Application of Seismic and Resistivity methods to investigate Amiriyeh (Iran) site geology characterization from seismic Micro-zonation point of view

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Abstract

This paper is devoted to compiling a site geology map for town of Amiriyeh, from seismic Macro-zonation point of view using geophysical methods of shallow seismic, down-hole seismic and resistivity surveys. In this map site geology has been classified based on shear wave velocity, according to the criteria for site geology classification offered in the Iranian code of practice for seismic resistant design of buildings. Amiriyeh is a small town with approximately 9000 inhabitants, located in Semnan province, central Iran. In the first step, the town was initially investigated from geological, topographical and facilities aspects for geophysical surveying and some locations were selected for the investigations. In each one of the selected locations, a refraction seismic profile involving 2 or 3 shot points and 24 geophones as well as a vertical electrical resistivity sounding was surveyed. A down-hole seismic survey was also carried out in a few existing wells. The acquiesced data was processed and interpreted and geological layers were identified according to the seismic and resistivity properties. Shear and compressional wave velocities for each layer were estimated. Then velocity maps were compiled for different thicknesses of the soil, (from the surface to various depths). Finally, a site geology Micro-zonation map was compiled for Amiriyeh town. In this map the zones were classified based on the soil (site) classification criteria offered in the Iranian seismic code. According to the obtained results, Amiriyeh is located over soft soils which are involved in groups of IV and III (very close to IV) of the seismic code.

Keywords: Site geology, Micro-zonation, Shear wave, Resistivity, Amiriyeh, Iran.

1–Introduction

From seismotectonic and seismology point of view, Iran is located in an active region and many earthquakes, even destructive ones occur in this territory and cause many fatalities and the loss of property. The return period of earthquakes is short (e.g. return period of events with Ms greater than 7 is only 10 years (Ramazi, 2009). Therefore, site investigation and engineering seismological studies are important for the development of measures to reduce the impact of earthquakes effects.

Seismic hazard analysis is one of the most common tools to estimate the expected level of intensity of ground motion which is related to seismic events, so it is the fundamental input into the decision-making process for earthquake loss mitigation (Moratto, 2007). Earthquake hazard zonation for urban areas is the first and most important step towards a seismic risk analysis and mitigation strategy in densely populated regions (Grasso and Maugeri, 2009a). Micro-zonation studies solve problems resulting from natural disasters such as earthquakes and landslides (Turk *et al.*, 2012). Seismic micro-zonation can be considered as the preliminary phase of earthquake risk mitigation studies (Korkmaz and Ozcep, 2010). It requires multi-disciplinary contributions as well as a comprehensive understanding of the effects of earthquakes that generate ground motions on man-made structures (Ansal and Slejko, 2001). Seismic Micro-zonation is evaluation and assessment of different inputs from different fields of earthquake engineering and engineering seismology. In most general terms, seismic micro-zonation is the process of estimating the response of soil layers under earthquake excitations and thus the variation of earthquake characteristics on the ground surface (Korkmaz and Ozcep, 2010). Seismic Micro-zonation and earthquake loss estimation scenarios are among the essential tools needed for city planning, disaster preparedness, risk reduction, hazard mitigation decisions, and urban rehabilitation actions in earthquake prone areas (Ansal *et al.*, 2010).

The Micro-zonation and site response studies require the characterization of subsurface soil properties of the site (Anbazhagan *et al.*, 2009). One of the most important input information for the ground response analysis is a subsurface model that represents the variation in thickness of the upper 30 m soil layers (Grasso and Maugeri, 2009b). Estimating the shear wave velocity of the deposit is a simple way to characterize the site conditions because there is a strong correlation between the ground motion during earthquakes and the average shear wave velocity (Mashewari *et al.*, 2010). Shear wave velocity–depth information is required for predicting the ground motion response to earthquakes in areas where significant soil cover exists over firm bedrock. Rather than estimating this critical parameter, it can be reliably measured using a suite of surface (noninvasive) and down-hole (invasive) seismic methods (Hunter *et al.*, 2002). Seismic tests are conventionally classified into borehole and surface methods. These methods enable one to determine the velocity of body waves [compressional (P) and/or shear (S)] and surface waves (Cavallaro *et al.*, 2004). A number of geophysical methods have been proposed for near-surface characterization and measurement of shear wave velocity using a large variety of testing configurations, processing techniques, and inversion algorithms (Anbazhagan *et al.*, 2009).

For the dynamic soil characterization, deep in-situ and laboratory tests are done. Among the in-situ tests, Down-Hole (D-H) tests, DTM and Seismic Dilatometer Marchetti Tests (SDMT) are very accurate, in order to evaluate the shear wave velocity (Vs) profiles. The SDMT is an instrument that combines a DMT blade with a modulus measuring the shear wave velocity. The SDMT provides a simple means for determining the stiffness at very small strains and in situ shear strength parameters at high strains in natural soil deposits (Cavallaro *et al.*, 2012). Some studies have used SDMT and DTM in order to evaluate the shear wave velocity; (Grasso and Maugeri, 2009 a,b), (Maugeri *et al.*, 2011; Cavallaro *et al.*, 2012; Grasso and Maugeri, 2014).

Combining electrical resistivity and seismic, helps to solve engineering geology problems of the studied area (Luis and Max, 2004), (Nardis *et al.*, 2005; Fatoba *et al.*, 2010; Dale *et al.*, 2011).

A large number of studies about site geology Micro-zonation were conducted in all earthquake prone areas of the world. according to obtaining result, the study area are classified to different groups from point of view of geological and seismic zonation (Fah *et al*., 2001; Hamzeloo *et al*., 2007; Kamaliana *et al*., 2008; Bianchi *et al*., 2008; Cardarelli *et al*., 2008; Carvalho *et al*., 2009; Korkmaz and Ozecp, 2010).

To compile a site geology Micro-zonation map in Amiriyeh town, integrated geophysical methods consisting of shallow seismic and resistivity sounding were performed.

2– The study area

The study area, Amiriyeh town is located in central Iran, Semnan province, 25Km west of Damghan city. From a seismotectonic point of view and according to the seismotectonic provinces and sub-provinces map of Iran (Ramazi, 2005), the town is located in Eastern Alborz , but it is very closed to the northern boundary of Central Iran provinces (Fig. 1). Many active faults exist in these provinces. The trend of the regional geological structures and lineaments involving major faults is NE-SW in the surrounding regions.

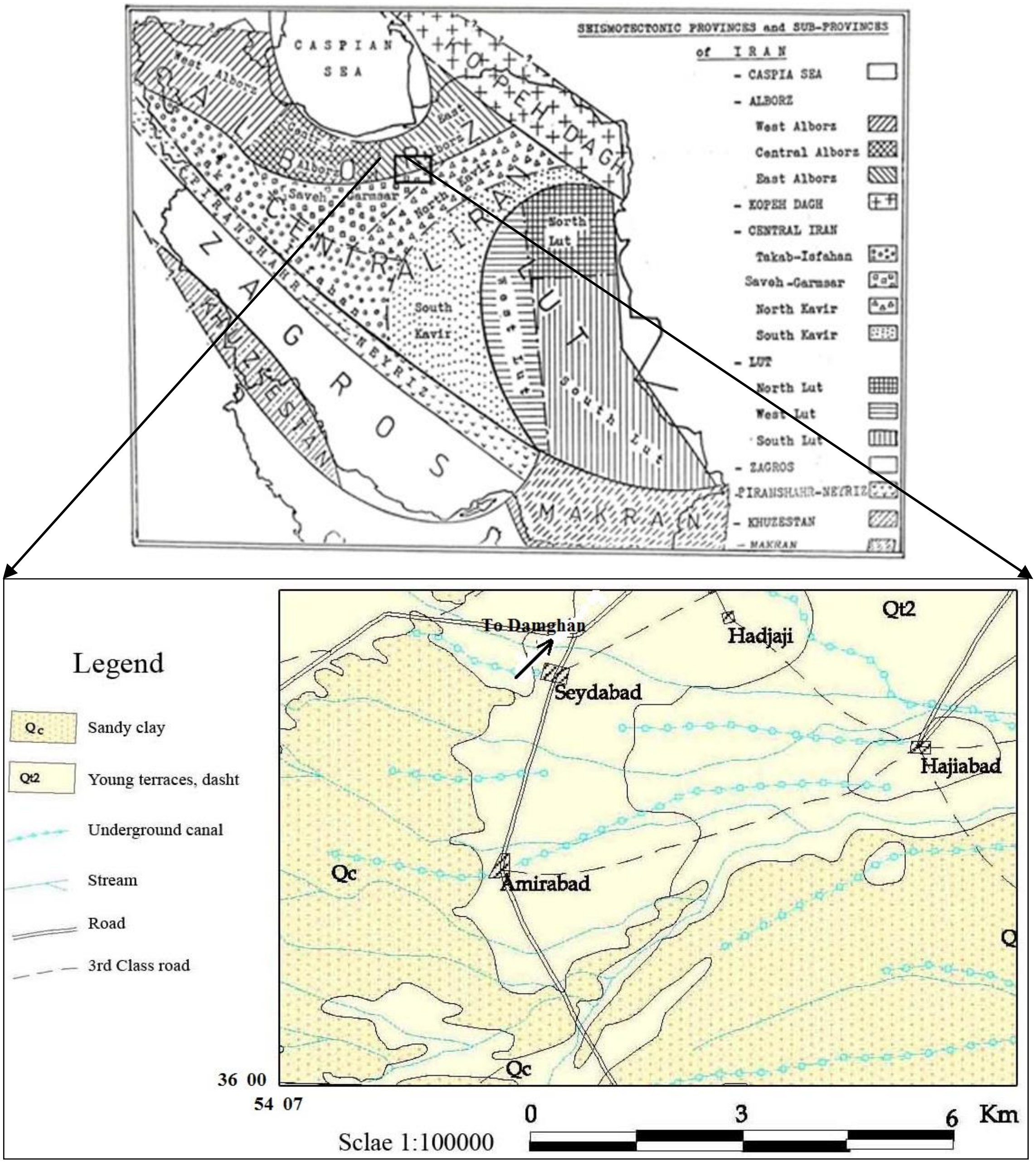

Figure 1) Location of Amiriyeh in Iran seismotectonic map and the Geology map of the studied area..

From geological point of view, and based on available geological maps Amiriyeh is located in an alluvial plain (Fig. 1). The plain is very large and there is not any rock outcrop around the town, for more than 10 kilometers. Some trenches and wells which existed in the town were investigated from site geological point of view. In the most of the studied locations alluvial deposits are very fine grained and consisting out of clay and silt (Figs. 1 and 2).

Figure 2) Surface geological situation in Amiriyeh.

From topographical point of view, Amiriyeh is located on a flat plain with very smooth topography and there are no considerable elevation differences. Topographical changes show lower than few meters in whole area.

3–Applied geophysical methods

Geophysical methods are widely used to solve engineering geology problems. If the methods are selected according to study results, the probability of success will increase (Patella and Patella, 2009). The application of geophysical methods has increased in engineering and environmental studies and also studies of geo-hazards such as earthquakes, landslides, etc (Prem, 1997).

To ascertain the effect of earthquake shaking on the ground surface, site characterization by evaluating shear wave velocity at a shallow depth would be essential. The seismic site characterization for calculating seismic hazard is usually carried out based on the near-surface (30m) shear wave velocity values (Anbazhagan *et al*., 2009).

In this study, shallow seismic, down-hole seismic and resistivity sounding were used to identify soil layers geometry and their dynamic properties. For estimating wave velocity in a vertical direction, seismic down-hole (vertical, seismic profiling) is a good option. Of course it requires the existence of wells in the area. Otherwise, surveying surface seismic profiles is a good option and the only option in many cases. Existing wells in the town were initially investigated. In spite of the existence of a few wells, only two of them were provided for seismic surveying. These two wells were used for down-hole measurements. In the other places surface profiles were carried out. In refraction seismic, depth of the investigation depends on many parameters of which the most important are: profile length, layer thickness, wave velocity ratio in layers, existence of blind layers, etc. Therefore, the surveying of surface profiles requires a large area, especially a long area which should be away from noises or objects which can produced seismic noises (while surveying) such as buildings and their foundations, traffic of heavy vehicles, etc. This issue is also raised in the vertical electrical sounding. Taking into account these factors, 9 locations were selected for the surveying (Fig.

3). At least a refraction seismic profile and a vertical electrical sounding was designed and performed in each one of the locations.

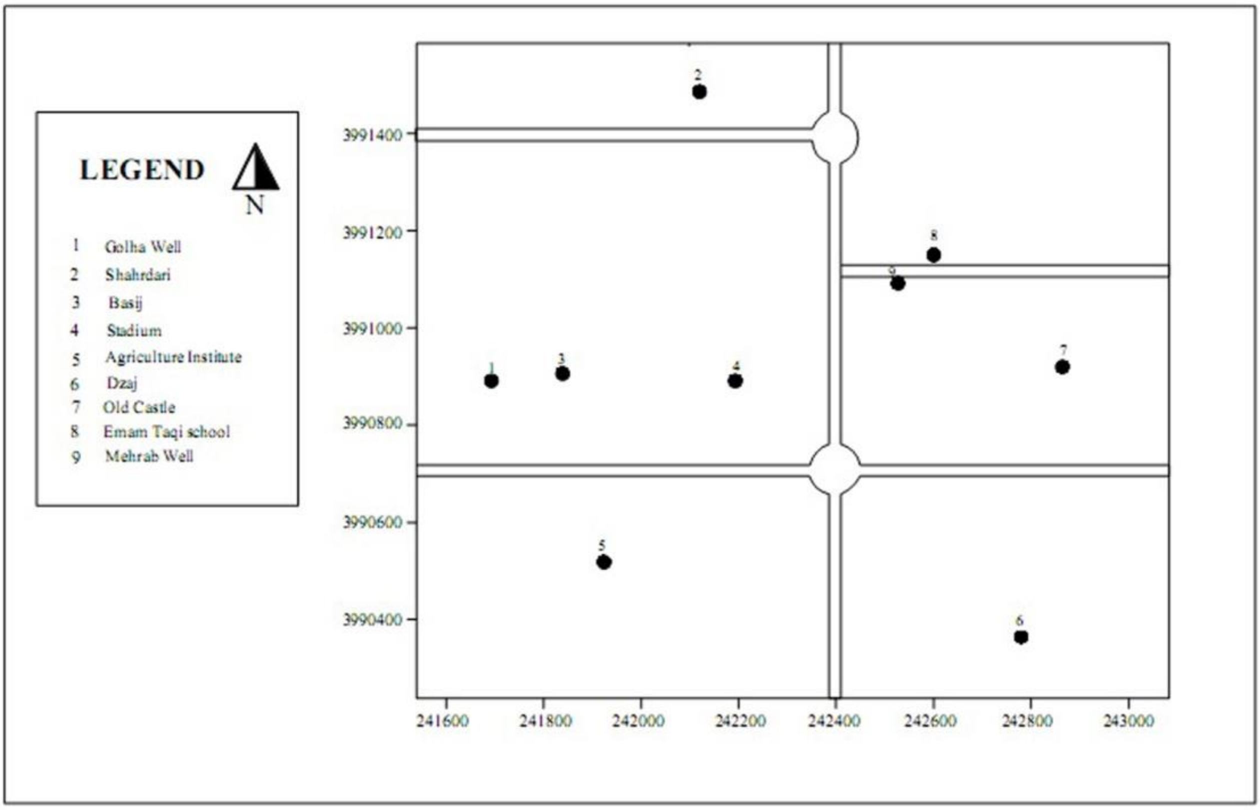

Figure 3)The position of the survey locations in Amiriyeh.

In the first step, one or two resistivity soundings were carried out in all of the selected stations (locations). According to aim of the study, the maximum current line for resistivity sounding in these investigations was 200m. The obtained data was initially processed and interpreted. This interpretation leads to the detection of a four layers model for soils in most of the locations in town of Amiriyeh. The surface layer is very thin (around 1m), thickness of the second one is around 3m, thickness of the third layer varies from 4 to 7m and the fourth one is a thick layer (at least 40m).

To determine velocities of shear and compressional wave for each layer detected based on resistivity results, the seismic refraction profiles were designed. Specification of the profiles was as follows: profile length; 50m, Geophone intervals; 2m (an additional geophone was used at a distance of 1m near each shot point), receivers; 24, shot points: 2 or 3 (beginning, middle and end of the profiles, respectively). In the first step, the profiles were surveyed for P waves. The obtained data was initially processed and interpreted in the field. The results had a significant accordance to the result of resistivity data and it was also recognized that the layers are more or less horizontal.

In the second step, the profiles were also carried out for shear waves. The extracted result from shear wave surveying also confirmed the previous ones. These measurements were performed in all of the selected locations.

4–Data processing and interpretation

According to the described patterns, the profiles were performed for all specified locations. The seismic and resistivity data were controlled, processed and interpreted, after the field operations.

Data processing and interpretation were performed in the following steps:

i) Reading the arrival times of P and S waves for each of the geophones;
ii) Preparing time-distance curves;
iii) Identifying the detected soil layers;
iv) Determining wave propagation velocity in each one of the layers;
v) Determining thickness of the layers.

The processing was the same for P and S waves. The time- distance curves showed a more or less horizontal dip of the layers along the seismic profiles. Despite of this fact, the techniques of Plus-Minus and Palmer method were also used to determine velocity and thickness of the investigated layers, in locations on which the data coverage was appropriate along the profiles. The results were more or less the same.

The resistivity data was also processed and interoperated as follows:

i) Calculating apparent resistivity for each reading;
ii) Preparing resistivity curves for each sounding;
iii) Identifying layers;
iv) Determining the real resistivity of each layer;
v) Determining thickness and depth of each layer.

The obtained data from seismic and resistivity methods were combined and a final geological model was compiled for each of the surveying locations. From site geological point of view, the locations were classified according to the criteria for soils (site geological) classification offered in the Iranian Code of Practice for Seismic Resistant Design of Buildings, (Iranian Standard 2800). In the Iranian seismic code, sites have been classified into four groups (Table 1).

4.1- Presentation of obtained results in some of the locations

As mentioned, based on primary studies and planning the geophysical measurements were carried out in 9 locations. The time-distance curves for P and S waves, resistivity curves for the electrical soundings and the results are presented for some of the surveyed locations, as some examples.

Table1) Site classification according to 2800 standard of Iran.

SiteType	Description	V_s (m/s)
I	a. Igneous rocks (with coarse and fine grain texture), stiff sedimentary rocks and massive metamorphic rocks (Gneiss, crystal layers silicate rocks), conglomerate. b. Stiff soils (compact sand and gravel, very stiff clay) with a thickness of more than 30m above bedrock.	>750 >750
II	a. loose igneous rocks (e.g. tuff), loose sedimentary rocks, foliated metamorphic rocks and in general rocks that has become loose and decomposed due to weathering b. Stiff soils (compact sand and gravel, very stiff clay) having a thickness of more than 30m above bedrock.	$375 \leq V_s \leq 750$ $375 \leq V_s \leq 750$
III	a. Rocks that are disintegrated due to weathering b. Soil with medium compact, layers of sand and gravel intragranular bond and clay with intermediate compaction	$175 \leq V_s \leq 375$ $175 \leq V_s \leq 375$
IV	a. Soft deposits with high moisture content due to high level of water table b. Any soil profile containing clay with a minimum of 6m and plastic index and moisture content exceeding 20 and 40 percent respectively.	<175 <175

4.1.1-Basij center (location 3)

Basij center is located in western area of Amiriyeh (Fig. 3). The seismic profile length was 50m with 3 shots and geophone interval was 2meters, in this location. The obtained results from processed and interpreted data are shown in Figures 4 and 5 as time-distance diagrams for compressional and shear waves, respectively. The resistivity curve is presented in Figure 6. By combining seismic and resistivity results, four soil layers specified in Table 2 have been detected in this location.

Table 2) Specifications of the soil layers - Basij center

Depth (m)	Thicknes s (m)	Rs (ohm-m)	Vp (m/s)	Vs (m/s)	Layers qualitative
0-0.5	0.5	22	290	145	clay and silt
0.5-5	4.5	40	330	175	Silt -clay
5-9	4	20	670	300	Clay- silt
9->30	>21	13	1000	360	Compacted clay

4.1.2-Agricultural Institute (location 5)

The Agricultural Institute is located in south western Amiriyeh (Fig. 3). The specification of the surveyed seismic profile as well as electrical sounding was the same as Basij location. The obtained results in this location have been presented in Figures 7 to 9 as time-distance diagrams for compressional and shear waves and resistivity curves, respectively. A combination of results extracted from the both applied methods leads to identification of four soil layers, mainly silt and clay layers (Table 3). As it could see in Tables 2 and 3 the site geology is more or less the same in this location and Basij location.

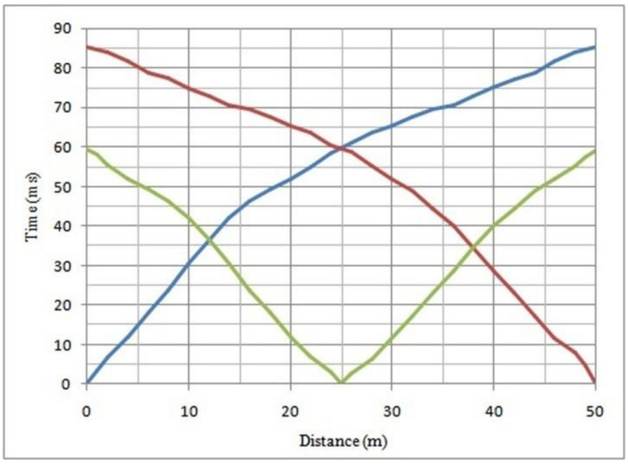

Figure 4) Time-distance curve (P waves)-Basij center

4.1.3-Mehrab well (location 9)

Mehrab well is located in the Mehrab Street. The depth of this well was about 16m, down hole seismic investigation was done in this well, using a sample intervals of 50cm. Obtained data was processed and the velocity-depth diagrams for compression and shear waves was prepared (Fig. 10). Four soil layers were also detected in this location as well as the other previous locations. Specifications of the layers are presented in Table 4.

Table 3) Specifications of the soil layers-Agricultural Institute

Depth (m)	Thickness (m)	Rs (Ohm-m)	Vp (m/s)	Vs (m/s)	Layers qualitative
0-0.5	0.5	16	285	145	Clay-silt
0.5-3	2.5	8	370	170	Clay
3-10	7	25	470	250	Silt- clay
>10	-	11	1050	380	Clay

As mentioned before, from geological point of view Amiriyeh is located in an alluvial plain. Thickness of the alluviums seems to be significant. According to the result obtained from the geoelectrical soundings, thickness of the alluvial layers which are mostly clay and silt is at least more than 50 meters. A combination of the result of seismic and resistivity investigation leads to conclude that the alluvial deposits are more or less homogenous in horizontal directions. While according to the seismic results, compaction of the alluvium increases due to depth increment. It is noteworthy that geophysical results correlated by geological observations especially in the investigated wells.

Table 4) Specifications of the soil layers – Mehrab.

Depth (m)	Thickness (m)	Vp (m/s)	Vs (m/s)	Layers qualitative
0-1	1	275	130	Clay-silt
1-3	2	340	155	Clay - silt
3-11	9	380	165	Clay
11-15	4	420	180	Clay

5–Velocity maps

Shear wave velocity is the only quantitative criterion for site geology classification, offered in the Iranian Code of Practice for Seismic Resistant Design of Buildings, (Table 1). This criterion has been applied in many site geology studies over the world. (Ansal *et al*., 2010;

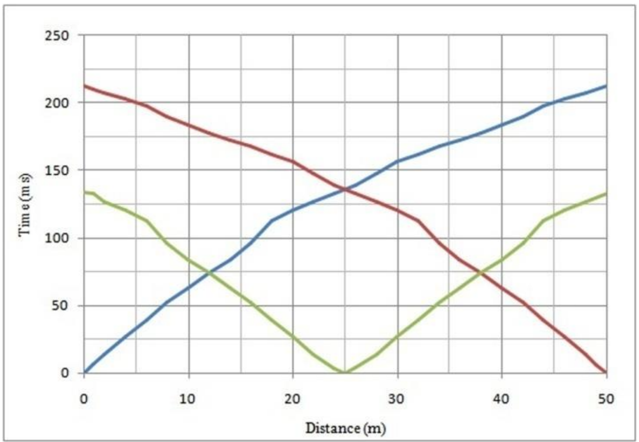

Figure 5) Time-distance curve (S waves) - Basij center

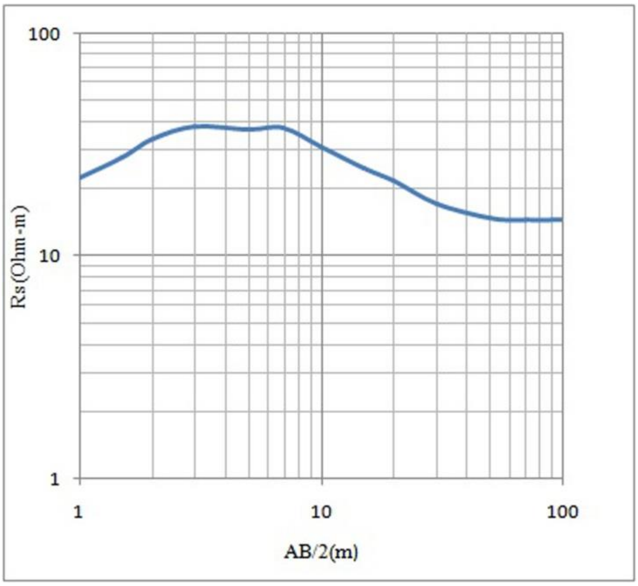

Figure 6) Resistivity curve - Basij center.

Anbazhagan *et al*., 2009; Andrei Bala *et al*., 2009; Maheswari *et al*., 2010; Mandrescu *et al*., 2007) Also in this study VS has been used for the classification of site geology in Amiriyeh.

Some shear wave velocity maps have been prepared, for various specified thicknesses of the soils. For example, in the velocity map for 5 meters, the layers (or some thickness of the last layer) from surface to depth of 5m have been involved and an equivalent shear wave velocity has been calculated (Eq.1).

$$V_S = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{V_{si}}} \qquad \text{Eq.1}$$

That; h; thickness, Vs; shear wave velocityn; number of layers involving from surface to the depth of interest.

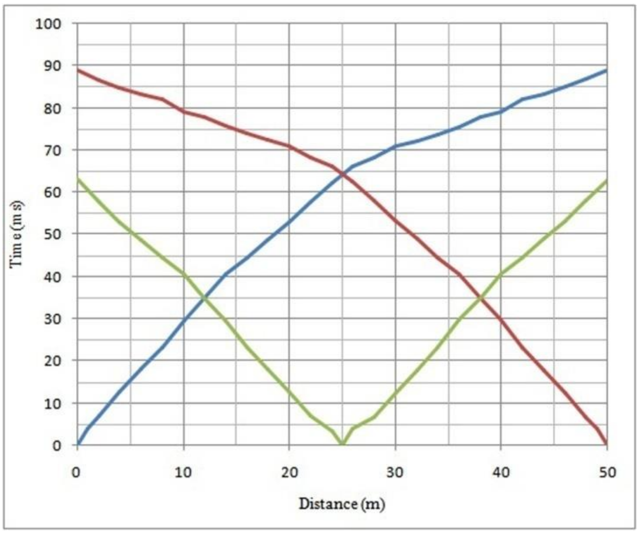

Figure 7) Time-distance curve (P waves)-Agricultural Institute.

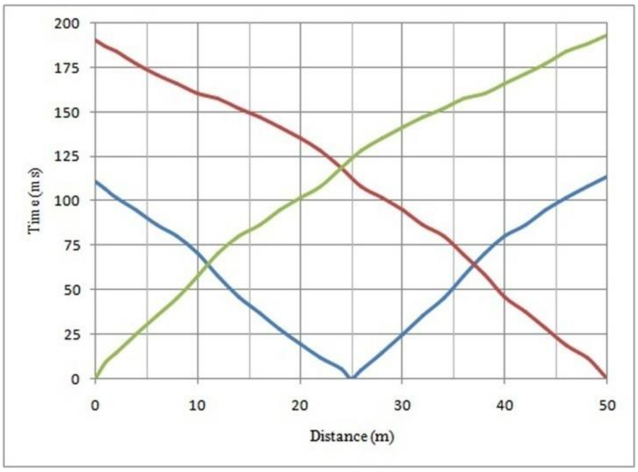

Figure 8) Time-distance curve (S waves)-Agricultural Institute.

5.1-Velocity maps up to different depths

To compile these maps, a shear wave velocity (as equivalent velocity) of the soil layers from ground surface to a desired depth has been taken into account. These maps have been prepared for depths of up to 1, 3, 5and 10 meters. The results have been provided in figures 11 to Figure 14. As shown on the maps, the velocity of Vs is very low in the north-east and it slightly increases towards the south-west. On the other hand, shear wave velocity gradually increases toward the depths.

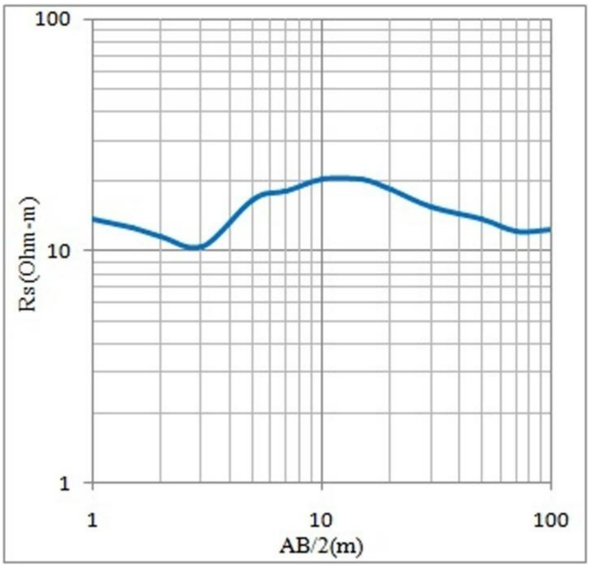

Figure 9) Resistivity curve - Agricultural Institute.

The surface layer is very thin and in most of the surveyed locations it is usually less than 0.5m (a few tens of centimeters). This layer is usually removed in all constructions. In most cases, the velocity of shear waves in this layer is less than 130 m/s which indicates its being very loose. The map compiled for depth up to 1 meter which mostly contains the surface layer is presented in Figure 11.

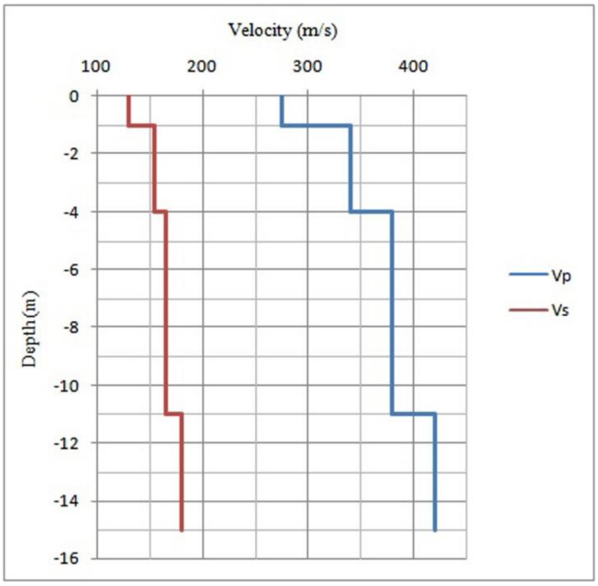

Figure 10) Velocity – depth diagram (Vp and Vs) - Mehrab well.

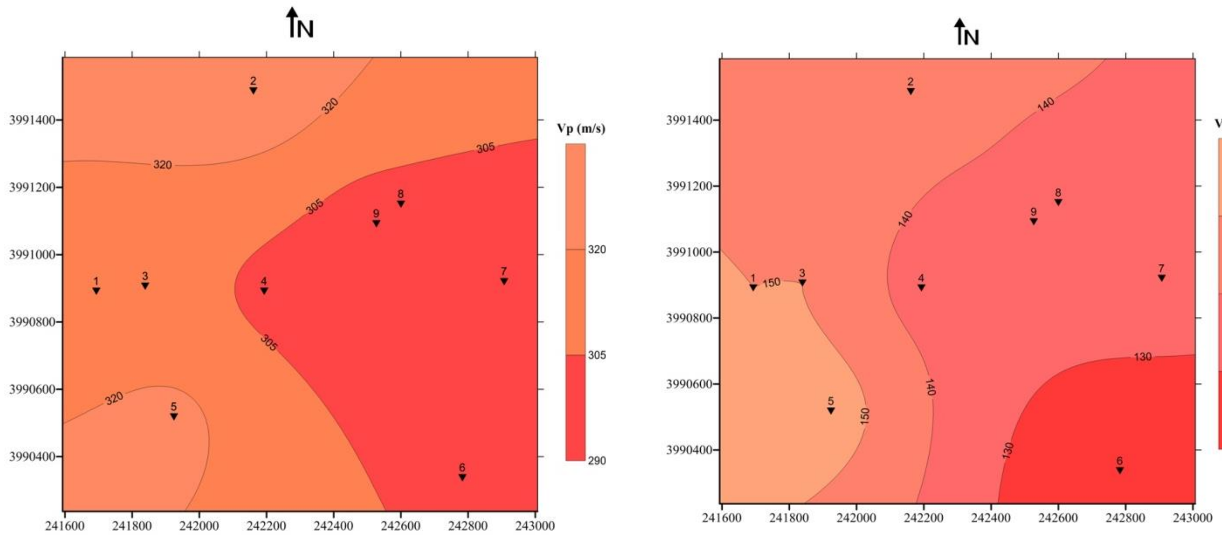

Figure 11) Velocity map up to depth of 1m.

5.2- Velocity map up to depth of 30m

According to the results of all studies in the city, the overall map of the velocity was prepared. In most cases, the depth of study can be extended down to 30m (the desired depth of the seismic code of Iran) by combining seismic and electrical methods. From this point of view, a total map was provided for the velocity of shear waves, and the results were presented in Figure 15. As observed in this map, the velocity of shear wave changes from less than 175 m/s in the northeast to 275 m/s in the southwest of the town.

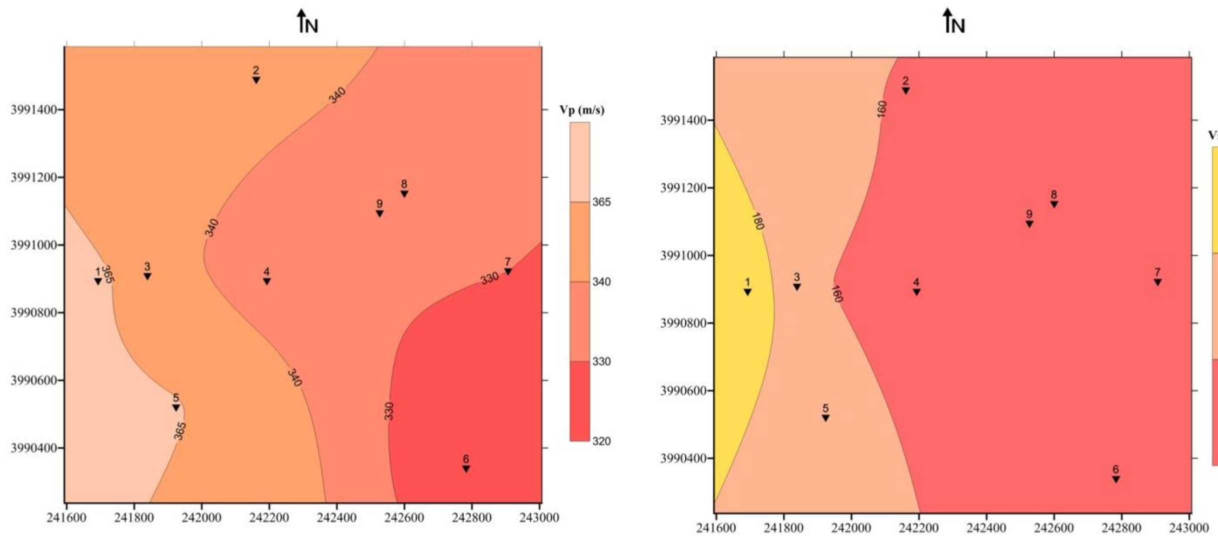

Figure 12) Velocity map up to depth of 3m.

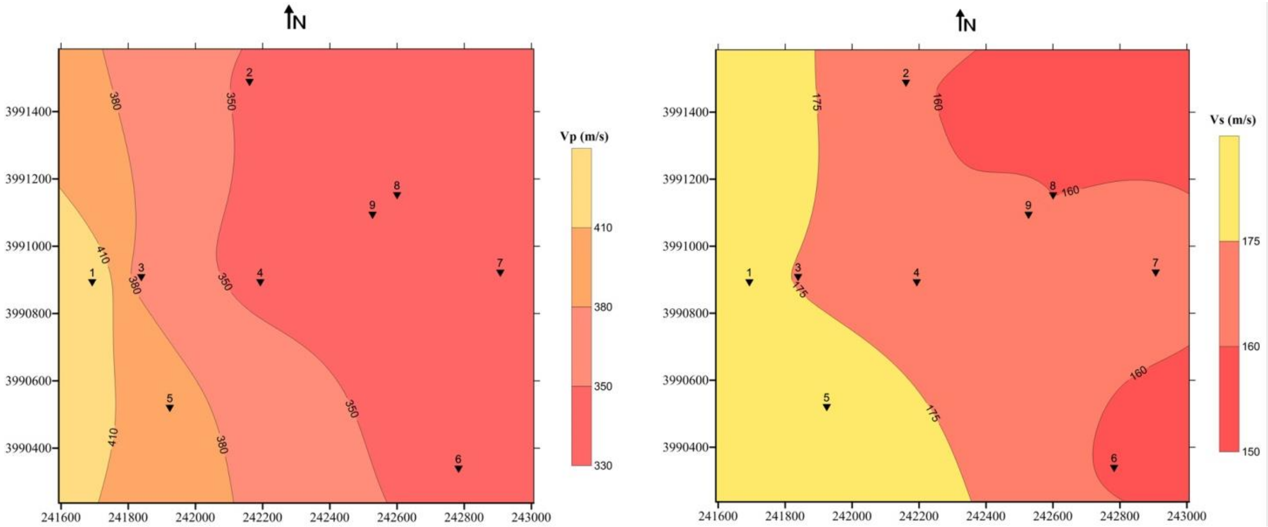

Figure 13)Velocity map up to depth of 5m.

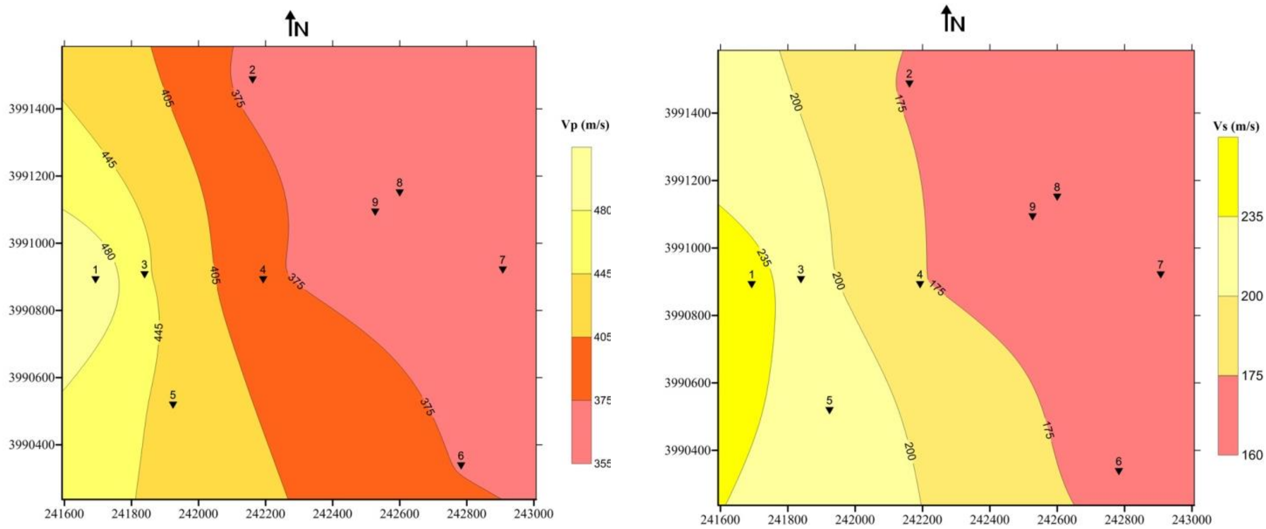

Figure 14) Velocity map up to depth of 10m.

5.3- Micro-zonation map

A site geology Micro-zonation map of Amiriyeh town was compiled according to the criteria for site geology classification offered in the Iranian code of practice for seismic resistant design of buildings (Fig. 16). To compile this map, the soil layers from the surface down to a depth of 30 meters have been taken into account.

As it is illustrated in Figure 16, the eastern area of Amiriyeh has been classified as group IV while the western area could be involved in group III (but very closed to the IV) of the Iranian seismic code. It should be noted that geotechnical tests are usually required parameters in seismic Micro-zonation studies, but in this research Micro-zonation map compiled based on geological and geophysical result.

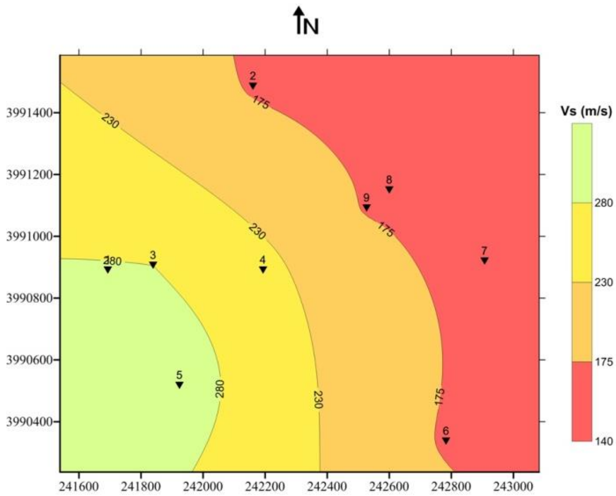

Figure 15)Velocity map up to depth of 30m.

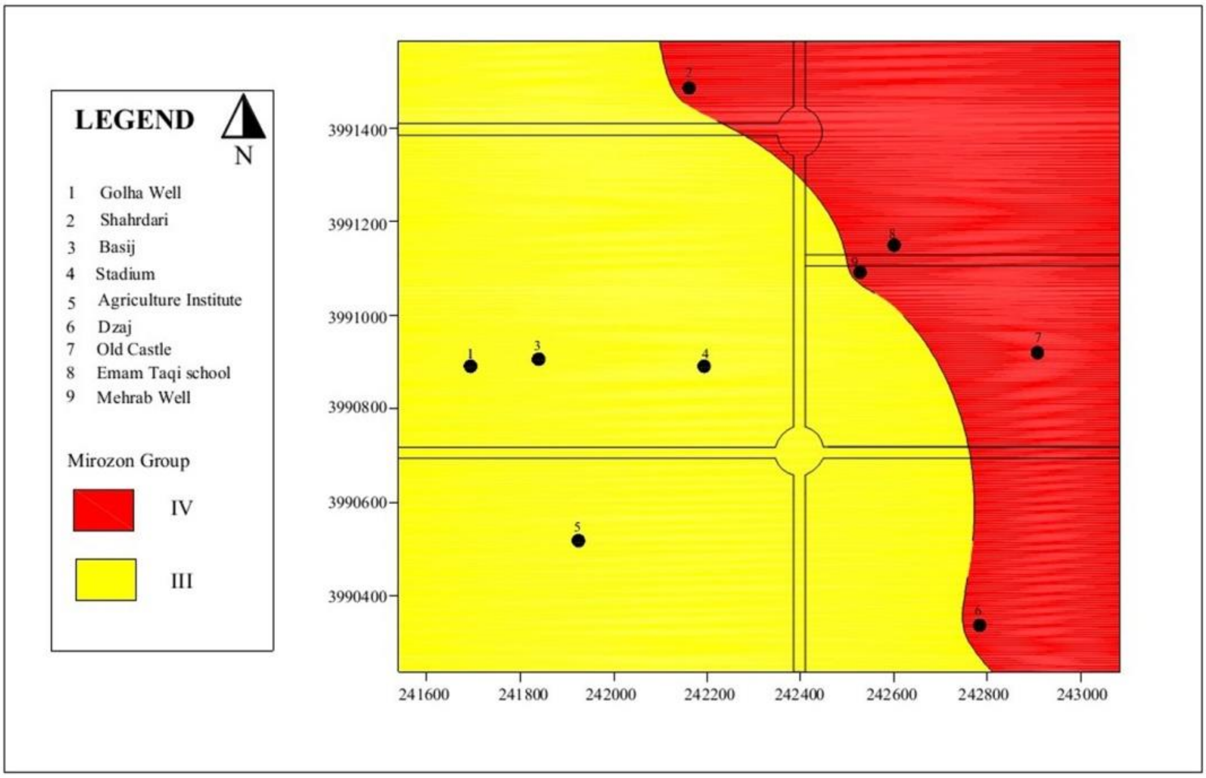

Figure 15) Site geology Micro-zonation map of Amiriyeh.

6–Conclusions

The results of this study could be summarized as follows:

From geological point of view, Amiriyeh is located in an alluvial plain with a very smooth topography. Thickness of the alluvial layers which are mostly clay and silt is at least more than 50 meters.

From the view point of site geology, the alluvial are more or less homogeneous in horizontal directions while, these materials are more compacted toward the depth.

A very weak surface layer composed of unconsolidated silts is present in almost all parts of the city. This layer is very thin and its thickness exceed to a few tens of centimeters. In some locations addition to the surface layer quality of the soils is very weak up to depth of 2 meters.

Considering descriptive point of soil classification offered in the Iranian seismic code, Amiriyeh could be classified in group IV (a considerable thickness of clay soil).

Regarding the prepared Micro-zonation map, the eastern area of Amiriyeh has been classified as the group IV(shear wave velocity less than 175m/s) while, the western area could be involved in the group III (but very closed to the IV) of the Iranian seismic code.

The results of this research could be used in urban planning and seismic resistant design of buildings.

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