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Seismic Analysis of Homogeneous Earth Dam and Optimization of Its Parameters Using Pso

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Abstract

In this paper the dynamic behavior of the homogeneous earth dam (Iran), considering dam-foundation interaction, under normalized Manjil earthquake- as input motion- has been studied. In order to assess the effect of the dam heights and the foundation widths, in the finite element model on the earthquake response, various dam-foundation coupled models are analyzed by Plaxis, a finite element package for solving geotechnical problems. In this research, the dam heights and the foundation widths has been chosen optimally using particle swarm optimization (PSO) method. The simulation results indicate considerable differences in the seismic responses.

Keywords: Dynamic analysis, homogeneous earth dam, Manjil Earthquake, particle swarm optimization

INTRODUCTION

In the past years, numerous researches have been conducted in order to determine how dams behave against the seismic loads. In addition, improvements in the different numerical methods have resulted in widespread use of these methods to study dynamic behavior of earth dams; and using dam-foundation coupled model has revealed various aspects of dam response to seismic shaking [1,2]. The finite element method is known to be an effective numerical tool for the solution of boundary value problems on complex domains. In this method for unbounded problems such as seismic wave propagation through the soil, a closed boundary must be considered for the foundation so the geometry of the model, which has a significant effect on the response changes.

In simplified dynamic analyses of structures, it is normally assumed that the structure is fixed at the ground level and subjected to a base motion [1, 2]. The base motion represents the ground motion anticipated at the proposed site and is influenced by the nature and extent of the soil deposit at the site. In addition, the presence of the structure could also influence this base motion. This mutual influence of the structure and the foundation on their responses is commonly referred to as soil-structure interaction. When the response at the base of the structure is essentially identical to that with no structure present, there is no interaction between the soil and the structure. On the other hand, when the response at the base is significantly different for the two cases, strong interaction exists between the soil and the structure. For cases where the interaction is strong, the soil and structure systems should be analyzed together using a coupled system. For cases where the interaction is insignificant, the soil and structure systems can be uncoupled and each analyzed separately.

Very little work has been done regarding the seismic response of dams on flexible foundations. Most of the research has been directed toward the analysis of dams on rigid foundations. Inaudi investigated.the foundation flexibility effects on the seismic response of concrete gravity dams [3]. Motamedi.studied the role of foundation in the seismic nonlinear behavior of concrete gravity dams [4].

Finn and Khanas also evaluated the response of an earth dam on a flexible foundation using the finite element method of analysis. Their results indicated strong dependence of the response on the ratio of the fundamental periods of the dam and the foundation layer[5]. Finn and Reimerg considered the interaction problem between the dam and the underlying foundation layer. They analyzed both the coupled and the uncoupled dam-foundation systems and showed significant differences in the response depending on the period of the systems compared to the fundamental period of the base input motion [6].

Chopra et al. by considering dam as an assemblage of two-dimensional finite elements, and the foundation as an elastic half space, determined the dynamic properties of earth dams including foundation interaction effects [7]. Their results indicate that foundation interaction may have significant influence on the frequencies and mode shapes of vibration of earth dams and the influence of foundation interaction depends significantly on the geometry of the earth dam cross-section, being relatively more important for dams with flatter side slopes. Among the geotechnical software, Quad4 and Plaxis can be used to seismic analysis of the dam-foundation model considering foundation-structure interaction. Quad4 is a dynamic, time-domain, equivalent linear two dimensional computer program to evaluate the seismic response of soil structures. Plaxis with dynamic module can be used to model advanced constitutive behaviors for the simulation of the nonlinear, time dependent and anisotropic behavior of soils and/or rock.

In this study dynamic analysis of Homogeneous earth dam (Iran) considering dam-foundation interaction, under Manjil earthquake (after scaling to a_{max} =0.28g), as input motion, carried out by Plaxis. In order to study the effect of the dam height and foundation width in the finite element model, on the calculated earthquake responses, several dam-foundation coupled models have been solved with Plaxis. In addition, dam heights and the foundation width effect on the displacement of the dam. In order to measure displacement of dam, we have used a nonlinear energy operator (NLEO). In this research, NLEO has been defined as a function of both dam heights and the foundation width. We minimize the cost function using PSO algorithm.

Soil-structure interaction (SSI) is an important issue, especially for stiff and massive structures constructed on the relative soft ground, which may alter the dynamic characteristics of the structural response significantly.

Thus, the interaction effects should be accounted for in the dynamic analysis of all soil-structure-system, particularly in severe soil conditions. The SSI system has two characteristic differences from the general structural dynamic system. These are the unbounded nature of the soil and the non-linear characteristics of the soil medium.

The radiation of the energy towards infinity, leading to the so called radiation damping, is the most prominent characteristic in an unbounded soil, which is not relevant in a bounded medium. Various studies and contributions have appeared in the literature regarding the effects of SSI on the dynamic seismic response of buildings [8].

This paper is organized as follows: The Homogeneous earth dam properties are described in Section 2. Section 3 presents the numerical modeling for the dynamic analyses. The theoretical foundation of NLEO and PSO has been presented in Section 4. The performance evaluation of the proposed method is provided in Section 5. Section 6 summarizes our conclusions.

MATERIALS AND METHODS

1. Definition Of Project (A Brief Introduction To The Homogeneous Dam)

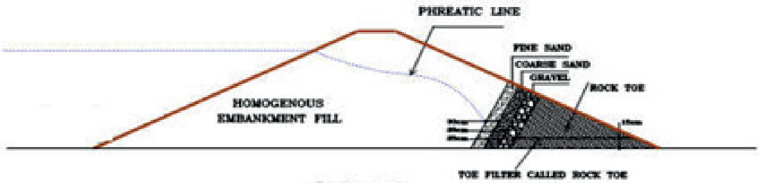
A homogeneous rockfill dam with 52m height is modeled on this study.

Table 1 provides the main features of the Homogeneous dam, and Fig. 1 show typical cross-sections of the dam body [9].

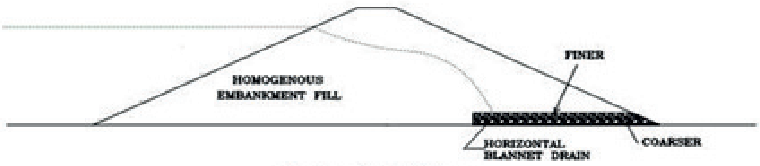
Fig. 2 shows typical cross section of the dam-foundation coupled model. which is located in Alborz seismic zone where active periods have been observed. One of the most important earthquakes that occurred in this area, was the 1990 Manjil earthquake, with Mb=7.3 and Ms=7.7.

Table 1 . Main feature of the Homogeneous dam

No	Description	Unit	Quality
1	Crest length	m	180
2	Crest width	m	8
3	Crest level	m	153
4	Height above lowest core foundation	m	51.5
5	Filter volume	m^3	19000
6	Normal water level	m	148
7	Dam height from river bed	m	54.5
8	Volume for reservoir	m^3	8*106



Rock Toe



Horizontal Fillter

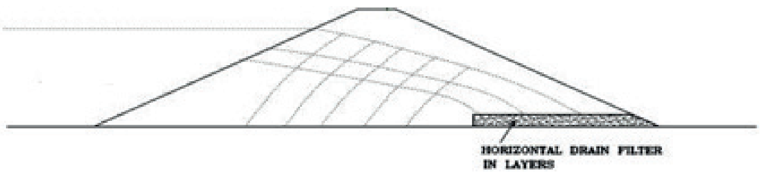


Fig. 1. Typical cross-sections of the dam body.

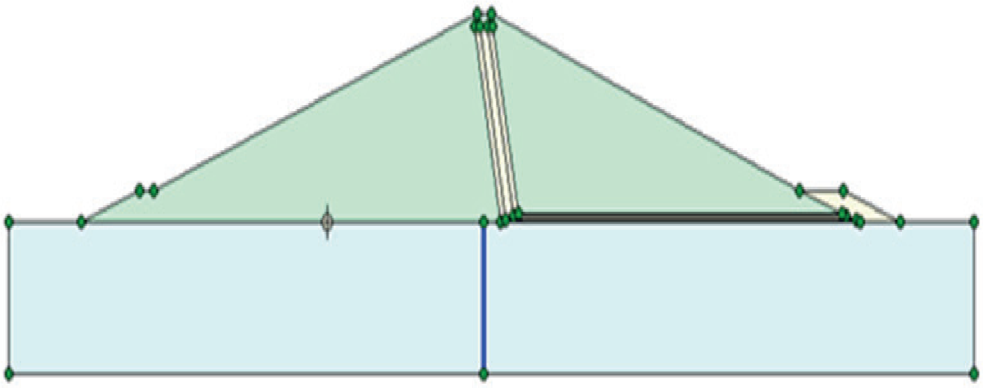


Fig. 2. Typical section of the dam-foundation coupled model.

2. Dynamic Analysis

The numerical modeling for the dynamic analyses has been performed using the Plaxis program, which are based on finite element method. Fig. 3 shows the geometry of the dam-foundation coupled model of the Homogeneous earth dam. Dynamic analyses were performed for the end of construction stage using the elasto-plastic Mohr-Coulomb model for material nonlinear behavior. Material properties of dam body and foundation have been presented in Table 2. In order to absorb the increments of stresses on the boundaries caused by dynamic loading, absorbent boundaries has been used. For accurate representation of wave transmitted in the model, the element sizes should be selected small enough to satisfy the following criteria expressed by Kuhlemeyer & Lysmer [10]:

$$\lambda \leq \frac{\Delta l}{10} \tag{1}$$

where λ is the wave length associated with the highest frequency component that contains appreciable energy and Δl is the length of element. Considering to these criteria, the element size have been selected as fine as possible.

It should be mentioned that shear modulus, G has been modified according to effective mean stress (σ_0) as

$$G = G_i \sqrt{\frac{\sigma_0}{\sigma_{0i}}} \tag{2}$$

Small viscous damping is added for dam body. This damper was given by Rayleigh damping: the damping factors were assumed 0.005 for the first and second natural periods.

Earthquake response analyses were carried out for Manjil earthquake. The acceleration time histories of the Manjil Earthquake as shown in Fig. 4, were normalized to a maximum acceleration of *0.28g* which has been considered inaccordance with Maximum Design Level (MDL).

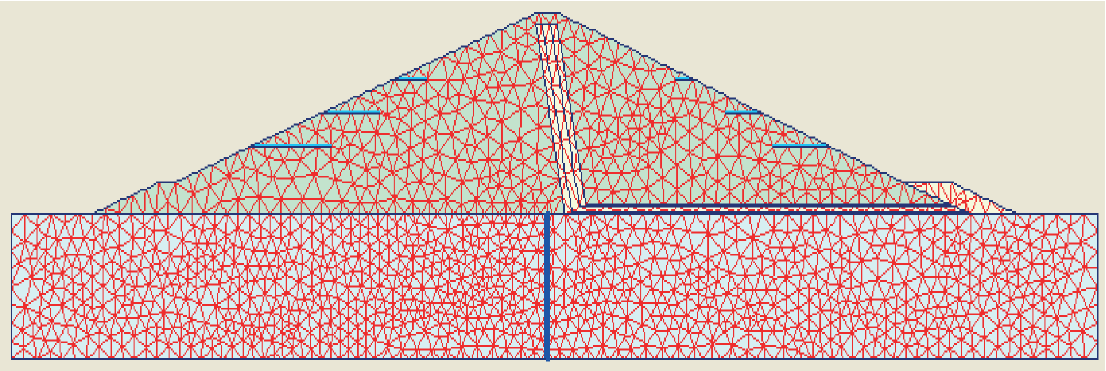


Fig. 3. model of dam-foundation and its elements.

Table2. Material properties of the Homogeneous earth dam

Type of material	γ (KN/m**3**)	C (KPa)	φ	E (MPa)	υ
Dam body	21.5	27	23	215	0.3
foundation	21.5	1	42	270	0.3
Drain material	20.5	1	42	345	0.25

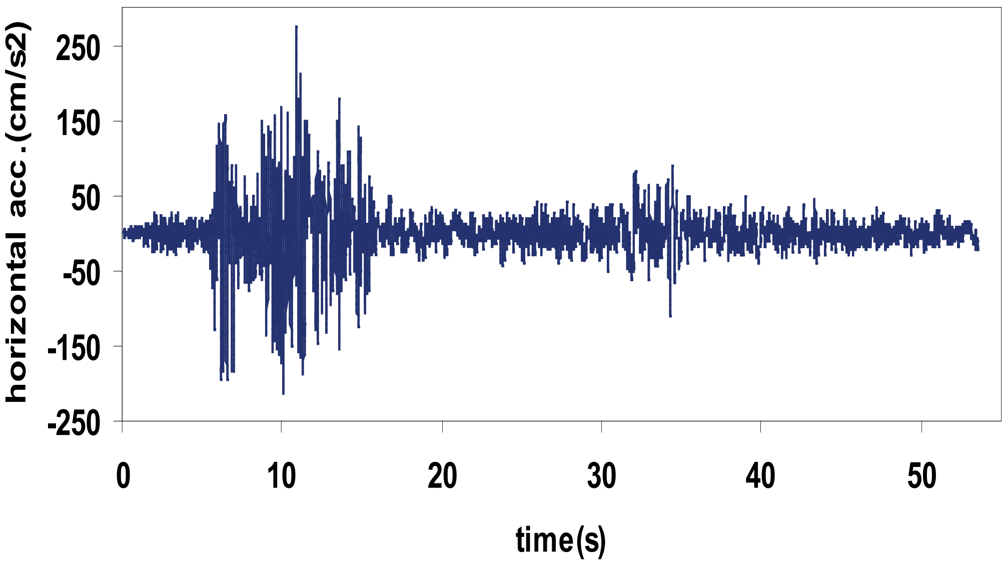


Fig. 4. Normalized horizontal component time history of Manjil earthquake.

3. NLEO (NonLinear Energy Operator)

Teager proposed (as presented in [6]) a simple NonLinear Energy Operator (NLEO) $\o_d$ given here in its discrete form as

$$\o_d[x(n)] = x^2(n) - x(n-1)\,x(n+1)$$

By using simulated signals, Kaiser [6] analyzed this operator and found that it can detect frequency and amplitude of these signals. One of its key properties for a pure tone can be summarized by the rule

$$Q_d(n) = \psi_d[A\,Cos\,(\omega_0\,n+\theta] = A^2\,Sin^2\,\omega_0 \quad (3)$$

The proven can be expressed as:

$$\begin{aligned} & Q_d(n) = \psi_d[A\cos(\omega_0 n+\theta] = A^2\cos^2(\omega_0 n+\theta) - A\cos(\omega_0(n-1)+\theta)* \\ & A\cos(\omega_0(n+1)+\theta) = \frac{A^2}{2}[1+\cos(2\omega_0 n+2\theta] - \frac{A^2}{2}\cos(2\omega_0 n+2\theta) - \\ & \frac{A^2}{2}\cos(2\omega_0) = \frac{A^2}{2} - \frac{A^2}{2}\cos(2\omega_0) = \frac{A^2}{2}[1-\cos(2\omega_0)], 1-\cos(2\omega_0) = 2\sin^2\omega_0 \\ & \Rightarrow Q_d(n) = \psi_d[A\cos(\omega_0 n+\theta] = \frac{A^2}{2}*2\sin^2\omega_0 = A^2\sin^2\omega_0 \end{aligned} \quad (4)$$

For ω_0 much less than the sampling frequency,

$Q_d(n) = A^2\,\omega_0^{\ 2} = cte$. Therefore, the output of

NLEO is proportional to multiplication of instantaneous amplitude and frequency of the input signal.

With the above motivation, Kaiser [6] used the second order differential equation governing the simple harmonic motion and the energy (sum of the kinetic and potential energies) required to generate the motion, to introduce a continuous-time counterpart of the NLEO,

$$\o_C[x(t)] = (x'(t))^2 - x(t)\,x''(t)$$

The instantaneous energy, E_0, of an undamped oscillator is constant and is proportional to the output of ***(3)*** [6].

$$\o_C[x(t)] = A^2 \grave{u}_0^{\,2} \quad \propto \quad E_0 = \frac{m}{2} A^2 \grave{u}_0^{\,2}$$

where $x(t) = A\,Cos\,(\omega_0 t + \theta)$ with $\grave{u}_0 = \sqrt{(k/m)})$

is the displacement of the oscillator and ***k*** is the spring constant and *m* is the mass. Kaiser gave an interpretation of **(4)** as the amount of energy required to generate a sinusoid. Unlike the classical mean-square error *(mse)* definition of energy, this definition depends not only on the amplitude but also on the frequency of the sinusoid. To illustrate this difference, consider two sinusoids with frequencies of 1 Hz and 1 kHz but with the same amplitude. It is clear that *mse* energy will be the same for both sinusoids, while **(4)** suggests different amounts of energy requirement to generate these two signals. The latter relates the energy to the physics of generating a sinusoid of a given frequency [7]. As such, we will refer to the output of the NLEO **(4)** as the frequency weighted energy (FWE).

4. Pso (Particle Swarm Optimization)

Particle Swarm Optimization is a metaheuristic search algorithm introduced by Eberhart and Kennedy in 1995 [11] to find optimal solution in engineering design optimization. PSO is based on the concept social models and swarm theories. The swarm consists of individual particles, which mutually try to find the solution in the search space. In each iteration, individuals (particles) move toward the best solution, which is experienced by them (Personal best) and concurrently to the best solution, which is obtained by the other particles (Global best). PSO is established based on few or even no assumption on the search space; this feature enables PSO to search the optimum solution in a wide search space. In addition, PSO can be used in the optimization problems which are irregular, noisy, or dynamic [12]. Recently, the PSO was used in different applications by various researchers worldwide [13, 14, 15, 16]. The basic operational principle of the particle swarm is reminiscent of the behavior of a group of a flock of birds or school of fishes or the social behavior of a group of people [17]. Each individual flies in the search space with a velocity, which is dynamically adjusted according to its own flying experience and its companions' flying experience, instead of using evolutionary operators to manipulate the individuals like in other evolutionary computational algorithms. Each individual is considered as a volume-less particle (a point) in the N-dimensional search space. At time step t, the i^{th} particle is represented as $X_i(t) = (x_{i1}(t)\ x_{i2}(t),\ldots,x_{iN}\ (t)$. The set of positions of *m* particles in a' multidimensional space is identified as $X = \{X_1,\ldots,X_j,\ldots,X_{l.},\ldots,X_m\}$. The best previous position (the position giving the best fitness value) of the i^{th} particle is recorded and represented as $P_i(t) = (p_{i1}, p_{i2},\ldots, p_{iN}\ )$.The index of the best particle among all the particles in the population (global model) is represented by the symbol *g*. The index of the best particle among all the particles in a defined topological neighborhood (local model) is represented by the index subscript *l*. The rate of the position (velocity) for particle *i* at the time step *t* is represented as $V_i(t) = (v_{i1}(t)\ v_{i2}(t),\ldots v_{iN}\ (t)$. The particle variables are manipulated according to the following equation (global model [18]):

$$v_{in}(t) = w_i * v_{in}(t-1) + c_1 * rand1() *$$
$$(p_{in} - x_{in}(t-1)) + c_2 * rand2() * (p_{gn} - x_{in}(t-1))$$

Where *n* is the dimension $(1 \le n \le N)$, c_1 and c_2 are positives constants. These factors are used to value individual and social experiences. Kennedy suggested value 2 for both in the original PSO version; while, recent studies recommend 1.494. regards 1.5 to 2 for C1 and 2 to 2.5 for C2 more efficient., $rand1()$ and $rand2()$ are two random functions in the range [0,1]. This parameter is used in order to prevent being trapped in local optimal points and to comprehensively probe searching space. It operates like mutation operator in genetic algorithm. , and w is the inertia weight. In order to control velocity and avoid its explosion, a coefficient is used as inertia weight coefficient. This value was constant in the original version; however, recent studies revealed that linear reduction of W from 0.9 to 0.2 responses better within algorithm iterations. This indicates high velocity at the beginning of probing and low velocity approaching optimal answer. Early versions of PSO applied Vmax parameter (maximum speed) to remove this problem such that the algorithm hinders exceeding the velocity and enables better searching.[19] For the neighborhood (*lbest*) model, the only change is to substitute p_{ln} for p_{gn} in equation for velocity. This equation in the global model is used to calculate a particle's new velocity according to its previous velocity and the distance of its current position from its own best experience *(pbest)* and the group's best experience *(gbest)*. The local model calculation is identical, except that the neighborhood's best experience is used instead of the group's best experience.

The constants c_1 and c_2 in above equation represent the weighting of the stochastic acceleration terms that pull each particle toward *pbest* and *gbest* positions. Thus, adjustment of these constants changes the amount of 'tension' in the system. Low values allow particles to roam far from target regions before tugged back, while high values result in abrupt movement toward, or past, target regions.

The inertia weight w controls the impact of the previous histories of velocities on the current velocity, thus influencing the trade-off between global (wide-ranging) and local (nearby) exploration abilities of the 'flying points'. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run (total number of generations prior termination), the PSO tends to have more global search ability at the beginning of the run while having more local search ability near the end of the run [20].

RESULTS

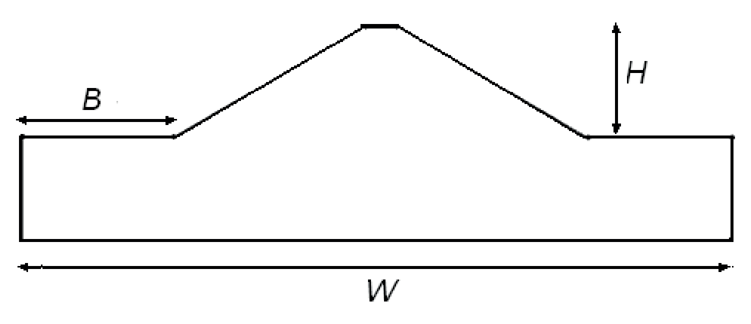
In order to evaluate the effects of dam height (*H*) and width of the foundation (*W*) on the finite element solution, some experiments had been carried out in the finite element model [9] (See Table 3). On the basis of experiments, it had been found that lateral extent must be selected less than twice the dam height in the finite element model. In this work, an energy fitness function has been defined so that horizontal displacement time history at the dam crest in the finite element model on the earthquake response is minimized. The fitness function has been considered as a function of *B/H* ratio and we minimize the cost function using PSO algorithm.

In this experiment, the following PSO parameters are used:

Population size: 30; $\text{Weight}_{max}=1$; $\text{Weight}_{min}=0.4$; C1 =C2 =2; Dimension=2; Iteration: 1000. *B* and *H* parameters change between 50-200 and 30-90, respectively. The PSO algorithm was implemented using MATLAB from Math Works. In this experiment, by using the PSO algorithm the *B/H* ratio should be equal to 1.29.

Table 3. Desired Dam Heights Lateral Extents And Foundation Width Lateral extent, earth dam height and the width of foundation

Model Number	H (m)	B (m)	W (m)
1	30	50	303
2	30	100	403
3	30	200	603
4	60	50	498
5	60	100	598
6	60	200	798
7	90	50	669
8	90	100	769
9	90	200	969



CONCLUSION

In this study, dynamic analysis of Homogeneous earth dam considering dam-foundation coupled model with various foundation widths and dam heights under horizontal component of Manjil earthquake has been performed using the Plaxis program. In the previous work, *B/H* ratio has been adjusted experimentally. However, in this research it has been found optimally using PSO algorithm. Several experiments has been carried out and the results shown the efficiency of the proposed idea.

REFERENCES

1) Baziar MH, Merrifield CM, Salemi SH, Heidari T. 2004. Three-dimensional dynamic analysis of alborz dam with asphalt and clay cores. Proc. of 5th International Conference on Case Histories in Geotechnical Engineering.

2) BAZIAR MH, NOORZAD A, SALEMI SH, GHANNAD Z. 2003. Evaluation of Earthquake response of 15th Khordad Earth Dam. Proc. of the 21st ICOLD International Congress, Montreal.

3) Inaudi JA, Matheu EE, Poeppelman RL, Matusevich A. 2012. Foundation Flexibility Effects on the Seismic Response of Concrete Gravity Dams. U.S. Army Engineer Research and Development Center, Sacramento, California, USA.

4) Motamedi MH, Amini A, Ghaemian M. 2009. The study of the foundation role in the seismic nonlinear behavior of concrete gravity dams. The 14th World Conference on Earthquake Engineering.

5) FINN WL, KHANNA J. 1966. Dynamic response of earth dams. Proc. 3rd Symp. Earthquake Engng, University of Roorkee, U.P, India.

6) FINN WL, REIMER RB. 1970. Effect of soil structures interaction on seismic response. Proc. Conf. Earthquake.

7) CHOPRA AK, PERUMALSWAMI PR. 1971. Dynamics of Earth Dams with Foundation Interaction. Journal of the Engineering Mechanics Division, 97, No. 2.

8) BEN JS, SHIOJIRI H. 2000.A method for three dimensional interaction analysis of pile-soil system in time domain. Trans Jpn. Soc.Comput. Eng. Sci.

9) Litkouhi S, Sharifi A. 2010. Asphalt concrete core of the Homogeneous dam in brief. Principal Geotechnical Engineer & Project Manager.

10) KUHLEMEYER RL, LYSMER J. 1973. Finite Element Accuracy for Wave Propagation Problems. Journal of Soil Mechanics & Foundation Division, ASCE, Vol.99, No 5.

11) KennedyJ, Eberhart R. 1995. Particle Swarm Optimization. Proceedings of the IEEE. International Conference on Neural Networks, 1942-1948.

12) Radavilela J, Johnston M, Zhang M. 2014. Population statistics for particle swarm optimization: resampling methods in noisy optimization problems. Swarm and evolutionary computation, 17:37-59.

13) . Kaveh A, Mahdavi V. 2011. Optimal design of arch dams for frequency limitations using charged system search and particle swarm optimization. Int J Optim Civil Eng. **1**:543-555.

14) Azad SK, Hasançebi O. 2013. Improving compu-

tational efficiency of particle swarm optimization for optimal structural design. Int J Optim Civil Eng. **3**:563-574.

15) Kaveh A, Nasrollahi A. 2013. Engineering design optimization using a hybrid PSO and HS algorithm, Asian J Civil Eng. **14**:201-223.

16) Shojaee S, Valizadeh N, Arjomand M. 2011. Isogeometric structural shape optimization using particle swarm algorithm, Int J Optim Civil Eng. **1**: 633-645.

17) Eberhart RC, Kennedy JA. 1995. New optimizer using particle swarm theory. PROC. ISMMHS, PP.39-43.

18) SHI Y, EBERHART RC. 1999. A Modified Particle Swarm Optimizer. in Proc. IJCNN: 69-73.

19) Hamzee Yazd HG, Arabshahi SJ, Tavousi M, Alvani A. 2015. Optimal Designing of Concrete Gravity Dam using Particle Swarm Optimization Algorithm (PSO) Indian Journal of Science and Technology, Vol. 8 No.12.

20) SHARAHI JM, ANISHEH SR. 2010. Seismic Analysis of Narmab earth dam (IRAN) considering dam foundation interaction. ICOLD Conference, Vietnam.