

EVALUATION OF SETTLEMENT PROBLEMS IN DAMS BY FINITE ELEMENT METHOD

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ABSTRACT

Dams have a very important position in water resources engineering. Surface water is accumulated and a reservoir is created, and irrigation water and drinking water are met with this reservoir. However, some of the biggest problems encountered in dams are as follows; the water leaking under the dam body reduces the bearing capacity of the ground, and as a result, the piping phenomenon is observed and the dam body is faced with the possibility of collapse. However, one of the biggest problems encountered in dams is that the bearing capacity, void ratio and water content are not the same in every region of the ground where the body of the dam will consolidate. Due to such problems, geotechnical and hydraulic engineers in dams need to do a lot of research on the ground and find solutions to these problems. In this paper, some published work on the calculation of piping events due to settlements, deformations and seepage in dams will be interpreted and evaluated. Since the analytical method to find the piping events that may occur due to leakage is laborious and the margin of error is high, the results were obtained by using the finite element program in these two papers published on these problems. A numerical solution method is both fast and has a low margin of error with the finite element method. Modeling of these dams was carried out with the PLAXIS finite element program. The settlement values of the experimental instruments placed on the dam body floor were compared with the settlements obtained with PLAXIS software. It has been determined that the settlement values of the inclinometer and extensometer instruments placed under the dam for these three dams are incorrect. For such reasons, settlement analysis results were obtained with PLAXIS finite elements. This compilation study reveals the settlement of hydraulic structures to be resolved by the finite element method.

Keywords: Dams, Geotechnical Engineering, Consolidation, Hydraulics, Civil Engineering

INTRODUCTION

In this paper, two published papers on the calculation of settlements, deformations and piping phenomena due to seepage in dams will be interpreted and evaluated. In the studies, the settlement analysis of three dams was performed by finite element method. These dams are Ozlüce Dam, Dim Dam and Muratlı Dam. It is useful to briefly give information about the morphology of these three dams. Ozlüce Dam, located on the border of Elazığ, Bingöl, on the Peri Stream, was built between 1992 and 2000 to generate energy. The dam has a rock body filling type with a body volume of 14.000.000 m³, a height of 144 m above the river bed, a lake volume of 1075 hm³ at normal water level, and a lake area of 25.80 km² at normal water level. The dam generates 413 GWh of electricity annually with a power of 170 MW. Dim Dam is a dam constructed between 1998-2004 on the Dim Stream in Antalya for irrigation, energy and drinking water supply purposes. The dam has a concrete and rock body filling type with a body volume of 5190 m³, a height of 135 m above the river bed, a lake volume of 250.63 hm³ at normal water level and a lake area of 4,70 km² at normal water level. The dam provides irrigation services to an area of 6,600 hectares and generates 127 GWh of electricity annually with a power of 38 MW. The dam also provides Antalya with 11 hm³ of drinking water annually. Muratlı Dam is a dam on the Coruh River in Artvin, built between 1999 and 2005 to generate energy. The dam is of rock body filling type with a body volume of 1,981,000 m³, a height of 44.00 m above the riverbed, a lake volume of 74.80 hm³ at normal water level and a lake area of 4.10 km² at normal water level. The dam provides 444 GWh of energy annually with a power of 115 MW.

To give brief information about the settlement and consolidation of soils; when soils are exposed to pressure, the void ratio decreases over time. With the pressure, this water and air in the ground are thrown out and settlement occurs. Consolidation consists of three stages, these are; Settlement due to sudden loading, Primary Consolidation, Secondary Consolidation. In settlement due to sudden loading, compression and settlement are not observed. In the second stage, Primary settlement takes place. The actual settlement and compression occurs at this stage. In the third stage, Secondary Consolidation occurs. Final settlement occurs in Secondary Consolidation. Final settlement takes place over long periods. Since consolidation does not occur immediately and continues for years, it should be monitored over a long period.

MATERIALS AND METHODS

In dams, settlement and consolidation in soils are observed and analyzed with a gradual approach. The dam body does not suddenly settle on the ground. The construction of dams lasts for years. Therefore, in order to accurately determine the results of settlement in the dams from the PLAXIS software, gradual loading was performed. If the loading in the PLAXIS finite element program is applied all at once, our results will be erroneous. Therefore, loading was done gradually. In order to observe the settlement in the ground in the PLAXIS program, the material model, the material model that is closest to the ground of the dam should be selected when selecting the type. When selecting the material in the PLAXIS program, the hardening soil model that is closest to the actual behavior of the soil should be selected. If the material parameter is not selected appropriately, the actual values will not be reached. Since consolidation takes place in three stages, the settlement values are obtained from the PLAXIS software by reading the settlements during the construction phase, at the end of construction and for the condition of full stability of the water in the upstream region of the dam. Table 1 shows the settlement analyses for the three days after the construction and when the water in the upstream region is fully stable, i.e. full. The problem to be solved by the finite element method is divided into parts and meshed to observe the stresses and deformations at each nodal point.

Table 1. Stability Analysis for Ozluce Dam

SITUATION	DEFINITION	FACTOR OF SAFETY	NOTE
1	Post-construction	1.70 1.77	<u>Downstream</u> Upstream
2	Sudden drop	1.65	Upstream
3	Operating position	1.70	Upstream
4	Operating position	1.69	<u>Downstream</u>
5	Post-construction(earthquake) Post-construction(earthquake) Operating position(earthquake) Operating position(earthquake)	1.24 1.27 1.04 1.22	Downstream Upstream Upstream <u>Downstream</u>

According to Tosun's (2008) research on Dim dam, deformations and settlements in horizontal direction were observed with PLAXIS package program. Deformation analyses of the dam embankment for static conditions were carried out with a package program (PLAXIS) based on the finite element method and the post-construction and operation were examined separately and the earthquake condition was analyzed for each case. In this analysis, the total and horizontal displacements were calculated as 174 cm and 15 cm, respectively, with the graded embankment model constructed in layers. After the displacements completed in the embankment, the largest total displacement value of the pavement was found to be 9.8 mm.

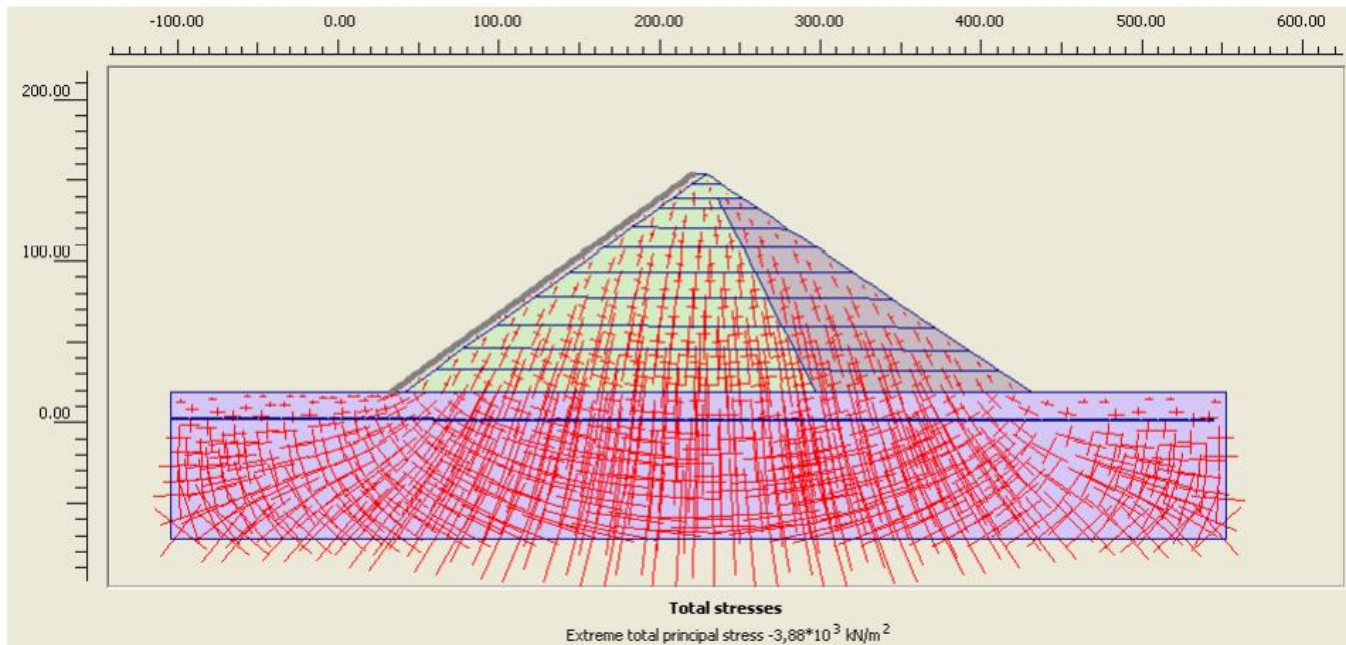


Figure 1. Lateral deformations of Dim Dam after construction

Unsever et. al. (2007) was modelled Muratlı Dam in PROXIS program and then the network of the dam was created. With the meshing process in finite elements, we can easily examine the stress, deformation relationship at each node.

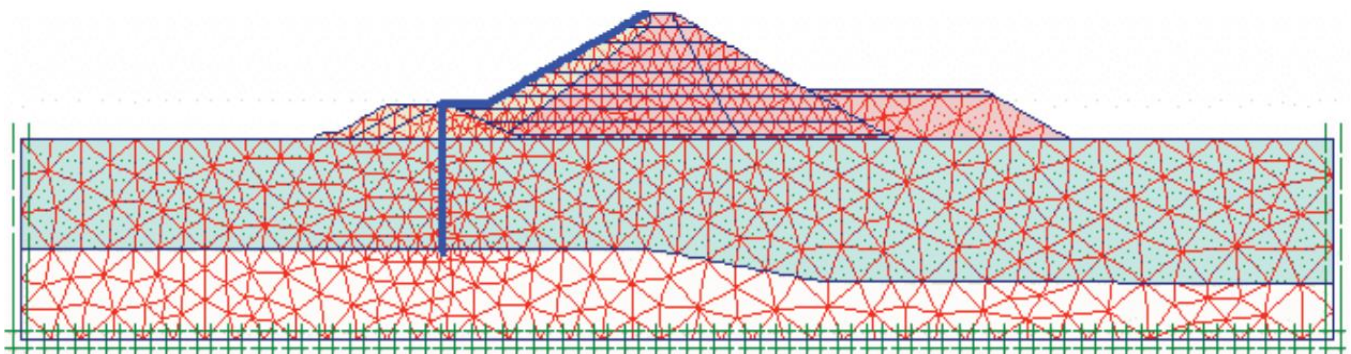


Figure 2. Meshing of Muratlı dam by Finite Element Method

In order to observe the behaviour of the foundation soil along with the dam, the soil beneath the dam is modelled together with the dam body. It is important to note that the analysis should be performed in stages, because the dam is not actually constructed in a single stage, but in stages. Therefore, there is a significant difference in terms of settlement mechanisms between the analysis performed in a single stage and in stages. In reality, the maximum settlement occurs in the middle of the dam body, but when the dam is modelled in a single stage, the maximum settlement is observed at the crest.

In this way, the analysis is carried out gradually. The total stresses found because of the analysis are in agreement with the values read during the water retention phase as well as at the end of construction.

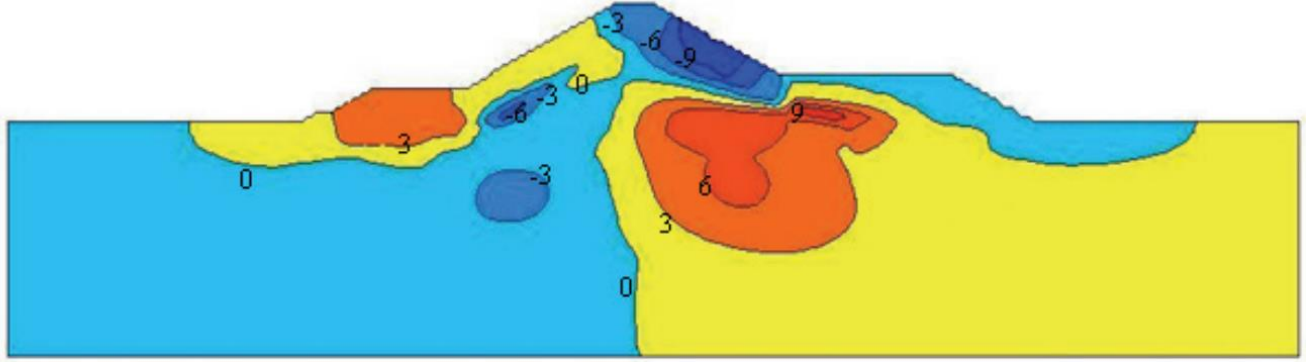


Figure 3. Horizontal displacement contours after the construction

RESULTS

The settlements of Ozlüce, Dim and Muratlı Dams were analyzed using the finite element method and it was observed that the settlements were not uniform along the dam body. Since the dams did not suddenly settle on the ground, but were constructed gradually, it was observed that the settlement increased during construction. After the construction phase of the dams, the settlement of the dam was also observed when the reservoir was fully filled with water. At the end of construction and when the reservoir is full of water, the settlements are observed to occur in approximately the same regions. At Muratlı dam, the maximum settlement at the end of construction was 110 mm within the dam body, corresponding to the center of the body. In Muratlı dam, the maximum settlement was calculated to be 70 mm when the reservoir was full of water and stable. In these dams, a separate analysis was also performed to calculate the deformations when the reservoir is filled with water upstream. These deformations occur mostly in the upstream part of the dam. It was found that the static stabilization results of Ozlüce Dam were greater than the required minimum safety factor of safety. Therefore, it is found that the static stability of Ozlüce Dam is appropriate and engineering controllable. It was also observed that the settlements in Dim Dam were concentrated in the middle of the dam body.

DISCUSSION

As a result of these studies, it is seen that settlement in dams cannot be measured properly with experimental instruments. It is essential to develop geotechnical instruments to measure settlement in soils. For this reason, the finite element method was used to measure the settlement of dams. While solving the settlements in dams with the finite element method, it is necessary to correctly enter the properties of the filling material and the soil to be placed on the ground. If the properties of the embankment material that will form the body of the dam are entered incorrectly, the correct results will not be obtained. In order to accurately determine the properties of the soil and embankment material, samples of the dam soil and embankment material should be taken and tests should be performed.

CONCLUSION

After a certain period after dams are built, settlement reaches its final state. These settlements continue for years. Since water will continuously leak from the upstream part of the dams, the void pressure will increase. Due to these void pressures, settlements will continue in the dams. In order to prevent settlement problems in dams due to long periods of settlement and uncertainties under the ground, new methods should be developed monthly or annually and the settlement of the ground should be monitored. At the same time, it is seen from these studies that the finite element method should be improved.

REFERENCES

- Mersin, D. (2022). Evaluation of Waste Materials in Transportation Engineering.
- Mersin, D. (2022). Estimation of Atterberg Limits of Soils by Artificial Neural Networks.
- Mersin, D. (2022). Geosynthetic Materials in Transportation Engineering.
- Ünsever, Y. S., Yıldız, G. S., Özkan M. Y., MURATLI KAYA DOLGU BARAJININ DEFORMASYON DAVRANIŞI ANALİZİ. (2007). 30.
- TOSUN, H. TOPRAK DOLGU BARAJLARDA STATİK STABİLİTE ANALİZLERİ VE DEFORMASYON HESAPLARI. National Seminar : Innovations on Design of Embankment Dam May 13-14, 2008 Eskişehir TURKEY.