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Analysis of Sluice Gates of Hydroelectric Power Stations

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Abstract In the paper are given basic steps necessary for analysis of strength, reliability and residual lifespan of sluice equipments used in hydroelectric power stations. The analysis is accomplished by numerical as well as experimental methods of mechanics and in some cases simple treatments of classical analytical methods are also used. Sluice gates and quick valves are very important parts of water power stations and their reliability is a key condition for their operation. At the first stage are accomplished numerical computations by the finite element methods that serve for first recognition of critical locations in the structure. In the next step, experimental measurements are used for determination of residual stresses and dynamic loading resulting from operation of equipments. Further computations and measurements are used for refinement of analysis. At the end recommendations for modification of structures for improvement of actual state are given.

Keywords: *sluice gate, finite element method, experimental methods, strain-gage, Hole-drilling Method*

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1. Introduction

Supporting elements of machines and equipments in heavy industrial engineering companies such as metallurgy, mines and power stations are besides of enormous loading exposed to other adverse influences. The most important are high temperatures, aggressive environment that support corrosion, impact loading and so on. Many of those equipments operate during long time and reliability is one of the most important aspects of their work. Besides of financial questions there arose questions of safety of those structural elements, because the people working near heavy loaded parts can be in danger during various possible working states. Department of Applied Mechanics and Mechatronics of the Faculty of Mechanical Engineering regularly from year 2001, time of first accidence at water power plant Ružín, that attempts the life of workers checking state of equipments, takes a part on evaluation of state and proposals of modifications of sluice gates and quick valves of power plants with the aim to ensure their reliable operation [3,4,5].

Assessment of state of such supporting elements depends on knowledge of various physical quantities by which different actual processes and states inside material of structure can be characterized.

That is the reason why we have developed methodology for assessment of state of water power plant. The aim of methodology is to describe measures that are necessary for analyzing actual state of structure, its renewal and finally for increasing of its reliability and safety [5].The methodology is based on two basic treatments of modern applied mechanics – numerical and experimental methods. Unique experimental and software equipment of author's workplace allows using combinations of those two working methods enriched by analytical procedures. Such a treatment gives synergetic interaction and effect that ensure high quality of results.

Quick valves of hydroelectric power plants, as results from their appellation, serve for quick closing of water flowing to or from generator. Sluice gates are then determined for long-time hatching of flow, e.g. for inspection purposes or reparation works. In the paper the authors devote their attention to description of analysis of closing equipment of water power plants. They describe their opinions and promote general methodology applied to the assessment and improvement of those structures.

In Figure 1 is given schema of water power plant Ružín, which can serve as typical representative of inlet hatching. In Figure 2 is shown vertical cross-section of inlet pipe.

In Figure 3 is given scheme and basic dimensions of typical equipment for inlet hatching – sluice gate.

Sluice gates and quick valves are composed of supporting main and side I-profiles covered by plate. In Figure 4 is a view to the design of sluice gate.

2. Preliminary Works

For the analysis of actual state of structure it is necessary to have information from available documentation and from investigations of operation conditions, number and amplitudes of loading cycles, material properties, corrosion, deformations, defective welds and so on. Some severe defects in the structure can be detected by visual control, e.g. extremely deformed parts and poor welds Figure 5, corrosion Figure 6.

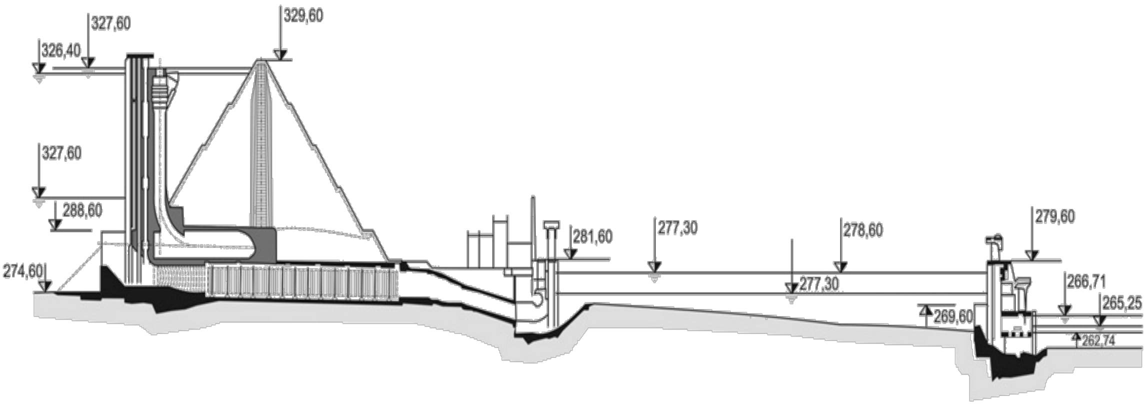

Figure 1. Schema of water power plant

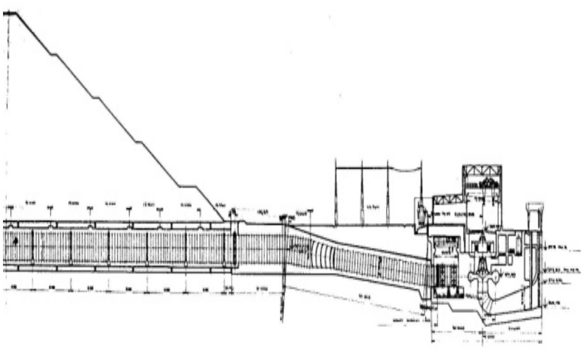

Figure 2. Vertical section of inlet pipe of power plant

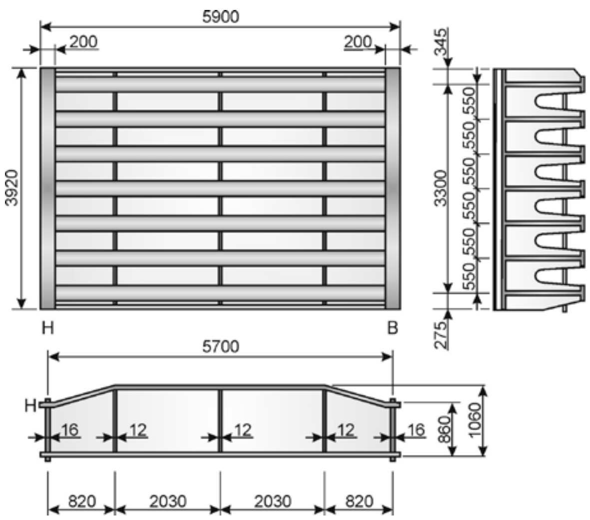

Figure 3. Typical representative of sluice gate - basic dimensions

Figure 4. View to sluice gates

Figure 5. Deformation of flange and poor weld

After sand blasting of structure the visual control of welds or measurement of dimensions can be realized. Further, quality of welds can be accomplished by the defectoscopy methods. The main aim of this control is detection of possible cracks in welds.

Figure 6. Corrosion of sluice gate structure

Because the structure works under water in severe corrosion conditions, the measurements of wall thicknesses have to be realized for cover sheets, webs, flanges and reinforcement ribs in order to use these dimensions in analytical and numerical computations. The measurement can be accomplished e.g. by ultrasound apparatus TG-400. Attention has to be devoted also to the stress concentrators that can be sources of initial failures and from the point of view of safety they are critical part of structure. For the detection of actual state of structure it is often necessary to provide measurement of cover plate surface evenness. The measurement is realized by robotic geodetic station Trible VX Spatial Total Station 305 while the quick valve or sluice gates are in vertical position.

3. Numerical Computations

The computation of strength is based on numerical procedures, but in case of simple structures the analytical methods are applied too. The computation comes out from fact that sluice gate is loaded during operation by water pressure *p*and it is simply supported in locations*H* and*B* Figure 7. Typical computational schema represents loading of single rib by pressure of water in depth *h*. Accordingly, continual loading *q*is acting on single rib (Figure 7b) and on the basis of classical theory normal shear and equivalent stresses in the structure are computed.

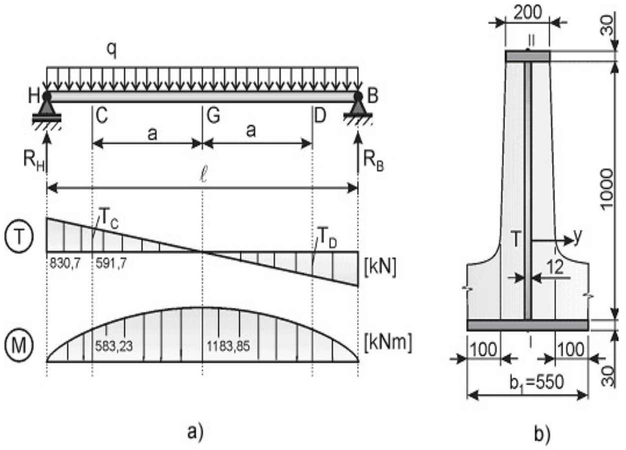

Figure 7. Computational scheme of one rib of sluice gate

Besides of strength conditions the profiles have to be checked (even there are compact cross-sections) for shear stability of walls according to part 6.7.3 of Standard STN 73 1401 and also transverse reinforcements have to be checked.

Computation by the finite element method is the most important numerical treatment and one example of meshed model is given in Figure 8. It represents mesh of shell finite elements for which characteristic field of equivalent von Mises stresses on bottom part of shells are given in Figure 9.

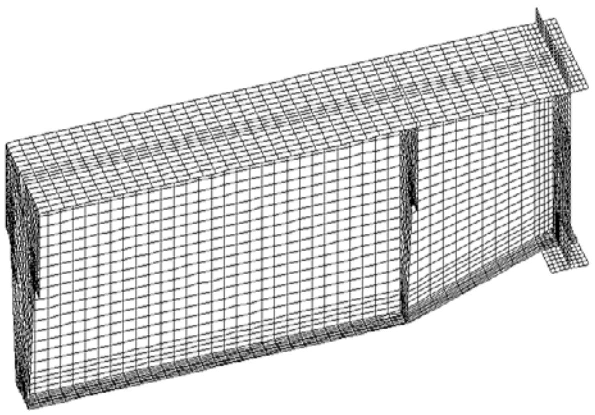

Figure 8. Mesh of shell finite elements

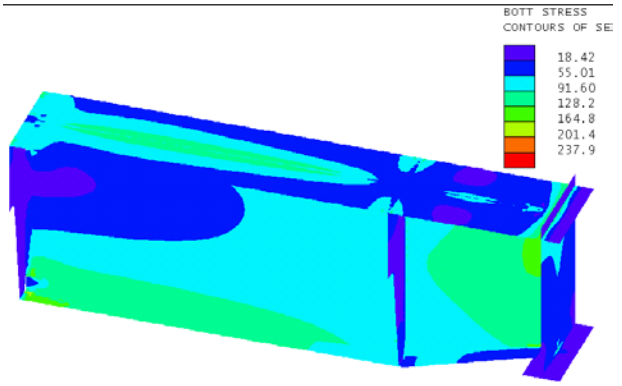

Figure 9. Field of equivalent stresses on bottom sides of supporting member

In order to provide investigation of stresses in the area of stress concentrators it is necessary to model whole closing equipment. During years different computational models of various sluice gates were used based on shells as well as volume elements. Examples of such computations are given in next figures. In Figure 10 are shown deformation fields and in Figure 11 the fields of equivalent stresses for two different structures.

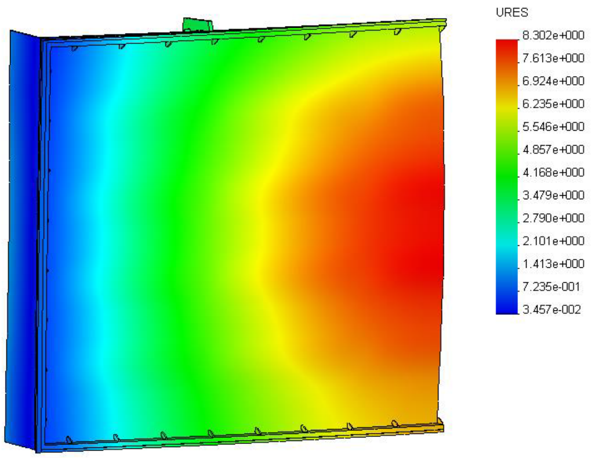

Figure 10. Field of deformations for bottom sluice gate on inlet

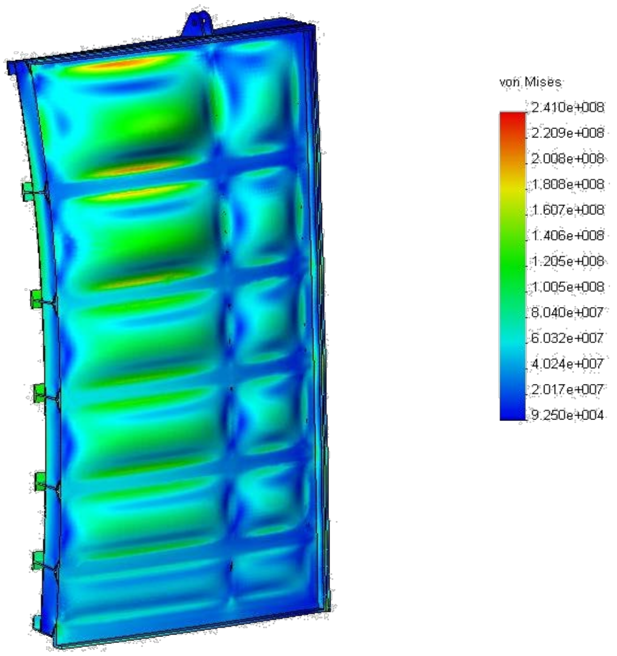

Figure 11. Fields of von Mises equivalent stresses on quick valve of different type

4. Experimental Measurements

Knowledge of actual state of structure is based on the following measurements [2]:
- measurement of residual stresses,
- strain gage measurements of time-dependent stress changes during operational loading of structure.

4.1. Residual Stresses

The most important method of measurement of residual stresses in the structure is the hole drilling method. The method is nowadays a standard method of measurement [1]. Despite of fact that the residual stresses frequently occur in the structure and they significantly influence their reliability, only very small attention is devoted to their measurement. Consideration of quantitative levels of residual stresses is still one of the forgotten parts of structural designing which is regrettable.

Figure 12. Measurement of residual stresses by system RS 200

The precision of hole drilling method depends mainly on following factors:
- strain gages and their installation,
- centering of drilling tool and hole drilling,
- apparatus for deformation measurement,
- knowledge of material properties of tested part.

Positioning of strain gages in rosette has been proposed and developed by Micro-Measurements and HBM especially for the measurement of residual stresses. Rosettes are equipped by centering signs for positioning of drilling tool in the centre of strain gage circle. This is a critical operation on which the precision of whole measurement depends. The most effective and appropriate equipment for the measurement in terrain is a portable static strain gage apparatus Model P-3 charged by battery, or apparatus RS 200 Figure 12. In laboratory conditions is very suitable to use automatic system connected with computer, e.g. Measurements Group System 4000, or SPIDER 8. Special off-line computer program is also suitable for using with System 4000. Program automatically provides procedures connected with computation of residual stress magnitudes in accordance with ASTM E 837-01. In the standard is recommended to drill the hole by small increments together with registering measured deformations and depth of drilled hole after each increment.

4.2. Determination of Operation Loading

By the strain gage measurement are analyzed also time-dependent charts of strains in the most loaded locations of hatching equipment [6,7]. For the joining of strain-gages with measurement apparatus are used shield cables. Measurement chain consist of strain-gage apparatus SPIDER 8 and notebook. On the sluice gate are applied strain-gages symmetrically to the vertical axis, Figure 13. Detail of strain-gage application is given in Figure 14. Two strain gages are used in order to avoid possible error of one strain gage due to relatively high water pressure and during manipulation with sluice gates by crane before realization of measurement.

Figure 13. Insulated strain gages on sluice gate before measurement

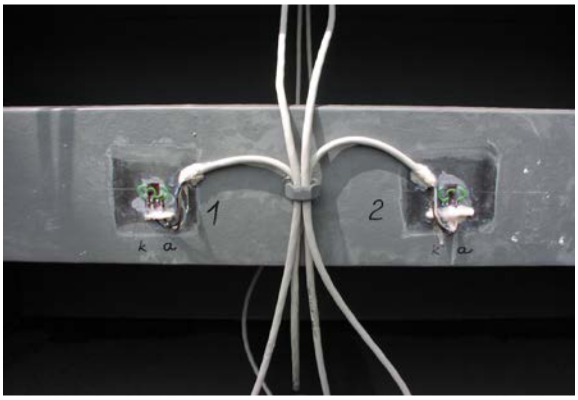

Figure 14. Detail of applied strain-gages

After activating of strain gages and their balancing the sluice gate was transported by crane over gate shaft and subsequently lowered into water. During whole process of transportation the stresses were recorded for future analysis. They did not exceed levels of several MPa. This measurement serves only for checking of strain gage functionality. After positioning of sluice gates, the measurements of stresses under operation conditions of this equipment were accomplished.

5. Conclusions

For determination of scheduled aims during solution of sluice elements of water power plants is, on the basis of our opinion, necessary:

- to study available documentation and to inspect the equipment with a failure,

• to determine analytically stresses in locations of extreme loading and to provide strength and stability analysis according to actual standards (check of welds and reinforcements),

• to determine influence of rib flange deformation to the stress state in sluice equipments

• to determine loading necessary for plastic deformation of rib,

• to determine stress states in supporting element of sluice equipment by the finite element method,

• to determine residual stress state in the most exposed supporting member after plastic deformation by the measurement system SINT MTS-3000 and program RESTAN,

• to determine locations for checking welds before accomplishing of surface treatment,

• to elaborate methodology for measurement and evaluation of stresses in sluice equipments,

• to apply strain gages and cables that are necessary for measurement of operational loading of sluice equipments,

• to accomplish measurement during positioning and operation of sluice equipments,

• to evaluate measurements – time-dependent charts of strains and stresses,

• to assess suitability and safety of sluice table design taking into account existing failures; to determine residual life time,

• to elaborate unambiguous conclusions concerning suitability or inadequacy of using of investigated sluice gates for further safe operation.

Acknowledgement

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