NUMERICAL SIMULATION OF REINFORCED CONCRETE CUT-OFF WALL WITH STEEL FIBERS UNDER DAM

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Abstract

One of the main components of dams is the cut-off wall, which any damage to this concrete structure could encounter the dam with danger. Flexural behavior of concrete is an important factor in view of creating and growing cracks in the cut-off wall. Few researches have been done on properties and application of fibers in the cut-off walls, but the advantages of using this type of concrete in other hydraulic structures have been proved. In the present research, numerical simulation of a reinforced concrete cut-off wall with steel fibers was performed and its behavior under hydrostatic and earthquake loads were studied using Finite Element Method (FEM). Results showed that by increasing the volume of fibers, the fracture strain of the cut-off wall becomes larger and more energy was absorbed. It can be concluded that using fibers in the concrete cut-off wall improve its flexural behavior.

1. Introduction

The stored water behind the dam is always looking for a way to escape because of its high potential, and therefore penetrates into the porous mass of foundation and bodies of earth dams and leaks to the downstream [1]. One of the most important points in the design and construction of earth dams is the leakage of the body and foundation of the dam [2]. Therefore, evaluation of methods for controlling or reducing water leakage in earth dams is necessary [3]. In the recent years, the concrete cut-off wall, which is one of the anti-seepage structures, has been widely used in the reinforcement of dam projects. For the earth-rock dams where the covering layer of the dam foundation was not thick, the closed cut-off wall was usually built in the dam, and directly embedded in the rock, usually extends deeply underground and affected by the surrounding formation and the construction process, so its own stress state is very complex [4,5]. Dopant performed tests on 28 beams with the actual size and examined the load-deflection values of the beam by changing the volumetric ratio of the fiber [6]. Pine et al. [7] also considered 1-2% volumetric percentage of fiber as the most suitable amount of fiber to achieve the best mechanical properties of concrete, which is almost confirmed by other researchers. Olivito and Zocarlo indicated that increasing the volumetric percentages and the length of the steel fibers increases the ductility and durability of the concrete [8]. Johnston and Zamap examined the effect of length to diameter ratio and fiber type on fatigue strength under flexural loading [9]. Researches on the concrete structures were recently focused on effect of using fibers and other additives [10-14]. In the present study, effect of using fibers in concrete cut-off wall on its behavior was compared the plain concrete cut-off wall in the dam using a numerical model.

2. Materials and Methods

The dimensions of this wall are 70×50×5 m in y, z and x directions, respectively. All simulations were performed in three dimensional (3D) and ductile form. The Abaqus software was used based on Finite Element Method (FEM). Geometry, mesh and boundary conditions of arches are shown in Figure 1. Cell size is considered cubic as 1×1×1 m in the model regarding the mesh sensitivity analysis. To assign boundary conditions, the cut-off wall bases were considered fixed with zero displacement in three directions.

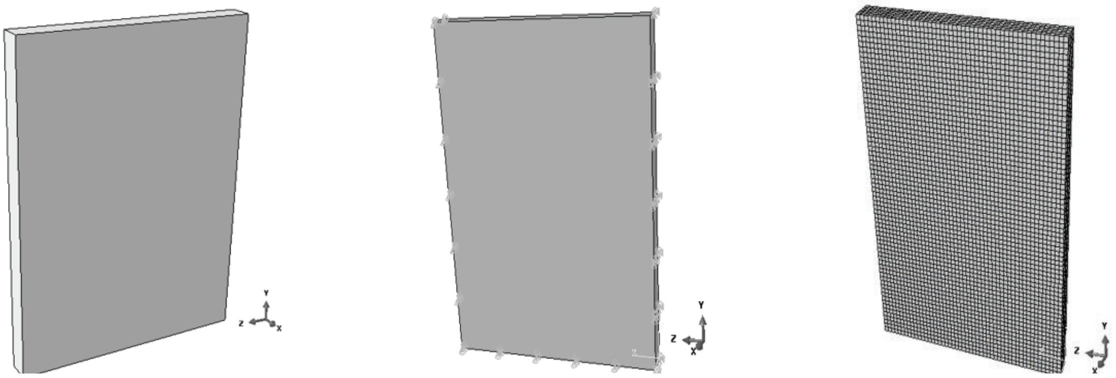

Figure 1: Geometry, mesh and boundary conditions.

To verify the numerical model, results of research by Ben Cardiou et al. on cylindrical and cubic samples of plain concrete and reinforced concrete with steel fibers and fiber content of 1%, 1.6% and 3% were used. Physical characterizes were used according Table 1 [15].

Table 1: Properties of steel fiber and concrete

	Portland cement of ASTM type I	**aggregate**	**silica fume**	**superplasticizer**	**steel fibers (length of 22 mm)**
Density (g/cm3)	3.15	2.65	2.2	1.15	7.85

The hydrostatic pressure load in collaboration with equal soil load on both sides of the cut-off wall which counterbalances each other were considered. The amount of applied load on the structure as a hydrostatic pressure is equivalent to a water pressure to an altitude of 50 m. Moreover, the cut-off wall with the same dimensions and the same volume of fiber was simulated under dynamic load of a recorded earthquake of Tabas as a significant earthquake. Using SAP software the 5% attenuation spectrum response was determined. After that, the response spectra were combined using a root sum square method. Moreover, a single combined spectrum was also constructed which was then compared at the next stage in the range of frequency times of 0.2T and 1.5T with the standardized design spectrum curve. The acceleration scale factor of the structure was found to be such that these mean values are by no less than 1.4 times the value of the standard spectrum. The terrain of Type II structure was assumed with a moderate relative risk and the main time of the fluctuations of the structure was considered to be equivalent to the structures with other systems [16].

$$T = 0.05H^{\frac{3}{4}}$$

$$B = 1 + S\left(\frac{T}{T_0}\right) \qquad 0 \le T \le T_0$$

$$B = S + 1 \qquad T_0 \le T \le T_s$$

$$B = (S+1)\left(\frac{T_s}{T}\right)^{\frac{2}{3}} \qquad T \ge T_S$$

where, B is the reflection coefficient of the structure represents the response of the structure to the motion of the earth, T is the time of the main frequency of the structure oscillation in seconds (s) and T_s and S are parameters that depend on the terrain and the seismicity of the region. The boundary conditions for this modeling are intended with the assumption that the wall at the bottom of its height Z = 0 is immersed in impermeable soil layers and is thus considered to be completely stuck. Boundary conditions for earthquake loading are intended as wall conditions in hydrostatic loading, and the loading is in the horizontal direction of the earthquake in x direction. The type of analysis for hydrostatic loading was selected in one step as dynamical implicit for nonlinear analysis of the structure, and the type of analysis in dynamic loading is considered as dynamic explicit analysis. The aim of this research is to provide a preliminary result including stress-strain behavior and displacement in a cut-off wall under dam. Because the area under the curve of the concrete with fiber volume of 1.6% and 3% is approximately equal, results of 3% and 1% fibers concretes are compared with plain concrete.

3. Results and Discussions

3.1 Under Hydrostatic Load

Since the loading conditions were symmetric in the y direction, evaluation of the results were conducted in the direction of the thickness and height of the cut-off wall (Figures 2 and 3). According to the Figure 2, it was observed that concrete with a 3% volume of fiber at the zero level, due to the greater length in the softening region, has the highest strain value in defining the materials and is 75% higher than that of plain concrete. Figure 3 shows that the total stress in plain concrete and concrete with 1% volume of fiber at the level of 16.67 m is about 30% larger than concrete with 3% volume of fiber. Due to the smaller strength and modulus of elasticity, the materials behavior for 3% volume of fiber in concrete should have a smaller stress and a greater strain. Figures 4 and 5 show the stresses in x direction and deformations in z direction, respectively.

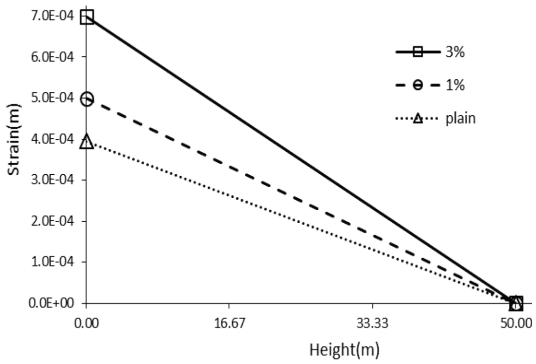

Figure 2: Comparison strains in z direction

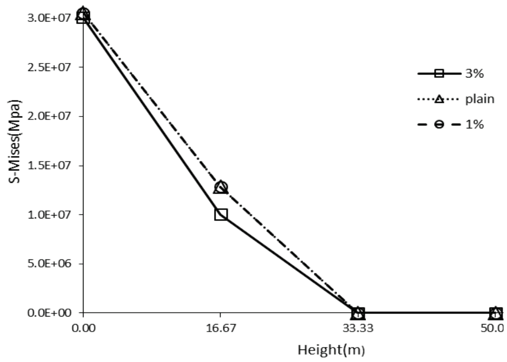

Figure 3: Comparison stresses in z direction

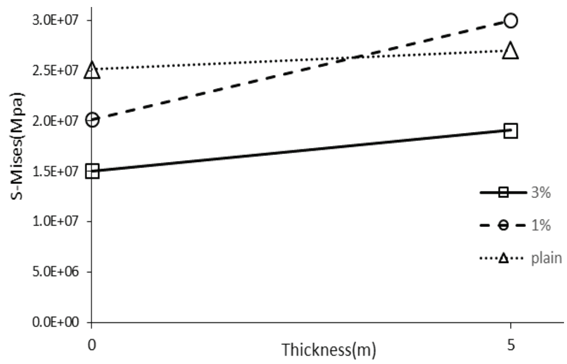

Figure 4: Comparison stresses in x direction

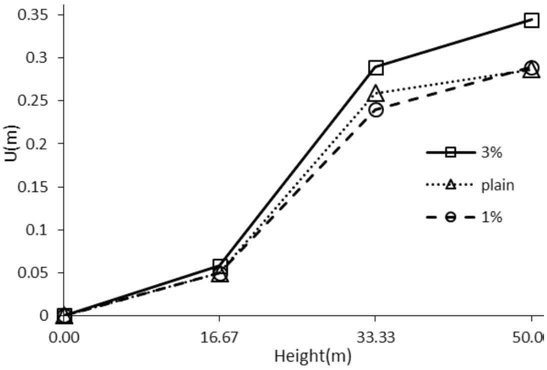

Figure 5: Comparison deformations in z

As can be seen from Figure 4, the minimum of stress is was occurred in concrete with 3% volume of fiber. In Figure 5 by comparing the deformations, concrete with 3% volume of fiber at the level of 50 m, had 19% more deformation compared to the plain concrete, which seems reasonable according to the small modulus of elasticity in concrete with 3% volume of fiber.

3.2 Under Earthquake Load

In the interpretation of the earthquake loading results, stress changes at height and in the direction of wall thickness were compared in Figures 6 and 7, respectively.

Figure 6 shows that the maximum stress in cut-off wall is related to the plain concrete at the level of 16.67 m, which is 66% more than the stress value in concrete with 1% volume of fiber. The behavior of the fiber concretes in the dynamic loading is softer than the plain concrete, and concrete with 1% volume of fiber, in spite of its compressive strength, is almost the same as the behavior of 3% concrete. Moreover, in direction of wall thickness, variations in stress are approximately equal. The strain and deformation changes are also compared to the height of the cut-off wall in Figures 8 and 9, respectively.

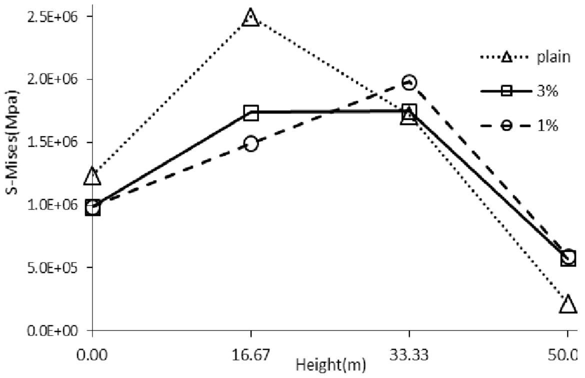

Figure 6: Comparison stresses in height

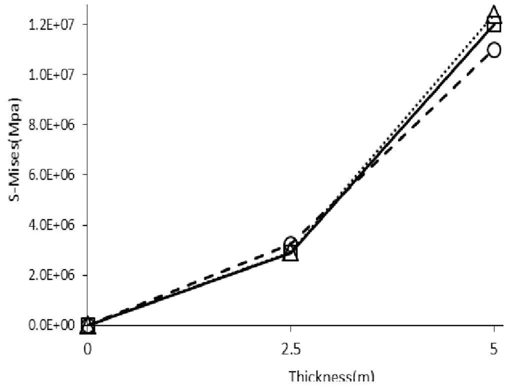

Figure 7: Comparison stresses in x direction

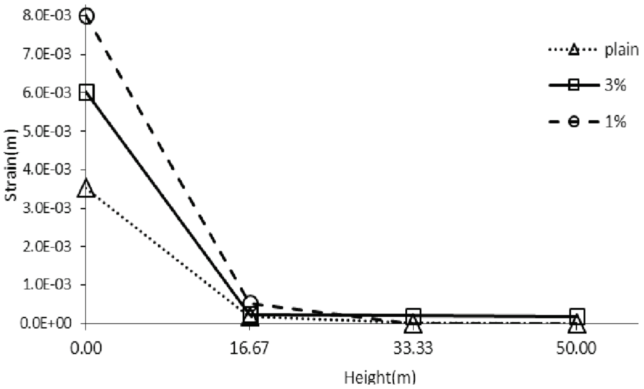

Figure 8: Comparison strains in z directions

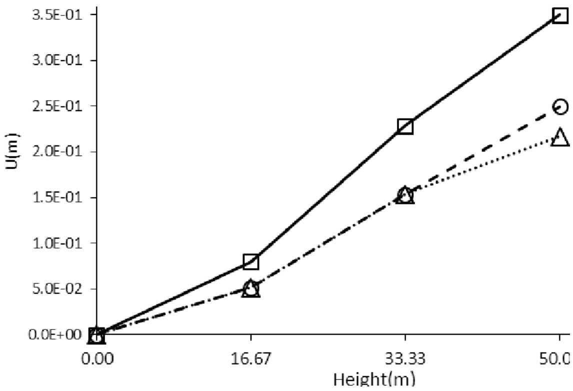

Figure 9: Comparison deformations in z

Figure 8 shows that the maximum value of the strain at the zero level is related to the concrete with 3% volume of fiber, which is different from the lowest value for the plain concrete of 128%. Figure 9 shows that concrete with 3% volume of fiber has the most deformation values, and only at the height of 50 m, the plain concrete has a deformation of 13% less than concrete with 1% volume of fiber.

Table 1: Amount of absorbed energy at the end of the analysis under earthquake loading.

Concrete type	Plain	1%	3%
The amount energy at the end of the analysis	0.1	0.25	0.5

The total energy related to the concrete cut-off wall with 3% volume of fiber is more in comparison with two other types and this means that the energy absorption to the structure in this type is larger than cut-off wall with plain concrete and 1% volume of fiber.

4. Summery and Conclusions

In this study, the concrete behavior of concrete cut-off wall was examined by adding different percentages of fiber to the total volume of materials under hydrostatic and earthquake loads. To do so, simulations were performed using the stress-strain curve obtained from the experimental results of Ben Cardiou et al. [14] for verification. Results of simulations of concrete cut-off wall with 1% and 3% volume of fiber show that the zero level of the wall, the minimum stress created in the structure related to the concrete with 3% volume of fiber, which is about 30% less than the concrete cut-off wall with 1% volume of fiber and plain concrete. In the direction of wall thickness, the minimum stress value is related to the concrete cut-off wall with 3% volume of fiber. Maximum deformation was for concrete cut-off wall with 3% volume of fibers and 19% with the other two other types. Moreover, the energy absorption at the end of the analysis time, absorption of the energy in concrete cut-off wall with 3% volume of fibers was more in comparison to the concrete cut-off wall with 1% volume of fibers and plain concrete. Strength of concrete against crack increased by adding steel fibers but effect of steel fibers decreased with increasing friction. Maximum deformation and strain under earthquake load was occurred in concrete cut-off with 3% volume of fibers.

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