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Simulation of preloading water-filled spiral case structure with weak simulation algorithm

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Abstract

Simplified algorithm (SPA) and simulation algorithm (SUA) is two basic method for preloading water-filled spiral case structure. In this paper, A weak simulation algorithm (WSA) based on the contact slippage is used to simulate this problem for NUOZHADU hydropower project. The methodology proposed is effectively to construct stress field of spiral case surrounding concrete. It overcomes the limitation of simplified algorithm in which the contact relationship of spiral case and concrete was ignored. However, that relationship is a key factor to make both interaction and transfer force characteristics more complicated. The focus of the paper is on the stress field of the concrete. The comparisons with simulation on the simplified algorithm are taken, and the results show that the method on WSA proposed in this paper is able to well captured the mechanics characters than SPA method; Due to friction the result is increased and conservative. The maximum stress of surrounding concrete mainly occurred at the top of spiral case at each sections where the influence of contact is the strongest. So, it indicates that the contact is indispensable for this problem.

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Keywords: spiral case; weak simulation algorithm; preloading water-filled spiral case

1. Preface

Since the shape of the spiral case is complex, it is impossible to ensure all parts work under in the ideal situation design load, and the deformation is not all inflation. Moreover, in the construction process of a constant internal pressure spiral case, the action of axial force from bulkhead under internal pressure also

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have a influence to spiral case deformation. So, the initial gap is non-uniform and local closed. Then, in the operation period, due to the change of boundary conditions, when the operation pressure reaches the initial pressure value, spiral case won't cling to concrete in all parts, even the gap will be closed in advance at local position. Considering this, the ideal situation of no gap, no energy transfer between spiral case and surrounding concrete is not existed, the real situation is more complicated[1-3]. So, both the initial non-uniform gap and contact relationship are key factors which should not be dismissed. Simulation algorithm (SUA) is the exact method to do this work.

At present, how to reasonably and accurately simulate this gap is the most difficult point. The simplification algorithm (SPA) based on common node on both spiral case and concrete is usually used to simulate concrete stress of preloading water-filled spiral case structure[4-7]. But the method has a fatal limitation that the non-uniform gap and contact relation have been neglected, so the structure stiffness has been increased indirectly and it can't really reflect the interaction and mechanics characteristics. In this paper, a weak simulation algorithm (WSA) based on contact sliding is used to simulate this problem for NUOZHADU hydropower project. It assumes that the change of boundary conditions is so tiny that it can't affect gap closing, and the possibility of two contact surfaces separating from each other is minimal, which is beneficial for convergence and enhancing computation speed. The comparisons with simulation on the SPA are taken. The methodology proposed is effective to construct stress field of spiral case surrounding concrete.

2 Contact theory

In this paper, the 3D surface-to-surface contact model is adopted to simulate the relationship of steel lining and concrete. Tangential contact conditions is the coulomb friction model, namely

\[
\begin{align*}
\tau &= \mu p + c \\
|\tau| &\leq \tau_{\text{max}}
\end{align*}
\]

Then \(\tau\) is equivalent shear stress, \(p\) is normal press of contact surface, \(\mu\) and \(c\) are friction coefficient and cohesion of contact surface respectively, \(\tau_{\text{max}}\) is maximum equivalent shear stress by man-made, show in Fig 1.

![The coulomb friction model](image)

Shell element is suitable for analyzing thin to moderately-thick shell structures, It's have six degrees of freedom at each node: translations in the x, y and z directions, and rotations about the x, y and z axes. The element has translation degrees of freedom only, unless the membrane option is used. The thickness of shell element is defined at each of its nodes and always located midway between the top and bottom surface when only one layer. By default, ANSYS does not account for the element thickness, and the penetration and gap distance is calculated from the mid-surface. So the thickness of shell element must be consider.
3 Computational model

The Nuozhadu hydropower station is located in Lancang River Yunnan province. It's a class I-type project. The installed capacity is 650 MW. The normal internal pressure of spiral case is 2.22 MPa, maximum pressure is 2.8 MPa, and the preloading pressure is 1.8 MPa. The three-dimensional nonlinear finite element analysis has been carried out by means of the well-known FEM software ANSYS. The model size is 28 m × 29 m × 17.55 m (L × W × H), the geometric model and finite element model is shown in Fig 2 and Fig 3. There are 138,169 elements and 80,213 nodes. Shell element is used for meshing spiral case and solid element for concrete, use TARGET169 with CONTA172 element to define 3-D contact pair. The material types of concrete and spiral case are: C25 concrete and Q235 steel respectively. The material parameter of cushion layers installed on straight pipe of spiral case entrance (about 4 m long): Elastic modulus is 2.5 MPa; Poisson's ratio is 0.35; Density is 1.75 kN/m3. The pressure handed down from upper structure is 0.306 MPa, the friction coefficient \( \mu \) is 0.25.

4 Result

Fig 5 is contact status of spiral case. It shows that most of spiral case are in sliding status, except the position of cushion layers, some top, middle, and bottom. The sliding is the principal cause which makes mechanics characteristics and interaction between spiral case and concrete complicated.

From the results obtained (Fig 6～Fig 8), we can get: The stress of concrete which from spiral case entrance to tail has the tendency of decreasing and the concrete thickness of spiral case entrance is so thin that the maximum value of stress and displacements occurred there. It's the dangerous position of crack initiation and propagation. In typical sections, the maximum tensile stress occurred at top position and the bottom takes second place, middle position endures compressive stress. Results above are as same as SPA.
The calculation indicate that the mechanics behavior is different from the SPA method (refer to table 1), the stress is increased after involving contact sliding and the hoop stress of top position is obviously influenced by contact sliding. To give a preliminary analysis, it's the friction force produced by sliding that increases the values of stress at the top. However the maximum stress of surrounding concrete appeared on that position. So considering the sliding of spiral case during deformation, is a more effective approach close to the real situation, and the results are also more conservative.

Table.1 The hoop stresses of surrounding concrete on typical sections comparing with simplification algorithm /MPa

| Section | Method | Representing point |
|---------|--------|--------------------|
|         |        | P1     | P2     | P3     |
| I       | WSA    | 2.240  | -4.281 | 2.209  |
|         | SPA    | 2.175  | -3.661 | 2.14   |
| II      | WSA    | 1.162  | -0.907 | 0.876  |
|         | SPA    | 0.775  | -0.540 | 0.675  |
| III     | WSA    | 1.071  | -0.228 | 0.510  |
|         | SPA    | 0.698  | -0.130 | 0.422  |
| IV      | WSA    | 0.964  | -0.720 | 0.858  |
|         | SPA    | 0.657  | -0.455 | 0.663  |
| V       | WSA    | 0.666  | -0.217 | 0.101  |
|         | SPA    | 0.460  | -0.153 | 0.116  |

5 conclusion

(1) The results indicate that the proposed method effectively solves the preloading water-filled spiral case problems. It overcomes the limitation of simplified algorithm that ignores contact relationship. The mechanics behavior is different from the SPA method and the results are more rational and conservative.

(2) The sliding is the principal cause which makes mechanics characteristics and interaction between spiral case and concrete complicated. This should not be dismissed.

(3) The maximum stress of surrounding concrete occurred at top position of spiral case and that position is obviously influenced by contact sliding. The middle position merely endures compressive stress.
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