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Investigating Stage Construction in High Concrete Arch Dams

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Abstract

Concrete arch dam is a complex geometric structure and designing such a structure requires experience and high knowledge. One of the important parameters in designing concrete arch dams is the tensile stress in arch concrete material. The static analysis results of high arch dam structure depend on structure analysis model, intensively. Stage construction is needed to be focused in modeling high arch dams. In this study, the necessity of considering stage construction in static analysis of dam structure is focused. Modeling stage construction uses Birth and Death technique of elements. Therefore, six stage construction models are provided including applying dam wall weight outright, two stage application including odd and even monoliths, 4-stage application, 8-stage application, 14 stage applications and 24 stage application. The applied structure analysis is finite element method, in this investigation. Increasing construction stages results in decreasing wall cumulative strain energy. Considering 8 and 14 stage constructions results in 2.6% and 1.3% errors in estimating strain energy. Finally, it is clear that considering stage construction results in decreasing maximum tensile stress and changing the location of maximum tensile stress, too. Dam designers can apply the provided methodology.

Keywords: Concrete Arch Dams, Finite Element Method, Foundation Flexibility, Stage Construction, Tensile Stress

1. Introduction

Today, the progress of preparing and developing technology in structure analysis software's with high speed processing lead to construct high concrete arch dams. High arch dams are called 90m height dams. Various studies were conducted on analyzing and designing high concrete arch dams[1–3]. Stage construction was not considered for structural model in mentioned studies. Placing and constructing concrete arch dams is in stages. Figure 1 show constructing a concrete arch dam. Each placing masses are called a monolith. In every placing the monoliths, two to three meter placing occurs which is called a lift. Increasing the monoliths height results from placing the previous concrete. Infusing grout between monoliths, in every 15-20 meter height the increment was done to accrete the structure wall. For example, a 325m height dam is placed in 108-162 stages. Considering the stages of constructing dam wall indicates that the structure can be transformed by weight, after each placing stage. On the other words, loading new placing occurs on transformed structure. Therefore, it is necessary to consider this effect in the structure analysis, for exact structure analysis. The importance of this phenomenon is much more in modeling and structure analyzing. In references[4–7], the stage construction was considered in finite element model and observed the effect through various methods of modeling. It is recommended in FERC 1999[8], that dam wall weight should not be applied in structure analysis because it results in imaginative tensions. It should be done after each steps of structure analysis. This study aims to investigate the effect of considering stage construction in finite element model, exactly. Also, it is tried to provide a methodology for dam designers.

2. Dam Introduction

The case study was conducted on a 325m height dam placed in a asymmetric valley with 50m base and 10m crest thickness, given in Figure 2. The river valley width is 450m.

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3. Finite Element Model

Finite element model of the dam – foundation was used with the mentioned dimensions shown in Figure 2. Discretization of dam wall was shown in Figure 3. The linear isoparametric twenty nodes elements were applied in discretization of dam wall and foundation. Each node contains three transmission degrees of freedom[9,10]. The wall diameter was modeled by three layer elements. The linear static analysis was done. Equivalent pressure of normal water level was applied instead of reservoir modeling to the water face of dam wall. Concrete modulus of elasticity was 24 GPa, Poisson's ratio is 0.18, density is 24 KN/m^3. Both flexible and rigid foundations are considered in structure analysis. Foundation for 7.7 GPa elasticity modulus is considered in state one and rigid foundations is seen in state two. The foundation was looked with no mass. Two load combinations applied in designing were given in Table 1. Safety factor of each load combinations were observed for tension and compression stresses. The dead load and simultaneous pressure were applied in SU1 static usual load combination; and only dam wall load in stage construction was applied for SUN1 static unusual load combination.

Figure 1. Stage construction of arch dam.

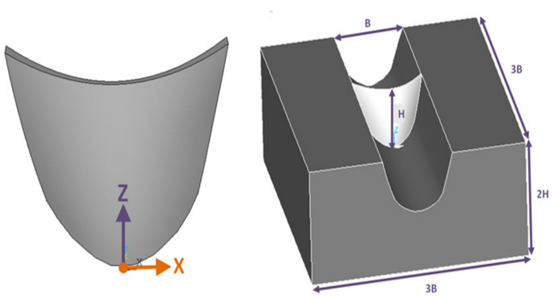

Figure 2. Geometry of studied valley and dam.

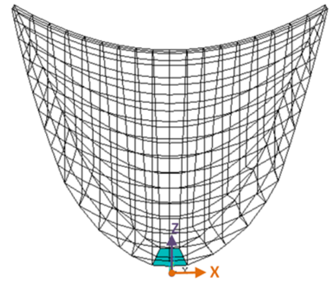

Figure 3. Discretization of dam wall.

Table 1. Designing loads combination

Combination ID	Load Combination	Single Load Parts		Factor of Safety	
		Dead weight	Normal water pressure	Tension	Compression
SU1	Static usual	✓	✓	2	3
SUN1	Static unusual	✓	-	1.5	2

4. Stage Construction

Averagely, 135 stages are required for modeling staging construction of a 325m height arch dam. It should be noted that at least two stages are needed in each height along with horizontal arch of dam, one of them for even monoliths and the other for odd monoliths. Making such a model takes cost and time for analyzing and results in limitations for the analyzer. Exact modeling the stage construction may not result in developing response accuracy. Therefore, six stage construction models are provided including applying dam wall weight outright, two stage application including odd and even monoliths, 4-stage application, 8-stage application, 14 stage applications and 24 stage application. The six mentioned models are given in Figure 4. Every placing lift was shown in separated colures. Modeling stage construction uses Birth and Death technique of elements. When an element is dead, it's elasticity of modulus and gravitational acceleration is zero. Next section discusses the results of structure analysis in flexible and rigid states.

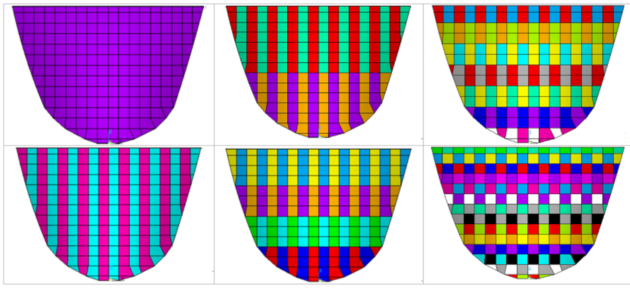

Figure 4. Stage construction models.

5. Discussion and Result

The main controlling parameters in designing dams include maximum principal tensile stress, maximum principal compression stress and abutment stability. In this study, abutment stability was not examined. Also, for concrete high resistance to compression loads, this element is not effective on static analysis of the investigation. Maximum principal tensile stresses for the six mentioned models are given in Figures 5 and 6. Figure 5 specifies that both flexible and rigid foundations contain principal tensile stress decrease if stage construction is done exactly in structure analysis model. In addition to, considering foundation flexibility results in decreasing principal tensile stress. Applying 8 and 14 stage constructions in flexible foundation decreases the error of estimate in principal tensile stress for 13 and 3.7, respectively. In addition to, stage construction in flexible foundation model, under SUN1 load, results in changing the location of maximum tensile stress, from left side of the crown to the left abutment in the middle of height; which is given in Figure 6. Figure7 shows the height of maximum principal tensile stress location to the base in flexible model. However, no changes was seen for maximum stress location in SU1 load combination, most locations of principal tensile stress decrease in SUN1 load combinations for 4 stage construction.

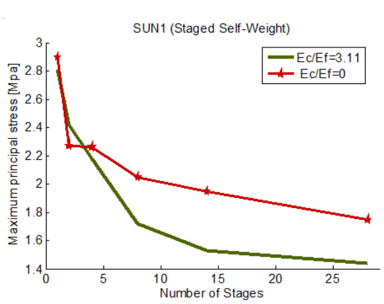

Figure 5. Changes of maximum principal tensile stress under static unusual load combination.

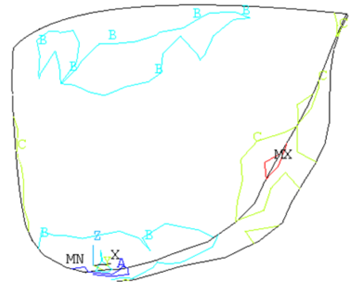

Figure 6. Location of maximum principal tensile stress in flexible foundation model.

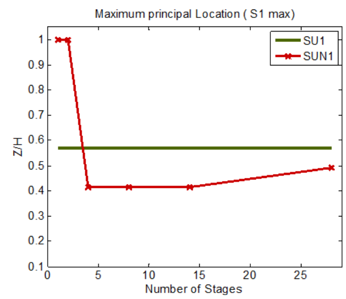

Figure 7. Height changes of maximum principal tensile stress in flexible foundation models.

Changes of maximum principal tensile stress under static usual load combination are seen in Figure 8 indicating tensile stress decrease affected by flexible foundation. Changing the number of stages in static usual load combination is not effective on tensile stress.

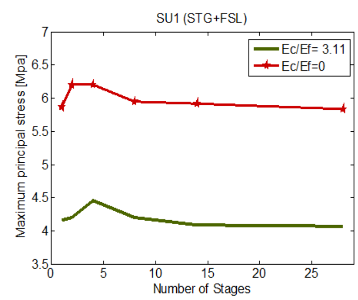

Figure 8. Changes of maximum principal tensile stress under static usual load combination.

Bodies tend to decrease their strain energy in nature. Thus, minimum strain energy explains a model closer to the reality of dam construction. Figure 9 shows the cumulative strain energy in dam wall of the six mentioned models. The results are related to flexible foundation models. Increasing construction stages results in decreasing wall cumulative strain energy. Considering 8 and 14 stage constructions results in 2.6% and 1.3% errors in estimating strain energy.

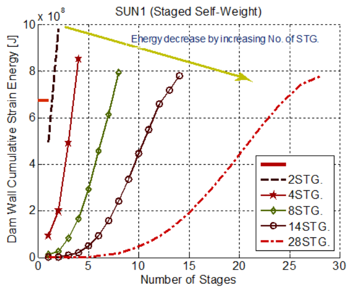

Figure 9. Cumulative strain energy in dam wall for flexible model.

6. Conclusion

The mentioned process in this study can be used in dam static analysis by the designers. Stage construction is needed to be focused in modeling high arch dams. Otherwise, calculating the amount and location of maximum principal tensile stress in the dam wall will have errors. Totally,considering foundation flexibility results in decreasing maximum principal tensile stress. In this case study, considering 14 stage construction lead to acceptable calculation of stresses, maximum stress location and wall strain energy.

7. References

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