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# Methods for Verification of Safety of the Sluice Gates in Water Power Plants

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## ABSTRACT

The aim of a paper is to show theoretical and experimental methods that are used in the process of evaluation of safe operation of sluice gates in water power plants. On several examples are represented various treatments that allow to provide identification of locations of possible failures on carrying elements of sluice gates.

## KEY WORDS

sluice gates, safe operation, stress and strain analysis.

## INTRODUCTION

Carrying elements of machines and equipments in mechanical engineering, metallurgy and power industry are mostly during their operation under extremall loadings that decrease their lifetime. For the assessment of their safe operation is suitable to use analytical, numerical and experimental methods of mechanics [10, 11, 12].
Sluice gates that are used in water power plants serve for closing of water flow on inlet and outlet of generator. After certain period of operation it is necessary to provide inspection of structural members that are parts of sluice gages in order to verify possibility of their further safe operation.

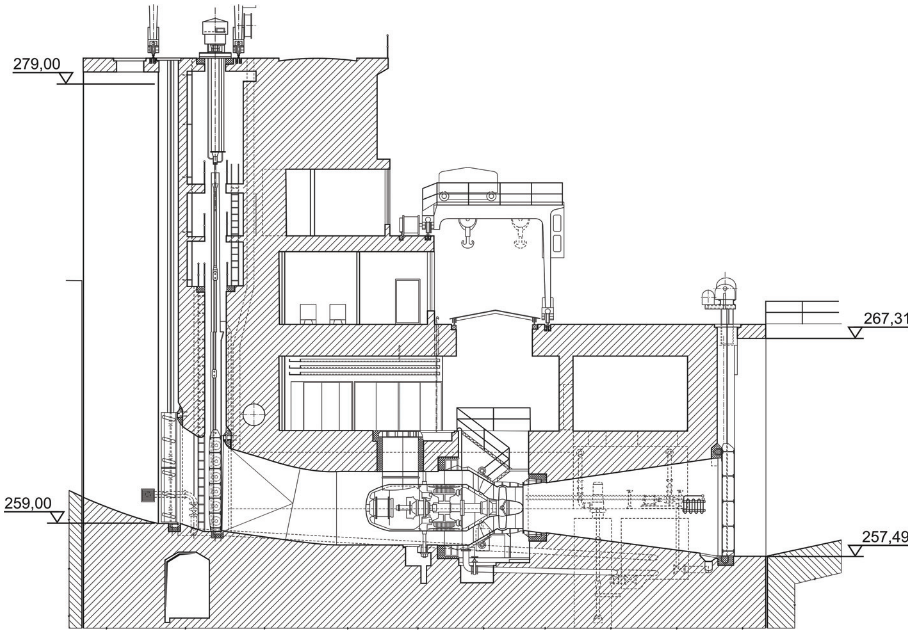



Fig. 1: *Schematic arrangement of water power plant.*

The paper is oriented to verification of safety of inlet and outlet sluice gages on the water power plant shown in Fig. 1. Carrying structures of sluice gates have to be designed such a way that they withstand with satisfactorily safety loading and influences that can occur during their building, operation and removing. Because of importance of inlet and outlet sluice gates their potential failure should cause considerable subsequent damages and this fact supports importance of their verification.

Geometry of sluice gates was assessed by measurement of planeness of their functional surfaces as well as by measurement of thicknesses of individual structural elements with considering shrinkages caused by corrosion.

Stress and deformation analysis of sluice gates under operational loading included their strength analysis according to prescribed standards as well as computation by the finite element method. Inextricable part of sluice gates verification was also determination of residual stresses in places that were localized by computation and subsequently recommendations for verification of welds [9].

## DETERMINATION OF WALL-THICKNESSES ON STRUCTURAL MEMBERS AND PLANENESS OF FUNCTIONAL SURFACES OF SLUICE GATES

The shapes and basic dimensions of sluice gates are given in Fig. 2 for inlet and in Fig. 3 for outlet.

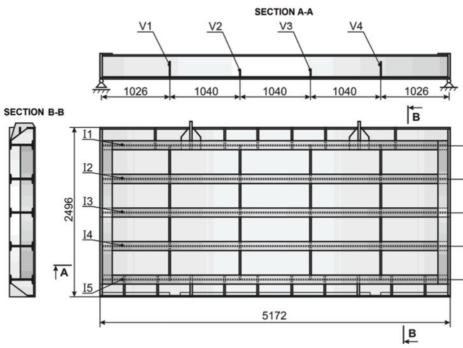



Fig. 2: *Shape and basic dimensions of the inlet sluice gate.*

As results from Fig. 2 and Fig. 3 the structures have character of plates and they are welded from sheets and rolled profiles made of material 11 373. Measurement of thicknesses of structural members was realized by measurement system TG-400. The real thicknesses of walls were measured in more than 300 locations on every sluice gate and these values were used in the process of stress and deformation analysis. In general can be stated that corrosion did not have substantial effect to determined stresses and deformations. State of sluice gates after steel-grit blasting is shown in Fig. 4.

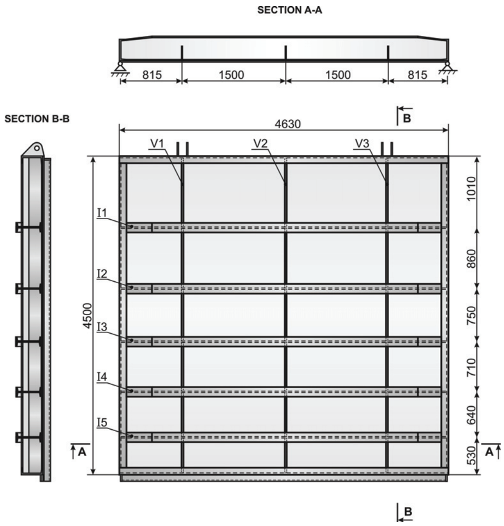



Fig. 3: *Shape and basic dimensions of the outlet sluice gate.*

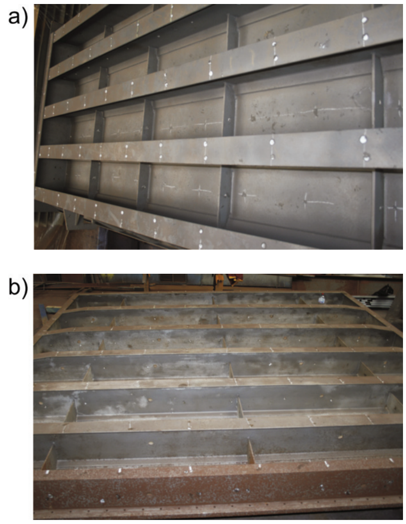



Fig. 4: *Surface of sluice gates. a) inlet sluice gate, b) outlet sluice gate.*

Planeness of functional surfaces of sluice gates was determined by robotized geodetic station Trible VX Spatial Total Station 305. Sluice gates were placed to vertical position and rear surfaces were discretized and measured in locations of intersections of stiffener ribs I and V (Fig. 2 and Fig. 3).

Space coordinates of points on the rear side were determined by polar method. On the base of geodetic measurements was for every sluice gate determined general equation of plane in the space by using least square method [2].

In Fig. 5 and 6 are shown 3-dimensional models of rear surface reliefs of inlet sluice gate (Fig. 5) and outlet sluice gate (Fig. 6) which characterize distances of surface points from designated plane oriented here horizontally.

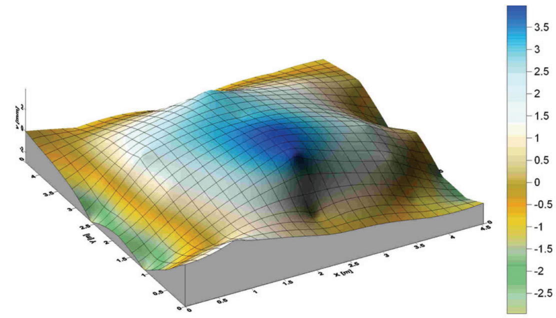



Fig. 5: *3D model of rear wall of inlet sluice gate.*

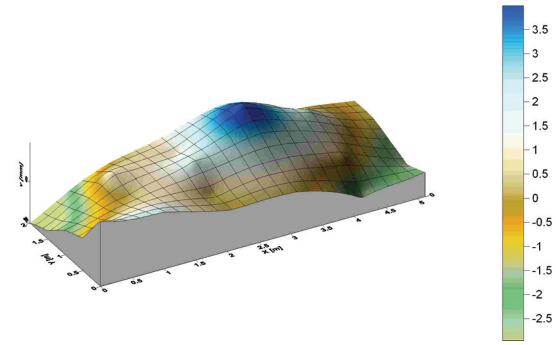



Fig. 6: *3D model of rear wall of outlet sluice gate.*

## STRENGTH COMPUTATIONS OF SLUICE GATES

For the strength, stiffness and, stability analysis of sluice gates was used the finite element method as well as analytical methods described in standards STN 73 1404 [5] and STN 73 1401 [4].

Computation was realized according to the theory of critical states. Critical states of loading capacity and serviceability were assessed on the base of results from analytical and numerical computations [7] with considering levels of residual stresses [3], [6].

Sluice gates are made of steel 11 373 and according to the standard STN 73 1401 it has yield stress $f_y = 235$ MPa. If we consider partial coefficient of reliability $\gamma_M = 1,1$, then allowed stress level of given material is 213 MPa.

The computations were provided under assumptions that both sluice gates are loaded with hydrostatic pressure that correspond to upper reach of water and that there are hinges on vertical boundaries (global bending moments and shear forces are transmitted by longitudinal ribs). Example of computational scheme for a rib No. 5 of inlet sluice gate is in Fig. 7.

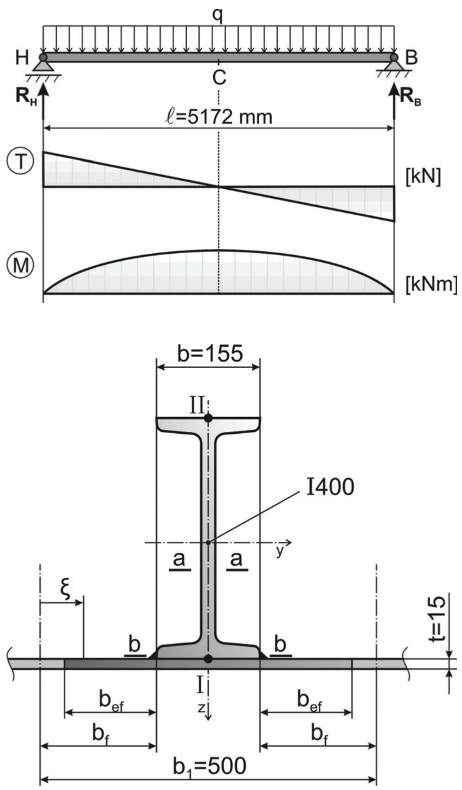



Fig. 7: *Computational scheme of rib No. 5 of inlet sluice gate.*

In accordance with section 34 of standard STN 73 1404 there is a non-proportional distribution of normal stresses in cross-section of beams with very wide bands. Wide bands have lover carrying capacity in tension and pressure due to shear lag effect. This is a reason why it is necessary to include in computation also certain width of a plate on rear side of sluice gate.

Combined width $b_{ef}$ of a beam with length $l$ that is loaded by proportional continuous load is according to section 36 of standard STN 73 1404 given by relation

$$b_{ef} = \rho_{ef} \cdot b_f,$$

where

$b_f$ – a half width of band with the whole width $2b_f$ between neighbouring ribs,

$\rho_{ef}$ – is the shear lag coefficient determined from Table No. 8 STN 73 1404.

The change of normal stresses in the band of cross-section due to shear lag effect is considered to be approximately parabola of fourth order in dependency on coefficient $\rho_{ef}$ and can be determined by relation

$$\sigma(\xi) = \left[ \left( \frac{\xi}{b_f} \right)^4 + \frac{5\rho_{ef} - 1}{4} \left( 1 - \left( \frac{\xi}{b_f} \right)^4 \right) \right] \sigma_{max},$$

where

$\xi$ – is a coordinate according to Fig. 7.

After considering combined width $b_{ef}$ for the inlet sluice gate, the maximal absolute value of normal stress in the rib due to bending moment did not exceed 190 MPa and maximal shear stress reached 50 MPa. Maximal deformation of rib at the center of inlet sluice gate was 9 mm.

The same procedure was used for verification of ribs on outlet sluice gate and here the maximal values of normal stresses in ribs due to bending moments did not exceed 150 MPa and maximum shear stress was 40 MPa. Maximal deformation of ribs at the center of inlet sluice gate did not exceed 7,0 mm.

It can be stated that ribs of sluice gates on inlet and outlet fulfill all necessary conditions from the point of view of strength and stiffness.

Rear sides of both sluice gates are covered by sheets. Sheet of inlet sluice gate has thickness 15 mm, sheet that covers outlet sluice gate has thickness 8 mm. They are welded to both, transversal and longitudinal stiffeners (Fig. 2 and Fig. 3).

According to section VII. subsection 29 and 30 of standard STN 73 1404 it is recommended to compute plane sluice gates that are reinforced with system of longitudinal and transversal stiffeners and loaded by hydrostatic pressure as plane rectangular plates fixed or free on boundaries and loaded by hydrostatic pressure of water.

In accordance with subsection 30 of cited standard the normal stress in a sheet of plate can be determined by equation

$$\sigma = \chi \frac{p \cdot \gamma_f \cdot a^2}{t^2} 10^{-2} \quad \text{[MPa]},$$

where

$\chi$ – is coefficient that depends on fixation of plate and on location where it is computed stress (it is determined by Table 7 STN 73 1404),

$a$ – is length of shorter side of plate [mm],

$t$ – is thickness of plate [mm],

$p$ – is water pressure in centre of plate [MPa],

$\gamma_f$ – loading coefficient ($\gamma_f = 10$).

With application of above described treatment was found out that maximal bending moment in rear wall of inlet sluice gate is 50 MPa and the condition for strength for material 11 373 is fullfiled.

In the rear sheet of outlet sluice gate the maximal bending stress reached 246 MPa in a location between profile U300 and profile I1. Stress level 238 MPa is in location between profile I1 and I2 (Fig. 3). In this locations was not fulfilled strength condition for rear wall of outlet sluice gate.

For sluice gates were used computational models given in Fig. 8. Here, due to the symmetry of shape and loading are seen only halves of sluice gates.

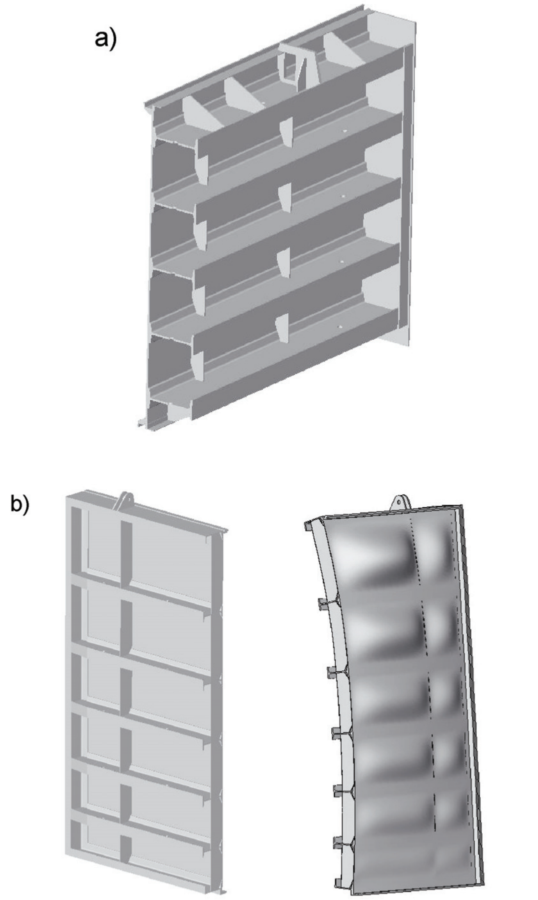



Fig. 8: *Computational models of sluice gates a) inlet sluice gate, b) outlet sluice gate.*

For illustration of results is in Fig. 9 shown field of displacements and in Fig. 10 field of equivalent stresses in inlet sluice gate.

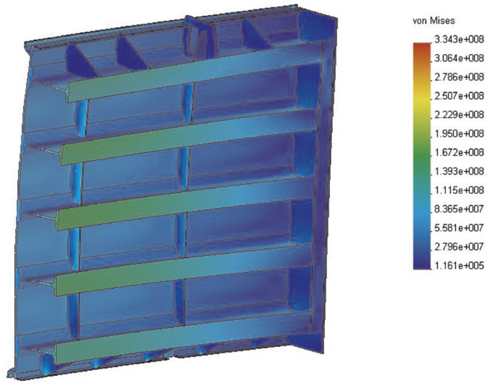



Fig. 10: *Field of equivalent stresses on the inlet sluice gate.*

In Fig. 11 is field of displacement and in Fig. 12 is field of equivalent stresses for outlet sluice gate.

As results from computations provided by finite element method as well as from computations according to standard STN 73 1401, the upper part of rear wall of outlet sluice gate does not fulfill strength conditions (Fig. 12).

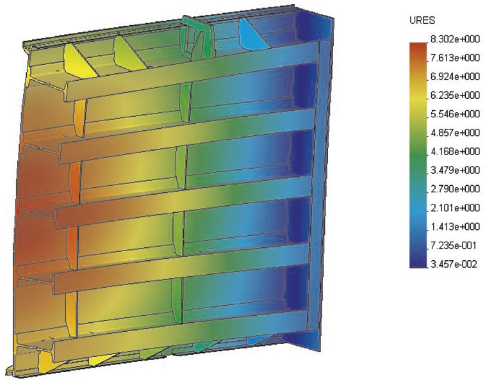
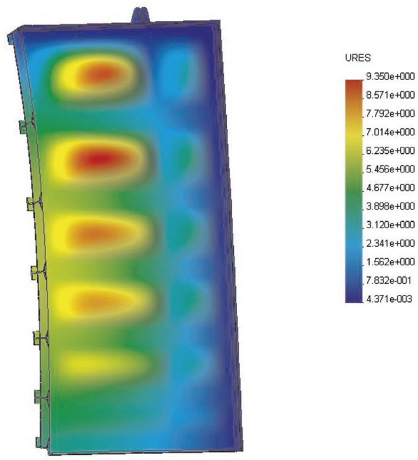



Fig. 9: *Fields of displacements on the input sluice gate.*



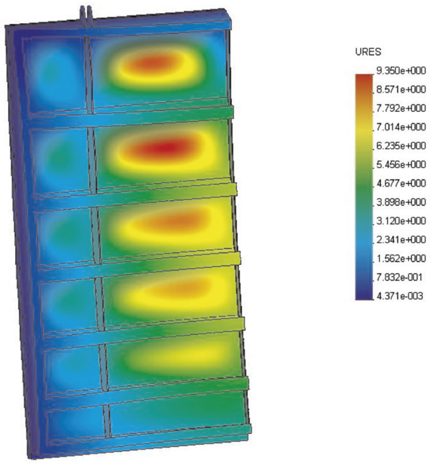



Fig. 11: *Field of displacements on the outlet sluice gate.*

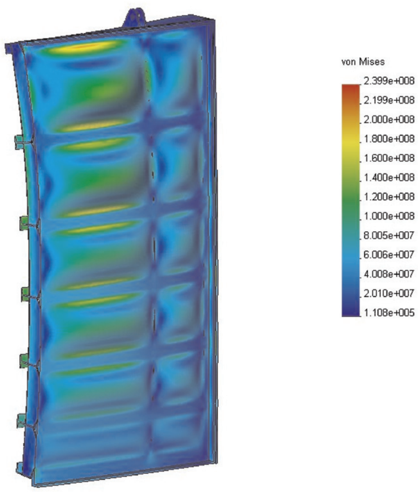



Fig. 12: *Field of equivalent stresses on the outlet sluice gate.*

## DETERMINATION OF RESIDUAL STRESSES ON INLET AND OUTLET SLUICE GATES

For determination of residual stresses in rear walls of inlet and outlet sluice gates was applied hole-drilling method. For the drilling were used strain-gages RY21-3/120 with electric resistance 120 Ω and *k* – factor on all grids 2,06. Drilling was realized with equipment RS-200 and the released strains were measured by strain-gage apparatus P3.

Localization of strain-gages on inlet sluice gate is shown in Fig. 13a and on outlet sluice gate in Fig. 13b.

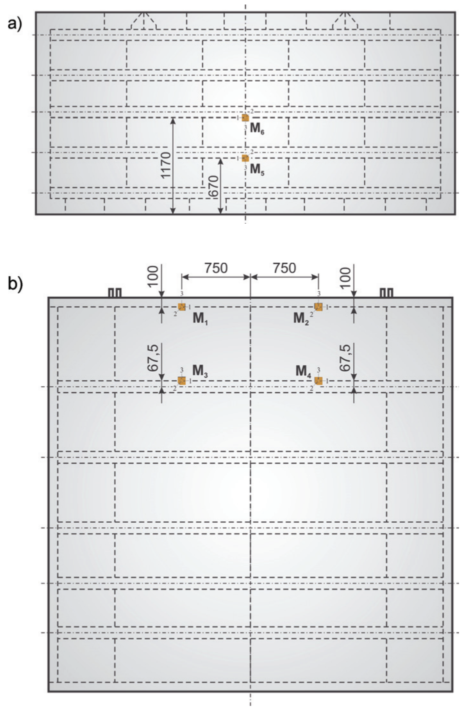



Fig. 13: *Positions of strain-gages RY21. a) inlet sluice gate, b) outlet sluice gate.*

The values of residual stresses computed from released strains were determined according to ASTM E837-01, by Integral Method and by Method of Power Series [1], [8]. In Table 1 are given computed values of principal residual stresses and their directions determined according to ASTM E 837-01 where φ is declination angle of stress $\sigma_{max}$ with respect to axis No. 1 of strain-gage.

As results from values of residual stresses in Table 1, the highest levels of residual stresses are in rear wall of outlet sluice gate in the area of extreme bending stresses determined both, by analytical computation and the finite element method.

## CONCLUSIONS

In the paper is described method for evaluation of safe operation of sluice gates in water power station. On the base of reached results is possible to state:

Table 1: *Residual stresses according to ASTM E 837-01.*

| Computed values | Positions of measurements – outlet sluice gate | | | | Positions of measurements – inlet sluice gate | |
|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 | M6 |
| $\sigma_{max}$ [MPa] | 211,18 | 113,35 | 189,32 | 169,92 | 100,26 | 103,7 |
| $\sigma_{min}$ [MPa] | -92,89 | -124,88 | -86,92 | -29,80 | -53,04 | -21,03 |
| φ [°] | 0,79 | 11,23 | 2,51 | -8,99 | 10,36 | 4,51 |

- corrosion shrinkage of walls in individual structural elements do not endanger safe operation of sluice gates,
- planeness of functional surfaces of sluice gates ensures satisfactory tightness from the point of view of their functionality,
- stiffener ribs of sluice gates fulfill all conditions for strength, stiffness and stability,
- rear wall of inlet sluice gate fulfill strength condition, but not so rear wall of outlet sluice gate,
- measurement of residual stresses on rear walls of sluice gate confirmed that rear wall of outlet sluice gate is overloaded in positions identified by computation.

On the base of results was recommended inspection of welds in chosen locations of sluice gates. At the same time were suggested possibilities to strengthen rear wall of sluice gate in order to ensure its further operation without failure.

## ACKNOWLEDGEMENT

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