Miodrag Arsić[1], Srđan Bošnjak[2], Simon Sedmak[3], Živče Šarkoćević[4], Zoran Savić[1], Dorin Radu[5]

DETERMINATION OF DAMAGE AND REPAIR METHODOLOGY FOR THE RUNNER MANHOLE OF KAPLAN TURBINE AT THE HYDRO POWER PLANT 'DJERDAP 1'

UTVRĐIVANJE OŠTEĆENJA I METODOLOGIJA POPRAVKE REVIZIONOG OTVORA NA KAPLANOVOJ TURBINI HIDROELEKTRANE "DJERDAP 1"

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Adresa autora / Author's address:
1) Materials Testing Institute, Belgrade, Serbia, email: miodrag.arsic@institutims.rs
2) University of Belgrade, Faculty of Mech. Engineering, Belgrade, Serbia
3) University of Belgrade, Innovation Centre of the Faculty of Mech. Engng., Belgrade, Serbia
4) High Technical School of Professional Studies, Zvečan, Serbia
5) University of Brasov, Faculty of Civil Engng., Romania

Keywords
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- manhole
- damage
- repair methodology

Ključne reči
- hidro turbina
- revizioni otvor
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- metodologija popravke

Abstract

Results of non-destructive testing of the Kaplan turbine runner manhole welded structure are presented, on the basis of which the repair methodology is defined. During repair, the welding technology for elements of the manhole is modified along with the proposal given for the modification of its structural design, because the finite element method calculation proved that the rectangular welded structure of the manhole was significantly better than round welded structure when it comes to integrity and service life.

Izvod

Prikazani su rezultati ispitivanja bez razaranja zavarene konstrukcije revizionog otvora Kaplanove turbine, na osnovu kojih je definisana metodologija popravke, uključujući modifikaciju tehnologije zavarivanja elemenata revizionog otvora. Takođe je izmenjeno projektno rešenje, jer je proračun konačnim elementima pokazao da je pravougaoni oblik zavarene konstrukcije revizionog otvora znatno povoljniji od kružnog oblika, kada se analizira integritet i vek konstrukcije.

INTRODUCTION

Vertical Kaplan turbines manufactured in Russia of nominal power 200 MW, Fig. 1, have been installed in 6 hydroelectric generating units at the hydro power plant 'Djerdap 1'. Hydroelectric generating sets are designed for the service life of 40 years due to structural design and limited possibilities for periodic inspections.

Turbine and hydromechanical equipment is subjected to stresses that occur during the production of components and assembly of equipment (residual stresses), during regular operations (stationary and dynamic loads), as well as during irregular operation (non-stationary dynamic loads). An additional impact of the operating environment (corrosion, erosion, cavitation) makes it clear that the stresses can not be expressed only by a model that predicts uniform modification of parameters during operation. No wonder that during regular maintenance extensive damage has been found, leading to detailed non-destructive testing. The visual testing (VT), penetrant testing (PT), magnetic particle testing (MT) and radiographic testing (RT) are carried out to determine damage occurrence at the Kaplan turbine runner manhole welded structure (Figs. 2 and 3).

Repair methodology for the runner manhole is defined based on results of non-destructive tests. Modification of welding technology for segments of the manhole is carried out and a proposal regarding the modification of its structural design is given, since finite element method calculation showed that the rectangular welded structure of the manhole would be significantly better than the round welded structure, concerning structural integrity and service life, /1/. Maximum operating pressure within the internal space of the manhole, made of steel St 3, /2/, is p = 4 MPa.

NON-DESTRUCTIVE TESTS

Experimental non-destructive tests (VT, PT, MT and RT) are carried out in order to determine the state of the Kaplan turbine runner manhole welded structure.

Visual testing

A segment of the flow tract in the manhole area is presented in Fig. 4 (numbers and letters mark the elements and welded joints at the manhole), while areas in which the water leaking occurs are shown in Fig. 5. Some of the characteristic spots in the parent material and welded joints of the manhole where damages occur, detected by visual inspection /3/, are shown in Figs. 6 and 7.

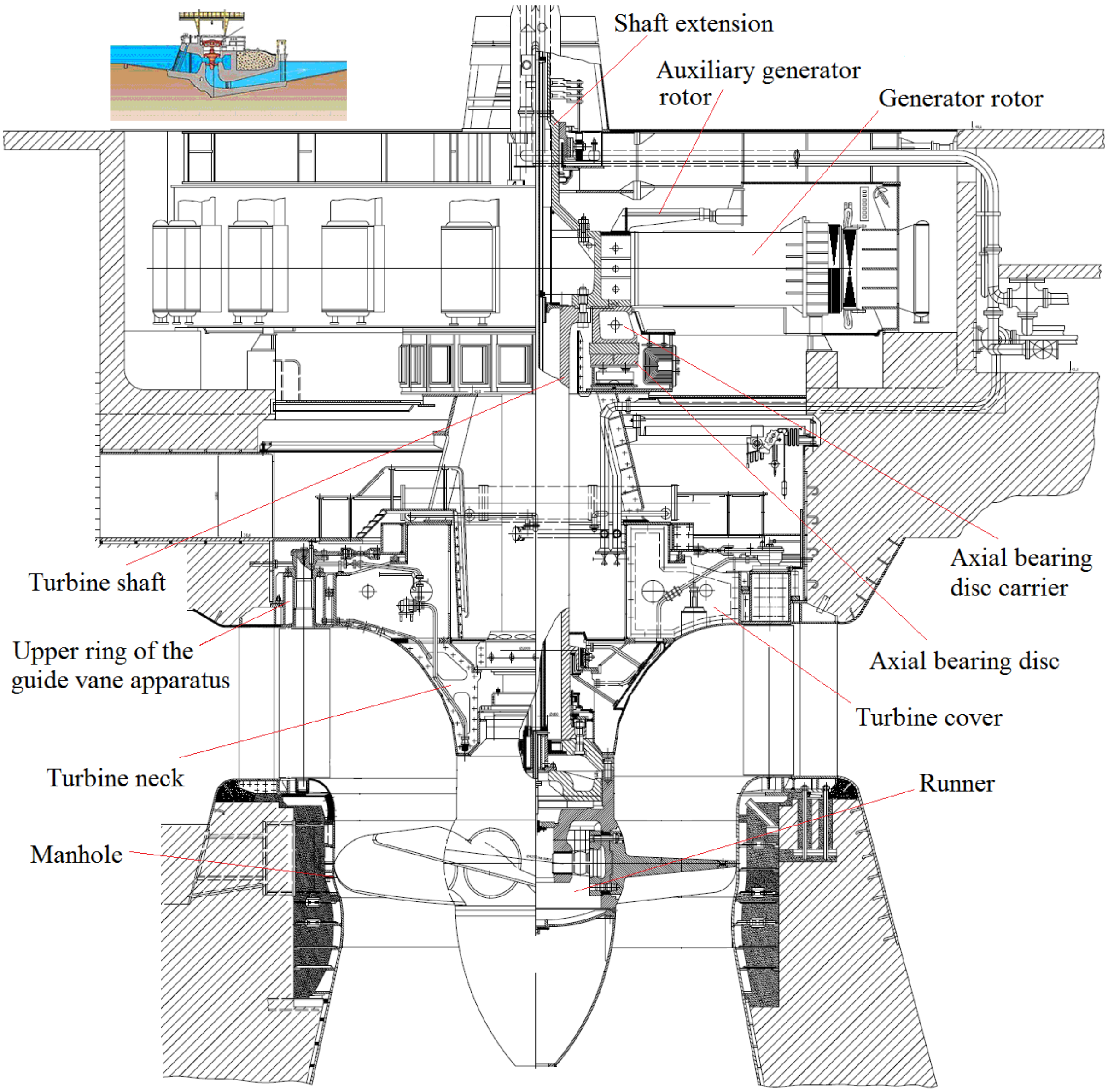


Figure 1. Appearance of the vertical Kaplan turbine, nominal power 200 MW.

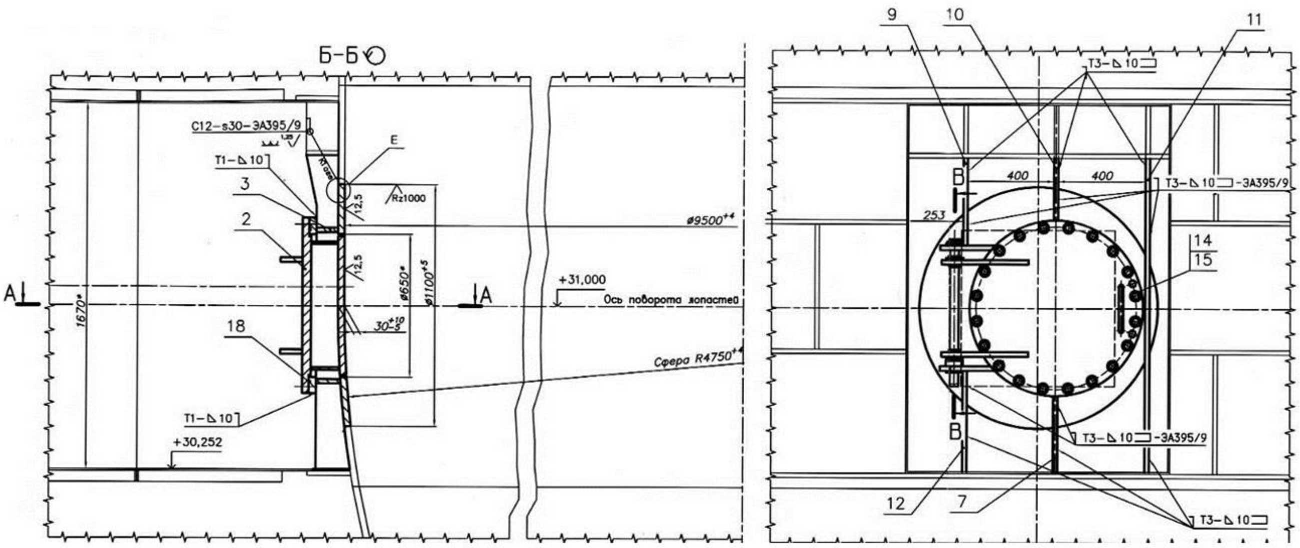


Figure 2. Drawing of the Kaplan turbine runner manhole, as part of the hydroelectric generating set A4 at hydro power plant ‘Djerdap 1’.

Figure 3. Kaplan turbine runner manhole as part of the hydroelectric generating set A4.

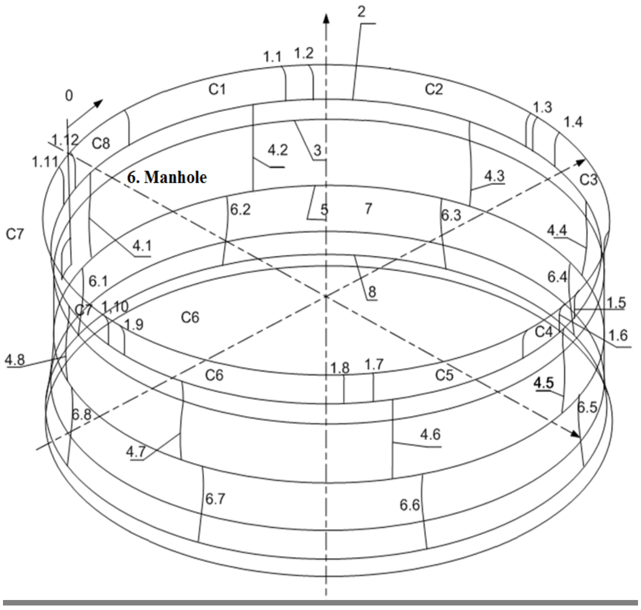


Figure 4. Appearance of a segment of the flow tract in the manhole area.

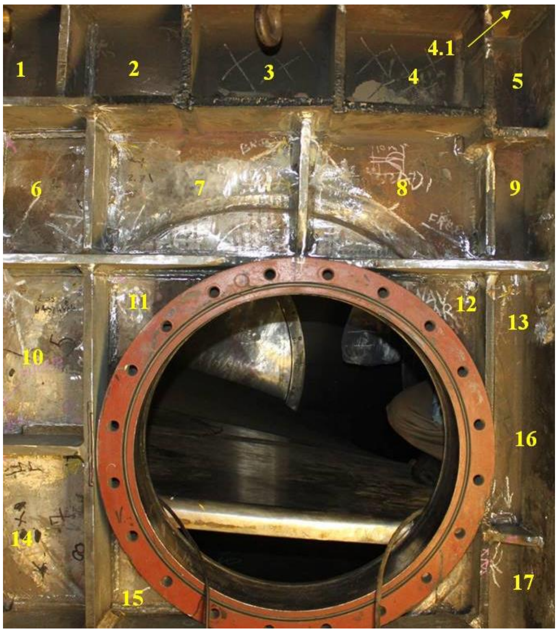
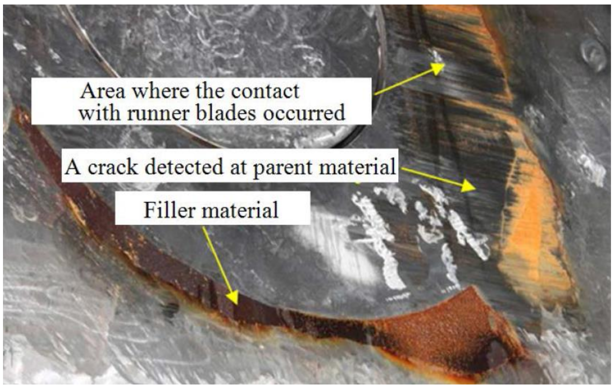
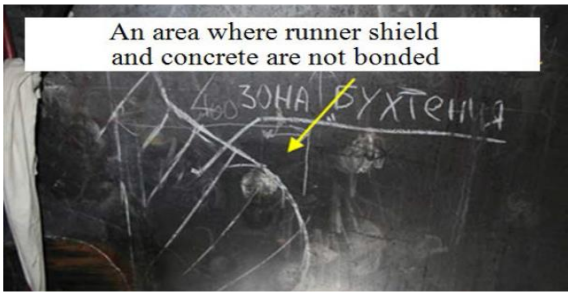


Figure 5. Appearance of manhole area at which leaking occurred.



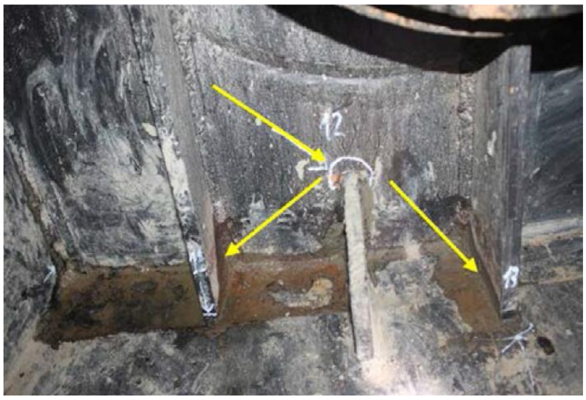
a) Damage in a manhole area toward the runner



b) Damage detected at the runner shield

Figure 6. Damages that occurred in the manhole area.

a) Crack at the welded joint of runner shield with concrete



b) Cracks at welded joints between rib sand runner shield

Figure 7. Appearance of a crack in welded joints.

Penetrant testing

A few characteristic areas where surface damage occurred in the parent material and weld metal of the manhole, detected by penetrant testing /4/, are shown in Fig. 8.

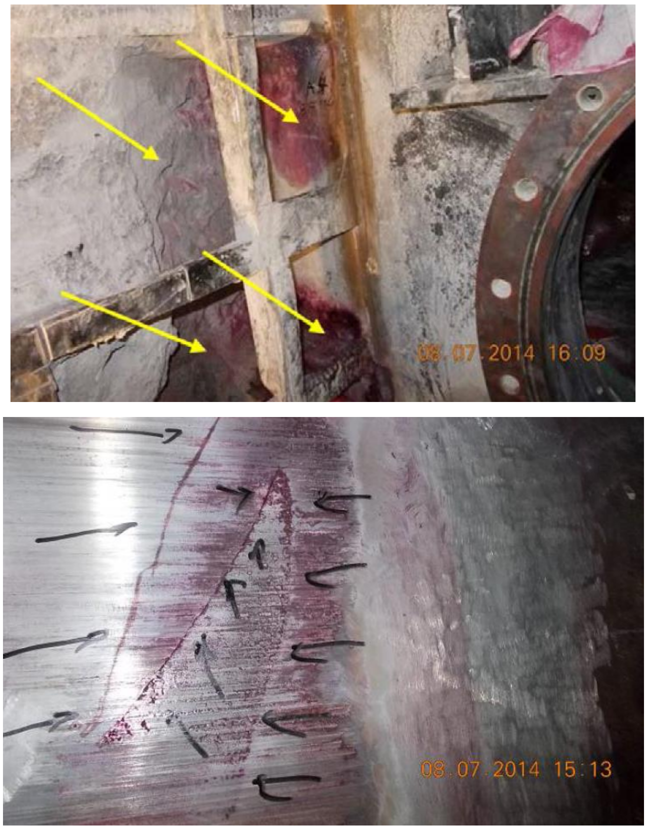


Figure 8. Characteristic surface damages in parent material and weld metal in the manhole and runner areas.

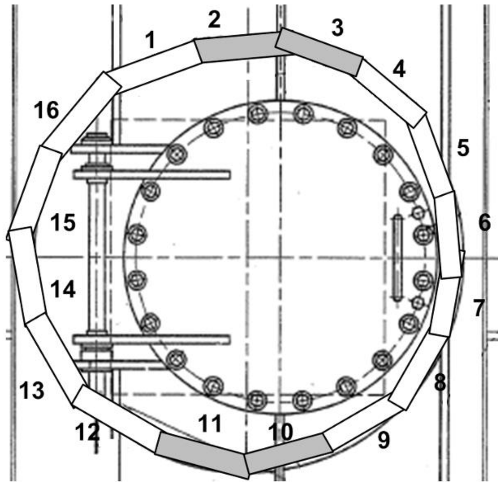
Magnetic particle testing

A few characteristic areas where surface damaging at the parent material and weld metal of the manhole and runner, detected by magnetic particle testing occurred, /5/, are shown in Fig. 9.

Figure 9. Surface crack detected by MT at the welded joint, between the strengthening rib and runner shield.

Radiographic testing

Radiographic testing is performed in order to check the homogeneity of the circumferential butt-welded joint, /6/. Disposition of the radiographs are shown in Fig. 10.



Radiographs at which unacceptable defects in the butt-welded joint are detected.

Radiographs at which no unacceptable defects in the butt-welded joint are detected.

Figure 10. Radiographic testing of the homogeneity of the circumferential butt-welded joint, disposition of radiographs.

REPAIR METHODOLOGY FOR THE WELDED STRUCTURE OF THE MANHOLE

As based on the results of non-destructive tests, the repair methodology for the runner manhole is defined, and modification of the welding procedure for the manhole elements has been carried out. Structural design modification is performed, since the finite element calculation has proved that the welded structure of the rectangular shaped manhole would have significant advantages over the round-shaped manhole, when it comes to integrity and service life, /9/.

Welding procedure

The analysis of parameters on which the selection of the repair welding/surface welding procedure depends (weldability of material, energetic possibilities of the welding procedure, geometric complexity of the structure, economic parameters) proved the applicability of procedure 111.

It was determined that the electrode with basic coating ЭА 395/9, in accordance with GOST standard (ISO E16.25. 6B20, DIN E16.25.6B20) /7/, provides good properties of weld metal and welded joints as wholes, during the execution of repair/surface welding of large structures or materials with limited weldability. Chemical composition of pure weld metal and mechanical properties of electrode material are presented in Tables 1 and 2.

Table 1. Chemical composition of pure weld metal (mas. %).

Electrode	C	Si	Mn	Cr	Ni	Mo	N	S	P
ЭА 395/9	0.09	0.50	1.60	15.5	24.5	5.70	0.12	0.009	0.020

Table 2. Mechanical properties of electrode material.

Electrode	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation A_5 (%)	Impact energy (J/cm^2)
ЭА 395/9	470	690	37	210

The basic principles of the welding/surface welding procedure executed in areas where damages and cracks occurred at the welded structure of the runner manhole are comprised by the following:

– areas where damages or cracks occurred, after the preparation of surfaces by grinding using suitable grinders, have been locally preheated at 150°C;
– welding/surface welding is executed by electrode ЭА 395/9, with diameters ranging from 2.5 to 4 mm;
– after the execution of welding/surface welding, treated areas are heated to 150°C for another hour, and then isolated from all sides and left to cool slowly;
– after the repair is performed in areas with damages and cracks by welding/surface welding, these areas are treated by suitable grinders in order to achieve demanded geometry and surface roughness.

It is necessary to carry out the marking and to cut out damaged elements through the use of appropriate patterns, and then install the new ones using the identical welding procedure.

Proposal modifying the structural design of the manhole based on numerical calculation

It was necessary to check the structural design of the runner manhole due to detection of a large number of damages and cracks, through the use of non-destructive tests. The numerical calculation is carried out by applying the finite element method /8/, taking into account the maximum operating pressure in the internal space of the runner manhole p = 4 MPa. It is determined that the rectangular welded structure of the manhole, Fig. 11, would be significantly better than the round-shaped welded structure when it comes to integrity and service life, /9/.

Figure 11. The reconstructed Kaplan turbine runner manhole welded structure.

CONCLUSION

Modified structural design of the manhole in the hydroelectric generating set A4 at the hydro power plant 'Djerdap 1', based on numerical calculation, has been verified by the manufacturer, the company 'Power Machines' from Saint Petersburg, because they provided the guarantee for the manhole to be in service until the next turbine refurbishment, scheduled to be carried out in approximately 40 years.

The presented methodology for modifying the structural solution is also applicable for other structures and components of turbine and hydromechanical equipment subjected to various causes of damage occurrence during service.

ACKNOWLEDGEMENT

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