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Full Length Research Paper

A case study for testing the capability of an intermediate generated geotechnical based computer software on seismic site response analysis

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The aim of this paper is to assess the effects of seismic loads on the earth dam for design purposes by developed graphical user interface computer software. The Ghohoord earth dam in Hamedan province of Iran which is located in a high seismic zone named as Sanandaj-Sirdjan seismotectonic province is used as a case study. A seismic geotechnical based method of analysis was used by employing a designed and developed computer code, with earthquake record analysis for evaluation of 1D site response, thereby saving computational time. The records were determined based on Building and Housing Research Center web site of Iran. This method and its modeling are being implemented using the combination of several computer codes with MATLAB programming tool. The data used in this study include geologic maps, an elevation model, borehole data, shear wave velocities and ground motion records.

Key words: Ghohoord earth dam, site characterization, geotechnical investigation.

INTRODUCTION

Dams are manmade structures built to impound water. They are built for many purposes, but the main purposes are indicated in Figure 1. Other dams are built for flood control, recreation, navigation, hydroelectric power or to contain mine tailings. Dams may also be multifunctional, serving two or more of these purposes.

Large modern dams almost have control mechanisms such as gated spillways or outlet pipes for releasing water in a controlled fashion. Typically, dams are operated to smooth natural variations in water flow. During high water flow periods, water is stored behind a dam, while in low water flow periods, water is released to increase flows. Controlled releases typically result in lower peak (flood) flows and higher minimum flows than in uncontrolled streams. The specific patterns of water

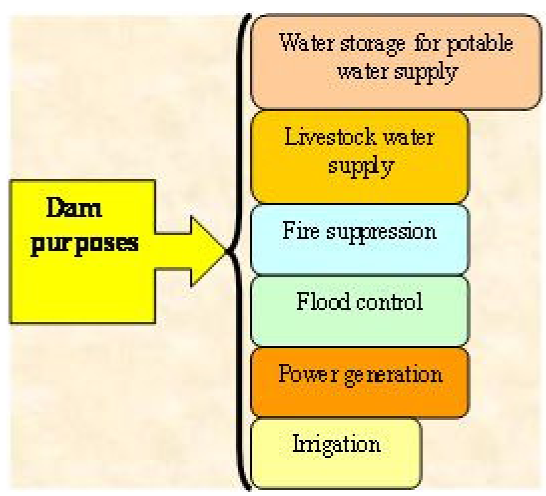

Figure 1. Main purposes for dam construction.

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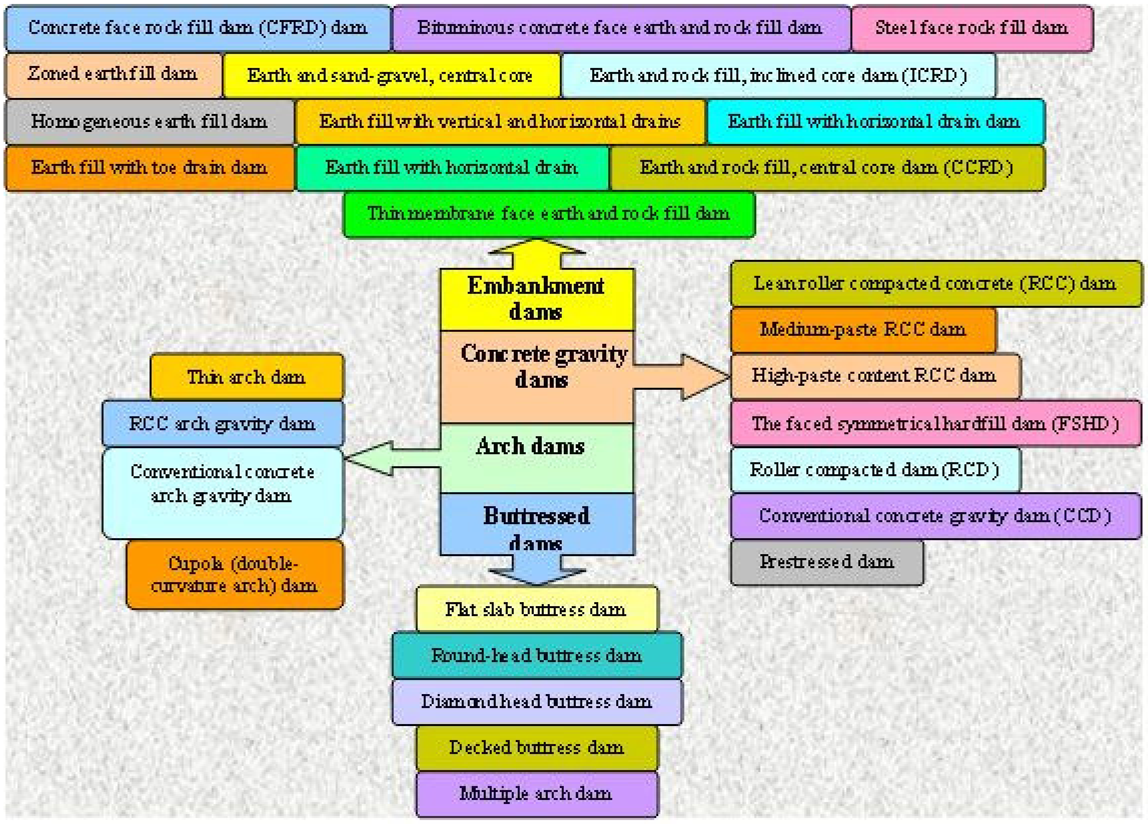

Figure 2. Types of dams.

storage and release vary from dam to dam, depending on the primary purpose(s) of the dam and on a wide variety of economic, regulatory and environmental considerations.

With reference to Figure 2, modern dams (whether embankment dams or concrete dams) are typically constructed on a foundation, which may be concrete, natural rock or soils, or compacted soils. Dams are usually constructed along a constricted part of a river valley to minimize cost. Dams are also connected to the surrounding natural valley walls, which become the abutments of the dam structure itself.

Embankment dams are commonly termed earth fill or rock fill dams, depending on the primary material used in their construction. By consideration of Figure 3, which shows the main effective factors on dam type, a wide range of earth and rock materials have been used historically to construct embankment dams, with various construction techniques including hydraulic fill and compaction. Embankment dams are broad flat structures, typically at least twice as wide at the base as their height. In cross section, embankment dams are typically trapezoidal, with a wide flat base, sloping slides and a narrower flat top.

Depending on the permeability of the materials used in an embankment dam, impervious layers may be added to the upstream side of the structure or in the center core of the structure. Embankment dams are subject to erosion by running water. Thus, modern embankment dams always have erosion-resistant materials used in the water release and control mechanisms of the dam. Typically, concrete spillways with concrete or steel gates are used to control releases. Many dams also have outlet pipe systems with concrete or steel pipes as part of the water release control system.

THE SITE CONDITION OF EARTH DAM

Assessment of the seismic hazard in low seismicity regions like Hamedan area is often given little attention due to the infrequent occurrence of large, damaging earthquakes. However, when factors such as high population density and a large number of critical facilities are considered, the necessary accurate seismic assessments become apparent for large urban regions. A relatively small amount of variation in spectral acceleration values can make a significant difference in seismic design of the structure in the area of low to moderate seismicity.

The local site conditions are an important factor in the recorded waveform of ground motions. Different site

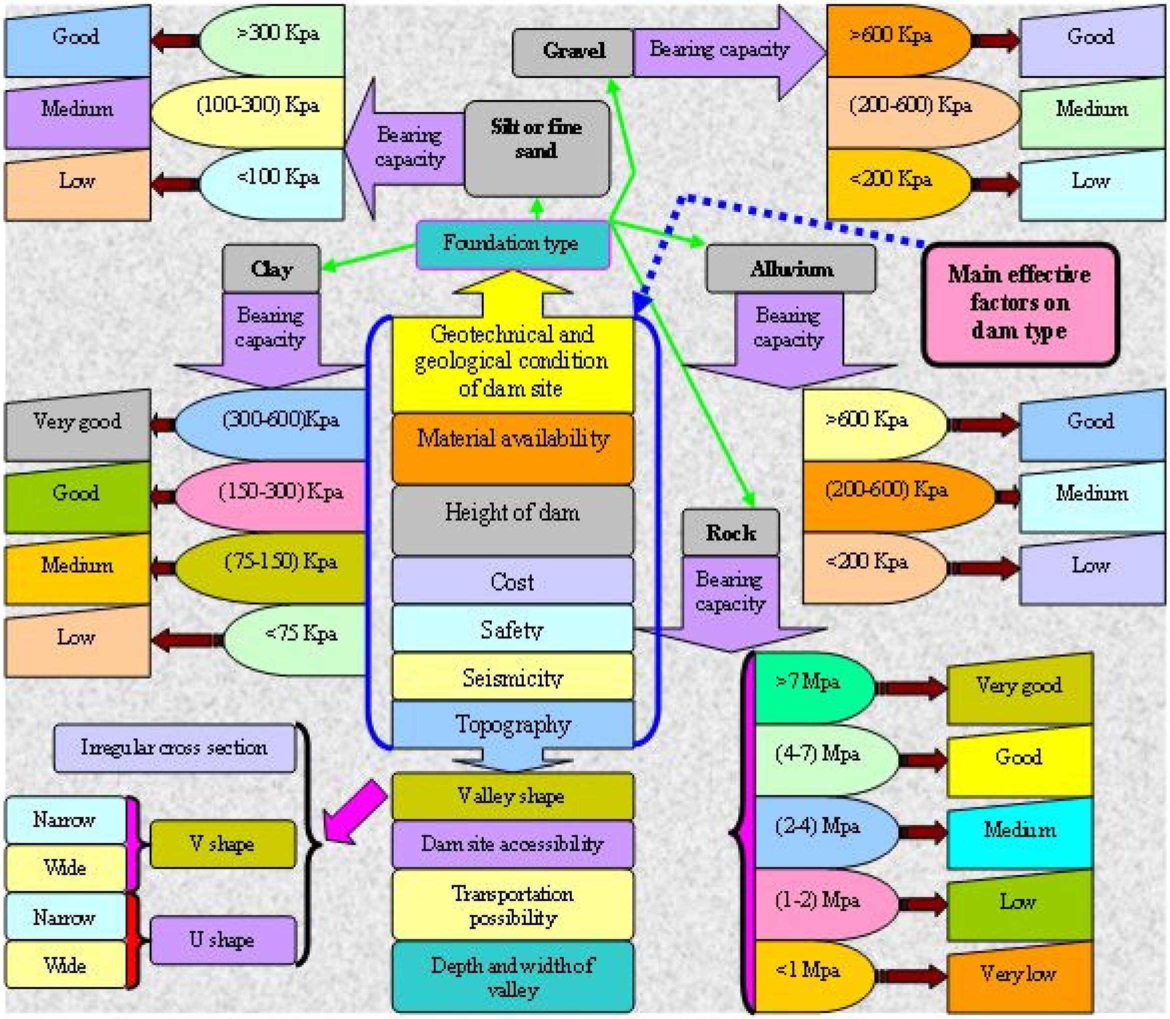

Figure 3. The main effective factors on dam type.

conditions can induce amplifications of different period ranges in the response spectra (Seed et al., 1976; Mohraz, 1976). Therefore, the local site conditions become important in ground motion analysis and in earthquake resistant designs. An earthquake response spectrum compatible with local site condition, anchoring to appropriate PGA, is a common input for structural dynamic analysis.

Classifying a group of strong motion station sites into several classes so that the conditions within the same site class are similar, and the design engineers may understand the general site condition by the class that it belongs to, is the objective of site classification. The geologic condition of interest at a site is commonly restricted to the upper-most layers. Most site effect studies of ground motion are based on the soil properties in the upper 30 m (Anderson et al., 1996). For the fact that the quantitative subsurface soil properties are not commonly available for every site, the use of surface geology becomes important in understanding the subsurface geologic conditions. Empirical relationships between the surface geology and the subsurface shear-wave velocity have been developed and used in ground motion amplification predictions (Joyner and Fumal, 1985; Boore et al., 1993; Borcherdt, 1994a, b; BSSC, 1998; Park and Elrick, 1998; Castro, 1997). Borchertdt (1994a, 1994b) had combined the use of surface geology and shear wave velocity for site classification. The classification of site conditions and an estimation of the site amplification ratio obtained by using surface geology and geomorphologic units have also been performed in Tokyo and Kanagawa, Japan (Yamazaki et al., 2000).

Earthquake response spectra alone are also useful for site classification, when geologic data are not sufficient. Seed et al. (1976) used the normalized shape characteristics of strong motion response spectra at a 5% damping ratio to explore site conditions. However, strong motion data from different sources and paths may produce different spectral shapes (Yamazaki and Ansary, 1997).

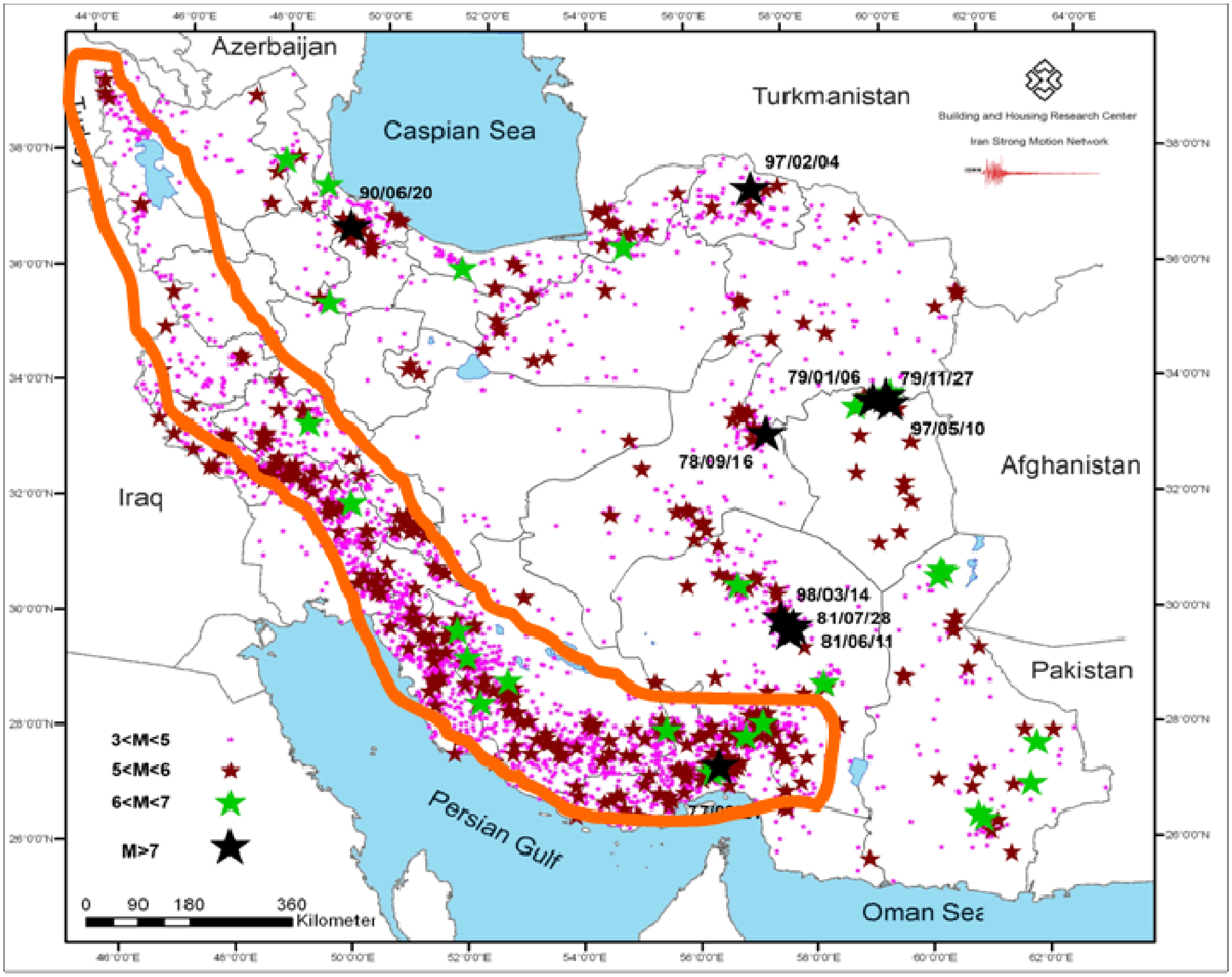

Figure 4. Seismicity of the Zagros region (www.bhrc.ac.ir).

SEISMOTECTONIC AND SEISMICITY

Iran is located on top of the collision zone between the Arabian plate (to the southwest) and the Eurasian plate (to the northeast). A reverse fault called the Main Zagros Reverse Fault divides the two plates. The Arabian plate is moving northwards at 25 mm (1 inch) a year, compressing the Eurasian plate. Earthquakes release the pressure created as the two plates grind together. Over millions of years, the collision raised the Zagros Mountains over 4,000 m, and shifted river valleys more than 50 Km. Hamedān or Hamadān (Old Persian: Hegmatana; Ancient Greek: Ecbatan) is the capital city of Hamedan province of Iran which is located in Zagros region that is one of the most active region of Iran. It had an estimated population of 550,284 in 2005 (Cities in Iran: 2005 Population Estimation).

Hamedan is believed to be among the oldest Iranian cities and one of the oldest in the world. Hamedan has a green mountainous area in the foothills of the 3574 m Alvand Mountain, in the western part of Iran. The city is 1850 m above sea level. As shown in Figure 4, the main strike of the active fault in the Zagros is in NW-SE. With reference to Figure 5, the Silakhor earthquake occurred at 4:47 a.m on March 31, 2006 in the south of Borujerd with several foreshock and aftershocks on the Doroud Fault which is a section of the Main Zagros Reverse Fault called the Main Recent Fault.

In this study, the L component of Silakhor earthquake is recorded in Chalanchoolan station. It separates the accordion folds of the Zagros fold belt from the High Zagros. The Zagros fold belt is a region of sinuous parallel mountain ranges created by the compression of the Arabian and Eurasian plates' margin, similar to the

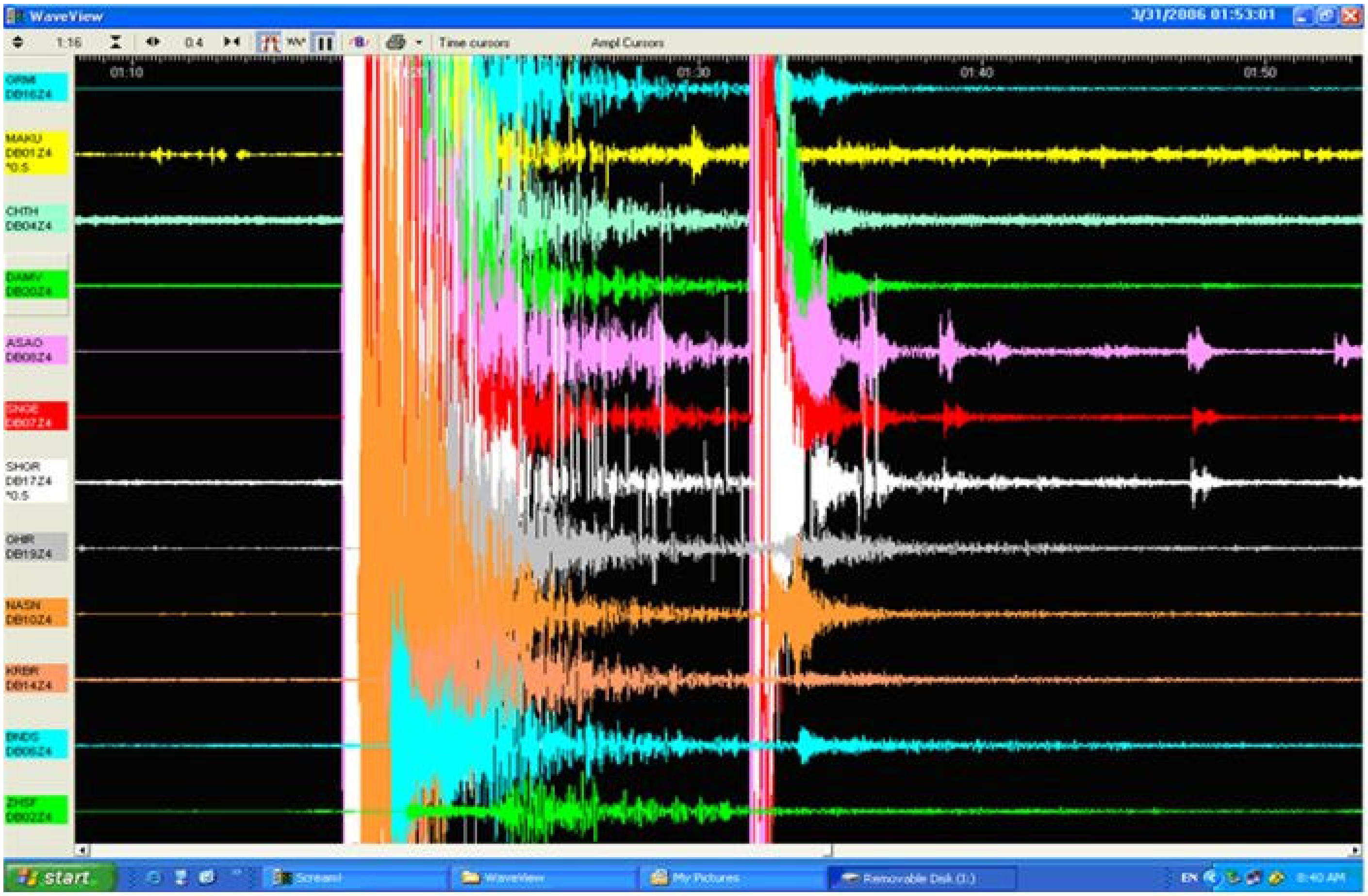

Figure 5. Records of the 31/3/2006 Silakhor earthquake at the IIEES broadband stations (INSN) (www.iiees.ac.ir).

folds created by pushing the edges of a fabric sheet together. In contrast, the High Zagros comprised a block of the Eurasian plate that has been uplifted by the oncoming Arabian plate. Stresses created by this earthquake will likely lead to more quakes nearby in the coming decades.

The occurrence of this earthquake shows the main Zagros fault (a section of Dorud fault) and the probability of further activity from this fault. The greater magnitude of this event indicates the continuous activity of the current fault plain in the earthquake stricken region.

DATA AND METHODOLOGY

The target area of this study is located in 48°2′ to 48°8′ east longitude and 34°14′ to 34°28′ north latitude in northwest of Hamedan province. Due to the youth of the geological formations of Ghohoord area, its geology is so simple and has no particular intricacy of the condition. This area includes youth lithologic units with low dip and no considerable folding. In most of the places of the studied area, the dip of bedding layers varied from 0 to 5°. This area is located in the Sanandj-Sirdjan seismotectonic province in west of Iran with a complicated tectonic structure. The outcropping lithotypes are marl-sandstone which is covered by quaternary sequence units that includes multi layered alternation of marl, marlstone and mudstone with sandstones as intra layers sequences. These geological units with yellow to yellow brownish color in weathered surface and yellow grayish in fresh ones have a thin to moderate irregular beddings. This tectonic regime is also the main cause of the current seismicity of the area, and the history of seismic sequence was the most recent manifestation of the activity of this area. On the base of the field investigation, which is shown in Figure 6, the drilled borehole was examined and the results of two of them were indicated in Tables 1 and 2. In view of this, no attempts were made for developing the regression correlation based on the entire dataset and N values from locations where tests were conducted; thus for this study 40 pairs of N value and V_s were applied and a formula which explained V_s as a function of N value was determined for the selected area as shown in Table 3 and Figures 7 and 8.

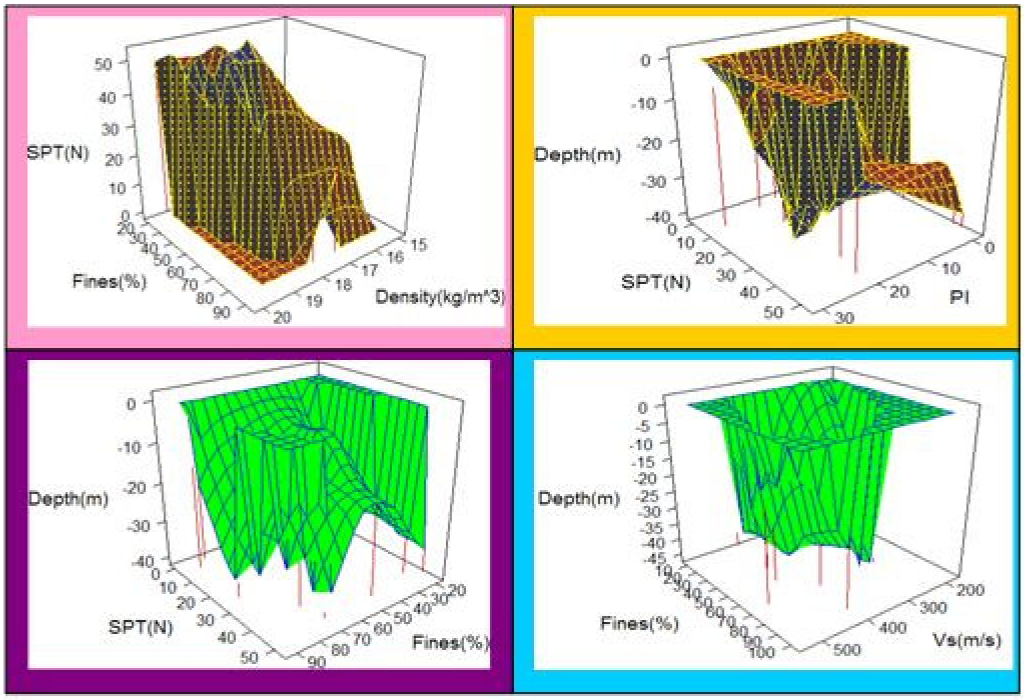

Figure 6. Variation of parameters on the base of field investigation. The red lines show the drilled boreholes ("Abbas converter" and Mintab).

Table 1. Soil profile of GH-C3.

Thickness	Soil type	Depth	SPT	γ	FC (%)
2	CL	2	4	15.5	84
1.6	SC	3.6	6	15.8	34
1.4	CL	5	10	16.1	62
1.5	SC	6.5	18	17	51
1.5	CL	8	17	17.4	56
4	SC	12	15	17.8	38.5
2	CL	14	8	18	89
3	SC	17	50	18.4	50
9	CL	26	42	18.8	75.5
4	SC	30	47	19.1	29
4	GC	34	50	19.7	22.5
2.5	CH	36.5	28	17.2	89
2.5	CL	39	50	18.5	73

Table 2. Soil profile of GH-C2.

Thickness	Soil type	Depth	SPT	γ	FC (%)
3	SC	3	5	15.3	29
2	SC-SM	5	3	15.8	20
4.5	CL	9.5	7	16	37.25
6.5	SM	16	36	16.2	56.8
2	CL	18	50	16.4	72.5
3.5	SM	21.5	23	17	37
2.5	CH	24	36	17.1	98
9	CL	33	38	17.4	73.75
3	SC	36	50	17.9	45
5.5	GC	41.5	50	18	12.9
2.5	CL	44	18	18.4	73

Table 3. Correlation results of V_s- N for the selected region.

Model	a	b	c	R	S	Computed by
$V_s = aN^b$	103.75	0.4511		0.9979		Excel
$V_s = a+bN$	195.22	9.5452		0.9865		Excel
$V_s = a+N^b$	232.1129	1.4824		0.771	65.557	Curve expert 1.3 and MATLAB
$V_s = a+b^N$	245.344	1.1196		0.4380	92.562	Curve expert 1.3 and MATLAB
$V_s = ab^N$	221.814	1.019		0.7555	67.449	Curve expert 1.3 and MATLAB
$V_s = ae^{bN}$	220.51	0.262		0.9563		Excel
$V_s = a+bLnN$	-60.62	157.69		0.9874		Excel
$V_s =aN^2 +bN+c$	-0.1364	15.344	148.05	0.9979		Excel
$V_s = ab^{(1/N)} N^c$	99.6382	1.1479	0.4618	0.9984	5.7863	Curve expert 1.3 and MATLAB

a, b and c: Constant parameters; R: Correlation coefficient; S: Standard error.

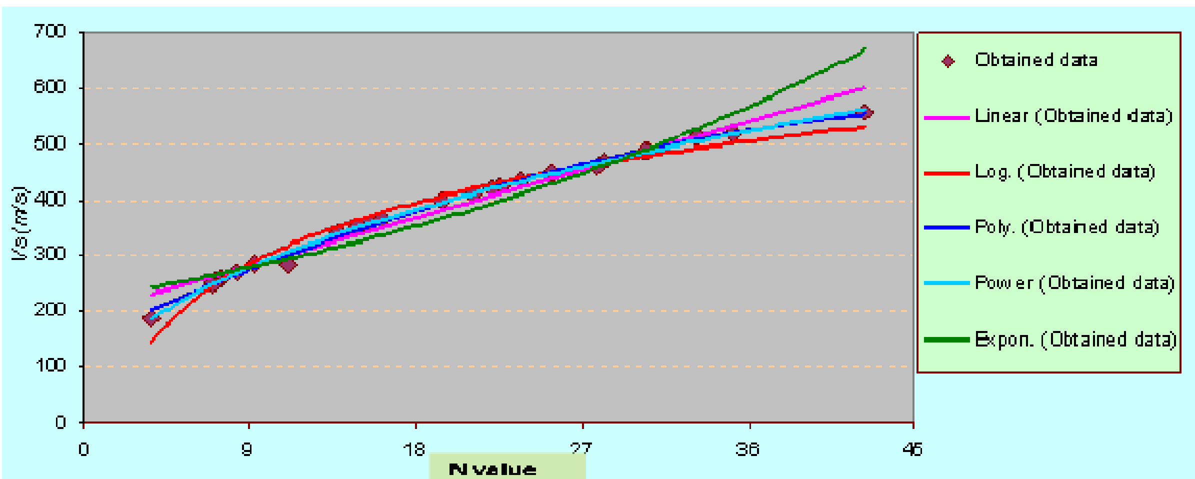

Figure 7. Comparison between used models for V_s-N correlation (excel, curve expert 1.3 and MATLAB).

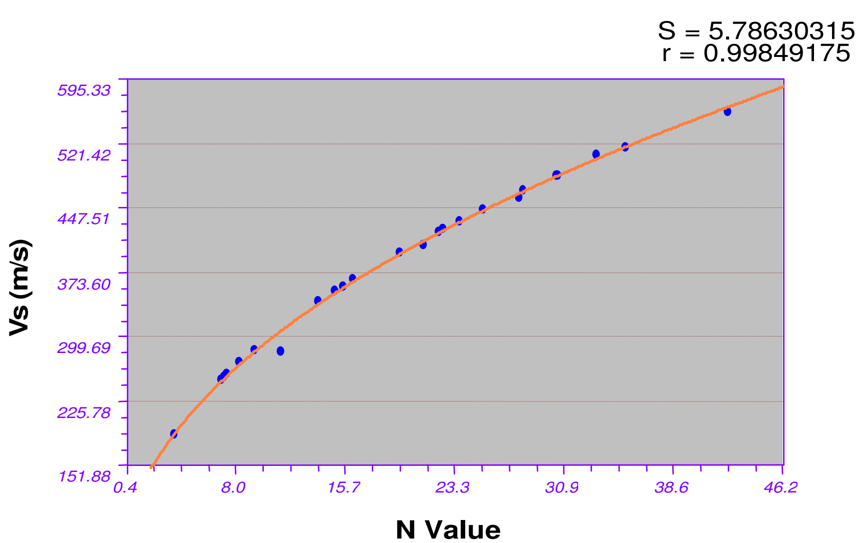

Figure 8. Accepted correlation of V_s-N (curve expert 1.3 and MATLAB) $V_s = 99.6382 \times 1.1479^{\left(\frac{1}{N}\right)} N^{0.4618}$ $(r = 0.9984, s = 5.7863)$.

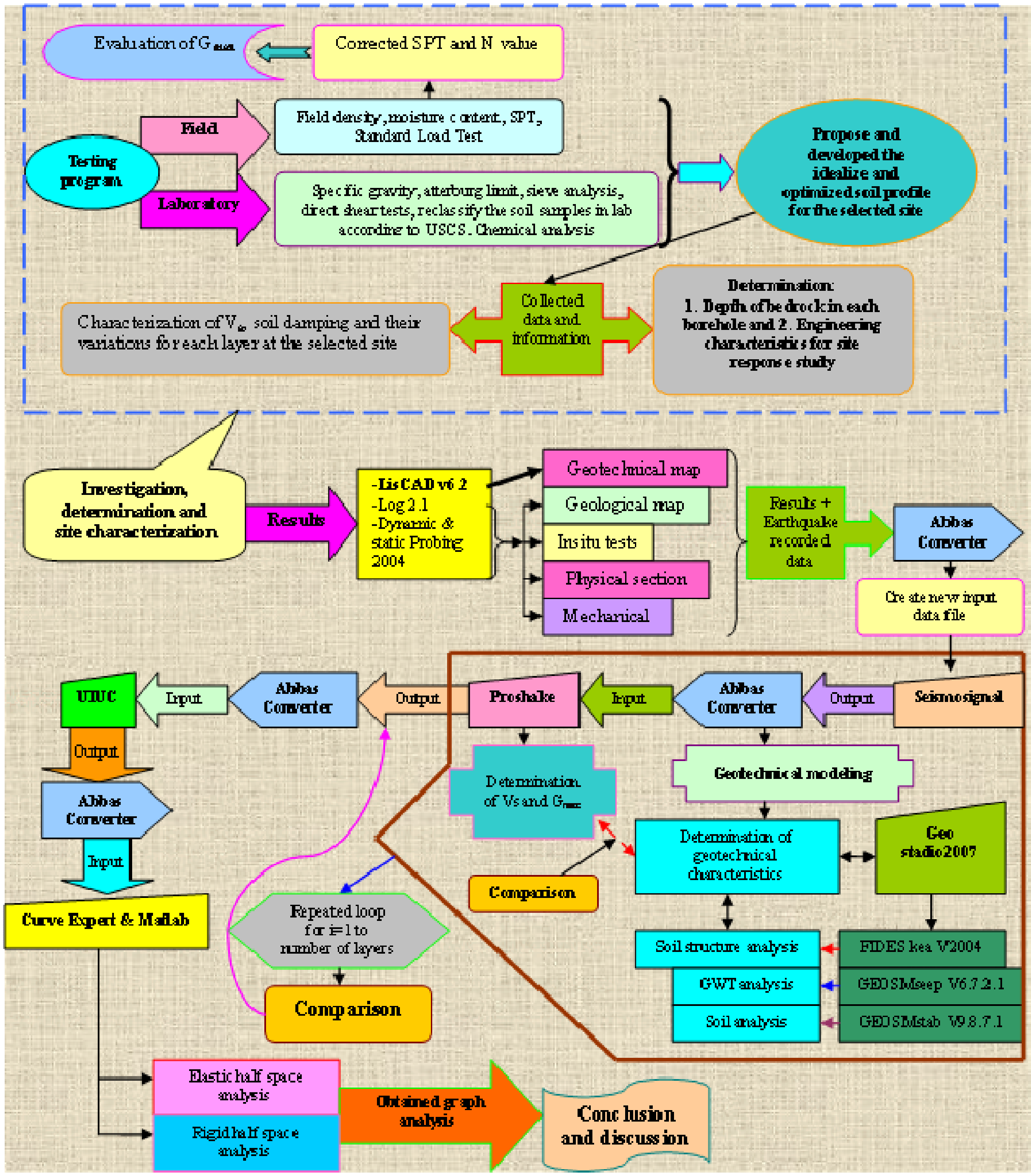

Figure 9. Proposed method for this study.

The proposed flowchart and its simplified procedure are indicated in Figures 9 and 10. As indicated by these figures, the methodology of the proposed procedure is on the base of the software combinations by the aid of a generated computer code by authors. The parameters Gmax (maximum shear modulus) and ξ (damping ratio) are used to describe the dynamic behavior of soils in site response analysis. Dynamic soil parameters (Gmax and ξ) are calculated with "Abbas Converter" utilizing geotechnical data collected at geotechnical properties database. Gmax can be calculated from empirical relationships for clays (Hardin and Drnevich, 1972) and for sands (Seed and Idriss, 1970). It can also be determined from the corrected SPT-N values (Ohta and Goto, 1978; Imai and Tonouchi, 1982). The variation of the modulus ratio (G/Gmax) and damping ratio (ξ) with

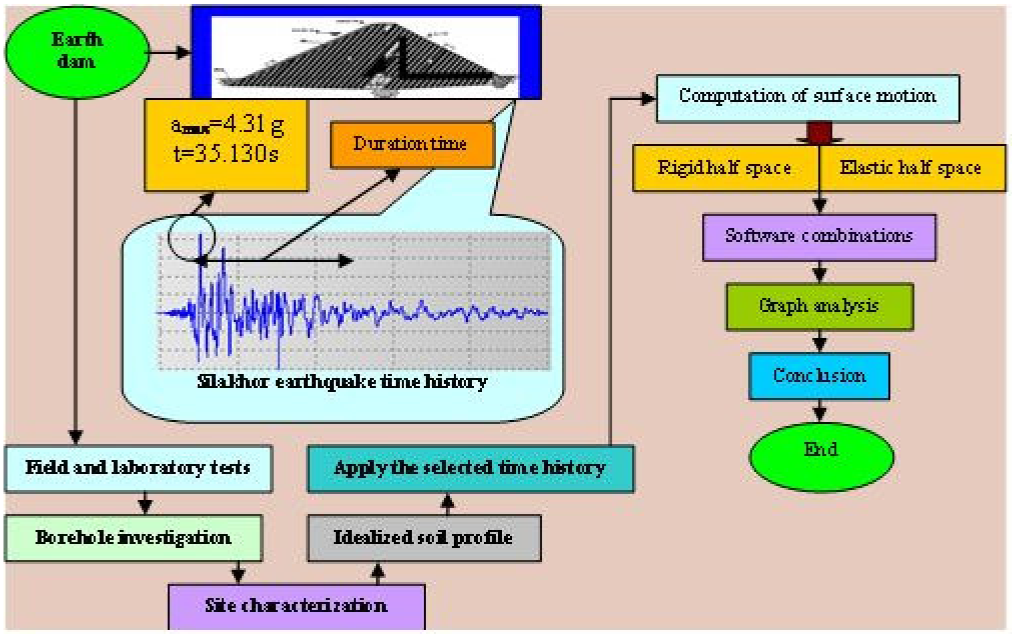

Figure 10. Simplified procedure in this study.

Table 4. Site classification.

Site class	Generic description of the soil profile	Average values for top 100 feet of the soil profile		
		V_S [ft/s]	SPT [blows/ft]	Undrained shear strength, S_U[psf]
S_A	Hard rock	>5,000	-	-
S_B	Rock	2,500 to 5,000	-	-
S_C	Very stiff/dense soil and soft rock	1,200 to 2,500	>50	>2,000
S_D	Stiff/dense soil profile	600 to 1,200	15 to 50	1,000 to 2,000
S_E	Soft/loose soil profile	<600	<15	<1,000

shear strain (γ) is computed from Ishibashi and Zhang (1993) formulations. Modulus ratio and damping ratio values for each layer of the soil profile are calculated for shear strains varying between 0.0001 and 10% using "Abbas Converter" and software combinations.

In order to establish the site classes as shown in Table 4, the soil and rock types in the geologic maps are examined in detail. In general, geotechnical characterization shall be based on site specific information. This information may be obtained from existing or new sources. However, if existing or non site specific information is used, the geotechnical engineer of the record shall provide adequate justification for its use. Site specific investigations shall include, at a minimum, borings and/or cone penetration tests, soil classifications, configuration, foundation loading and an assessment of seismic hazards. The array (number and depths) of exploratory borings and cone penetration tests (CPT) will depend on the proposed or existing structures and site stratigraphy.

If the geotechnical data other than SPT and CPT are used, an adequate explanation and rationale shall be provided. Quantitative soil information is required for a depth of 100 feet below the mud line, for assigning a site class. When the data to a depth of 100 feet is unavailable, other information such as geologic considerations may be used to determine the site class. As shown in Figure 11, the interfacing software "Abbas Converter" was developed following the construction of geotechnical database. This code is capable of reading the geotechnical data from the database, performing calculations of dynamic parameters for dynamic site response analyses, and preparing a data input file for analysis in the other used codes. The capability of the software was increased then in order to perform liquefaction analysis and calculation of post liquefaction settlement (Abbaszadeh et al., 2009, 2010). The major part of the study is development of the software that can perform the afore mentioned tasks of a geotechnical earthquake engineering problem since the geotechnical

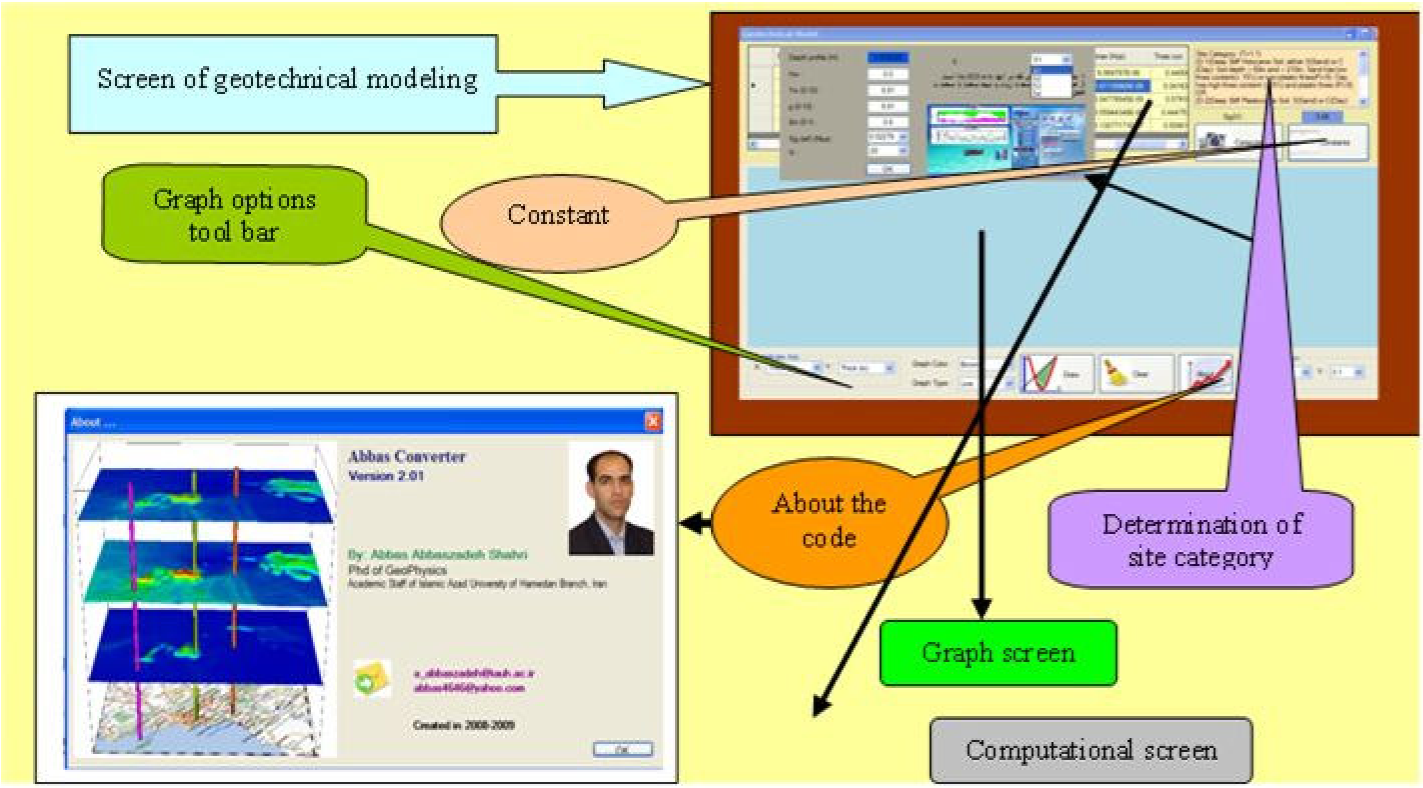

Figure 11. Summarized detail about the geotechnical model section of the generated code.

data can be used in the dynamic site response and liquefaction analyses, following additional calculations. One of the main properties of this software is to provide efficient communication with the other used softwares which is used to perform site response analyses. This code provides a graphical user interface (GUIS) in order to link the constructed databases with the used software. "Abbas Converter" includes the subroutine forms of C Sharp, while the geotechnical data, which were collected in geotechnical properties database, were read using this code and calculations performed for the dynamic parameters. The data input file for site response analysis is prepared using this software. Liquefaction analysis is performed also with "Abbas Converter". Connection between geotechnical properties, strong ground motion databases and analysis by used softwares are provided with this code (Abbaszadeh et al., 2009, 2010).

Site class B (rock) and site class C (soft rock or very dense soil) can be distinguished by their geologic age and rock type. Site class B may include igneous rocks, metamorphic rocks, limestone and hard volcanic deposits. Sandstones, shales, conglomerates and slates of Miocene age or an older age are classified as class B. Pliocene and Pleistocene sandstones, shale/mudstones and conglomerates are considered as soft rocks and thus classified as class C. Volcanic breccias and pyroclastic rocks of a similar age can also be grouped in class C. Lateritic terraces commonly consist of several-meters-thick laterite with several-meters to more than ten-meters-thick sandy gravel deposits overlaying the bedrock. Both the lateritic highlands and the lateritic terraces are classified as class C.

Late quaternary deposits, other than lateritic terraces, such as loose sand, silt, clay and gravel deposits, are considered as engineering soils, and classified as class D (stiff soil) or class E (soft soil). Soils in class D are fluvial terraces, stiff clays and sandy gravel deposits, while Holocene alluvium flood plains or recent fills usually form soils in class E. To differentiate between stiff soil and soft soil sites, SPT-N values from borehole data are used. The average SPT-N values are calculated for the top 30 m of the soil. Soils with average SPT-N values greater than 15 are defined as class D, while others are defined as class E. In areas without boreholes, geomorphologic units control the class E boundary.

With reference to the aforementioned methodology, the comparison between the input and computed surface motion, the spectral acceleration and amplification ratio for the elastic and rigid half space condition were executed and shown in Figures 12 to 15. To indicate the accuracy of this method, the computed motion and response were determined separately by the use of "Abbas Converter" and the result of this is pointed out in Figure 16. The obtained results from these figures are

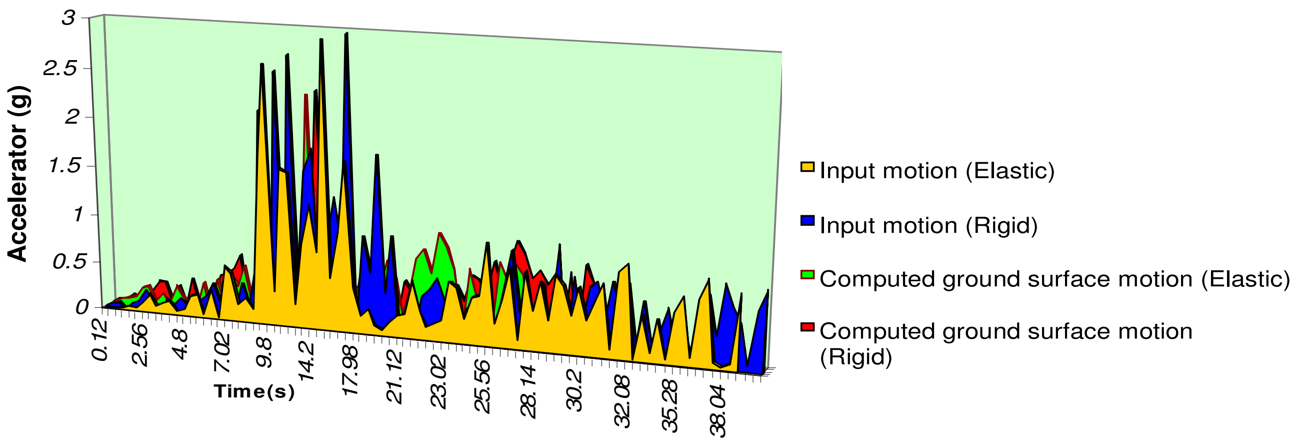

Figure 12. Comparison between input and computed motion in elastic and rigid half space conditions ("Abbas Converter, Excel and Mintab).

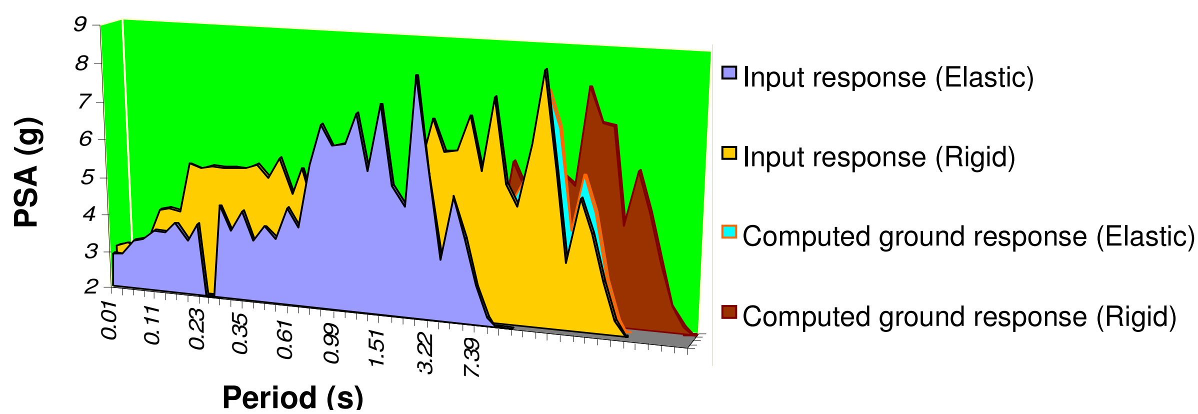

Figure 13. Comparison between input and computed response in elastic and rigid half space conditions ("Abbas Converter, Excel and Mintab).

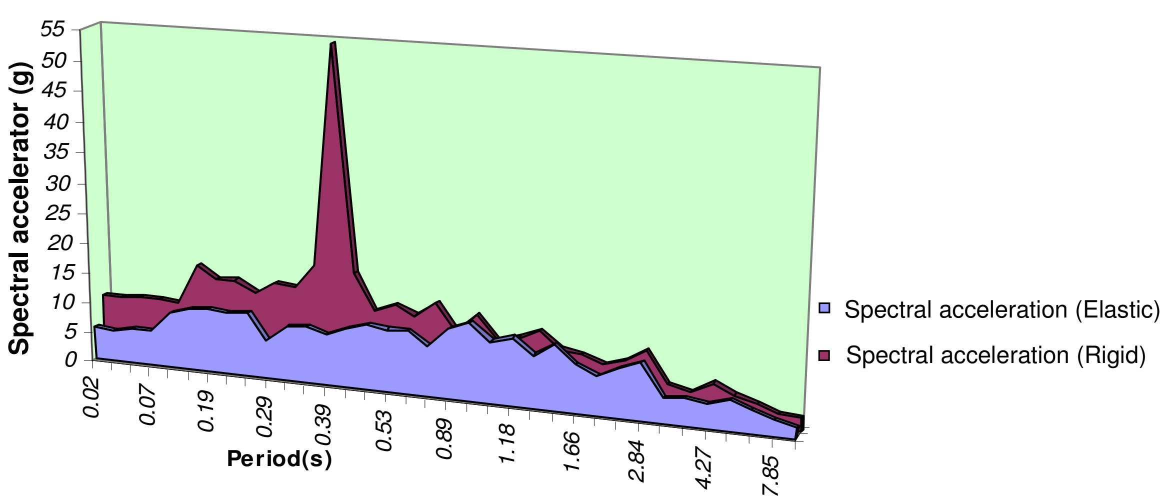

Figure 14. Comparison between spectral acceleration in elastic and rigid half space conditions ("Abbas Converter, Excel and Mintab).

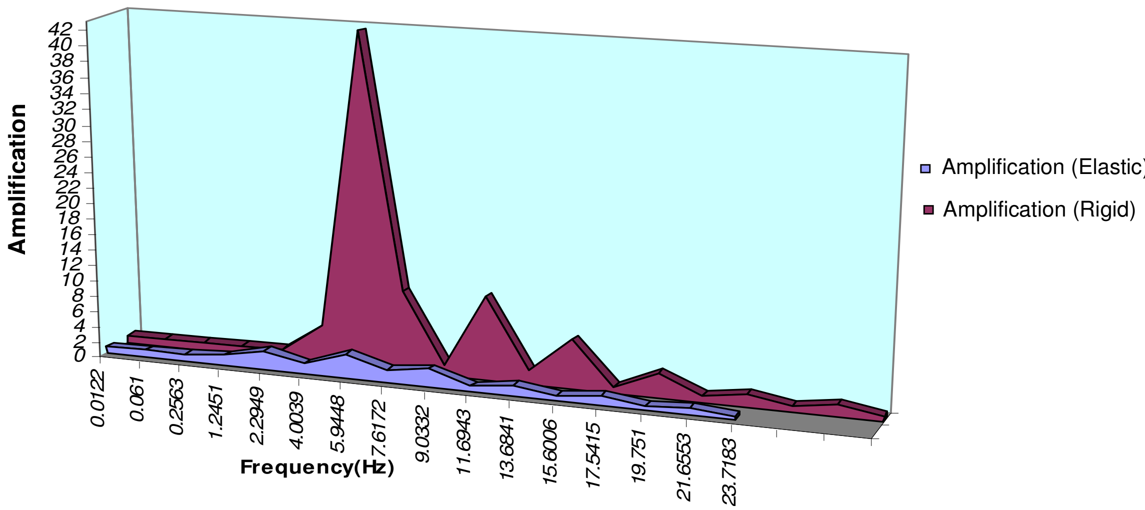

Figure 15. Comparison between amplification ratio in elastic and rigid half space conditions ("Abbas Converter, Excel and Mintab).

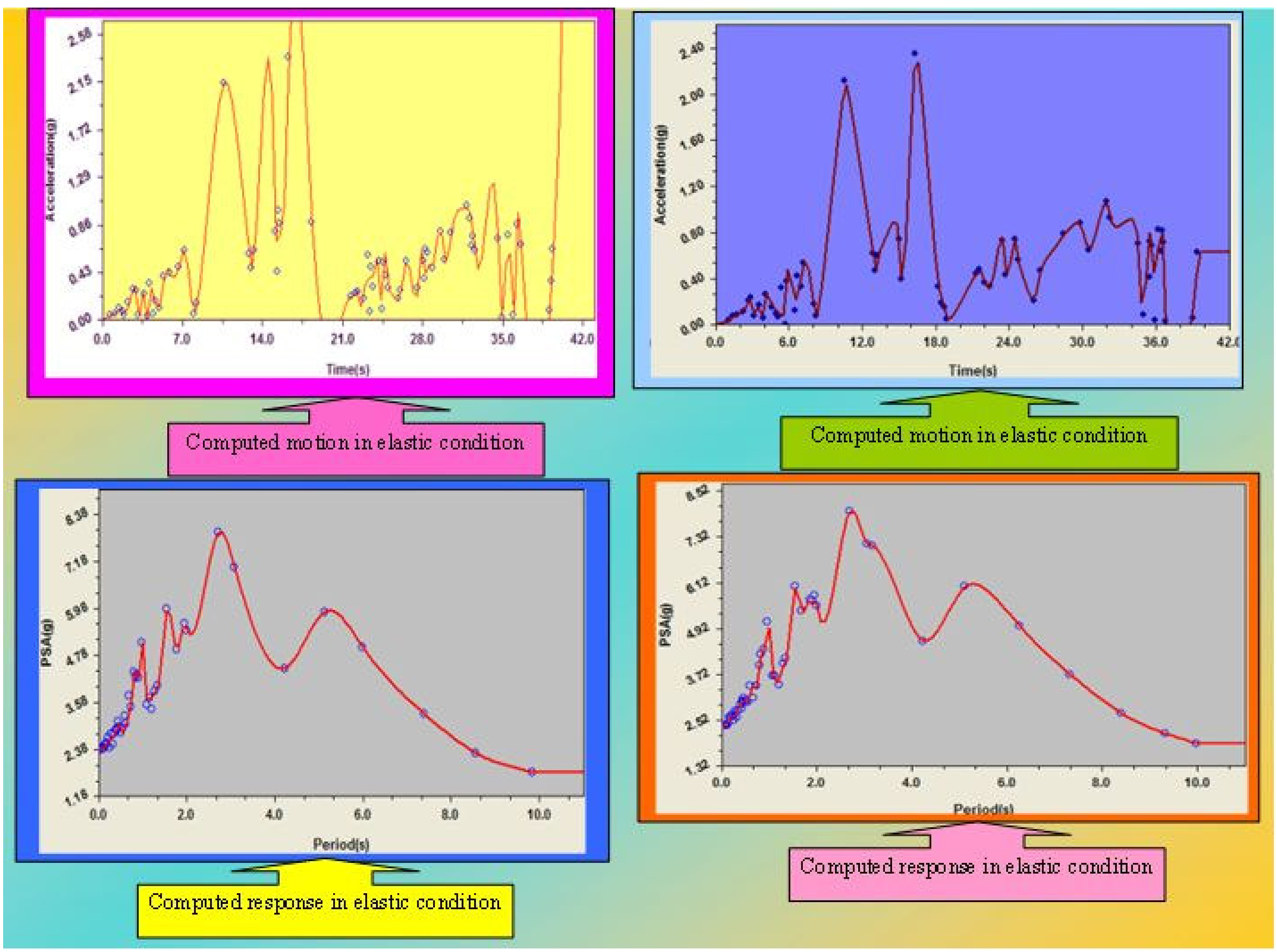

Figure 16. Computation of the site response by the proposed procedure ("Abbas Converter" and Curve expert 1.3).

Table 5. Numerical comparison between input and computed parameters.

Parameter	Maximum input at	Maximum output at …
Motion (Elastic half space)	g 2.92 g (15.74 s)	2.348 g (16.28 s)
Motion (Rigid half space)	2.98 g (15.74 s)	2.377 g (16.28 s)
Response (Elastic half space)	8.19 g (2.76 s)	7.91 g (2.71 s)
Response (Rigid half space)	8.47 g (2.77 s)	8 g (2.7s)
Amplification (Elastic half space)	-	3.19 (5.9444 Hz)
Amplification (Rigid half space)	-	42.6 (2.2705 Hz)

summarized in Table 5.

CONCLUSIONS

In the simplest terms, dams are impervious structures that block the flow of water in a river or stream and thereby impound water behind the dam. Dams have been built for thousands of years from a wide range of materials, including earth, stone, masonry, wood and concrete.

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 a 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. This paper has been amended to improve predicted earthquake accelerations on soil and rock sites at a selected earth dam in Iran and the effects of the subsurface soils, subjected to earthquake vibrations on the seismic response of earth dams, were studied. As a basis, such estimations utilize the description of soils and rocks as given by the defined zones. These zones are primarily based on the measured travel time, weighed on the average shear wave velocity of a site from the surface to several depths especially up to 30 m. Application of the generated computer code proves its ability on the estimation of the soil profile response under applied stimulations. The borehole data were analyzed and the average SPT-N values for the upper most 30 m were put into the database. However, the shear wave velocity data were also examined.

A geotechnical based computer program with a graphical user interface, was produced and developed to compute the response of each soil profile under the assumed base stimulations with the same capability in the site category. The obtained results showed the ability and capability of the generated code. It was noted that the length to height ratio of the dam has a marked effect on the dynamic characteristics of the dam and on its seismic response. It was also found that the dam response can be sensitive to the assumed spatial variation of ground motion along its base. Nonetheless, the nonlinear behavior of the studied area is computed using software combinations and this methodology is illustrated by a real case study earthquake response, and as such, the results of the numerical calculations are compared for elastic and rigid conditions.

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