DURABILITY DESIGN OF WELDED STRUCTURAL SYSTEMS WITH DEVELOPING DAMAGES

V.V.Moskvichev* and S.V.Doronin

Main features of durability design of welded structural systems containing initial technological defects are considered. These features are : structural analysis of welded structure, simulation of limit states and assessment of reliability of weldments, optimization and ensuring of given reliability. Structural scheme of excavator arm beam is demonstrated. The main results of computer simulation are : fatigue curves , reliability functions , complete stochastic lifetime diagrams and stochastic durability surfaces.

INTRODUCTION

Strength and reliability of welded structural systems are limited by carrying capacity and durability of weldments. In this connection the ensuring of given reliability and durability of large-size welded structural systems requires to solve the following problems.

1. Structural analysis of the welded structure for studying the influence of reliability of components on the structural system reliability, working out an algorithm of its assessment. The known decisions of this problem by means of mathematical reliability theory are not always correct for welded structures.

2. Reliability of welded structure components is determined by their physical and mechanical properties and loading condition. In this connection the following problem arises. It consists in simulation and calculation of typical weldment reliability values under the conditions of characteristic stress-strain fields.

3. Elaboration of an algorithm of structural optimization bazed on the requirements for the structural system functions, necessary reliability

*Computing Center of the Russian Academy of Sc. Siberian Division

level and main stuctural form. The paper is dedicated to a developed set of tools and a number of typical calculation methods which enable to make scientific problem of ensuring of given reliability and durability an engineering problem.

STRUCTURAL ANALYSIS OF WELDED STRUCTURE

Traditional problem of assessment of reliability of system containing components with given or computed reliability indexes is reduced to presentation of system in terms of logical schemes of series, parallel or combined connection of components. In case of series connection of components (i.e. any component failure is the system failure) reliability index of system is a product of structural components reliability indexes. The reasons which do not allow to get correct values with this approach are following.

1. Failures of welded structure components (including different limit states) are not independent events. Welded structures possess ability to distribute load to other components while developing failure in one structural component. Owing to this distribution stochastic values of these components load and durability are changed.

2. Failures are not sudden. Typical feature of welded structures is gradual developing of limit states. Frequently limit states are developing simultaneously in some structural components as a result of common damaging.

3. Practical impossibility to get correct experimental or calculated values of reliability indexes of structural components as parts of structural system.

Mentioned above and some other factors lead to necessity not to search mathematical and logical approaches to assessment of structural reliability but to work out methods based on the physical and mechanical laws. Among other attempts it is known proposed by Fukuda et al (1) employment of topological representation (i.e. graphic reflection of structural components interaction) in mechanical design. Studying of structural analysis of welded structures executed by authors of this paper is related to the same directions . The gist of the matter is graphic representation of welded structure as a scheme reflecting the interaction of weldments and details to be welded. As an example of such scheme the graphic representation of welded structure of excavator arm beam is represented by figure 1. This scheme clearly shows the ways of load stream distribution and its redistribution when some structural components reduce or lose their carrying capacity. This scheme can be easily formalized and transformed to a computer model which main essence is a set of relations between structural components. It allows engineer to analyse compound welded structures and classify weldments from the point of view of their influence on the welded structure durability. When the weldments which have many contacts with neighbour structural components fail or reduce their carrying capacity it is possible to redistribute load among these neighbour components. In other words under equal conditions failure of a component which has a few contacts with other components is more dangerous for the structure. Such tentative analysis enables to limit a number of structural components which reliability and carrying capacity values have to be obtained by computation or experiment.

SIMULATION OF LIMIT STATES AND ASSESSMENT OF WELDMENTS RELIABILITY

Computed or got by experiment reliability indexes of structural component cut of welded structure is not the same as the reliability index of component as a part of a system. It is caused by considerable difficulties in simulation of real loading conditions and studying structural components reliability under these loading conditions. Up to the present following approaches to assessment reliability of structural system and their components were mostly developed.

1. Utilization of results of numerical analysis of structure stress and strain state obtained by use finite and boundary element methods in probabilistic form and Monte-Carlo method. The paper by Raju and Atluri (2) is an example of this approach.

2. Utilization of probabilistic fracture mechanics to assessment reliability of cracked structural components. An example of this approach is the paper by Munz (3). Since design studying of stress and strain state is not limited by reliability assessment the calculation by means of numerical methods must be executed for all carrying welded structures. Joint analysis of the structural scheme (figure 1) and stress-strain fields allows to determine structural components which failures are more dangerous for the structural system.

The next step is simulation of limit states development for determined above dangerous components. The main limit state for welded structure is propagation of fatigue crack. An algorithm and component failure are worked out. The main features of these algorithm and model are :

1. The algorithm is based on the Monte -Carlo method and probabilistic linear fracture mechanics.

2. Weibull distributed size a_0 of technological defect is used as stochastic initial data for simulation. The other main various data are following : loading level σ/σ_Y, component thickness t , exploitation

temperature T.

3. Library of equations for calculating stress intensity factor for many standard components is used in the model. If the library does not contain an equation for any component the stress intensity factor is calculated by numerical methods.

4. The result of application of mentioned above models and algorithms which can be directly used in ingeneering design are fatigue curves (figure 2), reliability functions (figure 3), complete stochastic lifetime diagrams (figure 4), stochastic durability surfaces (figure 5). These graphic forms display multifactor reliability dependencies on the stress-strain state type, form and sizes od defects, exploitation temperatures and other parameters.

OPTIMIZATION AND ENSURING PREDETERMINED RELIABILITY LEVEL

Ensuring predetermined reliability level of structural components by means of obtained graphic results reduces to solving following durability design problems.

1. Determination of margin of safety which secures predetermined lifetime N with necessary reliability level R. Determination of lifetime which is secured with necessary reliability level of chosen margin of safety.

2. Determination of necessary increment of margin of safety to secure predetermined reliability level for given lifetime and deviation from this level when changing margin of safety.

3. Determination of durability which is secured with necessary probability for predetermined margin of safety. Determination of probability of achievement given durability at chosen margin of safety.

4. Sensitivity analysis of reliability functions shows the most effective way to control duraility by changing design parameters.

REFERENCES

(1) Fukuda, S., Nakamura, Y. and Takemase, F., JSME Int. J., Series I, Vol. 32, No. 2, pp. 269-273.

(2) Raju, I.S. and Atluri, S.N. " Finite - Element Alternating Method for Analysis of Cracked Three - Dimensional Solid", Proc. Int. Conf. Comput. Eng. Sci. "Comput. Mech. 88: Theory and Appl.", Vol. 1, 1988, pp. 15.II.1-15.II.4.

(3) Munz, D., "Cracked components in reliability assessment", Proc. Adv. Semin. "Adv. Struct. Rel.", 1987, pp. 139-164.

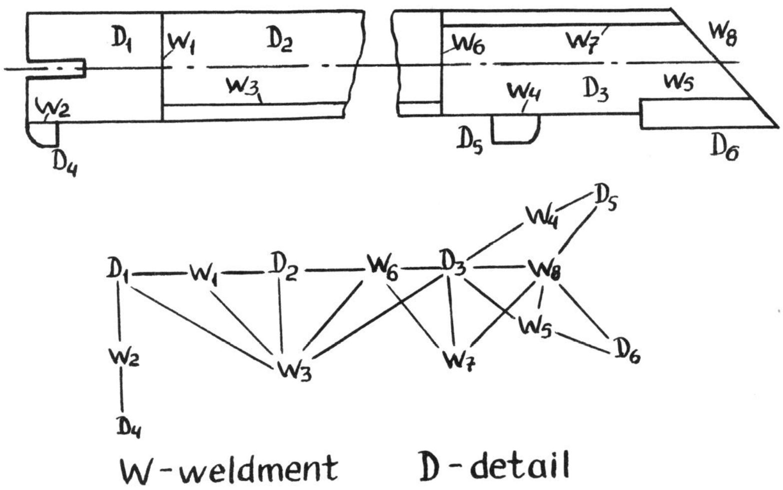

Figure 1. Structural scheme of excavator arm beam

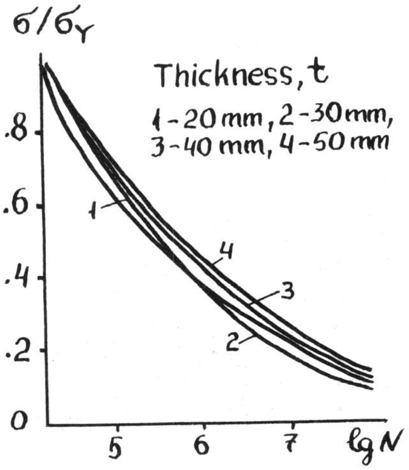

Figure 2. Fatigue curves of weldments

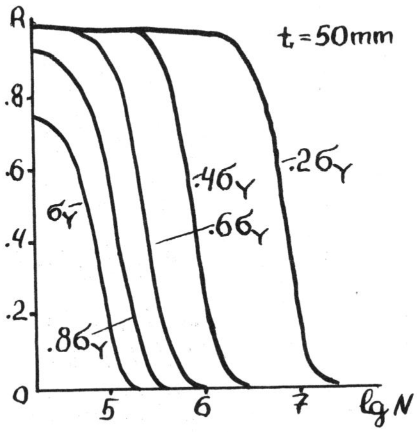

Figure 3. Reliability functions of weldments

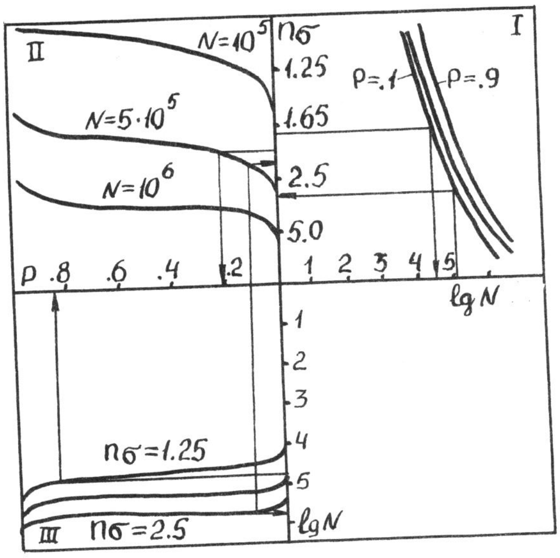

Figure 4. Complete stochastic lifetime diagram

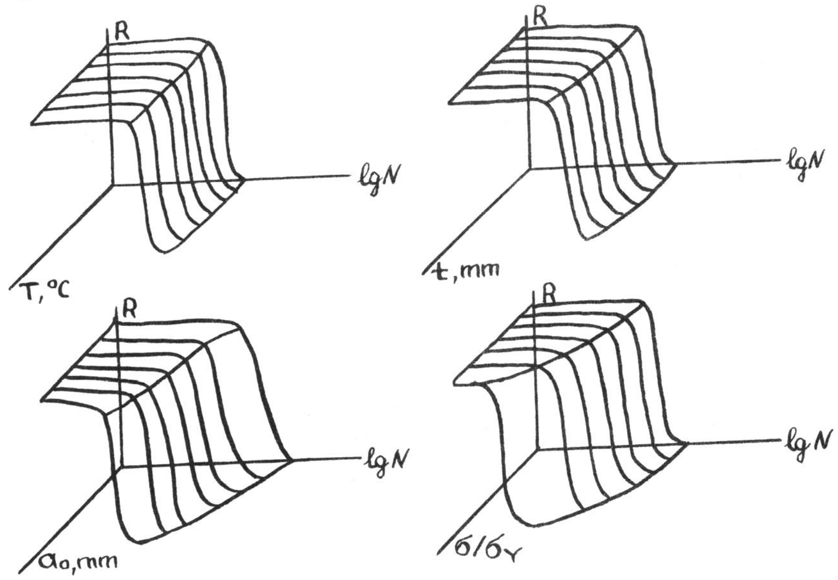

Figure 5. Stochastic durability surfaces