한국해양공학회 2000년도 춘계학술대회 논문집 PP. 205~209

평 블록의 용접변형 제어

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Weld Induced Deformation Control of Panel Blocks

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KEY WORDS: Accuracy control, Angular deformation, Inaccuracy, Panel block, Shrinkage, Weld deformation

ABSTRACT: *This paper is concerned with development of the production-oriented structural design information system to predict the inaccuracy level of panel blocks and to consider the result at the structural design stage. Emphasis is placed on that the inaccuracy during production should likely be considered at the structural design stage to reduce the undesirable adjusting work and therefore to enhance the productivity. The primary goal of the present study is to consider the productivity and the efficient design at the same time for a high quality product of panel block. Usefulness of the developed information are illustrated through some application examples.*

1. INTRODUCTION

In shipbuilding industry accuracy control takes place in the important part[1-4]. In order to produce a high quality products, the accuracy control should be probably managed from the subassembly stage of panel block. In addition the concept of accuracy control is to be also incorporated with the structural design so that the designer can produce a better design result accounting for the geometric inaccuracy. For this purpose, it is necessary to develop the production-oriented structural design information system, which is aimed at producing a better design result accounting for the information (or knowledge) about the inaccuracy level of panel block assembly.

In this paper emphasis is placed on that accuracy control is to be performed at the subassembly stage to keep higher geometric accuracy level at the following assembly stage and that it is important to keep the weld deformation be uniform along the joint line as possible to reduce the adjusting work at the next assembly stage. This paper does not go into detail of the developed system and the general concept of the present system is illustrated. Since fillet weld takes more portion than butt weld in panel block assembly, presented is how deformation due to fillet weld is affected by parameters such as weld leg length, initial deflection due to butt weld and span length (longitudinal space). Some application examples of the present system to subassembly of panel block are followed. Throughout the analysis the geometric inaccuracy arising from plate cutting, transportation, stock and so on is neglected.

This paper ends with discussion on the application results of the present system and extension of the present study aimed at enhancing productivity.

2. PRESENT SYSTEM

2.1. General

The present system is aimed at reducing the undesirable man power during production process at the structural design stage with referring to the information about inaccuracy level of panel block assembly and not aimed at obtaining the optimal structural design result. For this it is necessary to provide the information about how the deformation during block assembly would be kept both as low level and uniform as possible at the same time. With such system designer can grasp the resultant deformed shape or inaccuracy level along the joint line and then, one can try to change design (including rearrangement of structural members) to reduce the inaccuracy level. The present system consists of following program modules.

(1) Data input module
  - geometric data of panel block
  - joint line data
  - data for structural design
(2) Structural design module
(3) Predicting residual deformation module

Data of joint line include the joint type (fillet or butt weld) and welding condition for each weld line. Structural design module performs the structural design according to the Classification Society Rule when design conditions and parameters are changed. Predicting residual deformation module is to simulate the welding deformation which consistits of two steps : butt and fillet weld simulation. Simplified formulae of predicting various welding deformation described in the next section are used. Structural analysis is performed by the finite element method and equivalent load and/or displacement are applied to obtain the deformed shape. Data for structural analysis are automatically generated with information about panel block and structural design. Since butt weld is followed by fillet weld at the subassembly stage for panel block, the deformation during butt weld process is treated as the initial displacement in simulating fillet weld process.

2.2. Formulae of predicting weld induced deformation

Weld induced deformations are usually classified as follow [5] :

1) transverse shrinkage perpendicular to the weld line
2) longitudinal shrinkage parallel to the weld line
3) angular distortion around the weld line

The formulae for the above deformation are well summarized in many references [5,6]. As it has been mentioned, fillet weld takes a more portion than butt weld in panel block assembly, especially at the subassembly stage since many stiffeners are to be welded on panel. Concerning with the formulae of predicting the angular distortion due to fillet weld, most formulae do not account for the change of angular distortion along the weld line. Referring to the past experimental and numerical studies as well as the measured results for the real panel blocks in ship yard, it does significantly vary along the weld line. In this paper a modified formula is proposed to account for the change of angular distortion along the weld line, which has been derived based on the results of thermo elasto-plastic analysis[7]. Models for numerical analysis are listed in Table 1. In reference [7] following formula was proposed as the average angular distortion for FCAW.

$$\Phi_{fo} = 1.2427\, p^{1.8943}\, e^{0.165p} \quad (\times 10^{-3}\text{rad.}) \quad (1)$$

where p is heat input parameter defined as

$$p = Q/\, t^{1.5} \quad (2)$$

with t and Q are plate thickness and heat input per unit length, respectively. To account for the change of the angular distortion along the weld line it is expressed as:

$$\Phi_f = \Phi_{fo}\, F(p,\, x/\, w_l) \quad (3)$$

where Φ_{f0} is given as Eq.(1) and $F(\bullet)$ is the correction factor reflecting for the change along the weld line and w_l is weld length. The correction factor is assumed to be a linear function.

$$F(p,\, \frac{x}{w_l}) = C_0 + C_1 \frac{x}{w_l} \quad (4)$$

x is the distance from starting point of weld. Coefficients C_0 and C_1 are derived through the regression analysis based on the numerical analysis results for the models shown in Table 1 as follow:

$$\begin{aligned} C_0 &= 0.94 - 0.026p + 0.00094\, p^2 \\ C_1 &= 0.13 + 0.050p - 0.00170\, p^2 \end{aligned} \quad (5)$$

Comparison of the present formula with the numerical analysis results is illustrated in Figure 1. It can be seen that the proposed formula well agrees with the numerical analysis results.

For other deformation type appropriate formulae are used [5-7].

2.3. Welding deformation simulation

Weld induced deformations have been measured for several panel blocks in shipyard and the present system has been applied to show the validity the elementary parts consisting the present system. Table 2 shows the models measured in shipyard and the simulation results. Model A and Model B series denote the case that 28 pole and 10 pole automatic welding machine were used, respectively. The deflection at mid-span between stiffeners were measured. Figure 2 shows the modelling for the present simulation. Angular distortion and shrinkage are considered by applying the equivalent forces. Simulation results are summarized in the same table. Simulation results in general well agree with the measured results such that mean of the ratio between measured and simulated results is 1.076 as far as the measured models in Table 2 are concerned. It implies that the present system can reasonably predict weld induced deformation.

Table 1 Models for numerical analysis

Model	t (mm)	heat input, Q (cal/mm)	heat input parameter, p
N1	7.0	213.6	11.5
N2		356.5	19.2
N3	8.0	279.6	12.4
N4		367.1	16.2
N5	13.0	321.2	6.9
N6	15.0	298.3	5.1
N7		354.0	6.1
N8	18.0	298.3	3.9
N9		321.2	4.2
N10		354.0	4.6

Table 2 Measured results

model	t (mm)	s (mm)	Q (cal/mm)	measured result	simulated result
A1	12.5	840	190.9	1.30	1.01
A2	14.0	840	190.9	3.50	3.56
A3	15.0	700	190.9	2.00	1.94
A4	15.0	810	187.5	4.10	3.97
A5	17.0	830	183.0	2.90	2.66
A6	17.0	830	192.1	2.70	2.52
A7	17.0	830	188.2	1.80	1.72
A8	17.0	885	173.4	2.80	2.55
A9	17.0	830	224.3	1.45	1.44
A10	17.5	840	204.4	2.40	2.26
A11	18.5	840	166.9	1.70	1.49
A12	19.0	875	187.5	3.60	3.09
A13	19.0	840	167.8	1.85	1.59
A14	16.0	830	131.2	2.95	2.69
B2	18.0	850	319.5	3.10	3.12
B3	18.5	840	347.0	1.80	1.77

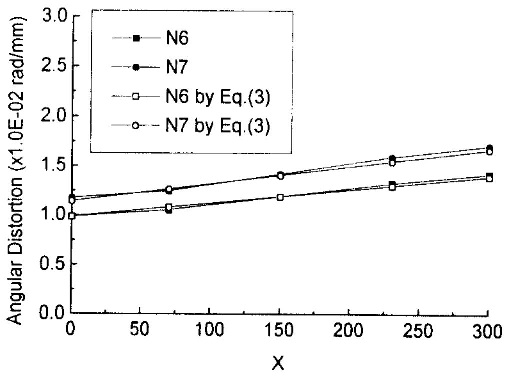


Fig.1 Comparison example

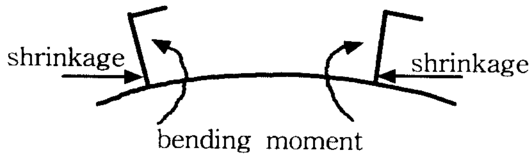


Fig.2 Analysis model for fillet weld

From the designer's point of view quantitative information how design parameters affect the welding deformation is useful at the decision making stage. Referring to the past researches the important parameters affecting the weld deformation during fillet weld process are not only weld leg length and span length (longitudinal space) but also the initial deflection occurring during butt weld process. Several parametric studies have been carried out to quantitatively show the affecting level. For the present parametric study plate thickness is 12.5, 14.0, 17.0, 19.0mm and weld length is 4000mm. Let δ, ϕ and s be the initial deflection due to butt weld, weld leg length and span length. Following three cases are considered.

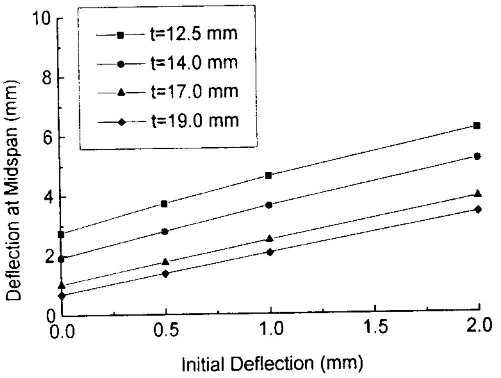
Case 1 : δ = 0.0, 0.5, 1.0, 2.0mm
with ϕ = 6mm and s = 840mm
Case 2 : ϕ = 6.0, 6.5, 7.0, 8.0mm
with δ = 0.5mm and s = 840mm
Case 3 : s = 700, 750, 800, 850, 900mm
with δ = 1.5mm and ϕ = 6.0mm

The same heat input of Q = 190cal/mm is assumed. Results of parametric studies are presented in Figure 3. It can be seen that deflection is generally proportional to the above three parameters regardless of plate thickness and that the initial deflection due to butt weld is the most affective parameter followed by weld leg length and span length in turn. This implies that accuracy control should be made at the previous assembly stage from production side and selection of span length is relatively open to the designer such that it gives the optimal structural design just satisfying the requirements specified in Classification Society Rules.

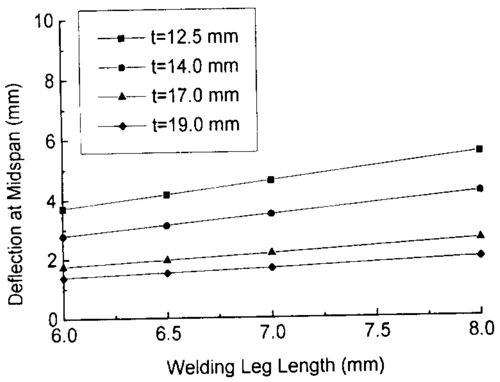
3. APPLICATION TO PANEL BLOCK ASSEMBLY

In this section presented is the application of the present system to subassembly stage with varying longitudinal space. Figure 4 shows a panel block model with five stiffeners. Following three panel block models are considered as for illustrating the present system.

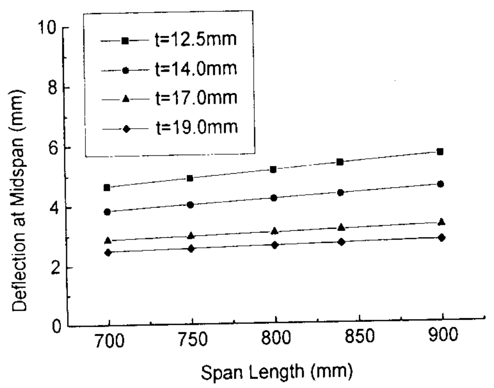
M1 : s = 800mm, no. of stiffeners = 5
M2 : s = 750mm, no. of stiffeners = 6
M3 : s = 850mm, no. of stiffeners = 5



(a) effect of initial deflection



(b) effect of weld leg length



(c) effect of span length

Fig.3 Result of parametric studies

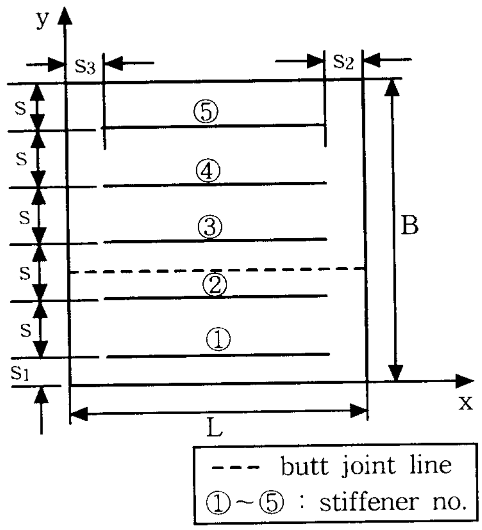


Fig.4 Example of panel block model

For all models L and plate thickness are 2250 and 14.0mm, and s_1, s_2, s_3 are 200, 600, 150mm. B depends on the number of stiffeners, and so B = 4000, 4550, 4200mm for model M1, M2 and M3, respectively. The same welding conditions, say the same heat input of Q = 190.0cal/mm is assumed and it is also assumed that there is a but joint line at mid of no.2 and 3 stiffeners.

The deformed shape magnified fifty times is shown in Figure 5 for M1, in which dotted line denotes the original panel. Deflection along joint lines, x = 0 and L are shown in Figure 6. As it can be easily expected, deflection significantly varies along side perpendicular to the weld line although its magnitude is not great while it is nearly uniform along the free edge joint lines (y = 0 and B).

There are a couple of ways to produce less and uniform deflection along the joint lines perpendicular to the weld line. One possible way may be attaching the temporary stiffener perpendicular to the weld line. This is not, however, expected to reduce deflection at mid of weld line, say along x = L/2. For model M1 the initial deflection between two stiffeners due to butt weld was 0.9, -0.4, 0.8, 0.6mm and from Figure 5 it is noticeable that the deflection between no.2 and 3 stiffeners having negative initial deflection is much lower than others. Giving the negative initial deflection is therefore another possible way to achieve both the deflection as uniformly distributed along the joint line and low geometric inaccuracy as possible. In the case that the all initial deflection at mid-span between stiffeners are -0.5mm for model M1, the deformed shape is shown in Figure 7. Comparing Figures 5 and 7, it can be seen the apparent reduction of deflection along the joint line except the free edge side, for which another way can be applied to reduce the deflection.

This kind of simulation can be rapidly carried out at the design stage with the present system. At this time it can be said that providing the quantitative information about how to reduce the inaccuracy level must be important at the design stage and very useful in enhancing the productivity.

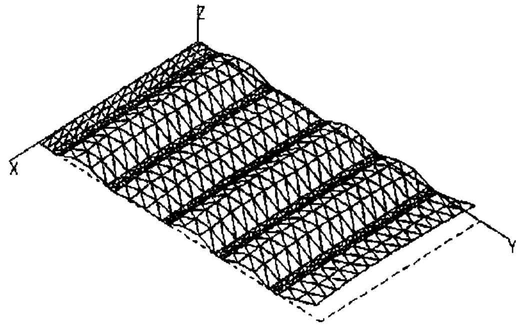


Fig.5 Deformed shape for panel block model M1

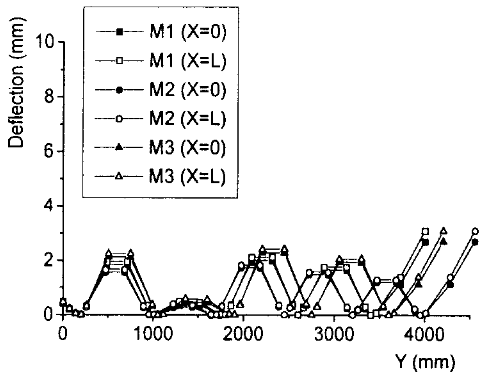


Fig.6 Deflection along joint lines

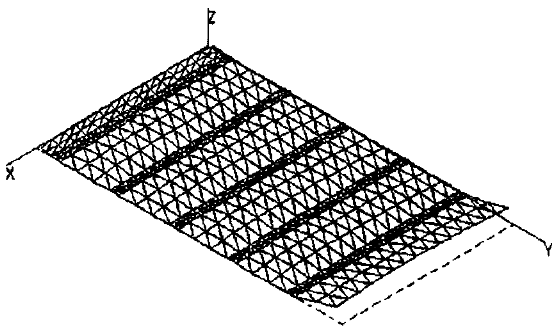


Fig.7 Deformed shape for model M1 with negative initial deflection between stiffeners

4. CONCLUSIONS

In this paper proposed is the general concept of the production-oriented structural design information system toward reducing the undesirable additional work at panel lock assembly stage. A prototype system has been developed and example application of the system is illustrated. As far as the results illustrated in this paper are concerned, it can be said that the present system can provide the useful information about the geometric inaccuracy to designer and hence one can produce a better design result with accounting for the productivity. The system can be extended to application the panel block before erection stage. The application example will be presented at the judicial proceedings in the near future.

REFERENCES

[1] M. Ichiji et al., Computer Applications to Accuracy Control in Hull Construction, Proc. ICCAS'85, Trieste, 1985

[2] K. Aoyama, T. Nomoto and S. Takechi, Basic Studies on Accuracy Management System for Shipbuilding, Proc. ICCAS'97, 1997

[3] T. Okumoto ,Study on Accuracy Control of Hull Structure, J. Ship Production, SNAME, 1994

[4] M. Yuzaki et al., An Approach to a New Ship Production System Based on Advanced Accuracy Control, J. Ship Production, SNAME, 1993

[5] K. Masubuchi, Analysis of Welded Structures - Chap.7 Distortion in Weldments, Pergamon Press, 1980

[6] K. Satoh and T. Terasaki, "Effects of Welding Conditions on Welding Deformations in Welded Structural Materials, J. Japanese Welding Society, Vol.45, No.4, 1976

[7] S.I. Kim, S.I., J.S. Lee et al ,A Study of the Accuracy Control of Block Assembly in Shipbuilding - simulation of residual deformation due to fillet welding, Proc. ICCAS'97, 1997