Modeling of Welded Structures Residual Strains

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Abstract

This paper explores simulation techniques for prognosis residual strains of welded structures, which consist of common steel parts joined together by means of arc welding. The approach is based on longitudinal and transversal shrinkage forces, applied to the 3d-model of plastic weld zones.

The calculations were made on ANSYS - LS-DYNA 970 MPP version on supercomputer SKIF-family located in United Institute of Informatics Problems of National Academy of Sciences of Belarus. The obtained results find good agreement with literature and practice data.

Residual welding strains techniques approved for welding tubes, beams and some machine building constructions.

Introduction

Welded structures are subject to more and more stringent requirements on strength, endurance and the accuracy of fabrication. Reliable quantitative and qualitative estimates, analysis and prediction of the stress-strain state (SSS) of welded structures in the conditions of multi-variant design of assembly-welding technological processes have become more and more important [1]. As we see it is necessary to determine residual strains and stresses for complicated spatial multi-component welded assembling units (WAU). However, the appropriate SSS calculations have not become the generally accepted practice of engineering plants. They are carried out exclusively in the development and repair of important structures.

No changes have been made in the situation by the application of universal packages of finite element analysis, which have appeared in plants and in design organizations but do not, as a rule, reflect the special features of welding thermal-strain processes. It is important to develop new procedures and approaches linked with the processes of unavoidable computerization of design procedures in the preparation of assembling and welding production.

LS-DYNA contains options like *boundary_thermal_weld, *constrained_generalized_weld, that reflect some aspects of welding nature. However, situation is more complex. As a rule, welding joints made by modern welding materials have strength parameters not worse than parent metal. Thus welded structures often failed rather far from weld zone and heat affected zone too. Strain, elasticity and strength of welded structure considered as an entire object under external dynamic loads are much influenced by welds. It seems that by means of LS-DYNA it is possible to estimate that influence and to show technological welding features.

Approach

Taking into account the simplified theory of welding stresses and strains according to which the calculations were carried out for the cooling stage of weld metal. It is assumed, as accepted in all theoretical models, that the welded joint is produced instantaneously along the entire length.

Modeling of welded structures residual strains is traditionally based on the notion of so-called shrinkage force [2]. It is assumed that by analogy with longitudinal shrinkage the transverse shrinkage is caused by some (in the general case) transverse fictitious shrinkage force, non-uniformly distributed in the weld plastic deformation zone. Internal shrinkage forces around plastic weld zones are formed in ANSYS software.

The nature of shrinkage forces is prescribed to the forces that appear on the boundary of melting metal as a result of expanding or contracting of the cavern. However, it is accepted way to deal with concentrated forces somehow distributed along the sample. In the proposed mechanism the weld is represented as a 3D volume loaded with adequate longitudinal and transversal forces (figures1a, 1b, 2).

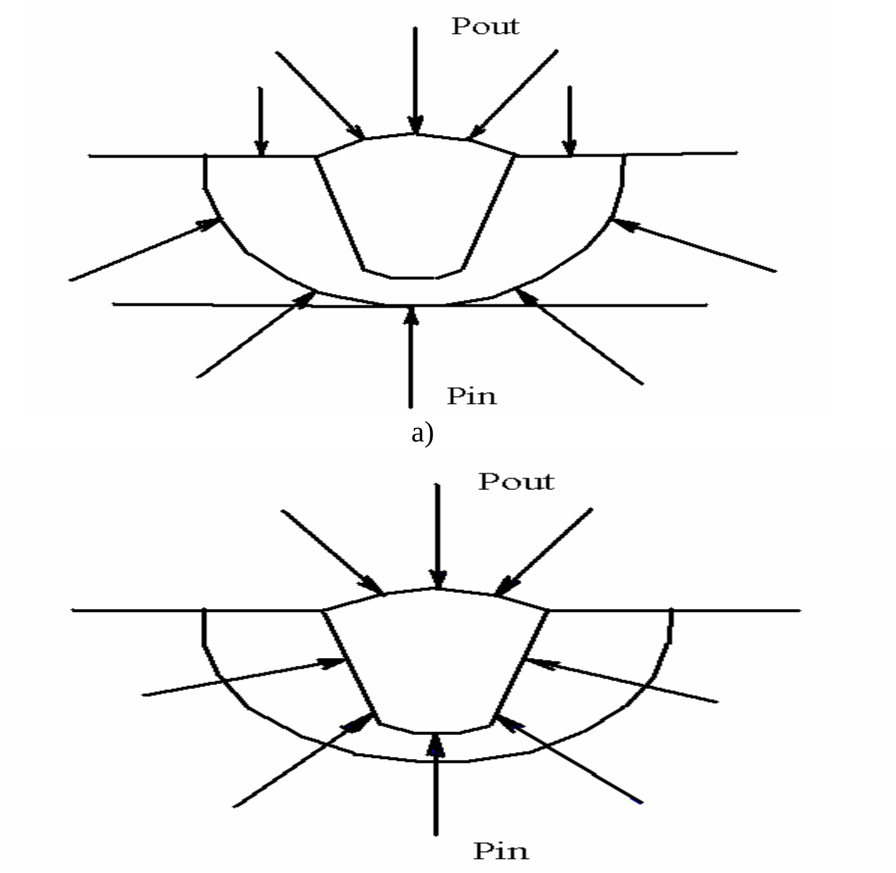


Figure 1. Scheme of the transversal loads applied to the plastic zone near weld (P_{in}, P_{out} are an internal and an external forces)

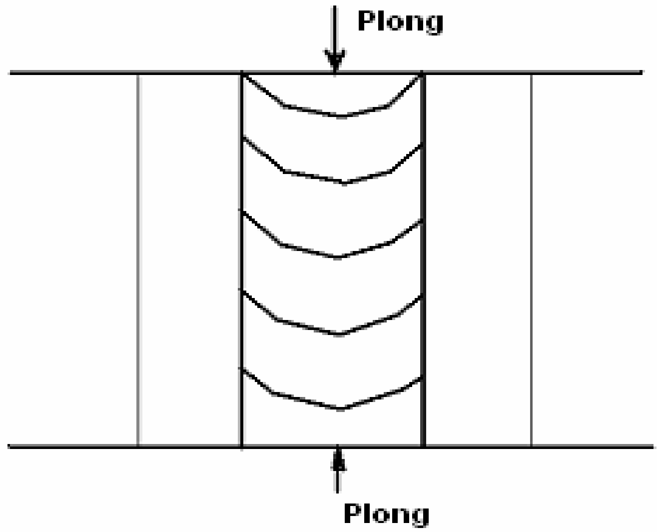


Figure 2. Scheme of the longitudinal loads. P_{long} is a longitudinal force

We presume that transversal forces are not the same along weld length. These differences help us to determine the beginning and the end of a weld and its direction. Special metal sample was made to know the real longitudinal and transversal forces after the seam was welded on its upper edge by the robot (figures 3, 4, 5). We use calibrated longitudinal and transversal force in LS-DYNA calculation. In welded plates with free boundary conditions there are both transverse shortening and angular

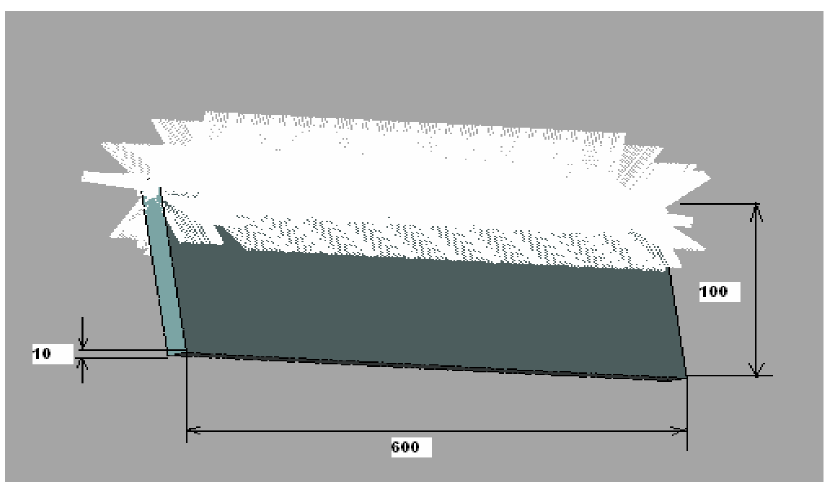


Figure 4. Loads applied to the weld plastic zone of the experimental sample

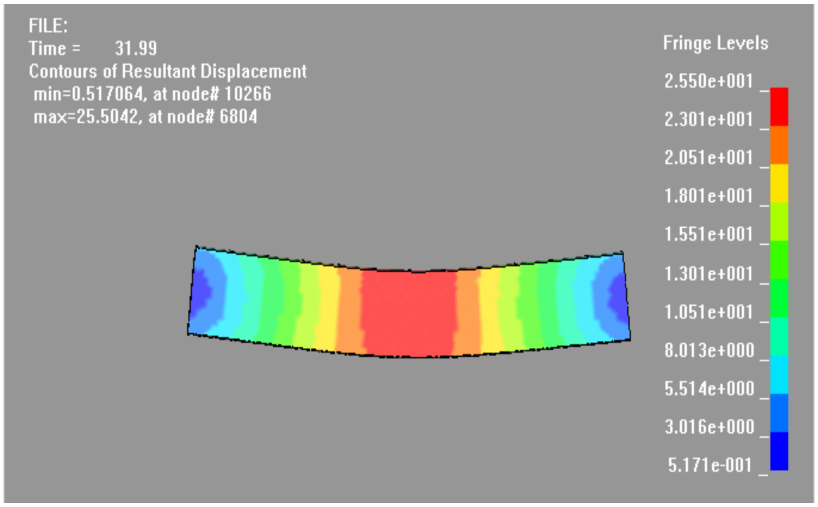


Figure 5. Contours of result displacement of the sample

deformations that are not constant along the length of the welded joint. The constant proximity of the components of the WAU in welding with the minimum gap or without the gap results in artificial fixing. It has a very strong effect for the components of large mass. Consequently, there are forces whose interactions in the vicinity of the welded joints lead to similar results.

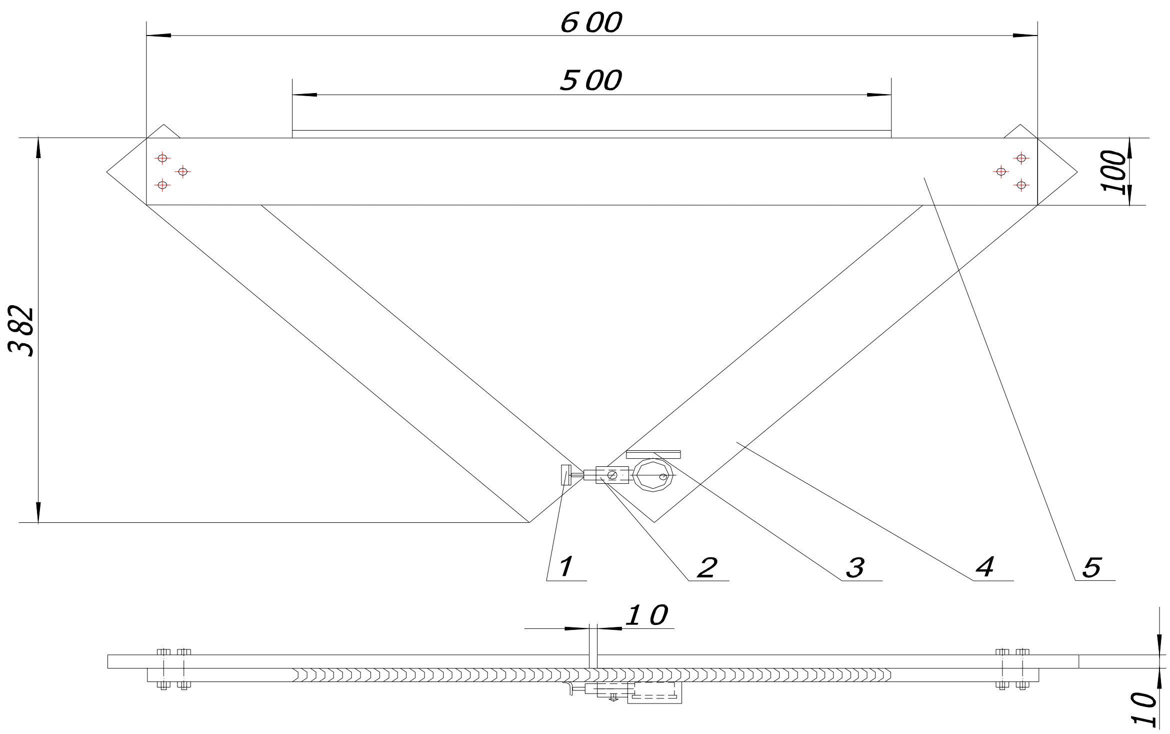


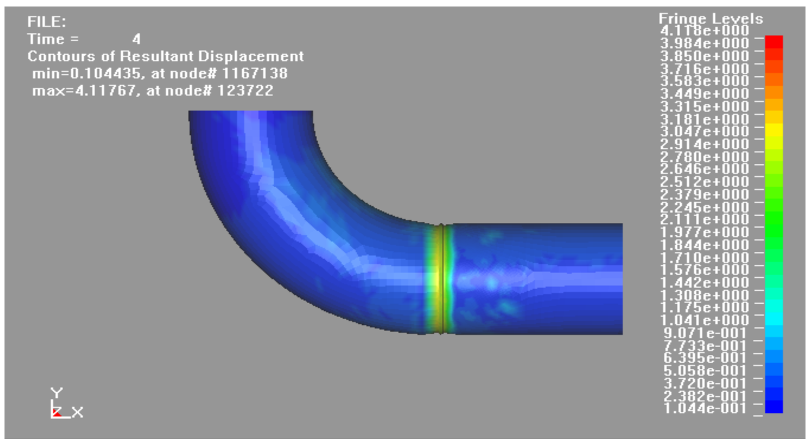
Figure 6. Scheme of the experiment for the calibration of the sample deformations

(Two ends of the girder 1 were fixed by two girders 2 by mean of four pins. Prefixing of the two plates 4 arranged at 45° angle to the explored plate 5 was made using bolts placed in the 10 mm diameter holes. Then clock type indicator 3 and support 4 were fixed on the free ends 2 of the plates 4).

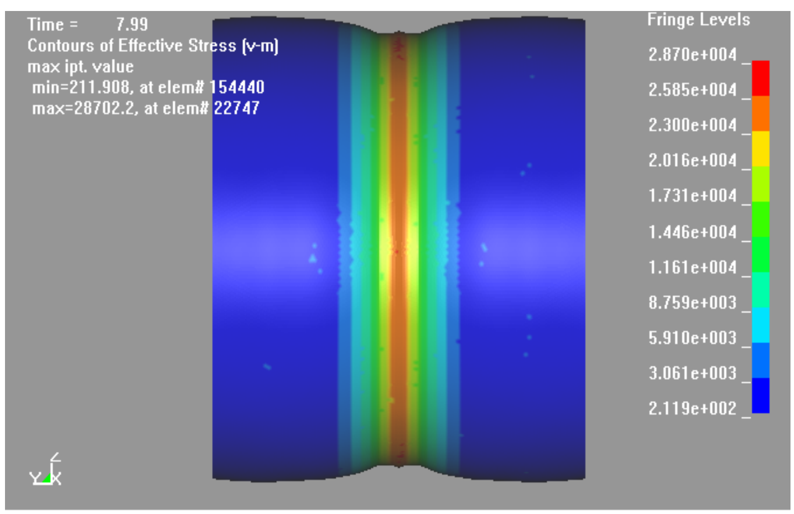
The value of the residual transverse shrinkage depends on the following factors: specific heat input and the parameters of the welding conditions; heat transfer from the surfaces of the welded component; preliminary stresses as a result of previously deposit welded joint; the conditions of fixing components; longitudinal plastic strains. The parameters of welding conditions and heat input in the explicit form are included in the equations for determination of the longitudinal fictitious shrinkage forces.

The conditions of fixing the components (the force factor) are practically identical with the method of installation-fixing in the WAU which makes it possible to obtain later a specific design form in the program complex of automated design of assembling-welding equipment [5].

To verify the method simulations in LS-DYNA 970 were carried out. The classical sample models were explored (figures 7a, 7b, 8, 9). Their behavior found good correspondence with the behavior of samples observed in the experiments that is widely represented in literature [3].



a)



b)

Figures 7. Welded tube structure under shrinkage forces applied to the coiled weld

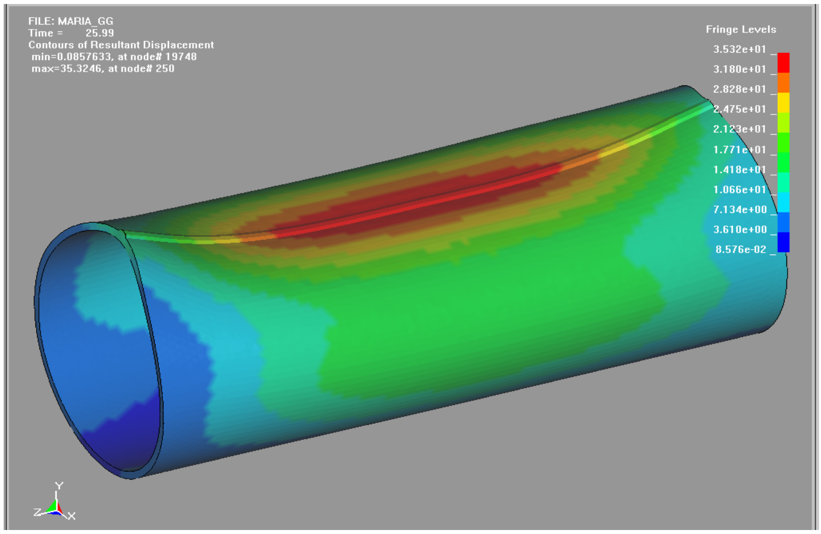


Figure 8. Welded tube structure under shrinkage forces applied to the longitudinal weld

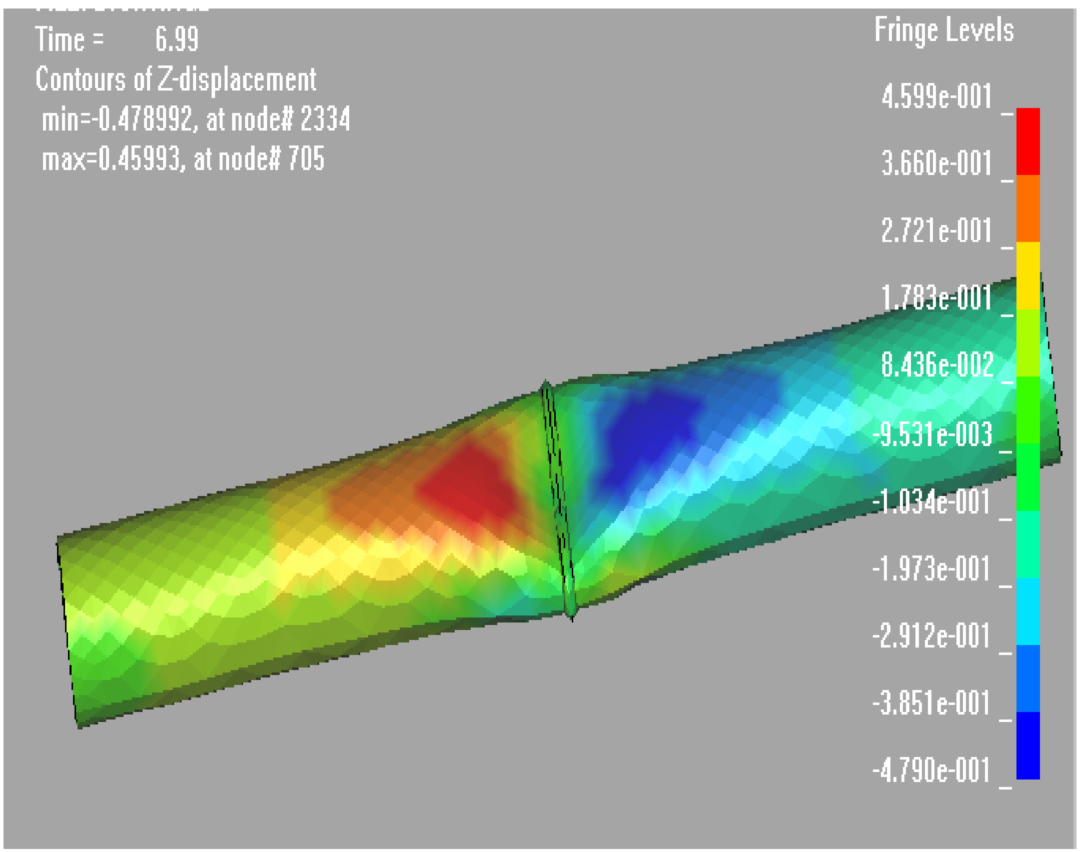


Figure 9. Loss of stability of the tube under shrinkage forces

The proposed technique was applied to the model represented on figure 10. It is a rolled up reservoir of 50000 m^2 volume described in [6]. Dimensions of the reservoir are:

diameter - 60 m,
height is 18 m,
wall thickness is 7-16 mm.

There is the problem of loss of stability of the reservoir after welding in insert plates. In [6] there were given experimental data about the areas of instability (figure 11) and 2D-calculations were discussed. Our technique allows to substitute two-dimensional approach by three-dimensional and makes it possible to take into consideration the previously made welds (figure 12). For the calculation a 7m x 18m part of the reservoir is chosen. The average thickness of the wall is 12 mm. Chosen rectangular part is fixed by the perimeter edges.

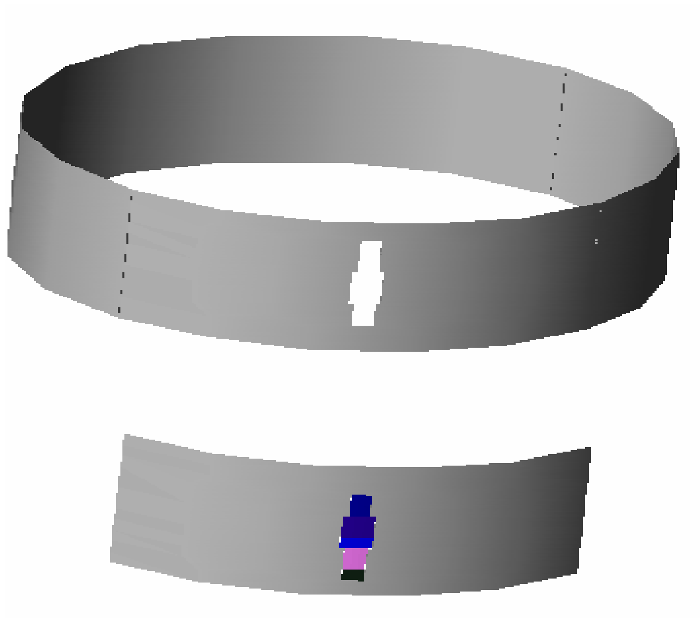


Figure 10. 3d-model of the reservoir

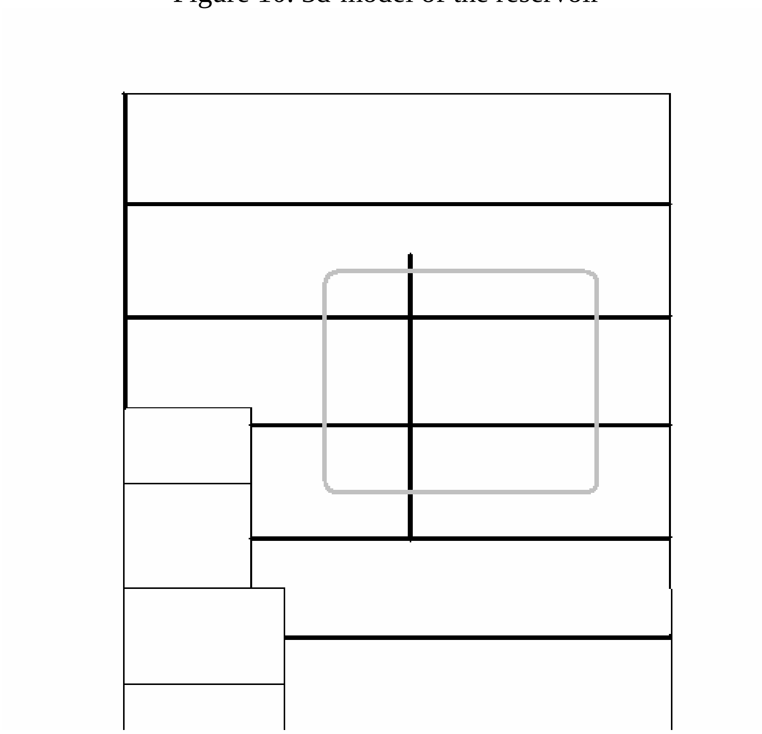


Figure 11. Areas of interest of the reservoir

(The black lines mark the old welds, the gray lines mark the new ones. The area of instability according to [6] is marked by curved gray contour).

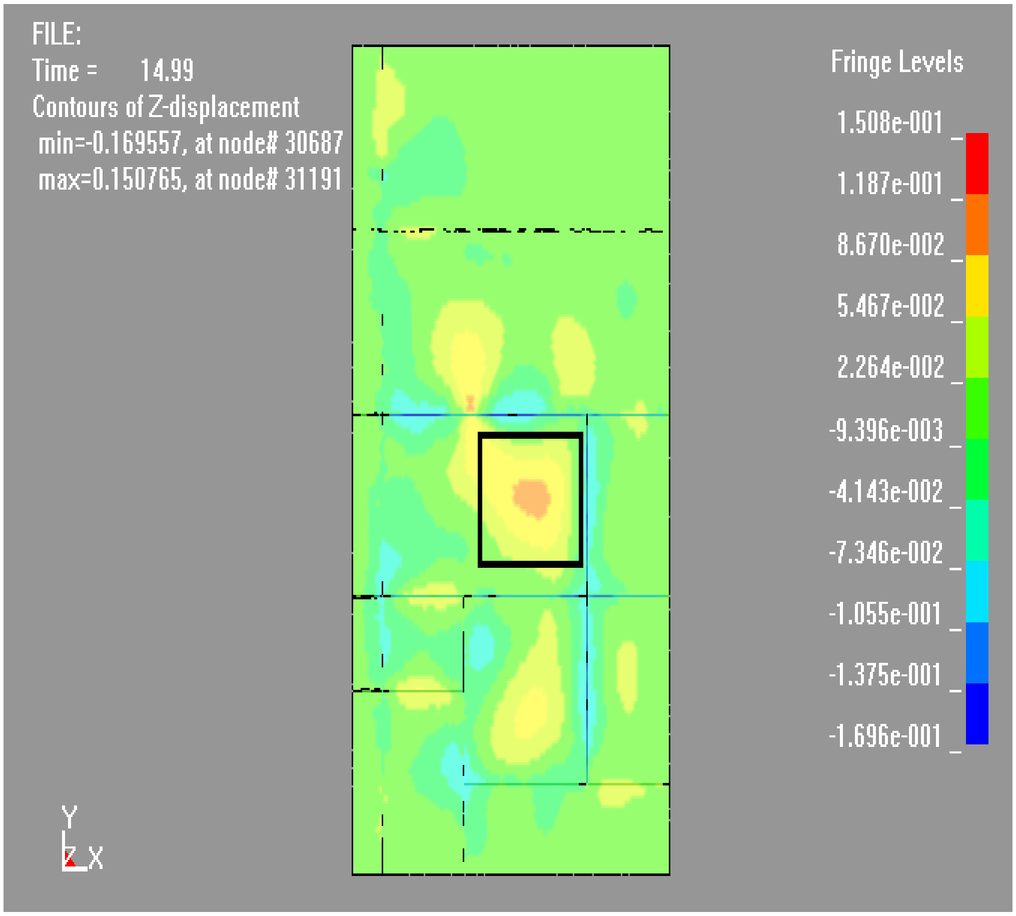


Figure 12. The area of maximum z-displacement found by means of application of shrinkage forces to the new and old welds

The explorations of models behavior gave true qualitative results in considered cases. The dependences between applied load forces and corresponding welding conditions is the subject of current and future studies. It is supposed to compare the results with those obtained by means of moving heat source though the last method includes efforts to appreciate the right form of the cavern in complicated geometry.

The proposed approach might preserve the simplicity of the shrinkage forces approach as compared with coupled thermal-structural calculations and put a bit of order into the shrinkage forces methods diversity. In that case it might compliment the LS-DYNA build-in weld models in technological aspect.

Other extensions of the described approach include a possibility to organize remote access from location of large industry objects like reservoir or collection of tubes to high-performance systems (HPS) running LS-DYNA software. It allows to pass geometry of objects and a certain variant of welding procedure as k-file for calculation on HPS and to return avi-video file from LS-PREPOST with desired characteristics (displacement in important direction, von-mises etc.).

Main advantage of such approach is an ability to estimate and to predict behavior of welded structures directly after welding processes.

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