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Residual welding distortions of a stiffened conical deck

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ABSTRACT: For quality assurance of welded structures it is important to prevent the residual welding distortions. Our calculation method helps the prediction of these deformations. After the summary of calculation formulae the residual radial displacements of the periphery of a stiffened conical deck are determined. The conical deck is stiffened by a circular and more radial flat ribs welded to the deck shell by double fillet welds. The shrinkage of these welds causes radial displacements of the deck periphery. The derived formulae make it possible to decrease the residual distortions to a prescribed size.

1. INTRODUCTION

One important point of view for the quality assurance of welded structures is the prevention of residual welding distortions to fulfil the fabrication tolerances. This task needs a simple calculation method to analyze the factors affecting the distortions. In IIW (International Institute of Welding) a special working group X/XV-RSDP (residual stresses and distortion prevention) has been organized.

This group has worked out a lot of documents discussed during the IIW Annual Assembly in San Francisco 1997. Our document [1] on the calculation method of residual stresses and distortions has been discussed and recommended for publication in the journal Welding in the World.

Our aim is to apply this relatively simple calculation method for analysis of different welded structures to show the factors affecting the distortions and to give aspects for the decreasing of these deformations.

2. THE BASIC CALCULATION FORMULAE

The derivation of calculation formulae worked out on the basis of the Okerblom's method [2] is described in our book [3]. For the calculation of distortion of beam-like structures due to shrinkage of longitudinal welds the following formulae can be used.

The specific strain in the gravity center G of a cross-section is given by

$$\varepsilon_G = \frac{0.3355\alpha_0 Q_T}{c_0 \rho A} \quad (1)$$

where A is the cross-sectional area, c_0 is the specific heat, α_0 is the coefficient of thermal expansion, ρ is the material density. For steels it is

$$\varepsilon_G = 0.844 * 10^{-3} Q_T / A \quad (2)$$

where the specific heat input is

$$Q_T = \eta UI / v_w = 3600 \eta U \rho A_w / \alpha_N \quad (3)$$

η is the coefficient of heat efficiency, U is arc voltage, I is arc current, v_w is speed of welding, A_w is the cross-sectional area of weld, α_N is coefficient of penetration.

For hand welding

$$Q_T(joule/mm) = 78.8a_w^2 \qquad (4)$$

and for automatic welding

$$Q_T = 59.5a_w^2 \qquad (5)$$

where a_w (mm) is the weld dimension.

The curvature due to the weld eccentricity is given by

$$C = 0.844 * 10^{-3} Q_T y_T / I_x \qquad (6)$$

y_T is the weld eccentricity, I_x is the moment of inertia of the cross-section.

The shrinkage of a weld causes a shortening of a bar $\Delta L = \varepsilon_G L$ where L is the length of the bar, the deformations caused by the curvature C can be calculated as an effect of a bending moment $M = CEI_x$.

Note that, for double fillet welds, the above deformations caused by a single weld can be multiplied by a factor of 1.5 instead of 2, when the second weld is welded after the cooling up of the first one.

3. EXAMPLE OF A STIFFENED CONICAL DECK

The deck structure (Fig.1) consists of a conical shell stiffened by a circular and more radial flat ribs welded to the deck by double fillet welds. The shell effect is neglected and only strips of shell are considered forming together with flat ribs T-shaped stiffeners. Thus, the deck is treated as a spatial rod structure consisting of a circular and more radial T-stiffeners.

The final radial displacement of the point B of a radial stiffener consists of two parts as follows. ΔR_{Br} is caused by shrinkage of welds of radial stiffeners and ΔR_{BC} is caused by the shrinkage of welds connecting the circular stiffener to the deck shell.

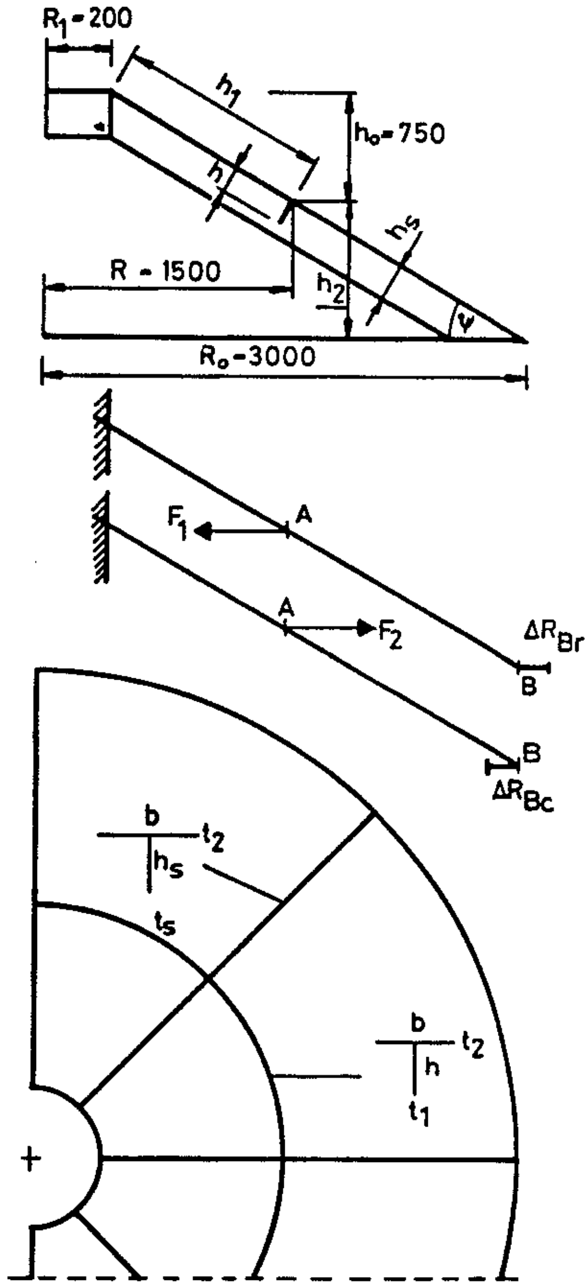

Fig. 1. Stiffened conical deck with eight radial stiffeners

The radial stiffener can be regarded as a cantilever beam the displacement of which is restrained at point A by the circular stiffener. The restraining forces F_1 and F_2 can be calculated from displacement equations as follows.

The displacement equation for F_1 expresses that the final displacement of radial stiffener equals to the radial displacement of the circular stiffener at point A:

$$\Delta R_{Ar}(C_S) - \Delta R_{Ar}(\varepsilon_{GS}) - \Delta R_{Ar}(F_1) = \\ = \Delta R_{AC}(F_1) \quad (7)$$

$\Delta R_{Ar}(C_S)$ is caused by the curvature due to eccentric longitudinal fillet welds

$$\Delta R_{Ar}(C_S) = C_S h_0 h_1 / 2 \quad (8)$$

$$C_S = 0.844 * 10^{-3} Q_{TS} y_T / I_S$$

$$Q_{TS} = 1.5 * 78.8 a_w^2 \quad (9)$$

We consider a T-shaped stiffener with a flange of width b and thickness t_2 and a web of height h_s and thickness t_s. The distance of the gravity center from the flange is

$$y_{GS} = \frac{h_S}{2(1+\alpha_S)}; \quad \alpha_S = \frac{bt_2}{h_S t_S}$$

$$y_{TS} = y_{GS} - t_2 / 2 \quad (10)$$

$$I_S = \frac{h_S^3 t_S}{12} \frac{1+4\alpha_S}{1+\alpha_S} \quad (11)$$

$\Delta R_{Ar}(\varepsilon_{GS})$ is caused by the shrinkage of longitudinal welds

$$\Delta R_{Ar}(\varepsilon_{GS}) = \varepsilon_{GS} h_1 \cos\psi \quad (12)$$

$$\varepsilon_{GS} = 0.844 * 10^{-3} Q_{TS} / A_S \quad (13)$$

$$A_S = h_S t_S + bt_2$$

$\Delta R_{Ar}(F_1)$ is caused by F_1

$$\Delta R_{Ar}(F_1) = \frac{F_1 h_0^2 h_1}{3EI_S} \quad (14)$$

E is the modulus of elasticity.

When the number of radial stiffeners is n, the uniformly distributed radial load acting on circular rib is

$$p_1 = \frac{nF_1}{2R\pi} \quad (15)$$

and the radial displacement caused by p_1 is

$$\Delta R_{AC}(F_1) = \frac{p_1 R^2}{AE} = \frac{nRF_1}{2\pi AE} \quad (16)$$

$$A = ht_1 + bt_2$$

The unknown force F_1 can be obtained from (7) as

$$F_1 = \left(C_S h_0 h_1 / 2 - \varepsilon_{GS} h_1 \cos\psi\right) / D$$

$$D = \frac{h_0^2 h_1}{3EI_S} + \frac{nR}{2\pi AE} \quad (17)$$

Similarly, F_2 is calculated from the displacement equation

$$\Delta R_{AC}(\varepsilon_G) - \Delta R_{AC}(F_2) = \Delta R_{Ar}(F_2) \quad (18)$$

where

$$\Delta R_{AC}(\varepsilon_G) = R\varepsilon_G \quad (19)$$

$$\varepsilon_G = 0.844 * 10^{-3} Q_T / A; \quad Q_T = Q_{TS}$$

$$\Delta R_{AC}(F_2) = \frac{nRF_2}{2\pi AE} \quad (20)$$

$$\Delta R_{Ar}(F_2) = \frac{F_2 h_0^2 h_1}{3EI_S} \quad (21)$$

Thus, from (18) one obtains

$$F_2 = R\varepsilon_G / D \quad (22)$$

Knowing F_1 and F_2 we can calculate the radial displacements at point B:

$$\Delta R_B = \Delta R_{Br} - \Delta R_{BC} \quad (23)$$

$$\Delta R_{Br} = \frac{C_S(h_0+h_2)^2}{2\sin\psi} - \varepsilon_{GS}(R_0 - R_1) -$$

$$-\frac{F_1 h_0 h_1 (h_0 + 1.5h_2)}{3EI_S} \qquad (24)$$

$$\Delta R_{BC} = \frac{F_2 h_0 h_1 (h_0 + 1.5h_2)}{3EI_S} \qquad (25)$$

It should be mentioned that the angular deformation of the inner ring is neglected.

4. NUMERICAL EXAMPLE: MINIMUM VOLUME DESIGN OF STIFFENERS FOR PRESCRIBED MAXIMUM RADIAL DISPLACEMENT

The optimum design problem is formulated as follows: find the optimum values of h, t_1, h_S, t_S and n to minimize the volume

$$V = 2R\pi A + nA_S L_S \qquad (26)$$

$$L_S = (R_0 - R_1)/\cos\psi$$

and to fulfil the constraint on residual welding displacement

$$\Delta R_B \le \Delta_{allow} \qquad (27)$$

where Δ_{allow} is the prescribed allowable displacement.

Numerical data in mm: R_0 = 3000, R = 1500, $R_1 = 200$, $\psi = 30^0$, $E = 2.1*10^5$, a_w = 4, t_2 = 4, b = 200.

To avoid the local buckling of flat stiffeners we take the limiting plate slenderness $h/t_1 = h_S/t_S = 14$, so the unknown dimensions h and h_S can be eliminated.

With these numerical data the volume (26) can be expressed as

$$V = 9425A + 3233nA_S$$

$$A = 14\ t_1^2 + 800,\ A_S = 14\ t_S^2 + 800$$

The other formulae take the following form:

(24): $\Delta R_{Br} = 2.6115*10^6 C_S - 2800\varepsilon_{GS} -$
$-3661.37F_1/I_S$

(17): $F_1 = (5.6288*10^5 C_S - 1300\varepsilon_{GS})/D$

$D = 1340.18/I_S + 1.1368*10^{-3}n/A$

(13): $\varepsilon_{GS} = 1.5962/A_S$

(9): $C_S = 1.5962 y_{TS}/I_S$

(11): $I_S = 228.667 t_S^4 \dfrac{t_S^2 + 228.571}{t_S^2 + 57.1429}$

(25): $\Delta R_{BC} = 3661.37 F_2/I_S$

(22): $F_2 = 1500\varepsilon_G/D$

(19): $\varepsilon_G = 1.5962/A$

Table 1. Optimum thicknesses (in mm) and the corresponding volume (in mm^3) in function of the number of radial stiffeners and of allowable displacement (mm)

n	Δ_{allow}	t_S	t_1	$10^{-7}V$
	10	11		5.80
6	8	12	4	6.42
	6	13		7.11
	5	14		7.84
	10	11		7.41
8	8	12	4	8.25
	6	13		8.80
	5	14		10.13

For the constrained minimization the Rosenbrock's hillclimb method is used. The computational results are summarized in Table 1.

5. CONCLUSIONS

It can be seen from Table 1 that the dimensions of radial stiffeners should be increased to decrease the radial displacement. The dimensions of the circular stiffener should be kept minimum to minimize the volume of the deck structure. The volume increases when the number of radial stiffeners increases

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