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Dynamic Analysis of interaction of gravity Dam and reservoir in time domain

Mohammad mehdi Heydari[1]

Abstract: *Each paper In the present study , some finite element softwares about interaction of dam and reservoir during earthquake in time domain are discussed. Impedance option is used as boundary condition of absorbent of reservoir and wave. For each software, time history analysis of pressure and displacement are done and finally suitable elements for dam structure and reservoir fluid are introduced comparing the results obtained from each software and reference results about Oued-Fodda dam (north -western Algeria) . Application of each software in various fields of Dynamic analysis of dam and reservoir interaction such as Euler – Lagrange model or Lagrange – Lagrange model , time history modal analysis (by using less numbers of vibration modes) and... is discussed, and LISA software for lagrange – Lagrange method or time history modal analysis and ANSYS software for Euler-lagrange method are introduced.*

Keywords: *Fluid-structure interaction,finite element software. Euler – Lagrange model, Lagrange – Lagrange model.*

INTRODUCTION

The finite element method has been widely used in Dynamic analysis of concrete gravity dams. Many researchers are interested in the impact of interaction between dam and reservoir in Dynamic analysis, particulary in time Domain [6-1]. In the most of these studies, it was used the model composed of water and structure elements in which displacement freedom degrees for dam's body and commonly pressure freedom degrees for reservoir water are considered . also, analysis in time domain has an important role, as it can be subjected to all nonlinear and none-elastic behaviors in the model, therefore, it is mostly used in non linear analysis of structures. For numerical solution of interaction problems that have a large amount of calculations, using commercial standard finite elements software packages can be useful. In this paper, finite element softwares LISA, ALGOR, ANSYS are discussed. The studied dam is Oued-Fodda in north-western Algeria . The main evaluation and examination are on suitable element selection for reservoir- dam interaction system and also analysis of time history for hydrodynamic pressure of floor joint and horizontal displacement of crest joint.

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Based on finite element theory, the matrix equation fore dynamic response of the structure to support excitation in time domain is shown as following:

$$[M]\{\ddot{r}\}+[C]\{\dot{r}\}+[K]\{r\}=-[M]\ [J]\{a_g\} \tag{1}$$

where M:mass index matrix, C:damping index matrix, K: structure stiffness index matrix, r: relative nodal displacements vector, J: unit matrix that is responsible for transferring support acceleration vector a_g to degrees of freedom of the structure it should be known that if a fluid like water placed into reservoir in back dam is subjected to support excitation, and equation similar to the above relation will be dominated on it :

$$[G]\{\ddot{p}\}+[L]\{\dot{p}\}+[H]\{p\}=-[B]\ [J]\{a_g\} \tag{2}$$

where G: pseudo mass index matrix, L: pseudo damping index matrix, H: structure stiffness index matrix, P: Hydrodynamic pressures vector, B: mapping matrix that causes the nodal acceleration transformation a_g to pressure flux and along with, J: matrix defined as before constitutes the right and side of matrix equation of fluid. When thestructure and the fluid are placed along side and affected by the same base acceleration, fluid and structure interaction problem becomes important and it causes changes in responses of the both of these parts. In this case, the mapping matrix B, in addition of transformation of support acceleration to pressure flux, has some other duties as transforming the structure accelerations to pressure flux and also transformation of dynamic pressure to applied forces to the structure. In fact, the matrix causes interactions in the structure and the fluid. In this case, two equations dominate on the structure and the fluid are placed together and fundamental relation is made:

$$\begin{bmatrix}[M] & 0\\ [B] & [G]\end{bmatrix}\begin{Bmatrix}\ddot{r}\\ \ddot{p}\end{Bmatrix}+\begin{bmatrix}[C] & 0\\ 0 & [L]\end{bmatrix}\begin{Bmatrix}\dot{r}\\ \dot{p}\end{Bmatrix}+\begin{bmatrix}[K] & -[B]^T\\ 0 & [G]\end{bmatrix}\begin{Bmatrix}r\\ p\end{Bmatrix}=\begin{Bmatrix}-[M]\,[J]\{a_g\}\\ -[B]\,[J]\{a_g\}\end{Bmatrix} \tag{3}$$

in the fact, continuous domain of gravity dam is considered flexible and also fixed in the bottom. Also according to Figure (1) and by taking into account compressible no adhesive and non rotary fluid, the equation dominated on reservoir domain and quadruplet boundary conditions of reservoir where the dam is more flexible, is as following:

$$\nabla^2 p=\frac{1}{C^2}\frac{\partial^2 p}{\partial t^2} \qquad \Omega_f \tag{4}$$

$$\frac{\partial p}{\partial n}=-pa_g^n \qquad \Gamma_1 \tag{5}$$

$$\frac{\partial p}{\partial n}=0 \qquad \Gamma_2 \tag{6}$$

$$p=0 \qquad \Gamma_3 \tag{7}$$

$$\frac{\partial p}{\partial n}=-\frac{1}{c}\frac{\partial p}{\partial t} \qquad \Gamma_4 \tag{8}$$

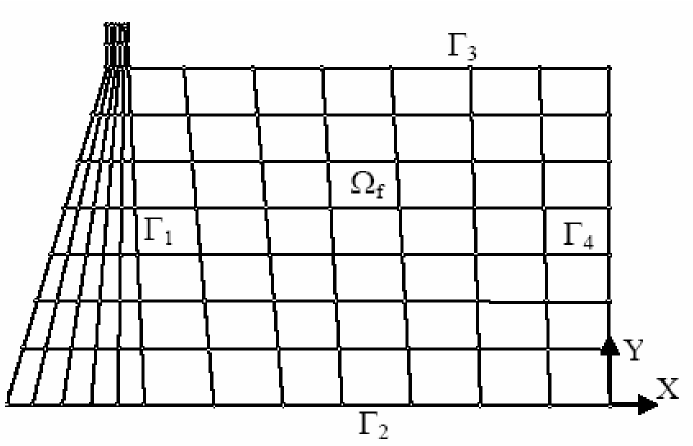

Figure 1. Dam-reservoir system and boundary condition of Dam and reservoir

The strategy that can be used for absorbing the wave is Sommerfield boundary condition. Sommerfield boundary condition (equation 8), is an approximate boundary condition in above relation p , t And n are pressure, time and normal vector perpendicular to the surface respectively. Sommerfield Boundary condition is approximate because the relation can absorb only one-dimensional waves that have right angle with it. In related softwares for doing dynamic analysis when there is interaction between dam and reservoir, we can use relation (3) to resolve the equations. It should be mentioned that to model Boundary condition of the end of reservoir and to do absorbing the wave in the above software, impedance loading is used. In application of the wave absorbing condition, the reservoir is modeled as rectangular satisfies Sommerfield Boundary condition. Due to using the condition, it should be given 1 value to MU (dynamic viscosity) in part of materials properties considered for water. Also it should be applied 1 value for impedance load to end of reservoir.

Modeling of dam and reservoir system

To modeling dam and reservoir system, we may use structural and fluid elements. Since gravity dam analysis is two-dimensional in softwares, two-dimensional elements Are used. there fore, in ANSYS software, for dam, PLANE 82 element that is 8 nodes and for reservoir, FLUID29 element that is 4 nodes, are selected. in LISA software, for dam, ISO 8-124 element that is 8 nodes and for reservoir, ISO 8-81 element that is 4 nodes are used. Also in ALGOR software, 2-D HYDRODYNAMIC element that has 8 nodes for dam and FLUID 2-D element that has 4 nodes for reservoir are selected. Dam structure element of the 3 softwares is of PLANE STRAIN type. The damping is considered of hysteric type and equal to 0.050. In this analysis, we have ignored the interaction of dam with flexible foundation and foundation dam and foundation reservoir are taken to be rigid. In ANSYS software, middle node PLANE 82 remains open because it does not couple with node from FLUID29 element(4 nodes), to prevent from the related error, freedom degrees of this nodes have coupled with [upper and lower nodes] the degrees of freedom. In LISA software, we have not coupling problems because of equality in the number nodes. In ALGOR software, with regard to that here is not node coupling order, we can use coupling element (COUPLING ELEMENT) that is 2-node element, so that two coupling elements are sited on the common side of the 2 systems and join middle node to upper and lower nodes. Geometry of the dam is as following: (Oued-Fodda.dam in west north of Algeria)

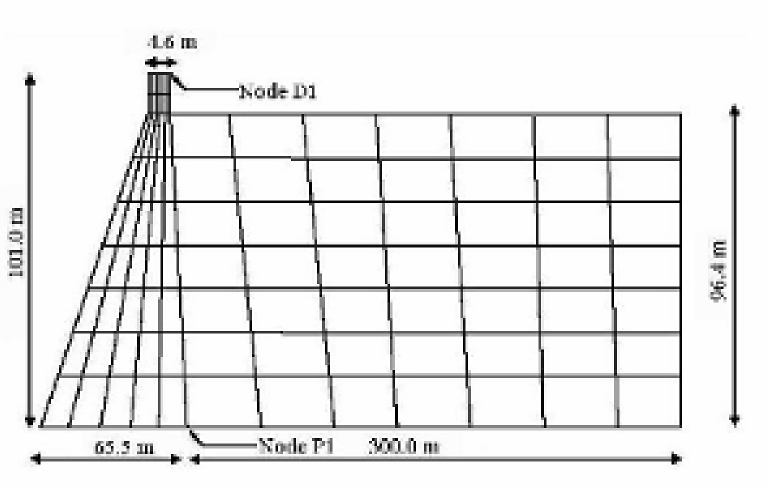

Figure 2. Finite element model used for the Oued-Fodda dam-water system (dam upstream slope 1)

The concrete is assumed to be homogeneous and isotropic with the following basic properties:Elastic modulus Ec = 22.00 GPa,Poisson's ratio νc = 0.20 ,Unit weight γc = 24.8 kN/m³.The water is taken as compressible, inviscid fluid, with weight density of 9.81 kN/m3 and pressure wave velocity of 1435.0 m/s. Meanwhile, studied models are 2 dimensional and carried out analysis's are in time domain (time history analysis). Loma Preita earthquake record is used for horizontal excitation (Figure3). Coupling system is done with reservoir length $L = 3H$ in which H is reservoir depth . The dam and reservoir bottom condition is assumed completely fixed .In the surface of reservoir, the pressure is zero and fluid loading of impedance to end line of the reservoir is applied 1 value , that in water properties part MU=1 is entered. Of course, impedance exists in the there software but MU option isn't in ALGOR software in water properties part, therefore , it is not considered in analysis.

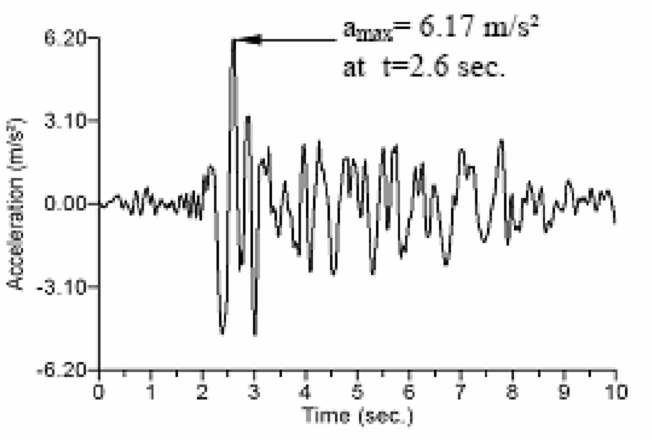

Figure 3. Main horizontal acceleration component of the 1 Loma Preita earthquake (first 1 seconds)

The results of first 5 modes from modal analysis obtained on dam as reference are given in Table 1 below:

Table 1.Vibration periods (sec.) and Frequency (Hz) obtained from Oued-Fodda.dam

Modes	1	2	3	4	5
Period (Sec)	0.3162	0.2585	0.2167	0.1648	0.1260
Freq (Hz)	19.871	24.335	28.995	38.126	49.867

Analysis of time history of the dam is according to dynamic response of the fluid-structure system is plotted in Figure 4(a) for the hydrodynamic pressures computed at the base of the dam (node P1) and in Figure 4(b) for the horizontal displacements computed at the dam crest (node D1) [1]. This reference solution [7] is obtained by using the F.E model with a radiation boundary located at a distance L=3H from the dam-water interface.

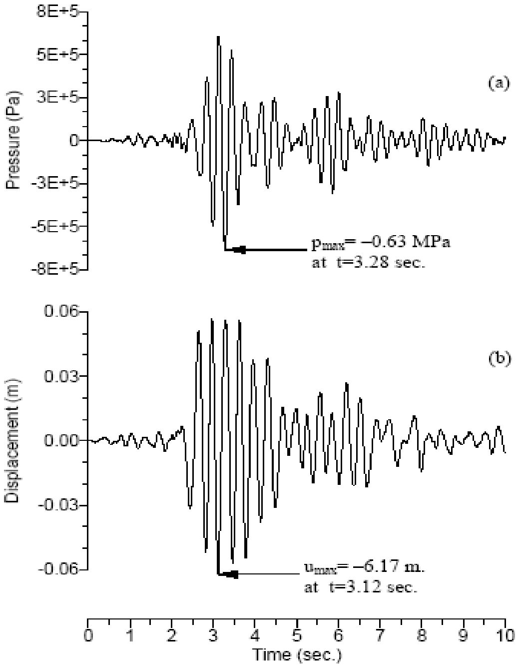

Figure 4. F.E. Reference solutions obtained at L 3H for: (a) for hydrodynamic pressures at node P1 and (b) horizontal displacement at node D1.

Numerical results

When the system with mentioned features in section 3 was modeled by the 3 softwares, was analyzed dynamically. In this analysis, interaction between dam and reservoir was considered and as previous part, system foundation was taken to be rigid and interaction of dam with foundation was ignored.

Modal analysis of dam-reservoir system Numerical results

In ALGOR and ANSYS software, analysis output of modal (rad/see or Hz). In LISA software, output of modal analysis is in terms of Eigenvalues. In the other words, it is equal to ω^2. Therefore, LISA program automatically computes $\sqrt{\omega^2}$. To change this value that has rad/sec or (Hz) unit, frequency amount is obtained from $\omega/2\pi$. The results of firs 5 modes from modal analysis obtained from softwares and reference are in following table:

Table 2. Comparison of vibration modes fre uency in dam ibration periods (sec)

Dam modal analysis results					
	Modes (Rad/sec)				
	1	**2**	**3**	**4**	**5**
Ansys	19,796	23,873	27,975	45,301	57,120
Lisa	19.866	24,320	28,976	38,102	49,851
Algor	20.354	23,471	23,665	36,131	55,901
F . E (Ref)	19.871	24.335	28.995	38.126	49.867

Time history Analysis of Reservoir-Dam system

The results obtained from time history analysis of pressure and displacement in softwares are on graphs in Figures 5 to 6 and are given in following tables 3 and 4 :

Table 3.Maximum value of hydrodynamic pressure(Pmax) and their occurrence time(T)

Time history analysis of pressure				
	F . E (Ref)	**Ansys**	**Lisa**	**Algor**
Pmax (MPa)	-0.660	-0.680	-0.530	-0.605
Differential Pressure (MPa)	-----	0.020	0.13	0.055
T (sec.)	3.280	3.280	3.160	3.420
Differential Time (sec.)	-----	0.000	0.120	0.140

Table 3.Maximum value of horizontal displacement(Ux max) and their occurrence time(T)

Time history analysis of displacement				
	F . E (Ref)	**Ansys**	**Lisa**	**Algor**
Ux max (m)	-0.0617	-0.0623	-0.0617	-0.0595
Differential displacement (m)	-----	0.020	0.13	0.055
T (sec.)	3.120	3.220	3.120	2.960
Differential Time (sec.)	-----	0.100	0.000	0.160

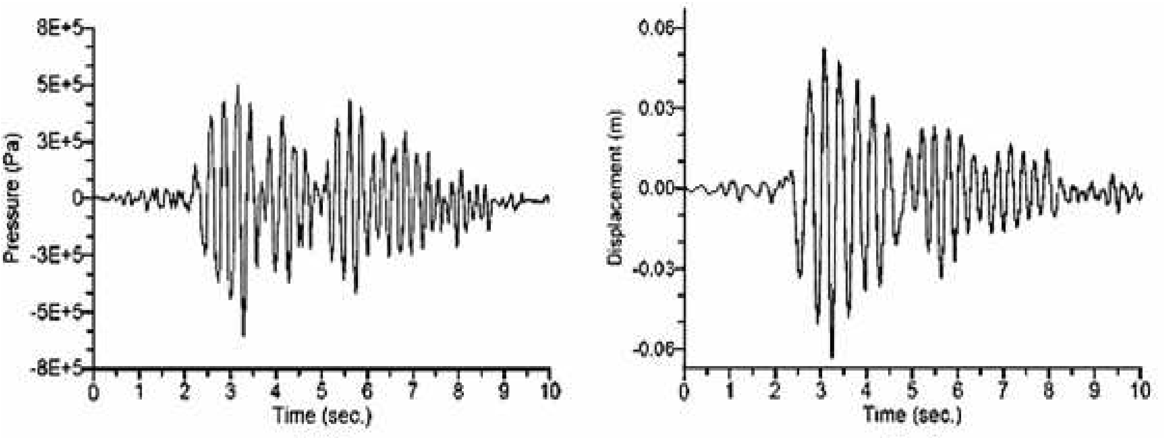

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Figure 5. ANSYS software: (a) Pressures at node P1 at L 3H (b) Displacements at node D1 obtained at L 3H

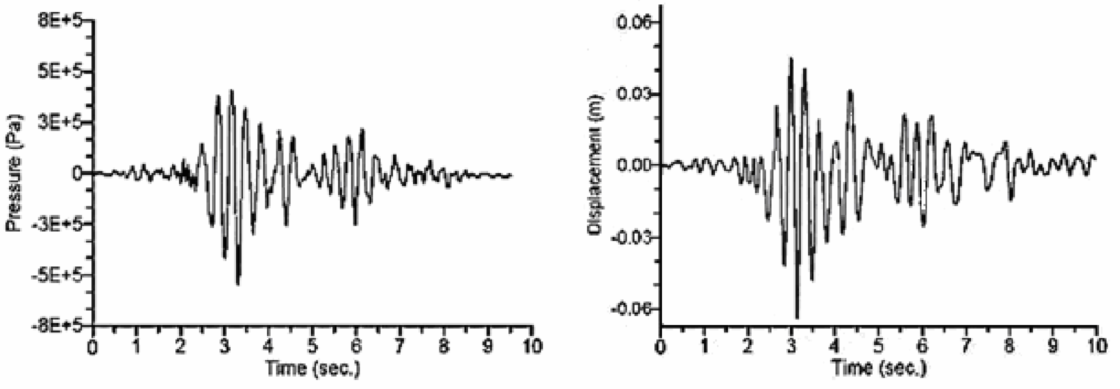

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Figure 6. LISA software : (a) Pressures at node P1 at L 3H (b) Displacements at node D1 obtained at L 3H

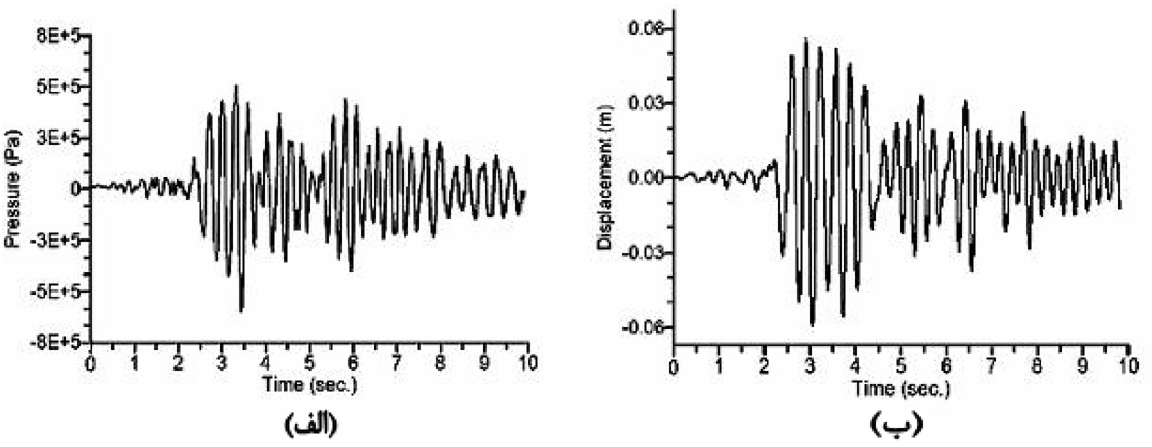

Figure 7. ALGOR software: (a) Pressures at node P1 at L 3H (b) Displacements at node D1 obtained at L 3H

CONCLUSIONS

1- Convergence between responses shows that we can use the existing elements in each 3 software for dynamic analysis of interaction systems of dam and reservoir.

2- In LISA software with regard to fluid element feature (Iso8-81) , we can conclude that in water-structure interaction analysis by Lagrange – Lagrange model by means of finite elements, that the variables of the both environments are taken to be displacements or time history modal analysis (by using less numbers of vibration modes), we can use the LISA software. Also, Lagrange – Lagrange model has the problem of applying suitable boundary condition for water-structure interface, That with regard to equality of the number of dam structure nodes and reservoir fluid nodes, we can solve the problem too.

3- With regard to fluid element feature (FLUID29) in ANSYS software, we can conclude that this software in structure-water interaction analysis by Euler- Lagrange model by means of finite element that nodal unknown in fluid environment is assumed to be hydrodynamic pressure or in Dam-Reservoir interaction with regard to the influence of surface waves during earthquake can be used.

4. In LISA software, with regard to considered element in Dam-reservoir interaction. The analyses can be carried out in frequency domain and compare the results with chopra and other reference results or transfer function graphs. The comparisons can also help in presentation the methods to optimizing the use of the software in dynamic analysis of dam-reservoir in frequency domain.

5- In ANSYS software, in addition to impedance option, the condition of wave absorbing influence in reservoir bottom by MP parameter and or other boundary condition in end of the reservoir and or placing the elements for this purpose (such as FLUID129-FLUID130), can be applied.

6-In ALGOR software, it is a difficult task to do modeling and meshing also presentation boundary condition of reservoir bottom.

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