Finite-element simulation of permissible load on gate elements of water-conveying structures to assess risks of anthropogenic accidents

M A Bandurin¹, V V Vanzha², V A Volosukhin¹, A V Mikheev¹, Y V Volosukhin¹ and I P Bandurina¹

¹ Platov State Polytechnic University (NPI), 132, Prosvescheniya St., Novocherkassk, 346428, Russia
² Kuban State Agrarian University named after I T Trublin, 13, Kalinina St., Krasnodar, 350044, Russia

E-mail: chepura@mail.ru

Abstract. It is ascertained that operation of mechanical equipment on technical state requires a switch over permanent inspection of elements instead of periodic examination since a possible failure of the mechanical equipment of hydraulic structure system in the headworks will result in emerging causes for possible anthropogenic accidents. Changes in stressed and strained state of the whole structure significantly influence the equipment strength. Corrosion and mechanical loads as well as emergency conditions arisen result in sites for corrosion cracking of elements. Forming and opening of such cracks occur transiently and even instantly, but their character and spreading velocity are difficultly fore casted. Computation was carried out with the help of a software complex SCAD office, operation of which is based on the method of finite elements and superelements, emergence of various possible defects is simulated and their maximum level for safe operation of the mechanical equipment by the criterion of stressed and strained state is determined.

1. Introduction

A significant part of the mechanical equipment for water conveying structure gates is being operated for several decades. Large enough age of mechanical equipment elements are objectively connected with the increased risk of anthropogenic accidents and failures under operation in the case of absence of the effective system to prevent them. In spite of apparent simplicity of structure construction, its failure during operation can result in human victims, significant material damage, environmental pollution and so on. The situation can be essentially improved owing to increasing diagnostics quality of welds and various elements when constructing and repairing. The mechanical equipment is a part of hydroschemes, hydraulic structures of water management and nature protection objects (complexes). Because of a large diversity of hydraulic structures, the mechanical equipment can be unstandartized and produced by individual designs approved by the fixed order. Operation conditions for each type of the mechanical equipment are determined in addition to technological functions by structures arrangement for a designed hydraulic engineering project taking into account erection stage, construction period and temporal operation of the project. The site of the headworks with dam water intake considered is located on the Kuban river at the distance of 698 km from the river mouth.
The main gates are designed for operation under the maximum head to control discharges. The gates are also designed for hoisting and sinking in running water and, if it necessary, for discharge of ice, sludge ice, garbage (floating and dragged things) and others [1].

When constructing equipment, machines and mechanisms, the following factors of maintainability are secured:

- accessibility, of equipment, constructions and their elements for which preventive maintenance and repair works are foreseen;
- convenience of service with human possibilities taken into account;
- admissible choice of working positions;
- limitation in a number of special instruments and devices;
- field of views;
- plain gates; litter treatment equipment should be serviced and repaired in the pulled down on the surface position on specially equipped ground.

In control systems for the mechanical equipment mechanisms, a possibility for the safe periodical inspection of serviceability of mechanisms and control means is foreseen. The design of the mechanical equipment and metallic constructions is carried out by two groups of limiting states (by strength and by deformations and movements). This design should be carried out by such a way that a certain reliability and guarantee of coming this or that limiting state take place; moreover, the degree of reliability is not constant for all cases and is differentiated depending on the function of a construction and possible consequences in the case of technogenic accident.

2. Materials and methods

During the operation of gates of a water conveying structure, sites of corrosion cracking due to the impact of load corrosion are arisen [2]. These corrosion and mechanical defects result in emergency conditions, decrease in service life and breakdown. Experience of structures operation shows that weld joints and near-weld zones are mostly subjected to corrosion. Weld breakdown analysis of constructions operating in different conditions confirms that defects in the weld unit area become the prime cause more often. Cracks in weld joints reducing their static and dynamic strength being concentrators of stress are of great danger. Spots corrosion and corrosion cracking localized in the form of cracks are the most widespread types of corrosion defects in the near-weld zone [3].

Laying out the total length of structure opening on separate spans determined by hydraulic design provided that the conveying water discharge is maximum, is determined by the system (complex) of technical and economical data concerning a hydraulic structures operation, the gate being its part. The gate span in the light equal to the opening width is determined, in particular [4]:

- by satisfiability of accepted gate type at its predetermined material and head;
- by possibility to use the most expedient for the given gate type of relationships of the span and height as well as constructive properties;
- by conditions to pass ice, logs and other floating bodies as well as by reasons of minimum water discharge for filtration;
- by suitable gate manoeuvring;
- by the lowest total cost of the whole structure (gates, lifters, bridges, supports, apron and so on);
- by the lowest maintenance charges [5].

A solid-state model of stressed and strained state for the mechanical equipment of the water conveying structure was built [6].

Computation was carried out by a software complex SCAD office whose operation is based on the method of finite elements and superelements. Stressed and strained state of finite elements under bending, torsion, compression and tension as well as their different combinations is considered. In the
process of simulation firstly it is necessary to creat a new local coordinate system with regard to which a defect is built where the coordinate system centre was wherein it is located. In statement of numerical computation, the task was set to determine an adequacy of the solid state model in stressed and strained state under the maximum water head to existing studies on location under different boundary conditions taking into account changes in the climatic and seismic conditions and increased risk of possible anthropogenic accidents. When assessing operational reliability, a numerical simulation was carried out, criteria of physical wear for single elements were received [7].

In figure 1 a diagram of total deformations with presence of the largest deformations in the places of forming rapidly growing cracks is shown. The change in element position due to loads and uncritical movement along edges of the gate is of great interest.

**Figure 1.** The diagram of total deformations for gate elements of the water conveying structure

According to the diagram of stresses received (figure 2) [8], it is possible to classify the state of elements for the mechanical equipment and to determine the critical depth of a corrosion spot. Simulation of the influence of two similar corrosion spots on the stress in the near-weld zone is also carried out. Stresses are given in the near-weld zone depending on the corrosion spot depth [9]. As it is seen, stresses increase with the rise in the depth of a corrosion spot, and under the depth of 4 mm they practically correspond to the metal-yield of strength. Simultaneously, plastic deformations resulting in failure of the material begin to develop [10].

It is evident that the critical depth of spots in this case decreases as compared with a spot: plastic deformations rise from the depth of 3 mm. Equivalent stresses exceed the ultimate strength of material several times that testifies to the further development of a cracks and failure of the mechanical equipment.
Figure 2. Diagram of stress intensity on von Mises under crack formation

A situation of possible various seismic impacts the mechanical equipment gate of the water conveying structure was also simulated (figure 3). The task was set up to determine the volume of anticipated landslide and scale of expected catastrophe [11].

---

International Conference “Complex equipment of quality control laboratories”

IOP Conf. Series: Journal of Physics: Conf. Series 1118 (2018) 012005

doi:10.1088/1742-6596/1118/1/012005
Figure 3. Diagram of tensile stress and compressive force

During the research carried out, the necessity and possibility to reduce a risk of possible anthropogenic accidents owing to study of regularities in changes of physical and mechanical properties of metal and weld joints in the process of operation are confirmed. This will allow one to determine service life of the gate construction for the water conveying structure with the purpose of keeping long-term failure-free operation [12].

Based on the numerical computation, the problems of ageing and wearing for the given constructions are revealed.

Analysis of a corrosion spot depth influence on the stress in the near-weld zone is carried out. The results of computation showed that if a corrosion spot has the depth of 4 mm, then stresses in the corrosion spot for the near-weld zone are practically equal to material yield of strength. Availability of corrosion defects [13] in the wear-weld zone results in the increase of stresses and decrease of safety margin and, as a result, failure in the near-weld zone and anthropogenic accident take place [14].

3. Conclusion

Allowable corrosion injuries of welds for sheet elements constitute:
- butt welds and the corner complete penetration ones located across the main force impact-up to the wear to the depth not below the surface of joined sheets;
- butt welds and corner complete penetration ones located along the main force impact - the wear up to residual weld thickness not less than 0.9 of the average residual thickness of the thinnest of joint sheets, but not more than 2 mm from the surface of this sheet.

It is necessary to determine the requirements for organization the operation of the hydraulic structure mechanical equipment and reclamation systems including functions of maintenance personnel, performance of which is compulsory for safe operation. The requirements are also necessary for both acceptance test of the mechanical equipment when putting it into operation and observance of vital activity and environmental protection.

References
[1] Bock T, Krapivin D, Aleksyuk S, Pritchin S 2002 Monitoring of the boring trajectory in underground channel 19th International Symposium on Automation and Robotics in Construction 3 519-522
[2] Degtyareva O G, Degtyarev G V, Togo I A, Terleev V V, Nikonorov A O, Volkova Yu V 2016 Analysis of stress-strain state rainfall runoff control system – buttress dam Procedia Engineering 165 1619-1628
[3] Yurchenko I F 2018 Information support system designed for technical operation planning of reclamative facilities Journal of Theoretical and Applied Information Technology 96 1253-1265
[4] Volosukhin, V A, Bandurin, M A, 2013 Software and hardware complex for carrying out monitoring and definition of the residual resource it is long the operated water carrying out constructions Bulletin of the Perm national research polytechnical university. Construction and architecture 1 57-68
[5] Gaydzhurov P P, Al-Dzhabobi S F, Al-Khazh M A 2017 Finite element modeling of force transmission the tension of the steel tendon on the concrete News of Higher Educational Institutions of North Caucasus region 2 73-78
[6] Gaydzhurov P P, Kravchenko G M, Savelieva N A 2014 Finite element modeling of elastic plastic bending of steel beams with use of rod end elements Construction mechanics and design of structures. 2 17-22
[7] Olgarenko V I 2009 Assessment of the quality of planning and implementation of water use in irrigation systems Bulletin of the Russian Academy of agricultural Sciences 2 35
[8] Volosukhin, V. A., Bandurin, M. A., 2017 Problematic issues of implementation of monitoring of water use in southern Russia in conditions of growth of technogenic loads and climate changes Vestnik of the Don State Agrarian University 2-1(24) 113-123
[9] Volosukhin, V A, Bandurin, M A, 2012 Methods of non-destructive control in modeling the technical condition of ferro-concrete facing of water-conducting channels Science and Security 5 9-17
[10] Olgarenko I V, Olgarenko G V, Olgarenko I V 2013 Integrated assessment of technical level of irrigation and drainage systems Irrigation and water management 6 8-11
[11] Yurchenko I F 2017 Methodological bases of creation of the information management system water use on irrigation Messenger of the Russian agricultural 1 13-17
[12] Chesnokov B P, Abdrazakov F K, Naumova O V, Krivoschapov D S, Strelnikov V A. 2017 The use of ionizing radiation for the tungsten preparation Journal of Industrial Pollution Control 1-12
[13] Yurchenko I F 2016 Water-saving technology for planning of technical operation of reclamation systems Water economy of Russia: problems, technologies, management 5 76-88
[14] Yurchenko I F, Trunin V V 2013 Methodology of creation of information technologies for operational management of water distribution at inter-farm irrigation systems Environmental engineering 4 10-14