REMOVAL OF POST-WELDING DISTORTION IN STIFFENED PLATE PANELS

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ABSTRACT

Welding deflection of stiffened plate panels is considered an inevitable distortion in fabricating the ship's hull plating. The undesired out-of-plane distortion can be removed through creating counter-distortion using the proper removal process. To have an efficient distortion removal process, using the flame heating, necessary information about appropriate heating positions and heating conditions are required in advance. Most of these information can be obtained from the counteracting strain field producing the necessary counter-distortion. This paper presents a study of the characteristics of the counteracting strain which is called the remedial strain. This remedial strain can be determined from the shape of counter-distortion. The practicable type of the remedial strain, bending and/or inplane, that can be created by the flame straightening process have been discussed. The relation between the welding deflection shape and the remedial strain has been clarified. In addition, the effects of the plate dimension and the maximum deflection on the remedial strain are examined. The remedial strain characteristics for four different post-welding deflection shapes are examined. Based on the remedial strain, decisions can be made to define the removal procedure using the flame-straightening process. The finite element method is employed in this analysis.

Keywords: Welding deflection, Distortion removal process, Remedial strain, Finite element method.

1. INTRODUCTION

It is well known that the deflection due to the welding process is an inevitable distortion in fabricating stiffened plate panels of ship's hulls. This kind of undesired distortion deteriorates the compressive strength of plates as well as the smoothness of the hull surface. There are different techniques that can be applied to remove undesired distortion such as flame-heating, vibratory stress-relieving, and electromagnetic-hammer techniques [1]. The flame heating technique, which is called the flame straightening process, is the most common distortion removal technique applied in shipyards.

The undesired post-welding distortion of stiffened plate panels can be removed by creating counter-distortion using a proper distortion removal process. When the flame straightening process is used as a removal process, plastic deformation is created to produce a counter-distortion. For this purpose, information about the heating position and heating condition producing the proper counter-distortion should be known in advance. Most of these information can be obtained from the counteracting strain field which produces the counter-distortion. Due to the complex behavior of the plate material during the heating process, many years of experience are normally required by skilled craftsmen for distortion removal. However, available information about the straightening process for stiffened plate panels is very little [1-2].

Utilizing the facility of the greatest advance in the computer technology, computer-aided identifying removal procedure for welding deflection of stiffened plate panels can be achieved. This paper presents a study of the characteristics of the counteracting strain field that produces the required counter-deflection as a first step. This counteracting strain is called here the remedial strain. The counter-distortion for a plate panel can be determined using the proper simulation for the welding process. Then, the remedial strain field can be obtained for this distorted plate. The practicable type of the remedial strains, bending and/or inplane, that can be obtained using the flame straightening method is discussed. The relation between the welding deflection shape and the necessary remedial strain to be given to the distorted plate has been studied. The influences of the plate dimensions and the maximum deflection on the remedial strain are examined. The remedial strain characteristics for four different post-welding deflection shapes are examined. The finite element method is employed in this analysis.

2. ANALYSIS OF REMEDIAL STRAIN

2.1. *Source of welding deformation*

During welding, the region near the weld line is affected by the heat input through the molten weld metal and transient thermal stress and deformation occur in the weldment. After completing the welding process, post-welding deformation and residual stress take place in the stiffener and the plate. As a result from the heating and cooling cycle, compressive plastic strain in the heat affected zone (HAZ), as shown in Figure (1), is produced. The created compressive plastic strain in the plate is the main source for the welding deformation of the plate panel. Therefore, the ideal situation to remove the post-welding distortion is to produce an opposite plastic strain distribution at the same position. That means, tensile component of plastic strain eliminating the compressive plastic strain must be produced at the same position. In this case, the deformation as well as the residual stress of the stiffened plate panel, due to the welding process, intuitively will disappear. However, producing such tensile plastic strain distribution at HAZ cannot be achieved using any available technique. Thus, to remove the welding deformation another counter-loading should be obtained through the known counter-deformation. This trend is commonly applied in removing the excessive distortion using the available process.

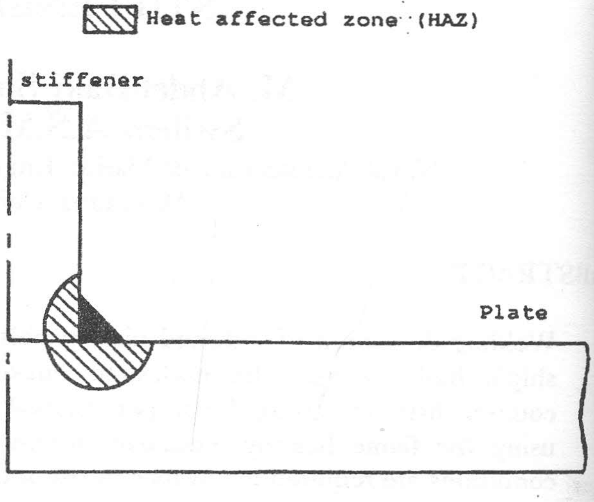


Figure 1. Schematic representation for the heat affected zone HAZ.

2.2. *Application of counter-deformation*

To discuss the counter-deformation, the welding deformation should be known at first. However, making a prediction for the post-welding deformation of a plate panel needs a thermomechanical analysis which is rather time consuming. Consequently, it is convenient to get the plate deformation through similar kind of loading for the plastic strain in order to examine the counter-deformation. This can be obtained by applying an initial strain to a flat plate in the proper position. Since the heat affected zone is located at the edges of the plate panel, the positions for the applied initial strain are assumed to be located as shown in Figure (2). When the initial strain is applied to the flat plate, then the plate will deform to a certain deformation shape. This simply simulates the deformation of plate due to the influence of an internal loading which is similar to that of the welding process. Instead of applying opposite strain to that of the initial strain in the same previous position, counter-deformation, which is equal in magnitude to that obtained previously but in opposite direction, is applied to the deflected plate. This means that the plate is forced to deform in the opposite direction until the deformation vanishes. Thus, the strain produced in a flat plate deformed to the desired counter-deformation is considered to be the required remedial strain. This simulation is performed using elastic-perfect-plastic plate finite element code with large' deformations [3]. The material behavior of the plate is assumed to be elastic throughout the analysis.

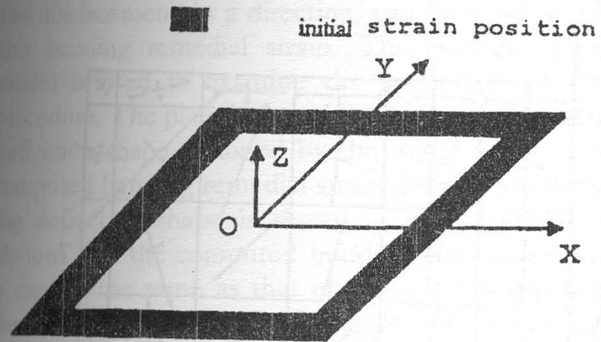


Figure 2. Position for assumed initial strain.

2.2.1. *Example model*

A simply supported square plate of dimensions 1000x1000x5 mm is considered to examine the characteristics of the remedial strain. The initial strain is applied to the plate in the equal strips, shown in Figure (2). The effective plastic strains due to the welding process are compressive components in *x* and *y* directions with negligible influence of the plastic shear strain. The distribution of each component through the thickness depends on the dimensions of the stiffened plate panel as well as the welding conditions. For simplicity, the components of the initial strain are assumed to be equal and to have a uniform distribution in x and y directions for the considered strips. On the other hand, the distribution through the thickness direction is assumed to be linear with zero magnitude at bottom surface.

The deformation of the plate due to applying the assumed initial strain is computed using the FEM. From symmetry, only one quarter is considered in the computation and the mesh division employed is shown in Figure (3). The computed deflection surface due to applying the initial strain is shown in Figure (4).

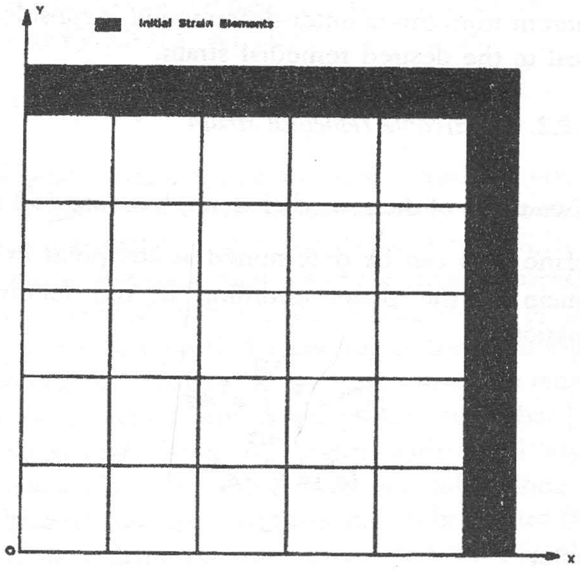


Figure 3. Mesh division (one quarter).

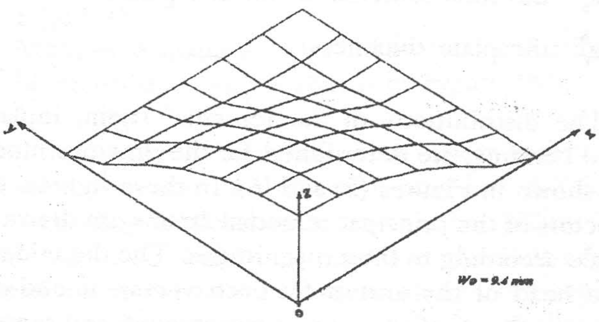


Figure 4. Deflection surface due to applying initial strain.

It can be noted from this figure that the obtained deflection shape along x and y axes is the same typical due to applying equal components of initial strain in the strips in both directions. When the distorted plate is forced to deform in the opposite direction until the deformation vanishes, the strain field in the plate becomes zero except the existing initial strain in the strips. This is done by applying forced lateral displacement which is proportional to the displacement at each node in an incremental manner. In this process, the opposite components of the displacements, *u* ,*v* and *w*, computed previously are used as the counter-deformation. Thus, the remedial strain for the distorted plate can be determined by forcing the flat plate to deform to the required counter-deformation. The computed strain inherent from this counter-deformation is considered equal to the desired remedial strain.

2.2.2. *Practicable remedial strain*

Two types of the remedial strain, bending (ϵ_r^b) and inplane (ϵ_r^m) can be determined at any point in the domain of the plate according to the following equations:

$$(\epsilon_r^m) = \frac{1}{t}\int_{-t/2}^{t/2} \epsilon_r^T \, dz \tag{1}$$

$$(\epsilon_r^b) = \epsilon_r^T - \epsilon_r^m \tag{2}$$

where,

ϵ_r^T the total remedial strain at a point.

ϵ_r^b the plate thickness.

The distributions of the remedial strain, inplane and bending, are determined for the previous model as shown in Figures (5) and (6). In these figures, the vectors of the principal remedial strains are drawn to scale according to their magnitudes. The direction of the head of the arrows for each vector, in-and-out directions, refers to compressive-and-tensile components of the remedial strain, respectively. It is clear from Figure (5) that, outside the initial strain position, the tensile inplane remedial strain is the predominant component. This tensile inplane remedial strain generally cannot be achieved by the flame straightening method which mainly produces shrinking deformation. In addition, the influence of the inplane remedial strain on the straightening process, generally, decreases as the plate thickness increases for the same distortion shape [3].

For the bending remedial strain, on the other hand, the heating process must be applied on the convex side of the plate surface to remove the bending distortion. Hence, the bending remedial strain can be considered as the practicable component of remedial strain which can be applied to remove excessive deflection of stiffened plate panels when the flame straightening is used. This conclusion is in agreement with the real practice of the flame straightening process. When the plate buckles due to the welding process, the flame heating technique cannot be applied to remove buckling distortion. This is because a dominant tensile component of the inplane remedial strain is necessary to eliminate this kind of buckling deformation.

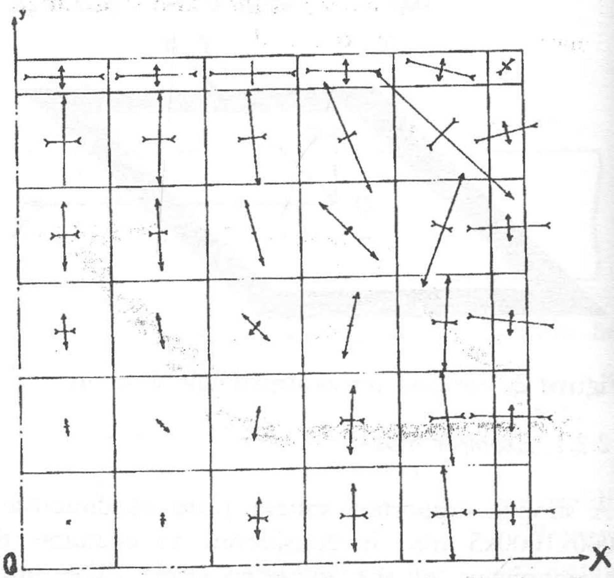


Figure 5. Inplane remedial strain distribution due to counter-deformation.

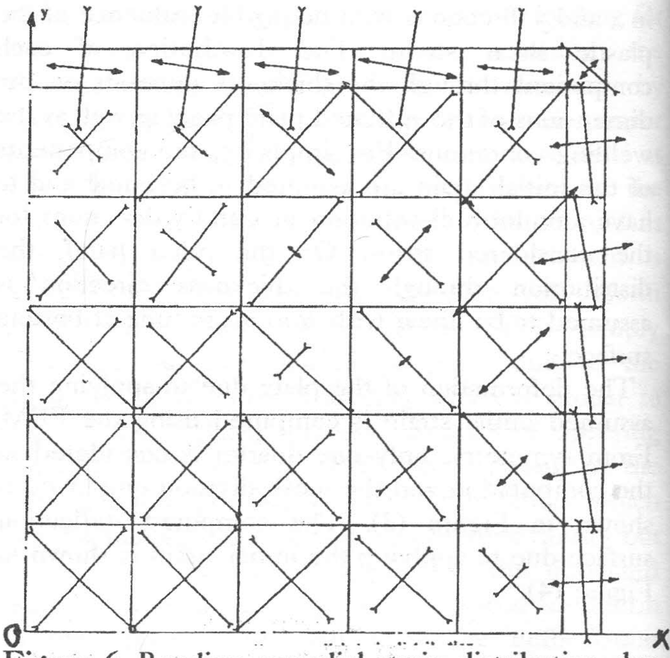


Figure 6. Bending remedial strain distribution due to counter-deformation.

2.3. *Application of deflection shape*

As concluded previously, the bending remedial strain is considered the practicable strain in the removal process using the flame straightening process. Thus, the shape of welding deflection, only the displacement in z direction, can be used to get this bending remedial strain. The previous plate model is used to examine the usefulness of this procedure. The plate is forced to deform to the same deflection shape obtained by the initial strain. The computed bending remedial strain distribution using the deflection shape is shown in Figure (7). It is obvious that the computed bending remedial strain is exactly the same as that obtained from applying the initial strain shown in Figure (6) except the changes in the strips which are considered out of the straightening process in the real practice. Therefore, although only the shape of welding deflection is used, the resulted bending remedial strain is the same. This agrees with the real practice of plate forming in which the same deflection shape can be achieved using different forming methods [4]. Thus, the bending remedial strain which can be developed to remove the excessive bending deformation is obtained using only the shape of welding deflection [5].

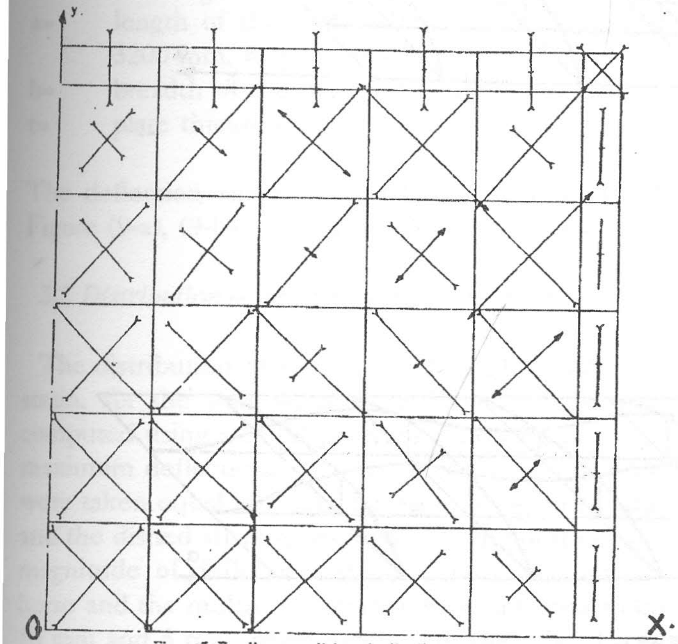


Figure 7. Bending remedial strain distribution due to deflection shape.

3. BENDING REMEDIAL STRAIN OF DIFFERENT WELDING SHAPES

3.1 *Shapes of welding deflection*

Several measurements were carried out to investigate the characteristics of post-welding deflection shape of plate panels for ships hull [6-10]. From the statistical analysis of the measurements, it was concluded that the deflection shape of plate panels can be classified according to the plate aspect ratio into four shapes. These four shapes are ranging from sinusoidal to multiwave pattern such that [10]:

a- Sinusoidal shape for plates with small aspect ratios $a/b = 1 \sim 1.41$ with one lobe along the breadth and the length as shown in Figure (8a).
b- Dished shape for $a/b = 1.41 \sim 2.45$ with one lobe along the breadth, as shown in Figure (8b).
c- Horse shape for $a/b = 2.45 \sim 3.46$ as shown in Figure (8c).
d- Multiwave shape for $a/b > 3.46$ which is dominant in length direction as shown in Figure (8d).

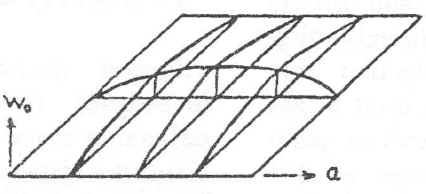
In this analysis, four different aspect ratios are selected to cover the above mentioned different post-welding deflection shapes. The plates are assumed to be simply supported at the four edges which are assumed to be undistorted. It is assumed that there is a symmetry in shape along the length and width directions so that the origin is chosen at the center of the plate. The chosen aspect ratios a/b, for the different four deflection shapes, are taken equal to 1, 2, 3, and 4,respectively. The sinusoidal, dished, horse and multiwave shapes can be represented mathematically using the sinusoidal function such that:

- *for sinusoidal shape:*

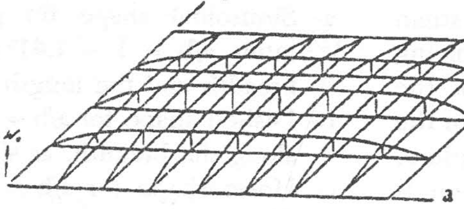
$$W = W_o \sin\left\{\pi\left(\frac{0.5a-x}{a}\right)\right\}\sin\left\{\pi\left(\frac{0.5a-y}{b}\right)\right\}$$

- *for dished shape:*

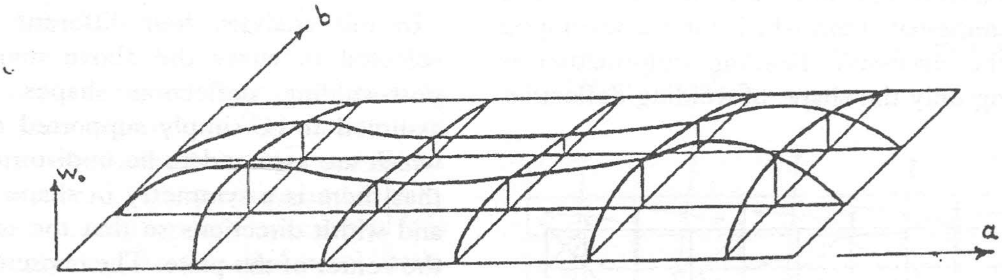
$$W = W_o \sin\left\{\pi\left(\frac{0.5a-y}{a}\right)\right\} \qquad \text{for } 0 < x < 3a/8$$



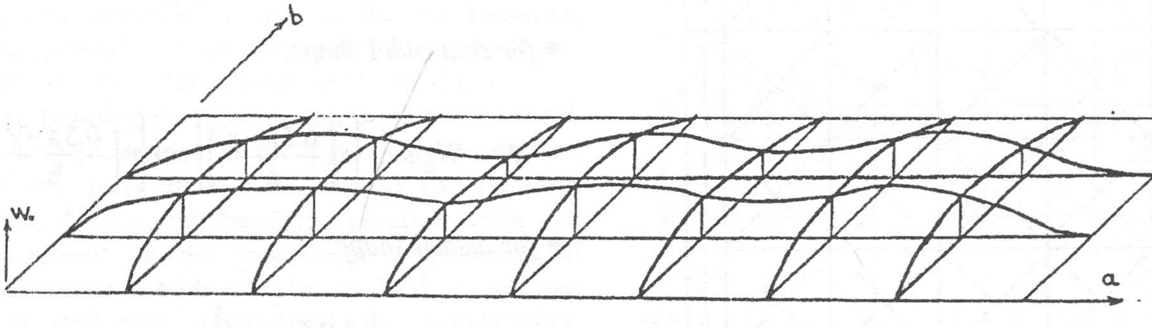
(a) Sinusoidal shape.



(b) Dished shape.



(c) Horse shape.



(d) Multiwave shape.

Figure 8. Shapes of welding deflection of plate panel.

$$W = W_0 \sin\left\{\pi\left(\frac{0.5a-x}{a}\right)\right\}\sin\left\{\pi\left(\frac{0.5a-y}{b}\right)\right\}$$

$$\text{for } 3a/8 \le x \le a/2 \qquad (4)$$

- *for horse shape:*

$$W = [W_0 \sin\left\{\pi\left(\frac{0.5a-y}{a}\right)\right\} + \qquad (5)$$

$$W_{03} \sin\left\{3\pi\left(\frac{0.5a-x}{a}\right)\right\}]\sin\left\{\pi\left(\frac{0.5a-y}{b}\right)\right\}$$

- *for multiwave shape:*

$$W = [W_0 \sin\left\{\pi\left(\frac{0.5a-y}{a}\right)\right\} + \qquad (6)$$

$$W_{04} \sin\left\{4\pi\left(\frac{0.5a-x}{a}\right)\right\}]\sin\left\{\pi\left(\frac{0.5a-y}{b}\right)\right\}$$

where,

W_0= the magnitude of deflection at the center of plate.

W_{03}= the component giving the maximum deflection at the shoulders together with W_O for the horse shape.

W_{04} = the component giving the maximum deflection away from the center together with W_O for the multiwave shape.

a= length of the plate = 800, 1600, 2400, and 3200 mm, respectively.

b= breadth of the plate = 800 mm.

t= plate thickness = 10 mm.

The deflection surface of each shape is shown in Figure (9-a), (9-b), (9-c), and (9-d), respectively.

3.2 *Distribution of bending remedial strain*

The distribution of the principal bending remedial strain, for the four welding deflection shapes are computed using a FEM program. The magnitude of maximum deflections, W_O, at the center of the plate were taken equal to 5 mm for each of the sinusoidal and the dished shapes, respectively. In addition, the magnitude of deflection at the center, W_O, for the horse and the multiwave shapes were selected to be 10 mm and 8 mm, respectively. On the other hand, the magnitude of the components W_{O3} and W_{O4} for the corresponding shape were chosen to be 6.5 mm and 2 mm, respectively. These values together with W_O at the center result in a maximum deflection equal to 11.93 mm for the horse shape and 8 mm for the multiwave shape.

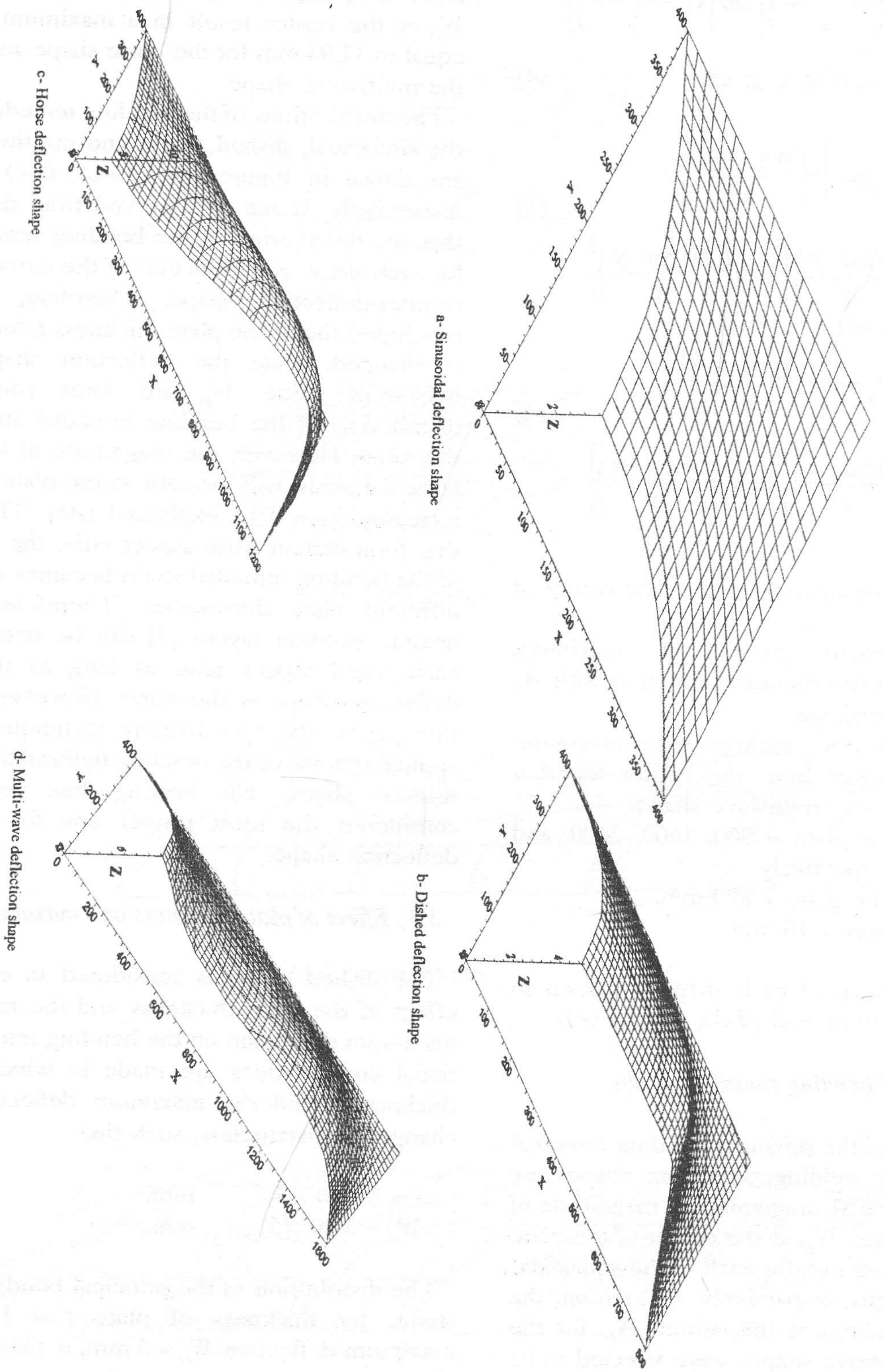
The distributions of the bending remedial strain for the sinusoidal, dished, horse and multiwave shapes are shown in Figures(9-a), (9-b), (9-c) and (9-d), respectively. It can be observed from these figures that the distribution of the bending remedial strain for each shape is a reflection of the curvature of the counter-deflection shape. Therefore, it can be concluded that if the plate thickness *t*, for any shape, is changed while the deflection shape and its maximum value W_O are kept constant, the distribution of the bending remedial strain will be the same. However, the magnitude of the bending remedial strain will increase as the plate thickness *t* increases, as will be explained later. This suggests that for a certain plate aspect ratio, the distribution of the bending remedial strain becomes the same for different plate thicknesses. Therefore, a unified heating position layout [3] can be determined for each panel aspect ratio as long as the welding deflection shape is the same. However, in case of thin plates, the spot heating technique is usually applied to remove the bending deformation while for thicker plates, the heating line technique is considered the most proper one for the dished deflection shape.

3.3 *Effect of plate thickness and maximum deflection*

The dished shape is considered to examine the effect of the plate thickness and the magnitude of maximum deflection on the bending remedial strain. Serial computations are made in which the plate thickness *t* and the maximum deflection W_O are changed as parameters, such that

t = 5 ,10 ,15 mm.
W_o = 5,10 ,15 mm.

The distribution of the principal bending remedial strain, for thickness of plate t = 10 mm and maximum deflection W_O = 5 mm, is shown in Figure (9b).



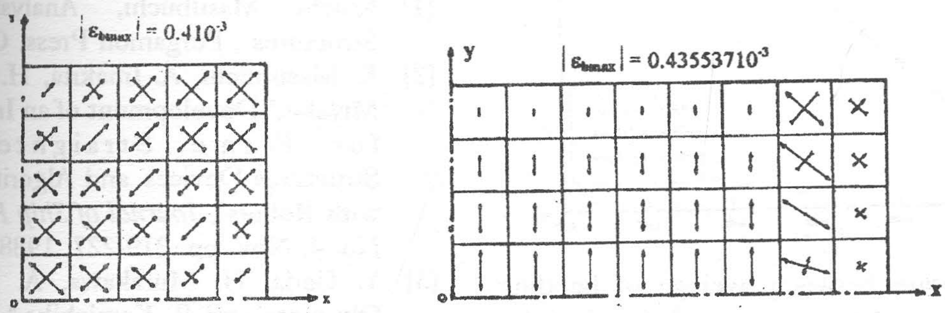
a- Sinusoidal deflection shape

b- Dished deflection shape

c- Horse deflection shape

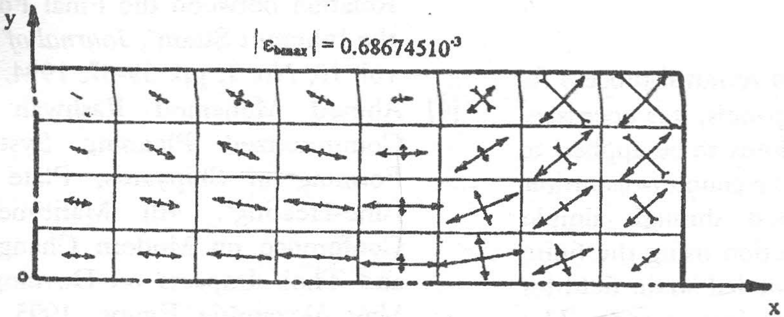
d- Multi-wave deflection shape

The effect of the maximum deflection W_o and the plate thickness on the bending remedial strain can be determined from Figure (10). The average of the bending remedial strain at the center is plotted against the dimensionless parameter (tW_o/ab). This parameter is related to the plate bending strain. It is obvious from this figure that as the parameter (tW_o/ab) increases, the magnitude of the bending remedial strain increases too. In addition, for the dished shape, the distribution of the bending remedial strain remains the same for the different maximum deflections W_o and plate thicknesses t. Thus, regardless of the plate thickness, t, and the magnitude of the maximum deflection, W_o, the bending remedial strain distribution will be the same for a certain post-welding deflection shape.

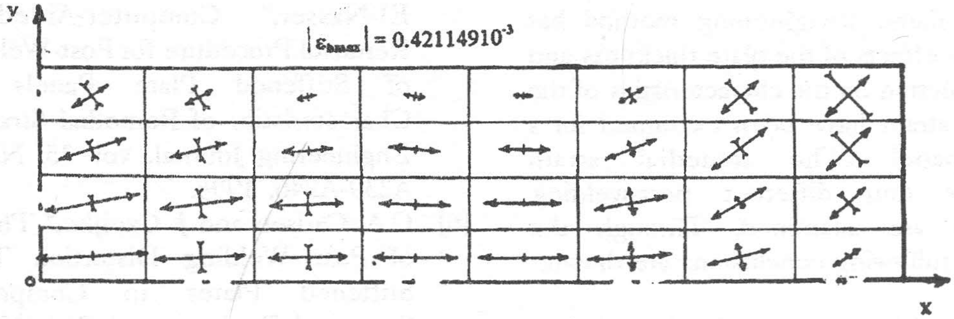


a- sinusoidal shape

b- dished shape



c- horse shape



d- multi-wave shape

Figure 10. Distributions of bending remedial strain.

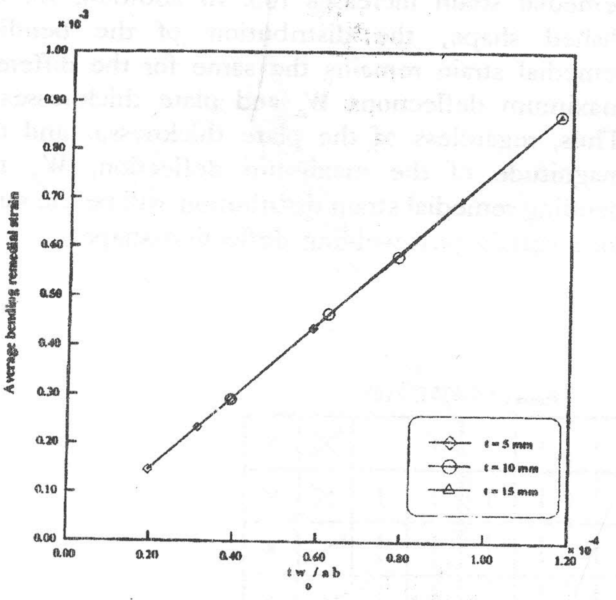


Figure 10. Relation between average of bending remedial strain at plate center and (tw_o/ab) for dished deflection shape.

4. CONCLUSIONS

To have an efficient distortion removal process for the welding deflection of plate panels, it is necessary to determine the proper procedures to be applied to create the counter-deflection. The counter-distortion for plate panels is determined through simple simulation of the welding deflection using the finite element method. Then, the remedial strain field for this distorted panel can be determined. The practicable type of the remedial strains that can be produced by the flame straightening method has been clarified. The effects of the plate thickness and the maximum deflection on the characteristics of the bending remedial strain have been examined for a square plate panel. The remedial strain characteristics for four different post-welding deflection shapes are examined. Through the present study, the following conclusions are drawn:

1) To remove excessive welding deflection of plate panels, using the flame straightening process, the bending remedial strain can be considered as the practicable remedial strain component that can be produced.
2) The necessary bending remedial strain to remove the bending deformation can be obtained using only the shape of welding deflection.
3) In case of different plate thicknesses t and different magnitudes of the maximum deflection W_O, the distribution of the bending remedial strain remains constant for the same deflection shape.

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