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Seismic Analysis and Durability Assessment of Nisa Dam of Bam in Empty Reservoir

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Abstract: The issue of earthen dams is very important and necessary around the world today due to the large size of these structures and their number and the issue of drought and dire need to water storage; and the country Iran is no exception regarding severe dehydration. Construction of earthen dam includes complex factors that cause design and implementation of these massive structures to be in category of the most important water engineering projects. Durability of earthen dams is assessed in two ways: static and dynamic. The static durability of earth dams means balance and prevention the movement in one of components of an earthen dam against the incoming static forces. In other words, an earthen dam is in balance and durability state when in each part of the dam result of tensions applied is smaller than resistance mobilized there and since this action and reaction is different and relative in every part of the dam, so in designing earthen dams relative durability is measured by a criteria called confidence coefficient and the higher it is the more durability is expected. In this paper, seismic analysis of Nisa dam was done by Geo - Studio software. In this study, it was concluded that in the case of empty water reservoir under earthquake record, the tension in the concrete surface is more than 4 MPa. Also under earthquake record, the highest acceleration in empty reservoir state was about 6.0 meters per second squared.

Key words: Earthen dam, durability, geo-studio software, Nisa Dam, second squared

INTRODUCTION

Iran as one of the most earthquake-prone regions of the world has been exposed to devastating earthquakes in past years. Natural and geological conditions of Iran, in terms of earthquake, have seriously been included in o agenda of engineers and planners. Since many dams have been built or are under construction in seismic regions, their safe design against earthquake is of significant importance. Close examination of seismic durability of earthen dams is one of complex issues in the area of ??soil structures. Variety of dynamic properties dam body and different material and thickness variation of the foundation which can have vital role in transferring, weakening and strengthening earthquake waves , presence or absence of active faults within the dam axis range, earthquake Specifications such as distance from centre to dam, intensity and time length of the earthquake, type and extension of the waves reached to dam and frequency content of waves are all factors that play an important role in dynamic response of dam. Rasoul Ghobadiani conducted a research on the effects of cut-off wall in discharge leak. In his research a computer model is prepared in which the general equation of water flow in soil is solved by non-identical heterogeneous saturation conditions in discrete finite volume method and system of equations by Gauss-Seidel method.In this model, the position of leakage line is determined by iterative method and deformed network. Validation of the model was performed using measurement data from physical model of earthen dam in a seepage reservoir dam in the laboratory. Position of leakage line and seepage discharge was measured and calculated for different conditions of water head upstream suggests accuracy of the model. After validation of the model, the impact of different positions and length of cut-off wall on seepage discharge and free leakage line was investigated.

The results of this research showed that under any circumstances presence of cut-off wall reduces seepage discharge. When the cut-off wall is placed under the middle of dam base , the highest seepage discharge is observed. By displacing the position of cut-off wall seepage discharge can be reduced up to 20% compared to cut-off wall in the center. The more cut-off wall is displaced from the heel side to the toe; free leakage line placed is placed in a higher position. By changing the cut-off wall position of the center base to the dam toe, mass volume of dam saturation increases up to 49%. In case the cut-off wall is constructed on the heels of dam, mass volume of saturation decreases to just 17.9%. (Ghobadian,, 2011) Seyedi *et al*., 2008 analyzed three-dimensional water seepage in the dam foundation and the main body of Ali Dolat (Fars province) by software Seep-3D .The results of this research showed that the use

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of cut-off wall reduces the amount of leakage. (Seyedi *et al*., 2008) Davoodi Nejad (2007) using the software SEEP /W evaluated the effect of cut-off wall on reducing the leakage from earthen dams. Afifi (2006), investigated cut-off wall effect on leakage from the earthen dams in heterogeneous environment by software SEEP/W and showed that by increasing the wall thickness from 0.5 to 2.5 meters, just 2% difference was observed in the rate of leakage. (Davoodi, 2007) Pakbaz *et al*. (2009) evaluated the plastic concrete cut-off wall in right and left fulcrum of Karkheh dam in reducing the amount of leakage through SEEP 3-D model. Their results showed that by making the left and right cut-off wall amount of leakage reduced by respectively 60 and 20% (Pakbaz *et al*., 2009). Sedghi Asl (2004) examined the effect of optimal position of vertical cut-off wall on leakage reduction and water flow rate in water infrastructures using numerical model and showed that the best place for leakage control and under washing is heel and toe of the dam (Sedghi, 2005).

Study of various sources indicate that most of simulation software of leakage in earthen dam are written based on finite element method researchers using these software investigated the effects of cut-off wall on the amount of leakage from the earthen dam. Also there are limited studies on position of free seepage line and mass volume of dam saturation which is very important in dam durability. Therefore, in this study in order to acquire knowledge of the best leakage control system, a computer-mathematical model based on finite volumes method is written.

Numerical methods for solving equation of water flow in saturated soils: Due to advances in computers, today numerical methods are used more for solving equations of water movement in the soil. In these methods, the aim is obtaining the value of the function (answer of equation) at certain points of the network. One of the advantages of numerical methods is that the problems can be solved with any initial condition and boundary condition. The most popular of these methods is finite differences method and finite element method that the finite element method has wide application in solving problems related to water movement in soil and can be divided to several methods. In this study, the equation of solving water movement in saturated soil (Laplace equation) with finite differences is described. Using explicit public equation of water movement in saturated homogeneous soils in two dimensions can be written as follows:

$$K_x \frac{\partial^2 h}{\partial x^2} + K_z \frac{\partial^z h}{\partial z^2} = 0 \qquad (1)$$

In finite differences method, the desired level (level X-Z) is divided into networks consisting of nodes. It is

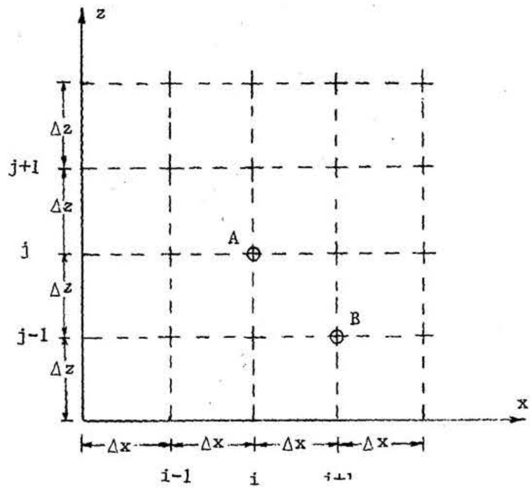

Fig. 1: Gridding to solve with finite differences method

identified by its X and Z coordinates that here will be shown with subtitles i and j. For example, the answer of Eq. 1 at point A is determined as and at point B as:

$$h_{i,}j \text{ and at point B as } h_{i+1}, j-1$$

H is the load of total potential, so is load of total potential at the point with length i and width j Fig. 1.

In finite differences method, partial derivatives are obtained using Taylor expansion. For example, calculating second order partial derivatives $\partial^2h/\partial x^2$ or $\partial^2h/\partial z^2$ is as follows: First Taylor expansion is written for $h_{i+1,j}$ and $_{hi-1,j}$:

$$h_{i,j} = h_{i,j} + \Delta x\left(\frac{\partial h}{\partial x}\right)_{i,j} + \frac{(\Delta x)^2}{2!}\left(\frac{\partial^2 h}{\partial x^2}\right)_{i,j} + \frac{(\Delta x)^3}{3!}\left(\frac{\partial^3 h}{\partial x^3}\right)_{i,j} + \qquad (2)$$

$$h_{i,j} = h_{i,j} - \Delta x\left(\frac{\partial h}{\partial x}\right)_{i,j} - \frac{(\Delta x)^2}{2!}\left(\frac{\partial^2 h}{\partial x^2}\right)_{i,j} - \frac{(\Delta x)^3}{3!}\left(\frac{\partial^3 h}{\partial x^3}\right)_{i,j} + \ldots$$

By summing the above relations, the following equation is obtained:

$$h_{i+1,j} + = h_{i-1,j} + 2\frac{(\Delta x)^2}{2!}\left(\frac{\partial^2 h}{\partial x^2}\right)_{i,j} + 2\frac{(\Delta x)^4}{4!}\left(\frac{\partial^4 h}{\partial x^4}\right)_{i,j} + \ldots \qquad (3)$$

By removing the sentences in which the expression power ( ) is above four, the following equation can be achieved:

$$\left(\frac{\partial^2 h}{\partial x^2}\right)_{i,j} = \frac{h_{i-1,j} - 2h_{i,j} + h_{i+1,j}}{(\Delta x)^2} \qquad (4)$$

For direction of Z s, similar to can also be used to achieve the following relation:

$$\left(\frac{\partial^2 h}{\partial x^2}\right)_{i,j} = \frac{h_{i,j-1} - 2h_{i,j} + h_{i,j+1}}{(\Delta z)^2} \quad (5)$$

By replacing the Eq. 4 and 5 in equation (1), the following relation can be written:

$$K_x \frac{h_{i-1,j} - 2h_{i,j} + h_{i+1,j}}{(\Delta X)^2} + K_z \frac{h_{i,j-1} - 2h_{i,j} + h_{i,j+1}}{(\Delta Z)^2} = 0 \quad (6)$$

Also $h_{i,j}$ can be obtained from Eq. 7:

$$h_{i,j} = \frac{1}{2(A+B)}\left[Ah_{i-1,j} + Ah_{i,j-1} + Bh_{i,j+1}\right] \quad (7)$$

Where $A = K_z/(\Delta z)^2$,$A = K_z/(\Delta z)^2$ For isotropic soils that $K_z = L_x = K$, ig, If $\Delta X = \Delta Z$ Eq. 7 can be written as follows:

$$h_{i,j} = \frac{1}{4}\left(h_{i-1,j} + h_{i+1,j} + h_{i,j-1} + hi,j+1\right) \quad (8)$$

The Eq. 8 shows that for determining total potential at each node, total potential in its surrounding nodes should be known. To solve a system of n equations n unknown there are several numerical solutions. For example Gaussian and Gauss-Seidel elimination methods and Newton-Raphson successive replacement can be named. Successive substitution method, that is sometimes called relaxation method, is a relatively simple method that is discussed in this study. In this method, first some numbers are assumed for the unknown quantities. For example, all of them can be considered zero. Then, using equations system (8) new values ??for the unknowns are calculated. Again, by replacing the new values ?? calculated in system of Eq. 8 newer values ??for the unknowns can be achieved. This practice should be repeated until the difference of values ??obtained in two successive iterations is very small. Obviously, the more initial assumed values ?? are closer to reality; the number of iterations to achieve real answer will be less. It is clear that if the level of the considered level is great and number of nodes is large, solving simultaneous equations manually would be very time consuming. Therefore, in such cases the use of computers is inevitable.

MATERIALS AND METHODS

Specifications of consumed materials: Specifications related to foundation are brought in Table 1 and

Table 1: Specifications of the soil related to foundation

Specifications	Foundation soil	Value	Unit
γUnsat	Unsaturated density	22	kN/
γsat	Saturated density	23	kN/
K_x	Penetration rate along x	0.026	m/day
K_y	Penetration rate along y	0.026	m/day

Table2: Specifications of concrete behavior model

Specifications	Cut-off wall concrete	value	Unit
γ	Density	23	kN/m^3

Fig.2: Considered model performed in laboratory

Specifications related to behavior of concrete used for cut-off wall are provided in Table 2 that is used in the software.

Generally, in analysis of each problem by numerical models, the most important part is introducing the model parameters. Other than the elements and definition of the boundary conditions and support conditions that each have a significant role in the results analysis, finding true and real parameters of the model and introducing them to application is the main part of numerical modeling. In Elasto-plastic analyses, plastic behavior of the soil is obtained through calibration or adjustment of data. Verification of the considered in the software is addressed in the following.

Model verification: Validation of the model was studied using results of the research by Varjavand entitled physical and numerical simulation of cut-off wall effect on the leakage from stratified foundations. In research of Varjavand behavior of cut-off wall with different penetration depth on soil is investigated. Figures 2 and 3 are respectively, related to laboratory models and the model in the software.

Accelerogram: According to the 2800 regulations of Iran, accelerogram that are used in determining effect of ground motion , to the extent possible, should reflect the actual movement of the ground at the site of the building,

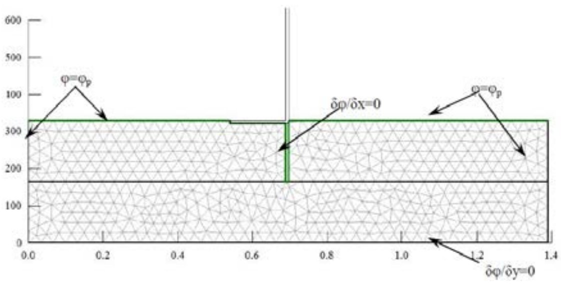

Fig. 3: Considered model in PLAXIS software

in earthquake time. To achieve this goal it is necessary to choose at least three pairs of accelerogram belonging to horizontal components of three different earthquakes registered with the following specifications (Seyedi *et al*., 2008):

- Accelerograms belonging to earthquakes that satisfy the conditions of earthquake design and magnitude distance from fault, and seismic source mechanisms are taken into account
- Building place of accelerograms should be similar to the ground of building as much as possible in terms of geological, tectonical, seismological, especially profile of earth soil layers
- The duration of strong ground motion in accelerograms is at least 10 seconds or three times the fundamental period of construction, whichever is greater. The duration of severe motions in accelerograms can be determined through valid methods, such as cumulative energy distribution.

The chosen Pairs of accelerograms must be compared in the following way: All accelerograms should be scale in their maximum amount. That is the maximum acceleration of all of them gets equal to the gravitational acceleration g. Acceleration response spectra of each pair of scaled accelerograms is determined by considering damping ratio at 5%. Combination response spectra of three pairs of accelerograms was averaged, and compared in range of time periods 0.2T and 1.5T with the spectrum of standard design. Scale factor is determined in a way that in this range average values ??in any case are not less than 1.4 times the corresponding value in standard range.

T: fundamental period of the building determined experimentally. Determined scale factor, should be multiplied by scaled accelerograms scaled in paragraph (a) and used in dynamic analysis. By regarding the above items, the selected accelerograms have magnitude 6-7 and distance from fault is between 15-25 km that are scaled for land Type II using spectrum design regulations 2800 of Iran. Specifications of accelerograms used in the nonlinear time history analysis are shown in Table 3.

Table 3: Specifications of accelerograms used

Earthquake	Date	Location	Magnitude	R(km)	PGA (g)
1Bam	2003	Bam	6.6	10	0.89
Manjil	1990	Manjil	6.6	14.3	0.43
El-centro	1984	-	6.4	14.5	0.27

Case study: Nisa dam is the first and largest rock fill dam with concrete surface (CFRD) in Iran and the second largest dam in Kerman Province after Jiroft dam. This dam is located 80 km away from Bam city and 280 kilometers from Kerman city. Useful reservoir of dam is 121 million cubic meters and its annual average estimation is 210 million cubic meters. This dam is to supply part of agriculture, industry and drinking water is in cities Bam and Baravat. Fifty million cubic meters of dam water is used in industry, 21 million cubic meters in drinking water and 60 million cubic meters in agriculture sector. This dam has also a 5-megawatt power plant.

RESULTS AND DISCUSSION

Model verification: After verification of the software, dynamic analysis is done using elastoplastic model and regarding foundation with depth up to 50 meters and water force. Then, stress distribution derived from this method is real since static analysis is done as modeling steps of dam construction and also presence of water in dam reservoir, in addition to the having hydrodynamic effects on the dam body , affects distribution and size of static stress . In Fig. 4-6 responses of two-dimensional model analyzed in the software including acceleration, speed and displacement at a point above the dam and close to the crest for 20 seconds under earthquake are given.

As can be seen in Fig. 3-5 the maximum acceleration rate at a point above the dam and close to crest has been about 3 seconds and approximately 8.0 meters per square second. The maximum speed rate for the mentioned point has occurred about 6 seconds, and a small amount more than 0.08 meters per second and the maximum amount of displacement along X for the point under study has occurred around the time 7.5 seconds and to extent lesser than 6 cm. In Fig. 7, the maximum axial stress for concrete surface, analyzed in the software under earthquake record is brought. The maximum axial tensile stress distribution is shown over the longitudinal axis of concrete surface and maximum axial compression stress distribution is shown on bottom of it (Fig. 8).

Distribution of axial stress is investigated to compare elasticity ??created on concrete surface and study potential of creating the tensile cracks on concrete surface. As previously mentioned the possibility of creating crack on surface, provides possibility of water

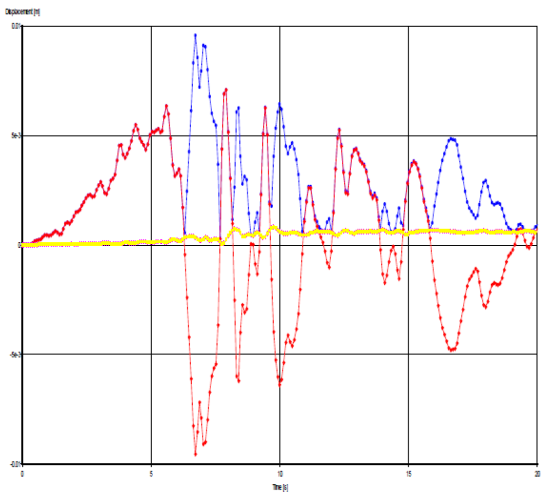

Fig. 4: Response time history of displacement related to the earthquake in empty reservoir state

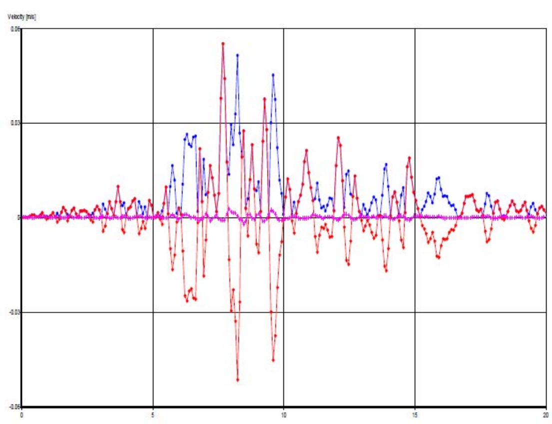

Fig. 5: Response time history of speed related to earthquake in empty reservoir state

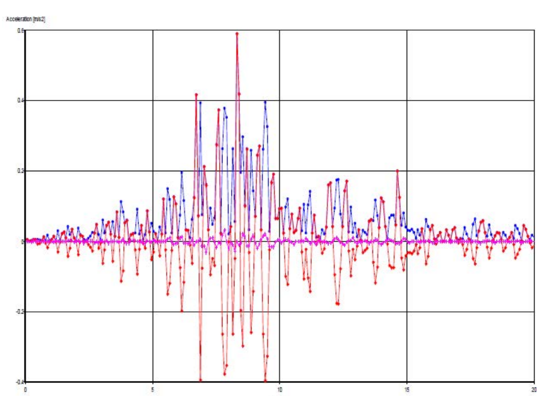

Fig. 6: Response time history of acceleration related to earthquake in empty reservoir state

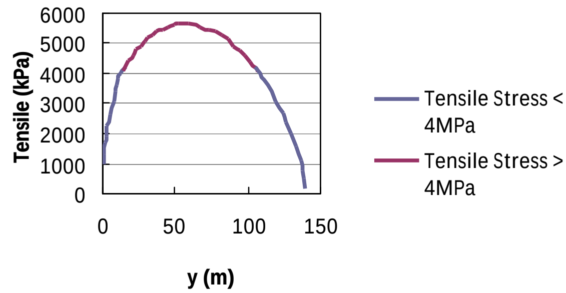

Fig. 7: The maximum amount of axial tensile stresses in the concrete surface in empty reservoir state

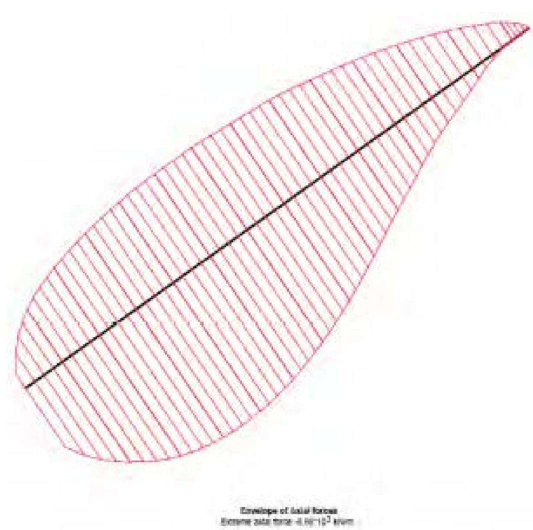

Fig. 8: Maximum amount of axial compression and tensile stresses in the concrete surface in the empty reservoir state

flow through concrete surface and in this case general durability of the dam may be compromised. The potential tension cracks in the concrete surface will be investigated. In order to evaluate the potential for tensile cracks, axial tensile stress in the concrete surface is compared with a tensile resistance of concrete which is intended to be 4 MPa. In areas of surface that the tension is more than 4 MPa, tensile cracks are likely to occur. According to the maximum axial tensile stresses in the concrete surface in elevation digits of 13.35-104.91 meters below the dam, the tension created is more than 4 MPa. As a result, the tension crack in this area is likely to occur.

CONCLUSION

In the case of empty reservoir under earthquake record, the tension created in concrete surface is more than 4 MPa. As a result, in elevation of 13.35-104.91 meters below the dam the tension crack is likely to occur.

Also in no part of the concrete surface during the earthquake the tension exceeded 4 MPa of tensile strength. The maximum rate of acceleration at a point above the dam and near the crest, in the case of empty reservoir has been about3 seconds and around 8.0 meters per second squared. The maximum displacement along the x for the point under study in the empty reservoir has occurred about 5.7 seconds and as less than 6 cm. Also under the Earthquake record, the highest acceleration in empty reservoir has been about 6.0 meters per second squared. It should be noted that the maximum displacement along the x for the point of study in empty reservoir occurred about 3.7 seconds and less than 6 cm and maximum speed has been about 0.07 meters per seconds.

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