, as shown in Fig.1 [1]. The formulae are also shown in Table1. Longitudinal shrinkage is calculated using F_T =0.2 Q_{net} [5].

If we correct the out-of-plane deformation as shown in Fig.2, we can use line heating method or application of roller press method. Since the welding residual stress is loosened in roller straightening, the length of welded member becomes longer. The quantity of loosed stress was decided from experiment and formulized.

When we straighten the angular distortion by line heating as shown in Fig.3, the amount of the transverse shrinkage will be occurred the same as by welding. So the width of welded member becomes shorter.
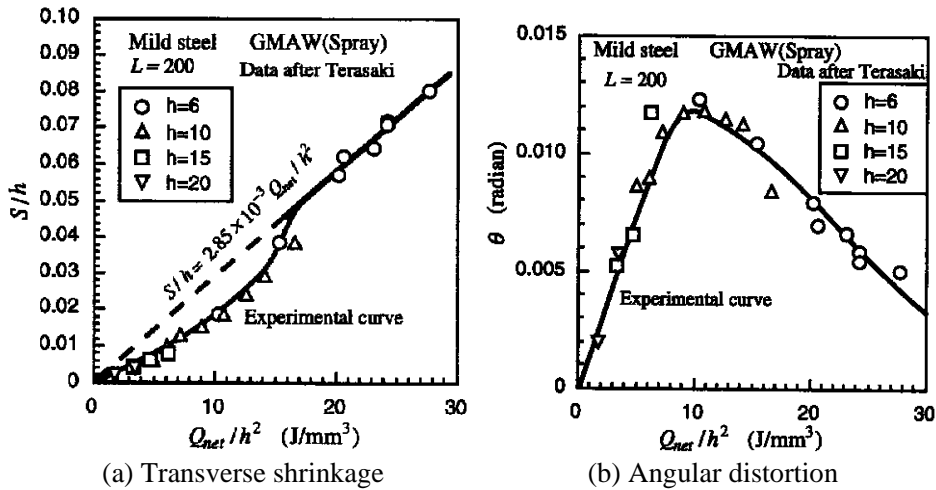

(a) Transverse shrinkage   (b) Angular distortion

Fig.1 Relationship between welding deformation and heat input parameter Q_{net}/h^2
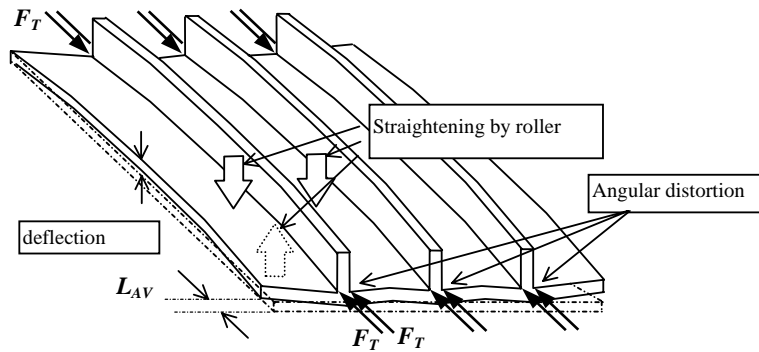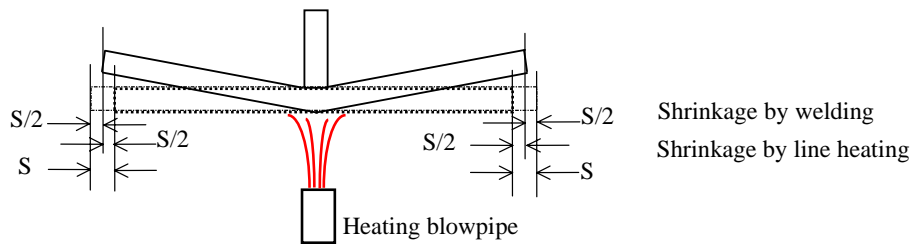

Fig.2 Deformation in panel welding

Fig.3 Deformation by line heating

Prediction of Welding Deformation for the Structure

In manufacturing a bridge, the shrinkage deformation in a plane poses a problem. The shrinkage deformation in a plane is calculable by the above-mentioned method.

The block of a bridge is not so wide. So a bending deformation occurs, if the welding part is arranged non-uniformly at the section. We gave tendon force to each welding part, and calculated the bending deformation in consideration of bending moment about the neutral axis of the member.

Using the developed method, we calculated the deformation in panel assembly of box girder shown in Fig.4.

Comparison of calculated and measured value is shown in Fig.5. The ribs are arranged equally in the section at the upper flange, and the ribs are arranged non-uniformly in the section at the lower flange. Bending deformation has been occurred in the lower flange. Moreover, the both members are extended in roller straightening.

In all processes, the difference of measured and calculated values are less than 0.5mm.They are good agreement.

Consequently we reduce the correcting work by line heating, and achieve the cost reduction in production.
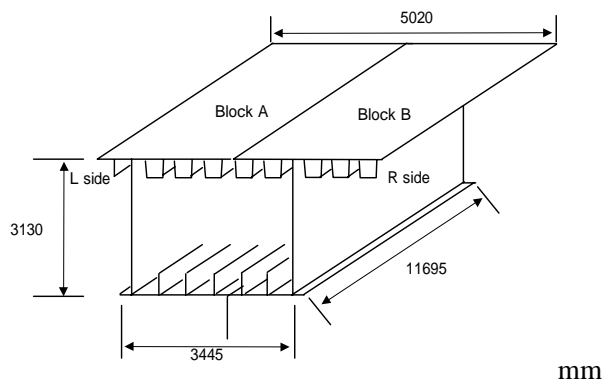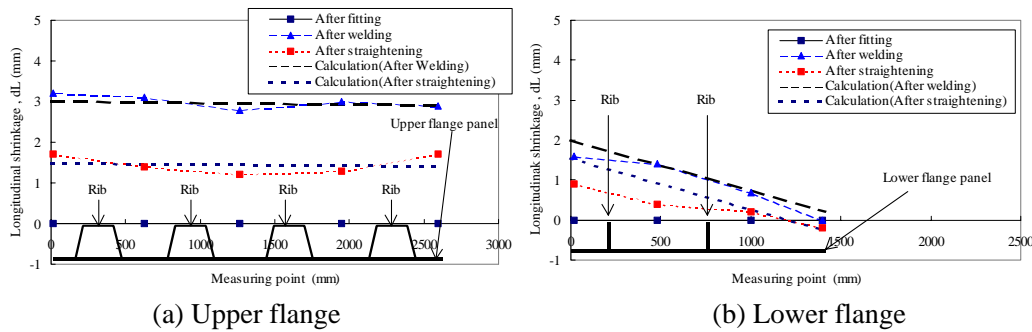

Fig.7 Box girder

(a) Upper flange   (b) Lower flange

Fig.8 Comparison of calculated and measured deformation in panel welding

Conclusions and Remarks

The obtained results are summarized as follows.

a) We established a prediction system of welding distortion for a large steel structure.

b) The prediction accuracy of the developed system was good in practical use.

c) It is expected that the developed prediction system enabled us to reduce the correcting work and production cost.

Reference

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