Sensitivity analysis of design parameters of main beam of radial gate

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Abstract. There are many parameters affecting the design of the main beam of radial gate, which makes designers feel confused. Based on the planar system design method, the three-dimensional finite element numerical simulation method is adopted; that is, considering the spatial cooperation of the components of the radial gate, the influence of the main design parameters of the box beam size on the stress of the components of the main beam is discussed, and the sensitivity analysis on the design parameters is carried out by combining Morris global sensitivity analysis method. The results show that the height-thickness ratio of the web is negatively related to the stress of the upper flange, lower flange, and the web, and is more sensitive to the stress of the lower flange and the web. The influence of the flange width-thickness ratio on the upper flange and the web stress is negatively correlated, and that of the lower flange is positively and negatively correlated. However, it is not sensitive to the stress of the lower flange and the web. The influence of support width between the two webs on the stress of the web and upper flange is negatively correlated. However, it is positively correlated with the stress of the lower flange, and the change of web spacing is more sensitive to the stress of the lower flange. The research results of this paper can provide a reference for the design of the main beam of radial gate.

Keywords: Radial gate; box beam; design parameters; Morris method

1 Introduction

A radial gate is a complex spatial structure widely used in hydraulic engineering, which can meet the needs of various spillways and can be arranged in surface and deep holes [1]. The main beam is the main load-bearing component of the radial gate, with the upper flange connected to the panel and the lower flange connected to the arm. The cross-section is generally I-shaped or box-shaped, which can be selected

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according to the gate span and acting head [2-3]. For box girder, there are some parameters that will affect its mechanical properties, such as flange width-thickness ratio, web height-thickness ratio, and web spacing. Therefore it is necessary to analyse the sensitivity of its design parameters.

Currently, most of the research on the main beam of radial gates is based on the planar system design method to simplify the mechanical model. Then, each component of the main beam is analysed separately, and there are more mature research results [4-5]. However, for this complex spatial structure of radial gates, the results analysed only by the planar system design method cannot accurately reflect the force and deformation characteristics of the spatial structure. Therefore, under the consideration of the spatial cooperative work of the main beam and other components, the planar system design method is combined with the three-dimensional finite element method, and a radial gate is taken as an example for numerical simulation using the three-dimensional finite element method. Then, the Morris method of global sensitivity analysis is used to analyse the effect of the design parameters of the main beam(the web height-to-thickness ratio, the flange width-to-thickness ratio and the web spacing) on the stresses of each component of the main beam(the upper flange, the lower flange and the web), to provide reference for the design study of box main beam of radial gates, and also to provide research ideas for the development of BIM technology of radial gates.

2 Calculation parameters and model

2.1 Calculation parameters

The radial gate in the calculation example, which uses Q235B, is an emersed gate. Modulus of elasticity E=206GPa, volumetric weight γ=78.5kN/m3, and Poisson's ratio μ=0.3;

The design parameters of the radial are as follows: the orifice size is 19.7m × 12m; the design water head is 19.2m; the panel thickness is 14mm; the widths of the upper and lower flanges of the main beam are both 60cm and the thickness is 2cm; the web is spaced 30cm apart, the height and the thickness are 102cm and 1.6cm, respectively; the length of the supporting arm is 23m; the widths of the upper and lower flanges are both 60cm and the thickness is 3cm; and the height and the thickness of the web are 100cm and 2cm, respectively.

2.2 Calculation model

In this paper, ANSYS was chosen for the three-dimensional finite element calculations. The coordinate system adopted for the simulation is as follows: the X-axis represents the water flow direction with downstream being positive; the Y-axis represents the height direction with a positive upward direction; and the vertical water flow is along the Z-axis, which is positive to the right bank. The panel, the horizontal secondary girder, the vertical secondary girder, the main girder, and the supporting arm of the radial gate were simulated using shell elements, while the hinge and supporting beam were simulated using solid elements. Nonlinear contact was considered between the panel and the upper flanges of the main beam and the secondary girder, between the upper flange of the main beam and the front end of the support arm, and between the support arm and the hinge. The contact elements selected were TARGE 170 and CONTA 174 [6]. The finite element model is depicted in figure 1. Calculated working conditions: normal water storage (self-weight + hydrostatic pressure + wave pressure)

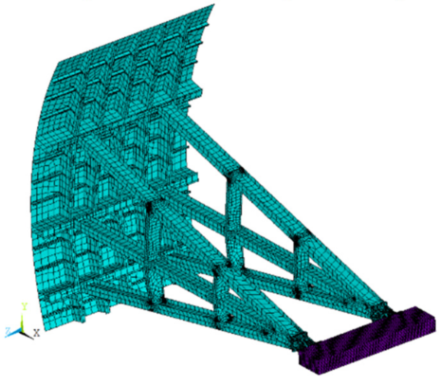

Fig. 1. Finite element model

2.3 Parameter range

The cross-section of the main beam of the radial gate is schematically shown in figure 2.

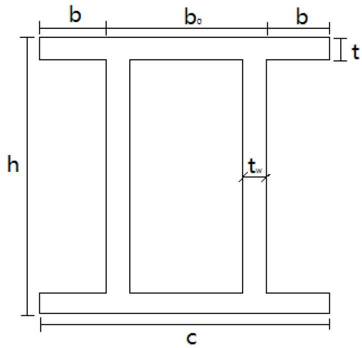

Fig. 2. Schematic diagram of the cross-section of the main beam

In figure 2, b is the free outreach width of the flange, cm; t is the thickness of the flange (cm); b_0 is the support width between the two webs (cm); h is the height of the beam (cm); t_w is the thickness of the web (cm); and c is the width of the flange (cm).

According to the standard for design of steel structures [7], the initial values and range of values for each design parameter of the main beam are shown in table 1.

Table 1. Initial value and parameter range

Design parameter	Initial value	Range
Height-thickness ratio of the web $\frac{h_0}{t_w}$	63.8	0~80
Width-thickness ratio of the flange $\frac{b}{t}$	7.5	0~15
Support width between the two webs b_0	30.0	0~60

3 Sensitivity analysis

3.1 Morris method

The primary function of the main beam of the radial gate is to support the water loads that are transmitted from the plate and vertical secondary beams. As a result, it experiences significant stress. The structure's stress distribution is complex, with the flange bending and the web shearing. Moreover, the magnitude and direction of stress vary, necessitating the use of the distorted energy density theory (fourth strength theory) for the flange, which considers equivalent stress as the output value, and the web, which employs the shear stress with the most significant absolute value as the output value.

The Morris method, proposed by Morris in 1991, is a global sensitivity analysis approach with high accuracy and efficiency [8-10]. It assesses the degree of influence that changes in model parameters have on output results within a specific range by altering one parameter at a time and calculating the “basic impact” of each parameter. In the case where all other parameters remain constant, the Morris method perturbs a single parameter using a fixed percentage change and calculates the sensitivity discriminant factor using the Morris formula based on the output value of the model. The formula for the factor is defined as:

$$S = \sum_{i=0}^{n-1} \frac{(Y_{i+1} - Y_i)/Y_0}{(P_{i+1} - P_i)/100} \Big/ (n-1) \tag{1}$$

where S is the sensitivity discriminant factor; Y_i is the output value of the ith run of the model; $Y_{i+1}$is the output value of the (i+1) th run of the model; Y_0 is the initial value of the calculation result after the parameter rate fixing; P_i is the percentage change of the parameter of the ith run; P_{i+1} is the percentage change of the parameter of the (i+1) th run; and n is the number of runs.

Table 2 displays the grading standard for parameter sensitivity based on the sensitivity discriminant factor of each parameter.

Table 2. Grading standard for parameter sensitivity

Sensitivity discriminant factor	Sensitivity grading
$0.00 \leq \lvert S \rvert < 0.05$	Insensitive

0.05≤|S|＜0.20	Moderately sensitive
0.20≤|S|＜1.00	Sensitive
|S|≥1.00	Highly sensitive

3.2 Sensitive analysis

According to Morris method, a parameter value is disturbed with a step size of C=3%. The maximum amplitude of disturbance is M = ±12%, and other parameters are guaranteed to be fixed. The output values are the equivalent stresses of the upper flange and the lower flange, and the shearing stress of the web. The sensitivity discriminant factors of each parameter are listed in tables 3-5.

Table 3. Sensitivity discriminant factor of the upper flange

S	Sensitivity index	Ranking	Sensitivity grade
Height-thickness ratio of the web $\frac{h_0}{t_w}$	-0.2838	2	Sensitive
Width-thickness ratio of the flange $\frac{b}{t}$	-1.2706	1	Highly sensitive
Support width between the two webs b_0	-0.2580	3	Sensitive

Table 4. Sensitivity discriminant factor of the lower flange

S	Sensitivity index	Ranking	Sensitivity grade
Height-thickness ratio of the web $\frac{h_0}{t_w}$	-1.0212	2	Highly sensitive
Width-thickness ratio of the flange $\frac{b}{t}$	-0.0357	3	Sensitive
Support width between the two webs b_0	1.4643	1	Highly sensitive

Table 5. Sensitivity discriminant factor of the web

S	Sensitivity index	Ranking	Sensitivity grade
Height-thickness ratio of the web $\frac{h_0}{t_w}$	-1.3926	1	Highly sensitive
Width-thickness ratio of the flange $\frac{b}{t}$	-0.0132	3	Insensitive
Support width between the two webs b_0	-0.2274	2	Sensitive

Tables 3-5 show that the height-thickness ratio of the web is negatively related to the stress of the upper flange, lower flange, and the web, and is more sensitive to the stress of the lower flange and the web. The influence of the flange width-thickness ratio on the upper flange and the web stress is negatively correlated, and that of the lower flange is positively and negatively correlated. However, it is not sensitive to the stress of the lower flange and the web. The influence of support width between the two webs on the stress of the web and upper flange is negatively correlated. However, it is positively correlated with the stress of the lower flange, and the change of web spacing is more sensitive to the stress of the lower flange.

4 Conclusions

Combining the planar system design method with three-dimensional numerical simulation, the spatial structure model of arc gate is established. Considering the spatial cooperation of the components of the radial gate, the sensitivity of the main design parameters of the main beam of the radial gate to the strength of the components of the main beam is discussed. When designing the main beam of the radial gate, a reasonable size can be selected according to the influence degree of each design parameter on the strength of each component of the main beam.

Acknowledgments

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References

1. Lin, J.Y., Zhang, S.R. (2019) Hydraulic Structures (6th Edition). China Water & Power Press, Beijing.
2. Wang, Z. Z., Zhang, X.C., Liu, J.L. (2017) Advances and developing trends in research of large hydraulic gates. Journal of Hydroelectric Engineering, 36: 1–18.
3. Liu, J.L., Wang, Z.Z., Shen, Y.K., Yu, W.H. (2010) Arm section optimization and optimal number of radial gate arms located in deepwater delivery structures. Journal of Hydroelectric Engineering, 29: 147–152.
4. Wang, Z.Z. (2022) Nonlinear Analysis Theory and Method of Hydraulic Gate. Science Press, Beijing.
5. The Ministry of Water Resources of the People's Republic of China. (2019) Design specification for gates of water and hydropower projects: SL 74-2019. China Water & Power Press, Beijing.
6. Jiang, M.S. (2019) ANSYS Workbench 19.0 Basic Getting Started and Engineering Practice. Posts & Telecom Press, Beijing.
7. Ministry of Housing and Urban Rural Development of the People's Republic of China. (2017) Standard for design of steel structures: GB 50017–2017. China Architecture & Building Press, Beijing.
8. Morris, M.D. (1991) Factorial sampling plans for preliminary computational experiments. Technometrics, 33: 161–174.

9. Liu, B., Jin, A.B., Gao, Y.T., Deng, F.G. (2016) Parameter sensitivity analysis of temperature field in single fracture rock mass based on Morris. Journal of Mining & Safety Engineering, 33: 152–157.
10. Wen, Z.J., Meng, X. H. (2022) Sensitivity analysis of airfoil aerodynamic characteristics based on NT-net method and Morris method. Chinese Journal of Engineering Design, 29: 438–445.