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Optimization of Assembly and Welding of Complex 3D Structures on the Base of Modeling with Use of Finite Elements Method

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***Abstract*—**It is known that residual welding deformations give negative effect to processability and operational quality of welded structures, complicating their assembly and reducing strength. Therefore, selection of optimal technology, ensuring minimum welding deformations, is one of the main goals in developing a technology for manufacturing of welded structures.

Through years, JSC SSTC has been developing a theory for estimation of welding deformations and practical activities for reducing and compensating such deformations during welding process. During long time a methodology was used, based on analytic dependence. This methodology allowed defining volumetric changes of metal due to welding heating and subsequent cooling. However, dependences for definition of structures deformations, arising as a result of volumetric changes of metal in the weld area, allowed performing calculations only for simple structures, such as units, flat sections and sections with small curvature. In case of complex 3D structures, estimations on the base of analytic dependences gave significant errors.

To eliminate this shortage, it was suggested to use finite elements method for resolving of deformation problem. Here, one shall first calculate volumes of longitudinal and transversal shortenings of welding joints using method of analytic dependences and further, with obtained shortenings, calculate forces, which action is equivalent to the action of active welding stresses. Further, a finite-elements model of the structure is developed and equivalent forces are added to this model. Having results of calculations, an optimal sequence of assembly and welding is selected and special measures to reduce and compensate welding deformations are developed and taken.

***Keywords*—**Finite elements method, modeling, expected welding deformations, welding, assembling.

I. Introduction

It is known that residual welding deformations give negative effect to processability and operational quality of welded structures [1], [4]-[6]. Therefore, selection of optimal technology, ensuring minimum welding deformations is one of the main goals in developing a technology for manufacturing of welded hull structures. To resolve this issue it is required to know mechanisms and rules of welding deformations appearance as well as to have calculation procedures to define the same.

Through years, JSC SSTC has been developing a theory for estimation of welding deformations. In the second half of 20th century, the procedure for calculation of expected welding deformations, based on analytic dependences, was developed [1]. The above procedure consists of two tasks: thermomechanical task and deformational task. Solution of thermomechanical task lies in definition of volumetric changes of metal in the weld area due to welding heating and subsequent cooling. Deformational task is to define structures deformations, such as changes in length, width and curvatures, arising due to volumetric changes of metal, calculated when solving thermomechanical task.

The procedure, developed in JSC SSTC, allows resolution of thermomechanical task with high accuracy. At that, wide range of factors is considered: structural rigidity, initial stress state, heat loss, mechanical and thermophysical properties of material etc. However, dependencies, used in this procedure for deformational task resolution allowed performing calculations only for simple structures, such as units, flat sections and sections with small curvature. This limits significantly the area of procedure application; also the above procedure can't be used for estimation of complicated 3D structures deformation.

In order to resolve this problem it was proposed to use additionally the finite elements method [2]. At that thermomechanical task is resolved as before – with use of analytic dependencies, and to resolve deformational task finite elements method is applied.

II. Method of Expected Welding Deformation Calculation with Use of Finite Elements Method

Resolution of deformational task with use of finite elements method looks as follows. In the beginning, finite elements model for specified technological stage of welding structure manufacturing is developed. Then, forces, equivalent to residual welding stresses are introduced in finite elements model. They are applied to longitudinal and transversal directions of plastic deformation area in accordance with diagram, shown on Fig. 1.

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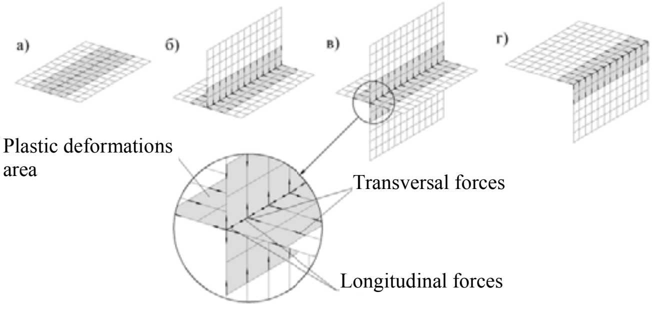

Fig. 1 Diagram of forces application to plastic deformations area

Forces values and plastic deformations area width are defined with use of following formulas:

$$P_{пр} = \upsilon \cdot E\,; \tag{1}$$

$$p_{поп} = \frac{w}{b_{ак}} \cdot E\,; \tag{2}$$

$$b_{ак} = \frac{w}{s \cdot \varepsilon_s}\,, \tag{3}$$

where $P_{пр}$ - Longitudinal forces value, *N*;
$p_{поп}$ - Transversal load intensity, *N/m*;
$b_{ак}$ - Plastic deformation area width, *m*;
υ and w - Longitudinal and transversal shortenings of weld joint per weld length unit and calculated in accordance with m^2;
E – normal elasticity module, N/m^2;
ε_s - relative strain, corresponding to yield point;
s - plate thickness, *m*.

Upon forces application, deformations, arisen due to the same are calculated.

Calculated deformations are in correspondence with expected welding deformations.

Advantage of such a composed approach is a relatively low labour intensity of calculations, accuracy, sufficient for resolving actual tasks and possibility to make calculations for structures of any complexity. This approach was applied to make multiple calculations for different maritime structures [3]. As example, let’s study calculations, made for pontoon of ice-resistant fixed platform Prirazlomnaya.

III. Optimization of Pontoon (Ice Resistant Fixed Platform Prirazlomnaya) Assembling and Welding Procedures

Pontoon of ice resistant fixed platform Prirazlomnaya is a welded pontoon, divided by longitudinal and transversal cofferdams in sixteen leakproof compartments. Dimensions of pontoon are 124x124x25 m, and the same is shown on Fig. 2.

Fig. 2 Pontoon of ice resistant fixed platform Prirazlomnaya

Pontoon consists of four superblocks, joining of the same was carried out afloat. Pontoon superblocks incorporate closed compartments, divided by cofferdams, double bottom and double boards. Thickness of structure’s components is 20 - 40 mm. Improved rigidity of superblocks in combination with significant dimensions of the same complicates support of required accuracy and alignment of superblocks when assembling. In order to provide joining of superblocks two tasks shall be resolved: choice of optimal sequence for welding and assembling of superblock’s internal joints and estimation of total welding deformations of pontoon.

To choose optimal sequence for welding and assembling of internal joints we defined stress and strain state of insert portions for two variants of their assembly and welding using finite elements method. First variant is installation of insert portions as ready units; second variant is installation and welding of insert portions from separate parts. In order to choose optimal variant residual deformations for both variants were calculated.

Insert portion model is shown on Fig. 3.

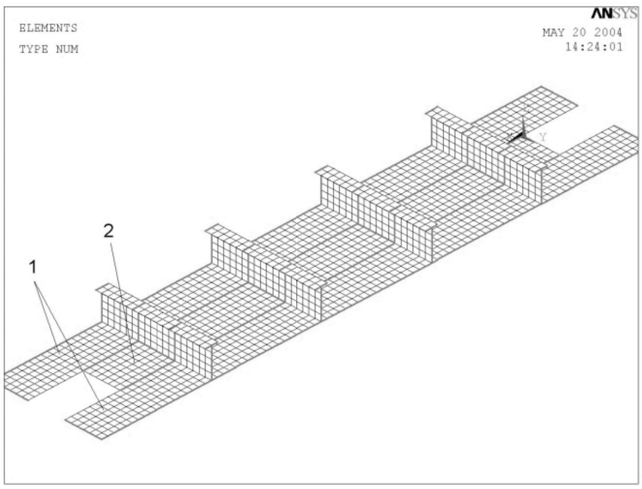

Fig. 3 Finite elements model of standard insert portion with adjacent structures 1 – Structures, adjasent to insert portion; 2 – Insert portion

In accordance with procedure, described above, we calculated welding deformations for two variants of insert portion welding-in. Calculation results are shown on Figs. 4 5.

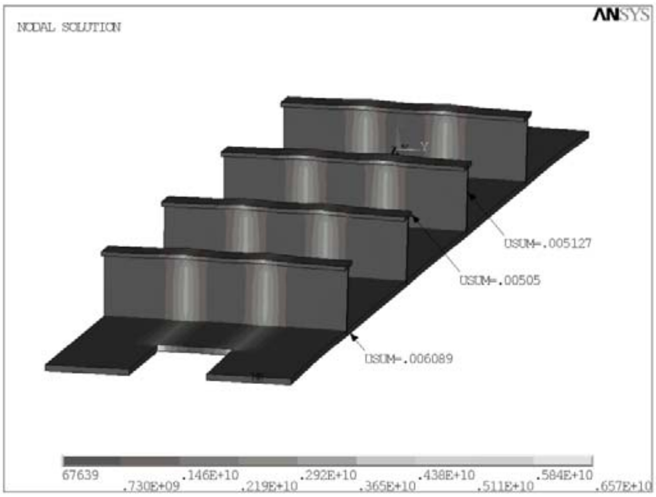

Fig. 4 Stresses and movements, appearing in insert portion when it is welded-in as a complete module.

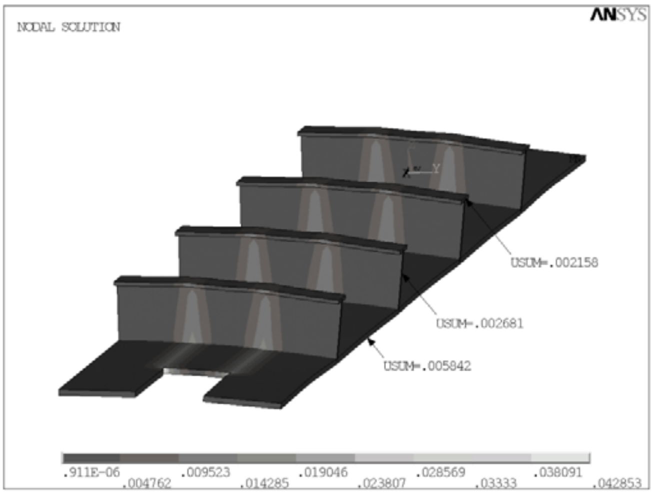

Fig. 5 Stresses and movements, appearing in insert portion when it is welded-in as separate parts.

As you can see, when welding-in insert portion as separate parts, much less stresses and deformations are observed. So, we chose second variant of described works.

Basing on approved internal joint welding procedure, we estimated changes in relative position of superblocks to be joined using finite elements method. For that, we shaped a complete finite element model of a pontoon. Model is shown on Fig. 6. As you see, near the joint finite element grid is rather small, because welding deformation appears in this area. In order to decrease rationally calculation time and required memory, finite elements, located on some distance from joint, are of bigger size.

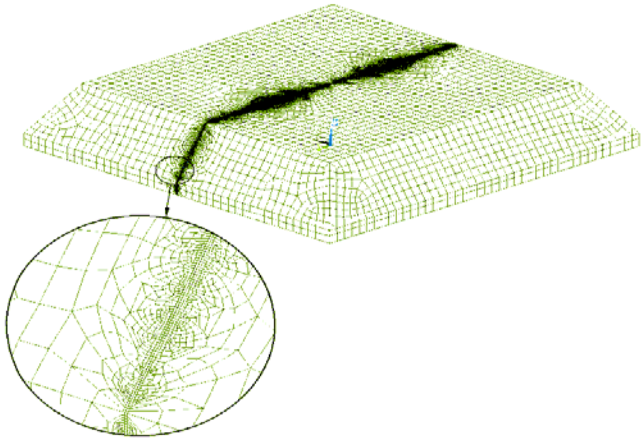

Fig. 6 Finite elements model of Pontoon of ice resistant fixed platform Prirazlomnaya

When calculating deformations, appearing as result of superblocks joint welding, we applied following sequence of works:

1) Welding of deck joint;
2) Welding of board insert portions above water line;
3) Welding of longitudinal cofferdams insert portions above water line;
4) Welding of structures below waterline.

In accordance with calculation results, expected shortening of each joint will be about 6 mm and one superblock will turn relatively to other one on angle of α = 1,32 ang. min. Increasing of mounting spacing and joining of superblocks with predicting incline between them allowed to compensate those deformations. Pontoon vertical shifts values are shown on Fig. 7.

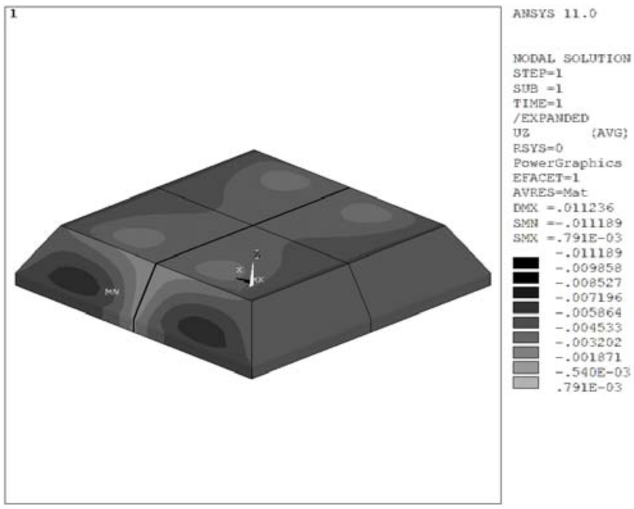

Fig. 7 Distribution of pontoon vertical shifts after welding

IV. Conclusion

Thanks to combined procedure, allowed to calculate welding deformations of large-scaled structures, optimal procedure for welding of pontoon of ice-resistant fixed platform Prirazlomnaya was chosen, and for chosen welding sequence expected deviation values were received.

In accordance with received results, measures for supporting required accuracy of pontoon construction were worked out.

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