A case study on risk and Liquefaction Potential analysis of earth dam under earthquake vibrations -Lar earth dam, Iran

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ABSTRACT: By attention to little knowledge in visualization of soil liquefaction behavior at depth, the present paper has an attempt to develop a scientific frame of studying the liquefaction behavior, because a number of embankments, natural slopes, earth structures and foundations failures have been attributed to the liquefaction of sands caused by static or seismic loading. This study aims to present the liquefaction behavior at different depths and uses a scientific judgment to enhance understanding of liquefaction phenomenon. A simple but applicable algorithm using geotechnical data, seismic recording of an occurred earthquake, interactive transfer functions with combination of several software packages and MATLAB programming environment has been applied to establish combined coupled techniques for evaluation of soil liquefaction behavior. Data from the experimental insitu and laboratory tests including cyclic shear stress and shear strain, acceleration and excess pore pressure as a function of time for different depths was collect and used. To modify, the proposed method was applied to Lar earth dam (Iran). The results indicated that the proposed method with scientific visualization is a valuable tool which able properly characterizes the liquefaction behavior and its comparison with other known procedures verified the proposed method.

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INTRODUCTION

Seismic hazard generally is defined as the physical effects such as ground shaking, surface faulting, land sliding or liquefaction that occur as the result of an earthquake. These effects may be negligible to severe depending on the earthquake magnitude, site distance from the earthquake epicenter and local site conditions.

Casagrande (1950) was one of the first persons noticed the problem of dynamic instability. Klohn et al (1978) had modified the simple pseudo-static method and proposed a methodology which couples a conventional pseudo-static method of dynamic analysis with an evaluation of the seismically induced pore pressures. Newmark (1965) introduced “sliding block method” to compute the seismic displacement of the dam. Clough and Chopra (1996) used the finite element method for two-dimensional plane-strain analysis of an embankment for evaluating the dynamic response. To understand the stability of coal-waste tailings dams, Zeng et al (1998, 2008) conducted field, laboratory and centrifuge tests.

Using software packages mostly based on Finite Element Method and/or Finite Difference Method some researchers such as Piao et al (2006), Seid-Karbasi and Byrne (2004) and Zhu (2009, 2011) carried out dynamic analysis of the earthen dams.

Soil structures in embankments and earth dams have been frequently damaged due to liquefaction of the embankment and/or foundation soils during past major earthquakes (Seed, 1968, 1970; Matsuo, 1996; Krinitzsky and Hynes, 2002). In most cases, large deformations occurred due to liquefaction of the supporting loose cohesionless foundation soil (Seed 1968; Tani 1996; Krinitzsky and Hynes 2002), resulting in cracking, settlement, lateral spreading, and slumping of the overlying soil structures. Such earthquake liquefaction hazard necessitates the development of appropriate remediation countermeasures (Ledbetter et al. 1994; Marcuson et al. 1996).

Liquefaction analysis is generally performed using simple procedures developed by Seed et al (1983). However in many situations it is necessary to evaluate liquefaction at very large depths. This is true for both homogenous and layered soils. In addition to the experimental approach, numerical studies have been recently performed to interpret response results to study the effect of depth on soil liquefaction for susceptible sand deposits (Amini and Duan, 2002a; Amini and Duan, 2002b; Abbaszadeh Shahri, etal, 2011a, 2011b).

SEISMOTECTONIC AND SEISMICITY OF SELECTED REGION

The investigation of seismicity at the sites of large reservoirs provides important data for the design of dams and other structures in the vicinity. The seismological problem is to predict the pattern of earthquake activity over the lifetime of the dam including the effects of constructing the dam and filling the reservoir.

Alborz Mountain is the main part of Alborz-Azarbaijan seismotectonic province with a high prone active seismic area and responsible for several large destructive earthquakes in the past decades. As shown in figure1, Alborz Mountains with EW trend in the north of Iran are considered as mountains without root that its uplift is due to thrusting of allochthonous masses over each other in a compressional tectonic regime. The depth of Moho in Alborz Mountains is less than 35km (Dehghani and Makris, 1983). So, Alborz Mountains can be considered as thin skinned orogen or thin and thick skinned orogen (Berberian, 1981). If this matter is correct, surface faults cannot be responding for seismicity of Alborz. Geological- tectonic investigations in the Alborz Mountains obviously show that these ranges have been formed by thrusting of folded rocks over each other (Stocklin 1968, Berberian 1983). This matter is reason for height of Alborz. The focal mechanism of Alborz's earthquake, (Mckenzie, 1972) indicate strike-slip mechanism with some reverse component. The south of Alborz mountain series is located Central Iran desert and Zanjan - Tabriz compressive depression (Ghorash and Ghasemi, 2003).

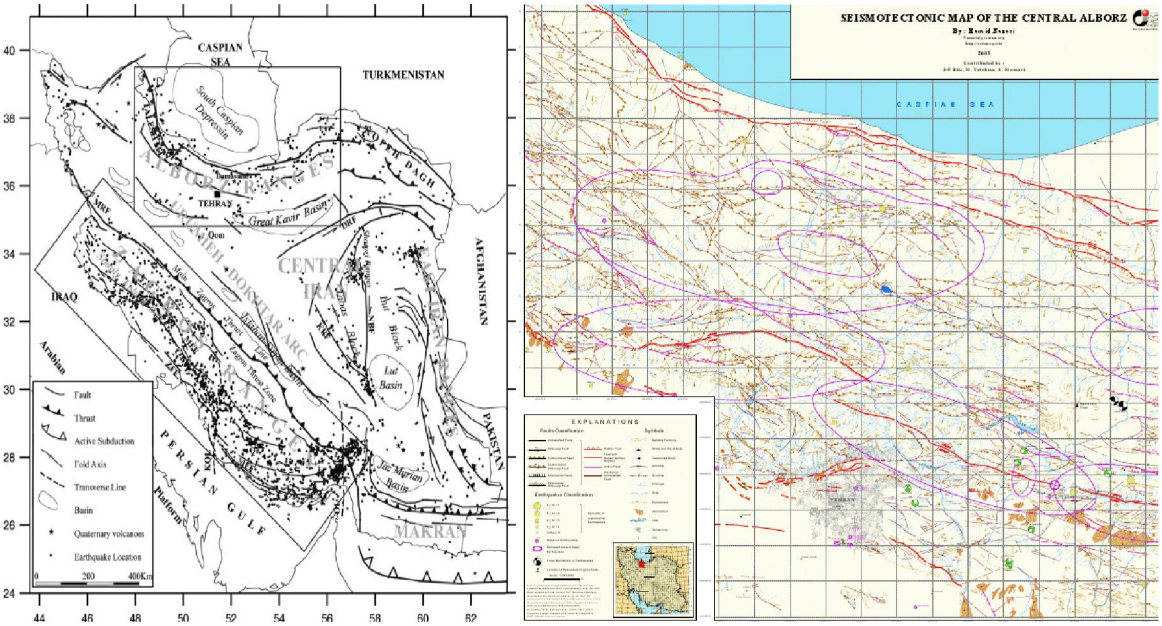

Figure1. Location and sesimotectonic map of the Alborz ranges (north of Iran)

APPLIED EARTHQUAKE FOR THIS STUDY

On 2004 May 28 an earthquake of Mw 6.2 occurred near Baladeh in the Alborz mountains, approximately 70 km north of the Tehran. Although of only moderate size, it was very significant for two reasons. First, it was the first earthquake of the modern seismological era to occur near Tehran, close enough to cause strong ground shaking and widespread panic within the city. According to figure2, Teleseismically recorded earthquakes in the Iran region in the period 1964–2004 (yellow dots), from the catalogue of Engdahl et al. (2006), with the velocities of points in Iran relative to Eurasia determined by GPS shown by red arrows (Vernant et al., 2004). The black arrow at the bottom of the map is the velocity scale. Major faults in Iran are shown by thin lines. The epicentre of the 2004 Baladeh earthquake, on the southern margin of the South Caspian Basin is marked by a black circle.

Map of the central Alborz, with SRTM digital topography colored to emphasize the high mountains (white) and the deep valleys (red) that penetrate the range. The lower hemisphere fault plane solution for the 2004 Baladeh earthquake is shown with compressional quadrant in red, positioned at our favored epicenter. Thrust faults are marked with teeth on the hanging wall as NT (North Tehran fault), Ko (Kojour fault), Na (North Alborz fault), and Kh (Khazar fault). The left-lateral Mosha fault (M) is marked by a line with no teeth. The blue star (D) is the western edge of the Damavand stratovolcano. White circles show the very approximate estimated centers of the damage regions of the 4th century BC, 855, 958 and 1830 earthquakes, from Ambraseys & Melville (1982).

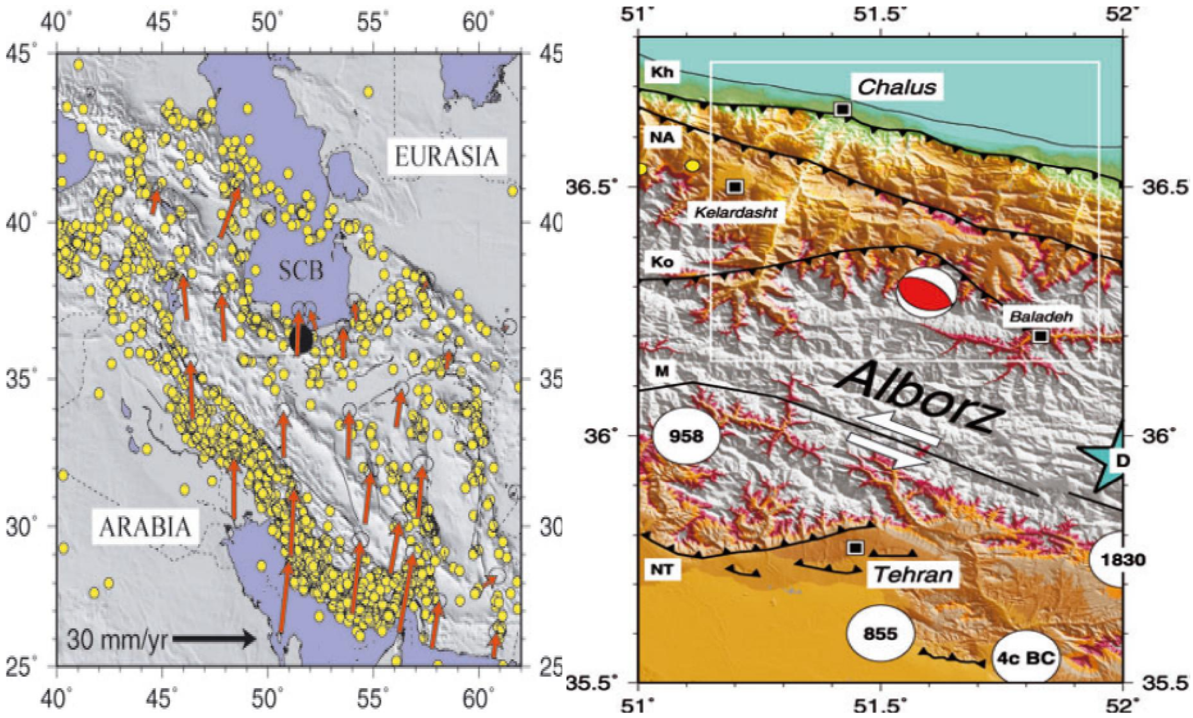

Figure2. Location of Baladeh event (left) and the map of central Alborz (right)

LAR EARTH DAM CHARACTERISTICS

This earth dam was located downstream of Lar river valley in the intersection of Lar and Delichai rivers. Lar River in Mazandaran province under the name of Haraz River goes to Caspian Sea. Delichai, Sefid Ab and Gezel Darreh are the main input rivers to this dam.

Regarding to figure3 the Lar earth dam which is located in 56.01 east longitude and 35.88 north latitude has constructed in 75Km distance from north east of Tehran for the purpose of water supply and power generation in Alborz Mountains at high prone seismic active area. This core clay earth dam with 105m height has a 29 Km^2 area and 17 Km long for the lake at elevation of 2531m. The dam crest line length at altitude of 2539m is 1150m with 13m wide at the top and 800m wide at the bottom in the river bed. According to figure4 which is show the geological section of the dam site, the upstream side of the dam had multiple longitudinal cracks indicating to movement towards to the reservoir, no visible cracks were observed on the downstream side. The foundation is sandstone and limestone with several meters surface deposit thickness. A total of $21Mm^3$ embankment and excavation operation were performed for this dam. This dam with a 100 years predicted operational period has a $960Mm^3$, 23 Mm^3 and 937 Mm^3 for total, dead and effective reservoir capacity respectively.

No site-specific information was available about the subsurface soils other than the qualitative information that the site is underlain by alluvial, loose to medium dense, sand-silt mixtures over shallow sandstone bedrock. Liquefaction susceptibility of the foundation soils was not considered in the original design.

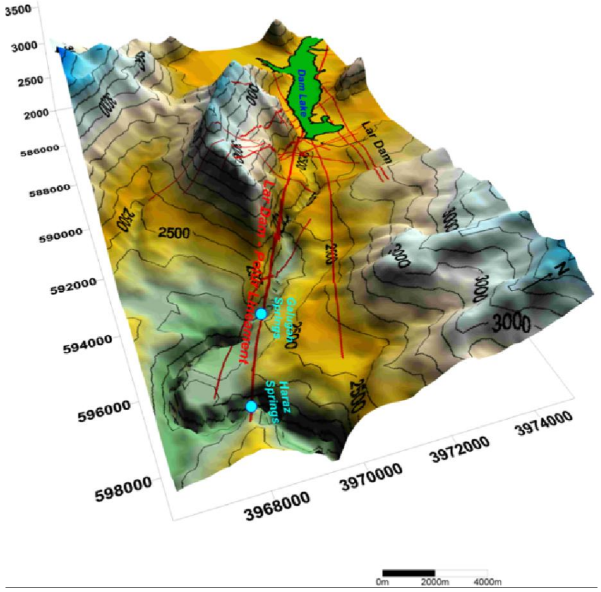

Figure 3. Topographic location of the Lar dam

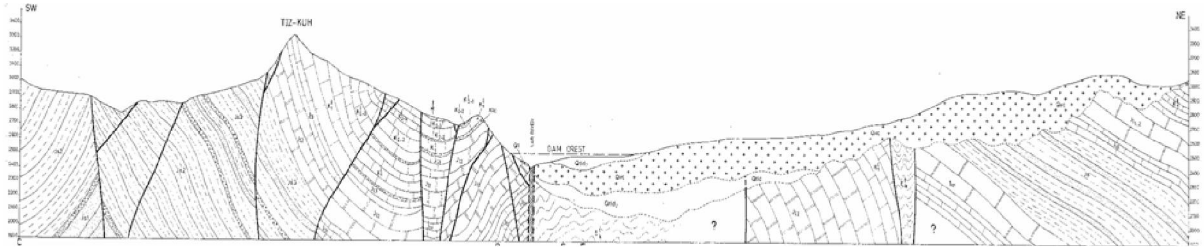

Figure 4. Geological cross section along Lar dam axis

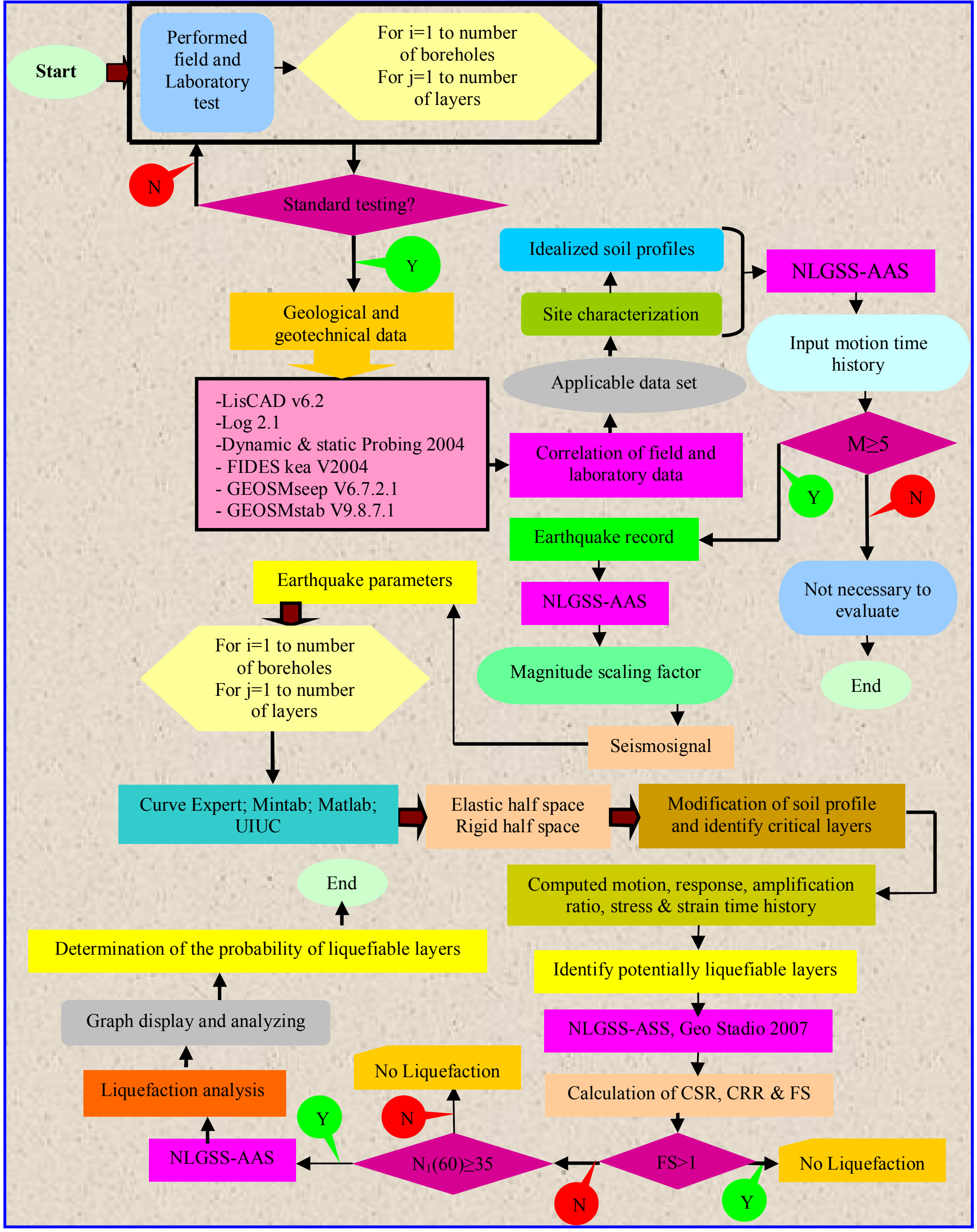

Figure5. Proposed flowchart of this study

PROPOSED METHOD

In an effort to evaluate earthquake liquefaction potential of soil media, several statistical models ranging from purely empirical to mathematically sophisticate have been devised. While deterministic methods define susceptibility of a soil structure to liquefaction, for a given seismic event, in the sense that the site does or does not liquefy, probabilistic approaches incorporate statistical properties associated with both the earthquake and site characterization. According to figure5, after selecting the appropriate earthquake, the motion for dam crest and toe (bed) and pore-water pressure was computed as shown in figure 6. The procedure for assessing liquefaction potential typically uses the Cyclic Resistance Ratio (CRR) as a measure of the liquefaction resistance of soils and the Critical Stress Ratio (CSR) as a measure of earthquake load. For cohesion-less soils, CRR has been related to normalized SPT blow count, (N1)60, through correlations that depend on the fines content of the soil from field performance observations from past earthquakes. The normalized SPT blow count is given by (N1)60 = N× (Pa/ Cvo)0.5 × ER, where N is the raw SPT blow count, Pa is the atmospheric pressure (D 100 kP a), Cvo is the effective vertical stress at the depth of testing, and ER is the energy ratio (0.92 in a typical Indian SPT setup). On base of performed laboratory and field test and by taking in to account the figure5, SPT blow count, pore and excess pore-water pressure were executed as pointed in figures 7 and 8.

At the next step, again by refer to figure5, and by combination of several software packages with the generated computer code name as "NLGSS_AAS" which is able to link with MATLAB programming environment the authors could get logic and suitable graph for interpretation. At the first for improved and proposed soil column, the required geotechnical parameters were calculated as indicated in table (1). The obtained results in this stage are input for software combinations. The output results of previous stage presented in figures 9 to 14 respectively.

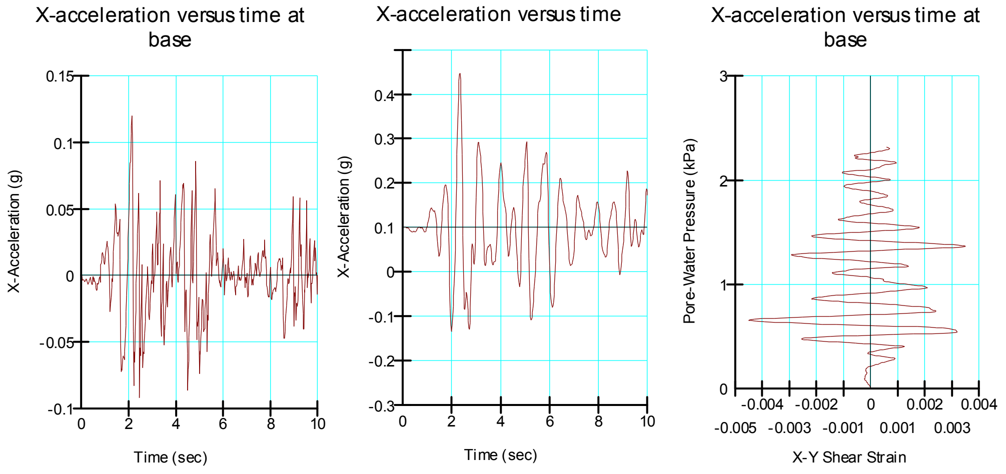

Figure6. Computed motion at crest (middle) and toe (left) and pore-water pressure of the dam

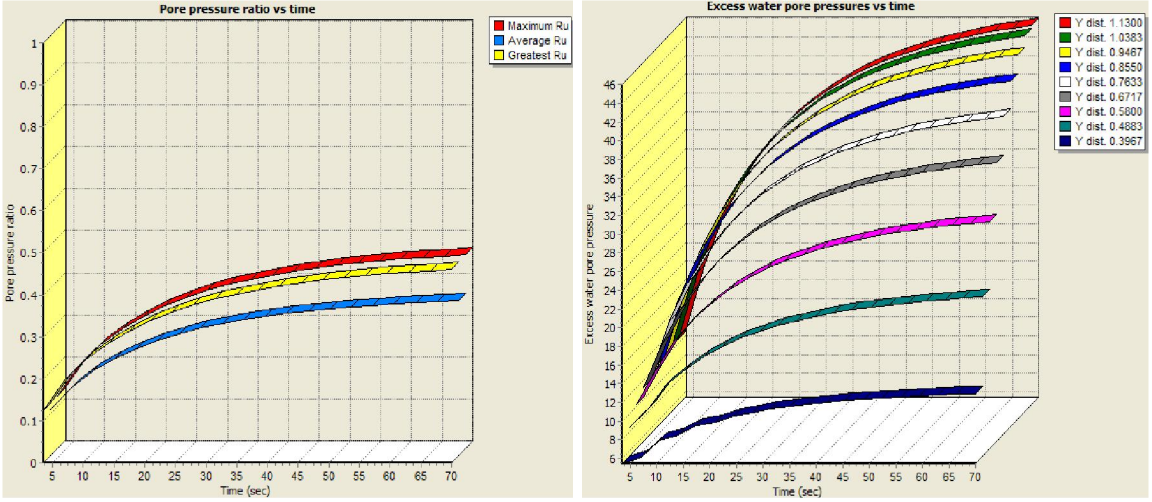

Figure7. Variation of pore (left) and excess pore pressure (right) versus time

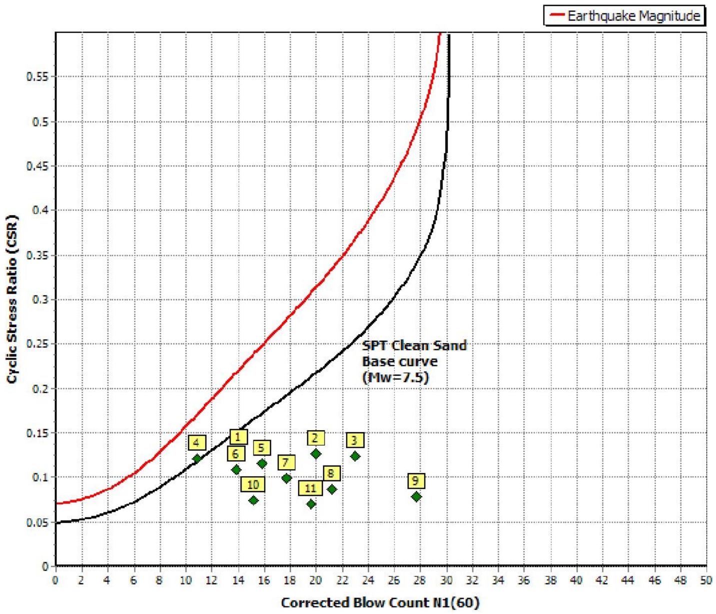

Figure8. Variation of SPT for tested boreholes in the selected area

Table (1). Computed required geotechnical parameters for selected area

No	Depth	gamma	% FC	sv (kPa)	s'v (kPa)	Nspt	N1(60)	DN1	CSR	CRRm	F.S.	%Fs
1	-2	15.5	0.59	31	31	7	14	7.2	0.13	0.22	1.72	0.12
2	-4	15.7	0.53	62.4	62.4	14	19.9	7.2	0.13	0.31	2.47	0.02
3	-6.5	16.1	0.49	102.65	102.65	19	22.9	7.2	0.12	0.36	2.92	0.02
4	-8.5	16.2	0.61	135.05	135.05	5	10.8	7.2	0.12	0.16	1.32	0.45
5	-10.7	16.9	0.51	172.23	172.23	13	15.8	7.2	0.12	0.22	1.91	0.85
6	-12.5	17.3	0.23	203.37	203.37	16	13.9	4.3	0.11	0.19	1.72	0.45
7	-15	17.6	0.2	247.37	247.37	27	17.7	3.6	0.1	0.23	2.33	0.17
8	-17.8	18	0.3	297.76	297.76	33	21.2	6	0.09	0.27	3.05	0.05
9	-20.5	18.3	0.35	347.17	347.17	50	27.7	7.2	0.08	0.38	4.81	0
10	-22.8	17	0.64	386.28	386.28	21	15.1	7.2	0.07	0.18	2.44	0.1
11	-25.5	18.8	0.22	437.03	437.03	45	19.5	4.1	0.07	0.23	3.25	0.01

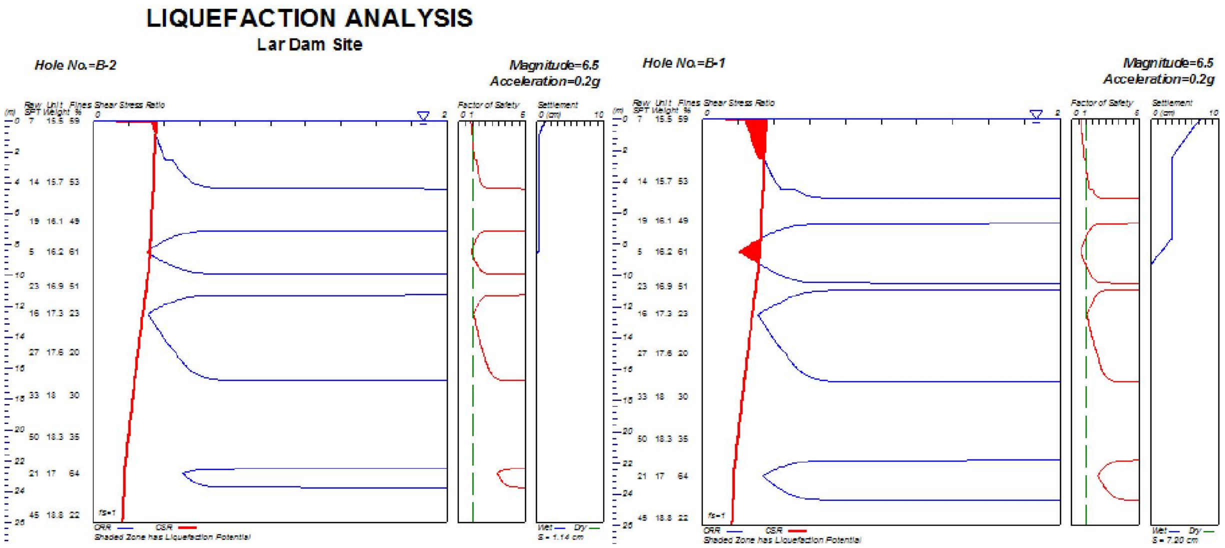

Figure9. Liquefaction analysis for 2 different boreholes of the selected region

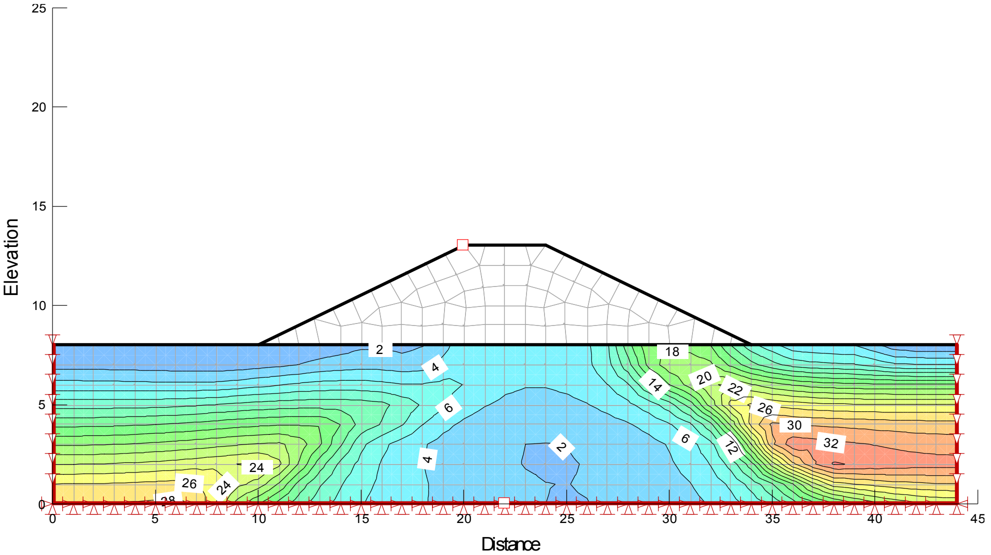

Figure10. Contour map of pore water pressure variation during the earthquake

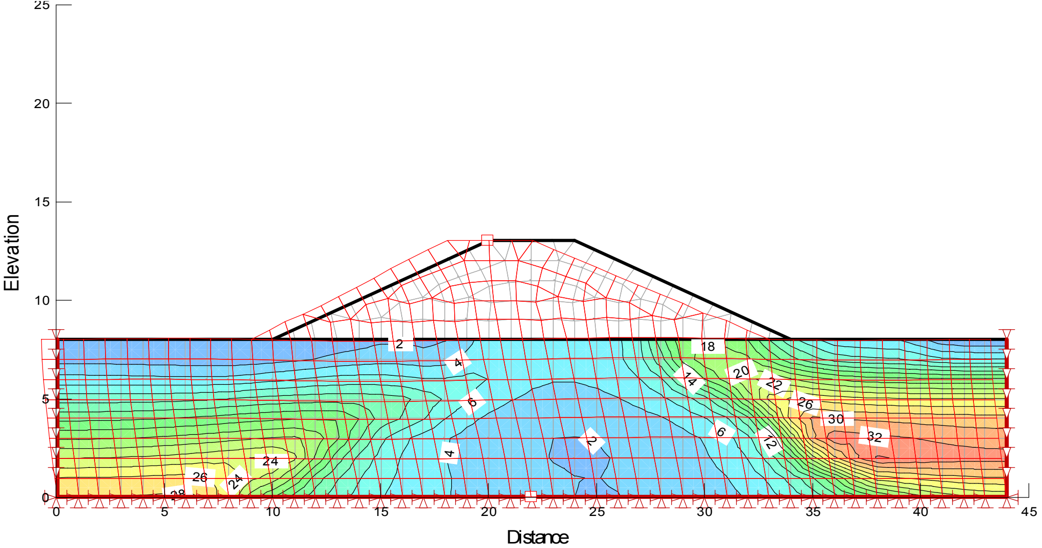

Figure11. Probable deformation of the dam after the earthquake event

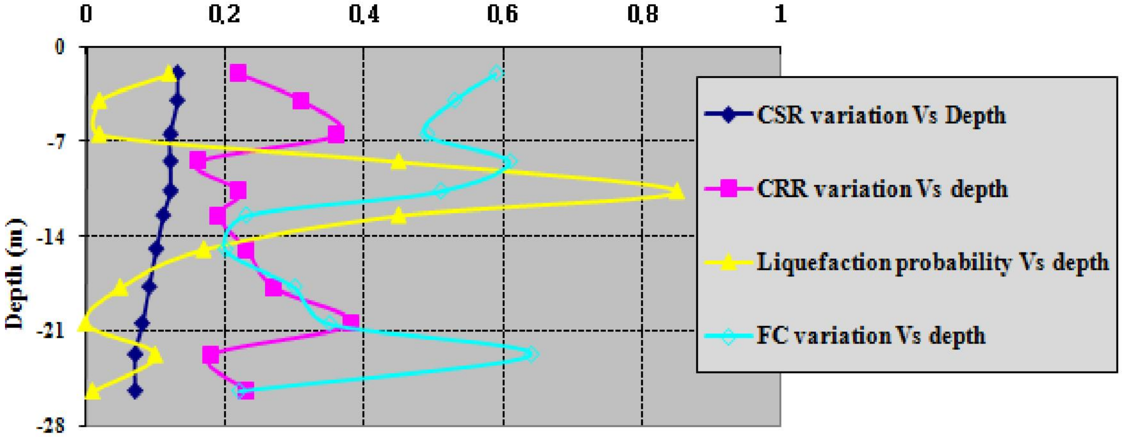

Figure12. Variation of CSR, CRR, probability of liquefaction occurrence and fine content versus depth

CONCLUSION AND DISSCUSION

Proper analysis for safe design of earth dam is necessary under static loading and more so under earthquake conditions to reduce damages of important geotechnical structure. This paper presents seismic analyses of a real case study earth dam in Iran.

The objective of this paper is to propose a geotechnical based and efficient numerical procedure for analyzing the dynamic response of geotechnical structures, which is considered as nonlinear system. This method provides essential information to reduce the indeterminacy of the associated parametric identification problem and ensure a proper model selection, calibration and validation. Application of the generated computer code proves its ability on estimation of soil profile response under the applied provokes.

According to obtained results from this study, by applying the Baladeh earthquake, the layers located in depth 8.5 to 12.5m have more susceptibility to liquefaction and more that the liquefaction occurred in foundation in both upstream and downstream slope due to cohesion-less soil in foundation and also because of the high density in contour map of the pore water pressure. It was also found that the dam response can be sensitive to the assumed spatial variation of ground motion along its base.

The procedure for assessing liquefaction potential uses the Cyclic Stress Ratio (CSR) as the measure for earthquake load. The procedure for assessing liquefaction potential typically uses the Cyclic Resistance Ratio (CRR) as a measure of the liquefaction resistance of soils and the Cyclic Stress Ratio (CSR) as a measure of earthquake load. For cohesion-less soils, CRR has been related to normalized SPT blow count, (N1)60, through correlations that depend on the fines content of the soil from field performance observations from past earthquakes. Factor of safety is obtained by ratio of cyclic stress ratio to the critical stress ratio. For prevention of liquefaction replace liquefied soil with well graded soil in foundation and get factor of safety above 1 which indicate non liquefied soil.

More that, a geotechnical based computer program with a graphical user interface, was produced and developed to compute the response of the each soil profiles under the assumed base provoke with capability in site category. The obtained results showed the ability and capability of the generated code.

This approach is derived from total stress procedures with two major advantages: 1) the triggering and post liquefaction response have been multi-lined into one analysis, and 2) the modeling of post liquefaction behavior is greatly improved. Analyses are performed in the time domain, allowing the imposed earthquake motion to affect both the triggering and post liquefaction deformations.

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