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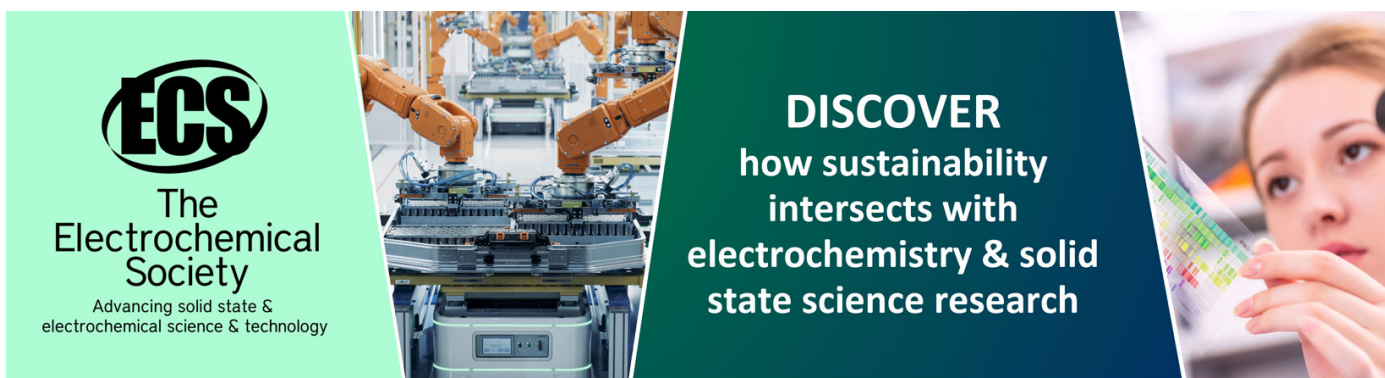
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Study on Iterative Method of Nonlinear Finite Element Analysis for High Arch Dam

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Abstract. The nonlinear FEM can simulate the real working behavior of arch dam, but its result is related to iterative method and convergence control standard. This paper proposes iteration convergence criterion based on two iterative methods of Newton iterative method and modified Newton iterative method. Taking Xiluodu arch dam as an example, the article has conducted research to the problems above, thus obtaining some beneficial conclusions.

Keywords: arch dam; iterative method; convergence control standard.

1. Introduction

Currently, there are many super-high arch dams building in China, such as Xiluodu (285.5m), Xiaowan (292m), Jinping (305m) and so on. Generally, high arch dam is located in the mountain-canyon area, where topographic and geologic conditions are complex. In order to ensure the arch dam is safe, it must be analyzed by different methods. Such as experience decision, model testing and numerical analysis [1].

According to different mechanics theory, combining with a variety of numerical methods, researchers can carry on reasonable simulation analysis to the simplified structure. Understanding the real stress state and safety degree need to simulate the real work behavior of arch dam. Among various numerical calculation methods, nonlinear FEM can accurately simulate the real working behavior of arch dams. The method can consider dam and foundation nonlinearity, various loads, dam construction process, dam and foundation defects and so on [2].

However, nonlinear FEM for the safety evaluation of arch dam equally has certain problems, for example mesh size, concrete and rock constitutive relationship, iteration method and convergence control standard. These problems have great influence on the calculation results; therefore it needs to conduct standard research [3].

This paper proposes the calculation principles of using constitutive relationship, iterative method, and convergence criterion. Taking Xiluodu arch dam as an example, the article has conducted researches to the problems above, obtaining some beneficial conclusions.



2. Calculation Principles

2.1. Constitutive relationship

This paper uses damage constitutive relationship, which using isotropic damage model compute damage variable value [4], combining with equivalent strains of four parameter [5].

2.2. Iterative method

There are three kinds of methods for solving nonlinear FEM equations, namely iterative method, incremental method and mixed method. Because mixed method contains the merits of incremental method and iterative method to some extent, avoids the demerits, this article uses the mixed method to calculate.

2.3. Convergence control standard

In order to study the convergence of solutions, when solving nonlinear equations using mixed method, the iterative convergence criteria must be given, otherwise it can not terminate the iteration. Unsuitable convergence criteria will make the results inaccuracy or fee machine. Generally the iteration convergence criteria are the following two, unbalanced force convergence criterion and displacement convergence criterion.

The procedure this article uses first judges unbalanced force convergence, if unbalanced force convergence satisfies, then judges displacement convergence.

After determining convergence criterion, the remaining problem is to choose a suitable convergence tolerance. If convergence tolerance is large, the calculations not converge, or although has converged, but not achieves the true solution. On the contrary, the convergence rate will reduce, and sometimes makes iteration not converge. This article makes a comparison on convergence tolerance respectively taking 10^{-4} , 10^{-5} , 10^{-6} .

3. Example confirmations

The dam height of Xiluodu arch dam is 285.5m. The computation load in this paper contains the follows: body weight of arch dam, upstream hydrostatic pressure, downstream hydrostatic pressure, sediment pressure, temperature drop load. The calculation method of temperature load can be found in the literature [6].

3.1. Basic data

The bulk density of dam concrete is 24kN/m^3 , the dam upstream normal water level is 600m, dam downstream water level is 378m, and sediment deposition elevation is 490m.

The elastic modulus of dam concrete is 24GPa, Poisson ratio is 0.17, linear expansion coefficient is $10^{-5}/^\circ\text{C}$, concrete compressive strength is 23.5MPa, concrete tensile strength is 2.25MPa, concrete fracture energy is 0.2 kN/m.

3.2. FEM mesh

On account of stress concentration exist nearby foundation surface, the place is required to go on local mesh encryption. The specific encryption methods see literature [7]. For the encryption mesh of Xiluodu arch dam, the point number is 79301, the element number is 63112. The overall FEM model is shown in Fig.1, and the dam FEM model is shown in Fig.2.

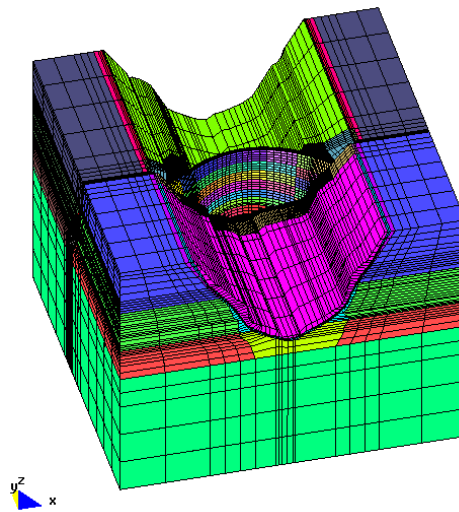


Fig. 1 Overall FEM model of encryption mesh

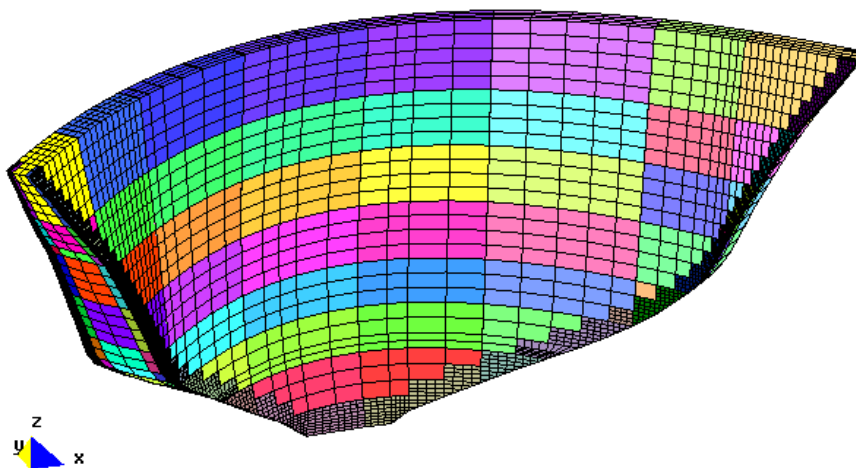


Fig. 2 Dam FEM model of encryption mesh

3.3. Iterative method

Carry on computation separately using Newton method and modified Newton method, obtain foundation surface relative damage area respectively (see Table 1).

From the results we can see, the result of Newton method and modified Newton method of different convergence control standard is the same. Because computing time of modified Newton method is relatively short, modified Newton method is more reasonable.

3.4. Convergence control standard

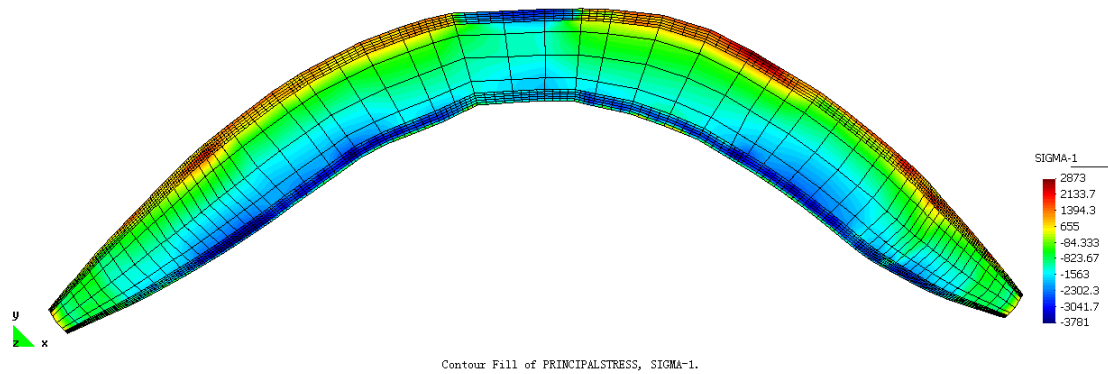
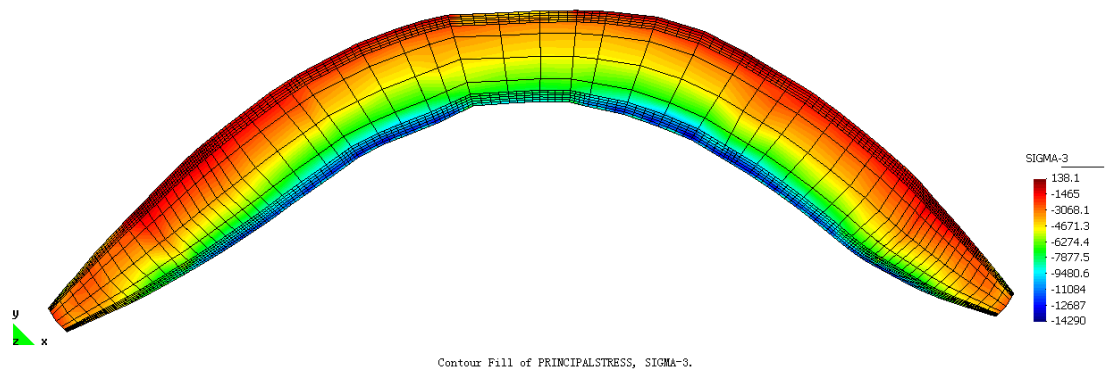
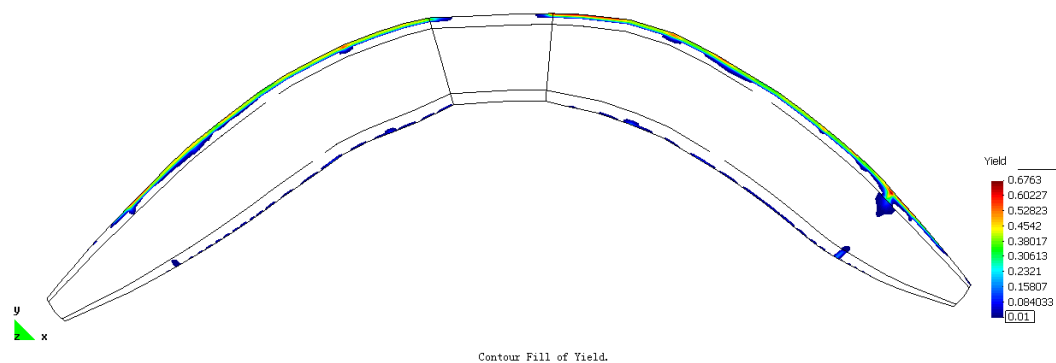
Unbalanced force and displacement convergence tolerance take three cases of 10^{-4} , 10^{-5} , 10^{-6} , obtain foundation surface relative damage area respectively (see Table 1).

From the results we can see, the result of unbalanced force and displacement convergence tolerance take 10^{-4} , 10^{-5} , 10^{-6} is the same. From the computing time and accuracy considerations, unbalanced force and displacement convergence tolerance take 10^{-5} is more reasonable.

The foundation surface first principal stress, third principal stress, relative damage area and value of modified Newton method and convergence tolerance take 10^{-5} is shown in Fig.3~ Fig.5.

Table 1. Foundation surface relative damage area of different iteration method and convergence tolerance

	10^{-4}	10^{-5}	10^{-6}
Newton iteration method	0.059	0.057	0.057
Modified Newton iteration method	0.059	0.057	0.057

**Fig. 3** Foundation surface first principal stress of modified Newton method and convergence tolerance take 10^{-5} (kPa)**Fig. 4** Foundation surface third principal stress of modified Newton method and convergence tolerance take 10^{-5} (kPa)**Fig. 5** Foundation surface relative damage area and value of modified Newton method and convergence tolerance take 10^{-5}

4. Conclusion

For iterative method, using modified Newton iteration method is more reasonable.

For convergence control standard, imbalance force and displacement convergence tolerance all taking 10^{-5} is more reasonable.

Acknowledgments

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