Estimation of Weld Load in Forecasting Complex Structures Service Life

S.V. Doronin[1, 2], A.A. Alshanskaya[2]

[1]Institute of Computational Technologies, SB RAS, Krasnoyarsk Branch Office, Krasnoyarsk, Russian Federation

[2]Siberian Federal University, Krasnoyarsk, Russian Federation

INTRODUCTION

Structural analysis of welded structures and joints is a very conservative area of engineering in which the main approaches and methods have not been changed significantly for a long time [1-8]. The analysis of domestic [1, 5, 6] and foreign [2-4, 7, 8] scientific and technical publications [5-8] and codes of calculation and design [1-4] shows that the estimation of the welded joints stress state is based on the following assumption. The force flow perceived by the welded joint and directly by the weld is known and can be described by a set of internal force factors – forces and moments. However, estimation of these force factors for complex structures containing a large number of parts of complicated configuration and different types of welded joints is generally not a trivial task and is not regulated. This leads to the lack of a consistent approach to the calculation of the complex structure systems in which their strength and service life are limited by a significant number of welds, the total length of which can reach tens and hundreds of meters. Designers and developers are responsible for ensuring structural strength. It makes them seek and create practical technologies for the stress state and strength of welds in the design of technical objects.

Such technologies are based on the use of numerical (finite-element) structural models and usually come down to inclusion of additional volumes into the model that simulate an idealized shape weld [8-10]. For the complex structures with a large number of welds, this usually leads to a sharp increase in the model dimension. In this case, the calculation is performed in two stages: 1) structural analysis with the "bonding" of parts in the weld zones to specify the most loaded zones; 2) detailed analysis of these zones using substructures with three-dimensional modeling of welds. In such a case, not the values of internal force factors for the analytical estimation of welds are obtained as the results, but directly the stress and strain in the sections of the welds. However, this creates an additional problem of an unlimited increase in stresses in the zone of sharp edges of the idealized geometry of the weld with a sequential decrease in the mesh pitch of the finite elements [11, 12]. This problem can be partially solved by extrapolating the numerical results obtained in the weld vicinity to the region of the sharp edge [10, 13, 14], but in each individual case the accuracy and reliability of the results remain a priori unknown.

Based on the analysis of the current state of the problem of analyzing the stress state and strength of welds in complex structures, it seems urgent to develop a synthetic approach that combines the advantages and lacks the drawbacks of both analytical and numerical solutions. It consists in a numerical analysis of internal force factors (this will allow for accurate enough consideration of the complex configuration of the structure) and analytical calculation of the stress state of the weld (which avoids problems with the singularity of the numerical solution and ensures compliance with regulatory calculation methods).

TECHNOLOGY FOR ESTIMATION OF WELD LOAD

The task is to develop and test the computing technology for obtaining individual estimates of the load of welded joints of complex structures for the analysis of their strength and service life forecasting. As a requirement for the developed technology, the possibility of its practical application using standard instruments and tools of modern finite element modeling (CAE-systems) packages is considered, which should eliminate difficulties in results obtaining and ambiguity in their interpretation.

The main idea is based on the "natural" decomposition of the structure – representing it in the form of a system of parts connected by welding. Their integration into a single deformable carrying system is performed using special boundary conditions – connections in which force reactions can be determined by the results of numerical analysis. They characterize the force flow perceived by the corresponding connection. These particular reactions are considered as individual loading characteristics of each welded joint. The following are estimations of the strength of welds using two methods (either of them, or both) – analytical, in accordance with the classical approaches, and numerical analysis in a three-dimensional statement of the stress state of the weld, taking into account all its geometric features.

We will further concretize the reasoning under the assumption of using the widespread ANSYS CAE-system. The finite elements of the MPC184 type, realizing various types of kinematic connections between nodes of the finite element mesh on adjacent surfaces of the parts to be joined, can be used for parts connection that simulate welds. On the ANSYS Workbench platform, the MPC184 finite elements are realized using the "fixed joint" tool with the possibility of local deformation – displacement of nodes relative to each other during joint work of the parts (selecting the "deformable" value of "behavior" option) to realize the connection of parts corresponding to the weld. Moreover, in some cases, a modification of geometric models of parts to be joined is necessary – they must have the corresponding geometric primitives, the binding of which will indicate the nature of the force flow transmission through the weld.

In the case of connecting irregular shaped parts with sufficiently long welds, it is necessary to take into account the possibility of a substantially uneven load distribution along the length of the weld. In this case, a simulated weld is performed by several consequently applied "fixed joint" tools. This allows building force factor diagrams along the length of the weld.

Thus, the proposed technology for estimation of the individual load of welds includes estimation of the degree of uniformity of the load of the weld (the ground is an expert opinion and (or) the results of preliminary numerical analysis of the strain-stress state; modification of geometric models of parts and their binding by rigid connections in the weld zones; numerical analysis and calculation of reaction components in the connections; calculation of welds taking into account their geometric features and design reactions in the connections.

NUMERICAL EXAMPLE

As an example, there is considered an estimation of the load on the welded joint of the pipe with an outer diameter of 326 mm and a wall thickness of 8 mm with casting of a metal structure of a biped rack for a mining excavator (Fig. 1). This rack design is typical of all mechanical shovel excavators. The rack is mounted on the platform with four cylindrical joints and is exposed to a force of 1.12 MN from the side of boom hoist rope and boom stays (Fig. 1a).

From the configuration analysis, loading conditions and structure deformation, there can be made an assumption about the uniform nature of the weld load along its length. Based on this, one connection of the "fixed joint" type is used to model the entire weld.

As a result of the modification of the geometric model of casting 2, a geometric primitive A (Fig. 1b) was created on its surface. The primitive A is the projection of the pipe end 1 onto the surface of the casting. When creating a connection, its local coordinate system is determined, in relation to which the resulting forces in the connection are calculated. As a result of numerical analysis, the following projection values of this force on the coordinate axis were obtained: F_x = 1 440 900 N, F_y = - 312 N, F_z = 934 N.

In accordance with [2], the calculation model of the weld involves the determination of stress components in the section passing through its root (Fig. 2). The calculated weld area is $A_w = a \cdot l_{eff} = 10 \cdot \pi \cdot 326 = 10242$ mm^2, where a is the thickness of the fillet weld, l_{eff} is the effective length of the weld.

Then, geometrically, the values of the stress component are determined as follows:

$$\tau_{\perp} = \frac{F_x \cdot \cos 45^\circ - F_z \cdot \cos 45^\circ}{A_w} = 99{,}4\ \text{МПа}; \quad \sigma_{\perp} = \frac{F_x \cdot \cos 45^\circ + F_z \cdot \cos 45^\circ}{A_w} = 99{,}5\ \text{МПа}; \quad \tau = \frac{F_y}{A_w} \approx 0\ \text{МПа}.$$

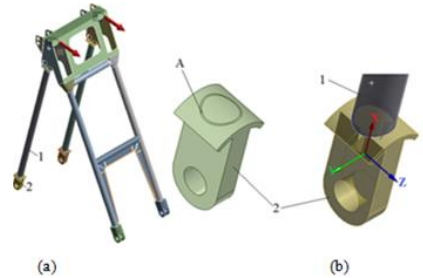

FIGURE 1. The connection for determining the welded joint load of the pipe with the casting: general view of the biped rack (a) and the creation of connection (b); 1 – pipe; 2 – casting; A – projection of the pipe end onto the surface of the casting

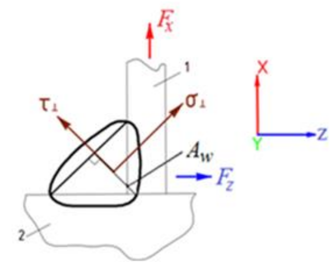

FIGURE 2. Design model of the welded joint of the pipe and casting of the biped rack

Similarly, the characteristics of the load and stress state of all welds that are of interest for estimation and ensuring the structures service life are determined.

CONCLUSIONS

Determination of the individual characteristics of the load and stress state of the welds allows for more efficient management of the service life and reliability of structurally complex welded structures at various stages of their life cycle. Solution of the direct problem of forecasting the individual service life of welded joints allows to group them into several repair groups with the determination for each group of rational periods of technical diagnostics and non-destructive testing at the operational stage, coordinated with the structure of the repair cycle of the technical object. Setting the inverse problem involves managing the resource of welded joints at the design stage by substantiating the geometric and technological parameters of the welds, based on the individual characteristics of the load and the required structure of the repair cycle.

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