Simulation of behavior the Kabudval Dam during construction with 3D numerical modeling

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ABSTRACT

Accurate prediction of pore water pressure, settlement, soil stress and pore water pressure coefficient (R_u) in the body of earth dams during construction is one of the necessary measures in the management of earth dam stability. Because the behavior of the earth dams is nonlinear, it is necessary to use finite element methods and a suitable soil behavior models. In the present study, which is a case study, a three-dimensional numerical simulation was performed using the Plaxis software for the Kabudval Dam located in Golestan province, Iran. The values obtained from the numerical simulation were compared with the corresponding measured values using the dam instruments. Calibration was carried out using back analysis method (BAM) and some dam geotechnical parameters were corrected based on BAM. The results showed that the hardening soil (HS) model with the statistical indicators of R^2, RMSE and GMER is more accurate compared with the Mohr- Coulomb (MC) model. The results of the numerical model were calibrated at the end of construction for Kabudval Dam and showed that the maximum increase in pore water pressure, stress, settlement and horizontal displacement occurs in the central part and its value in the axis and middle part of the dam is more than its sides. The middle part and close to the dam axis have similar changes with the fill process of the dam body; while with moving away from the dam axis due to the transfer of stresses to the sides, they have less impact from the dam filling process. In addition, in the central part, the effects of filter and drainage is low.

KEYWORDS: Kabudval Dam, Plaxis, Finite element method, Back analysis, Hardening soil model

1. Introduction

The safety and performance of a dam must be monitored during construction, first impoundment and during dam operation. Measurement of stresses, pore water pressure in dam body and soil settlements, have particular importance in this period [1]. In this study, by integrating the information of the installed instruments and the three-dimensional (3D) numerical simulations based on the Mohr-Columbus and hardening soil (HS) models, a case study of the behavior of Kabudval Dam during construction is investigated.

2. Methodology

Mohr-Columbus (MC) Model and Hardening Soil (HS) Model

The Mohr-Columbus model has five input parameters: Yang's modulus and Poisson's coefficient for soil elasticity, soil cohesion coefficient, angle of internal friction for soil plasticity and dilation angle. In the HS model, the yield level in the main stress space is not limited and due to the presence of plastic strains, the surface develops. In the hardening behavior model, the delivery plate is not limited to the main stress space and due to the presence of plastic strains, this plate develops. Back analysis is generally defined as a method that can provide controller parameters using output behavior analysis [2, 3].

Kabudval Dam

Kaboudwal Dam is located around the city of Aliabad, 40 km east of Gorgan, Iran. The cross section used in this study is section 19 [4]. To calibrate the numerical model, dam instrumentation data was used (Fig. 1).

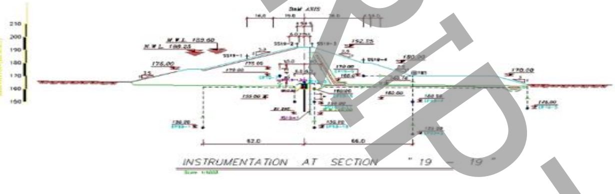

Figure 1. Cross-section and location of instruments installed in cross-section No. 19

Numerical modeling of Kaboudwal Dam

In Plaxis software, the construction of the layers in dam dam construction stages, the consolidation phenomenon and the fill process were simulated according to the dam implementation schedule. During the fill, dam impound is created by activating the water level in the desired height. In Tables 1 and 2, the specifications of the final materials are given after the return back analysis with the HS and MC models. Tables 1 and 2 provides soil geotechnical and mechanical factors including: C_{ref} =cohesion coefficient (effective), Φ =angle of internal friction, ϑ=Poisson's coefficient, γ_{sat}=specific saturation weight, γ_{unsat}=specific gravity of unsaturated water, E_{ref}=Hardness coefficient, k=soil hydraulic conductivity and E=Yang's module.

Table 1. Specifications of final materials after back analysis with HS and MC models.

$K_{x,y,z}$ (m/day)	Φ (°)	c_{ref} (kN/m²)	ν	E_{ref} (kN/m²)	γ_{sat} (kN/m³)	γ_{unsat} (kN/m³)	Type of materials	Material characteristics
0.000087	29	18	0.3	10000	20	17	Undrain	foundation
0.0001	25	22	0.4	10000	23	19	Drained	Body
8.64	36	12	0.25	2500	21	20	Drained	Filter and drain

Table 2. Complete specification of materials in the HS model

k_0^{nc}	E_{ur} (kN/m²)	E_{oed} (kN/m²)	E_{50} (kN/m²)	κ*	λ*	Material characteristics
0.5	50000	23700	2500	0.0001	0.001	Body

3. Results and Discussion

Investigation of pore water pressure and total stress

The results of the instrumentation along with the calibrated numerical model, showed that by constructing of the dam stage, with increasing the volume of the overhead, the amount of pore water pressure increases with time. Also, with increasing the fill leveling, the amount of pore water pressure and the total stress increases (Fig. 2).

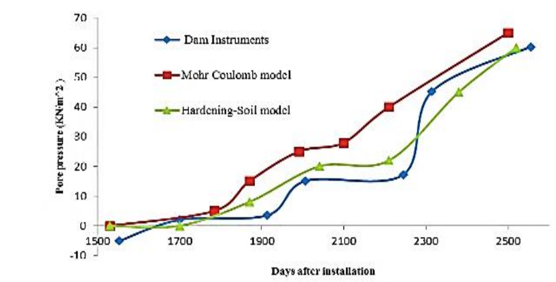

Figure 2. Pore water pressure changes with time, instrumentation and back analysis in the HS model.

Also, with increasing the fill leveling, the amount of pore water pressure and the total stress increases (Figs. 2-5).

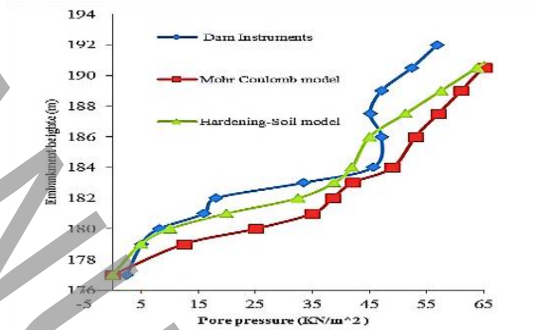

Figure 3. Pore water pressure changes with fill leveling, precision instruments and return analysis in HS model

This is because with increasing fill leveling, the amount of overhead and soil volume increases, causing these two factors to increase. In the length direction of the dam body, the pore water pressure from the top to the bottom of the dam increases but decreases after drainage and filtering.

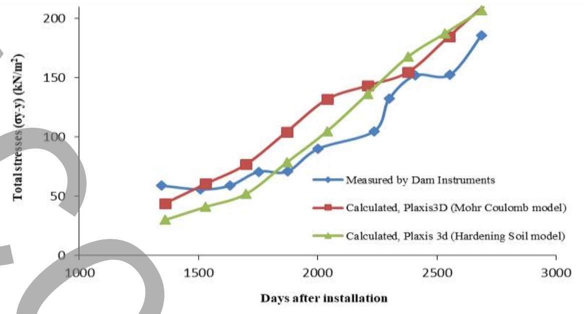

Figure 3. Total stress changes with construction time, instrumentation and back analysis in HS model

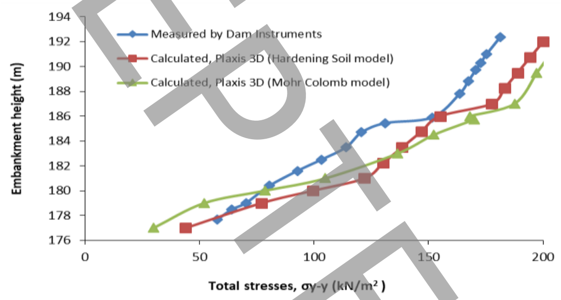

Figure 4. Total stress changes with fill level, instrument and back analysis in HS model

Statistical study between soil behavioral models

According to Tables 3 and 4, as well as statistical indicators, the results showed that in all cases, the HS model was better able to predict the behavior of the dam.

Table 3. Statistical parameters of pore water pressure for two soil behavioral models.

Statistical indicators			Model	Parameters
R^2	GMER	RMSE (kN/m²)		
0.95	1.06	11.93	MC	p.w.p with construction time
0.97	1.03	7.77	HS	
0.95	1.02	12.72	MC	p.w.p with fill level
0.96	1.01	7.94	HS	

Table 4 Statistical parameters of total soil stress for two soil behavioral models

Statistical indicators			model	parameters
R^2	GMER	RMSE (kN/m²)		
0/94	1/09	27/23	MC	total stress with construction time
0.97	1.07	22.92	HS	
0.96	*1.08*	24.20	MC	
0.97	1.07	16.65	HS	total stress with fill level

Dam displacements

According to Fig. 5, the amount of settlements at the dam axis and at the middle part of the dam is more than of sides, and its value in the lower part is almost equal compared to the upper part, and most of its changes are recorded at the axis and the middle part.

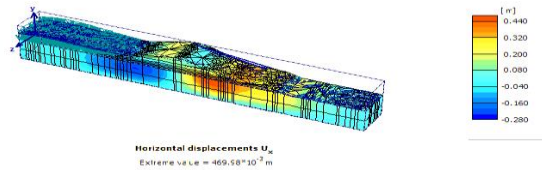

Figure 5. Settlement values in the last fill level, in HS model

4. Conclusions

One of the goals of this study is to achieve the actual parameters of the materials used in the body of the dam, which was achieved by back analysis. The results of the instrumentation and the numerical modeling showed that the two are well matched. According to results of the back analysis, the analysis of the construction of the dam stage in this study has been able to properly express the behavior of the dam during the dam construction. The results showed that in addition to the proper performance of both behavioral models with accurate instrument data, the HS model performed better than MC model. The results of the calibrated numerical model, at the end of the construction, showed that the maximum increase in pore water pressure, settlement, stress and horizontal displacement occurs in the central part of dam. The amount of stress in the dam axis is greater than its sides, and the amount of stress in the lower part is higher than in the upper part. The amount of settlement in the axis and at the middle part of the dam is more than its sides. It is suggested that appropriate soil models to be provided for drainage and filtering of the dam, which could be a good topic for future researches.

5. References

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