

EVALUATION OF LIQUEFACTION POTENTIAL OF THE ALLUVIAL SOIL WITH INITIAL ACCELERATION METHOD, PROVINCE OF BATMAN CASE

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Abstract

Soil structures which mostly have alluvial are the most problematic soils in terms of convenience to settlement. Especially in the areas where there are new settlements, it gains importance to evaluate alluvial soil structures in detail. For settlement, alluvial soil needs to be analyzed in terms of liquefaction risk, bearing capacity and durability. Liquefaction of soil which is one of the most important problems in the soil is that layers lose their strength and act like viscous liquid instead of solid. Soil structures of alluvial soils that contain sand, silt and sometimes pebble but do not contain clay have higher liquefaction potential. Liquefaction issue which causes different deformations in each soil type can lead to bigger damages by effecting settlements negatively. There is a relation between soil type and liquefaction risk which can happen in the soil. Underground water nearer than 10 meters to the surface increases liquefaction. Especially in the layers where groundwater level is high, it is seen that liquefaction risk of partly compressed silt and sand is much higher.

In this study, the focus is on the evaluation of liquefaction mechanism in alluvial soils and liquefaction potential of the soil. In the evaluation of liquefaction potential of the soil, there are various empirical relation, analysis and methods. In this study, various calculations and evaluations are made using Initial Acceleration Method (Dobry et.al., 1981) which is one of the main methods that examine liquefaction potential.

Key words: alluvial soil, liquefaction, acceleration, sand

1. INTRODUCTION

Liquefaction describes a phenomenon whereby the soil loses resistance, stiffness and density in response to earthquake shaking or other similar quick and massive loadings. The phenomenon generally occurs in granular (silty, sandy) soils.

Soil liquefaction occurs when the strata below the ground water level temporarily lose resistance and behave like viscous liquid instead of solid matter. Soils without clay, silts and sometimes gravels may have a particular potential for liquefaction. During earthquakes, seismic and particularly shear waves alter formation of granules while passing through the water-saturated granular strata and make loose granules to move and settle in a different zone and tighten (Celep, Z. and Kumbasar, N., 2000).

In case the shearing stress of soil decreases towards a level which is lower than the static shearing stress, the soil becomes exposed to massive deformations and gets liquefied (Seed, H. B., Idriss, I.M., 1982). The movements that lead to liquefaction of the soil are seismic waves and shearing waves, in particular (Youd, T.L., 1992). These waves deform the granular structure with the additional water pressure created while they pass through the water-saturated granular strata and cause a loss in resistance of soil.

In order to measure the liquefaction, all conditions of the soil should be evaluated. The soil is formed by aggregation of soil granules. The load formed by the strata of soil granules creates contact forces between granules and these contact forces keep granules together and determine resistance of the soil (Eskişar, T., 2002).

Liquefaction potential is affected by a wide range of geological and hydrogeological factors. Composition, stiffness, formation, stress conditions it is exposed to, ground water level, seismic development and conditions as well as soil type are among major factors that have impacts on liquefaction. Soil liquefaction may typically occur more frequently in loose sands that have a potential

to volumetrically become smaller under dynamic loads. However, other soil types should also be analysed to clearly reveal the liquefaction mechanism. According to a number of studies in this field, liquefaction may also occur in alluvial soils, especially those containing sands, silts and even gravels

2. LIQUEFACTION OF SOIL

Soil liquefaction occurs when the strata below the ground water level temporarily lose resistance and behave like viscous liquid instead of solid matter. Soils without clay, silts and even gravels may have a particular potential for liquefaction.

Soils may display complex behaviours based on different characteristics such as formation, structure and functions. Problems relevant to bearing capacity, settlement and slope (talus) stability create the basic challenges caused by static loads, while liquefaction, soil amplification and dynamic slope stability lead to other basic challenges caused by dynamic loads, such as earthquakes (Özçep, F et al., 2005).

As the seismic waves that occur during earthquakes create short-term movements, they do not give adequate time for the water among granules to be drained. In this case, pressure of the connate water will drastically increase as it cannot move away from the given zone of ground. This dramatic increase in connate water eliminates the contact force that keeps the soil granules together and makes them diverge. Therefore, the soil loses its resistance. Under these circumstances, the soil behaves like a liquid, instead of a solid matter like which it behaves prior to the earthquake, and moves towards the surface together with water and spurts out of the ground. This behavior of soil, caused by dynamic loads, is identified as liquefaction (Figure 1).

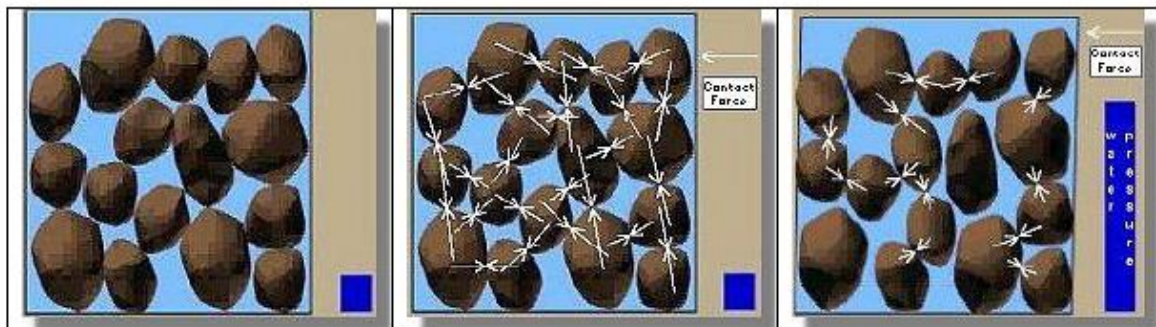


Figure 1. Soil granules; lengths of the arrows are in direct proportion to the contact force between soil granules. As the water pressure decreases, the contact force scales up. (Anonymous, 2006a)

3. GEOLOGICAL IMPACTS OF SOIL CHARACTERISTICS ON LIQUEFACTION

Various factors such as geological units, size of granules, SPT number, ground water level, magnitude of the earthquake and its distance to the center constitute significant conditions for liquefaction. As the geological units, particularly water-saturated, sandy, silty-sandy and clayish-sandy units with relatively low bearing capacities, which are present in the first 15-20 meters, may have higher risks of liquefaction. We may also observe occurrence of liquefaction inside the soils with sand-dominated geological compositions whereby the sedimentation and consolidation of the sand, uniform granule composition and inexistence of forces that bound the granules, create a liquefaction mechanism.

Geological age of soil stratum, together with sedimentation and hydrological conditions, gives significant clues about the potential for liquefaction. Geological areas that cause a loose settlement during the sedimentation process and younger sediments are known to have higher risks of liquefaction (Özaydın, K., 2007).

There is also a relation between soil type and the risk of a possible liquefaction. A number of studies in this field suppose that liquefaction does not only occur in cohesionless and clean sands but may also occur in low cohesive silts (Ishihara, 1984, 1985) and graveled soils (Youd et al. 1985; Yegian et al. 1994, Evans and Seed, 1987). Furthermore; alluvial sands, containing large and small gravels, sands and soils, carried and accumulated by the streams may also be clayish, calcareous or sandy and create the most problematic grounds for housing works.

As the ingredients that form alluvial soils have typically been carried by streams and accumulated in the current position not too long ago, the phenomena generally that shape soil compositions may not have adequate time to add any property to this kind. Besides ones accumulated a short while ago, alluvial soils may also be at hundred years of age.

Zonal conditions of ground may significantly affect earthquake motion parameters and resistance of the soil. Particularly, functions of momentum spectra (Figure 2) and infiltration of high frequencies in alluvial grounds may create the liquefaction mechanism.

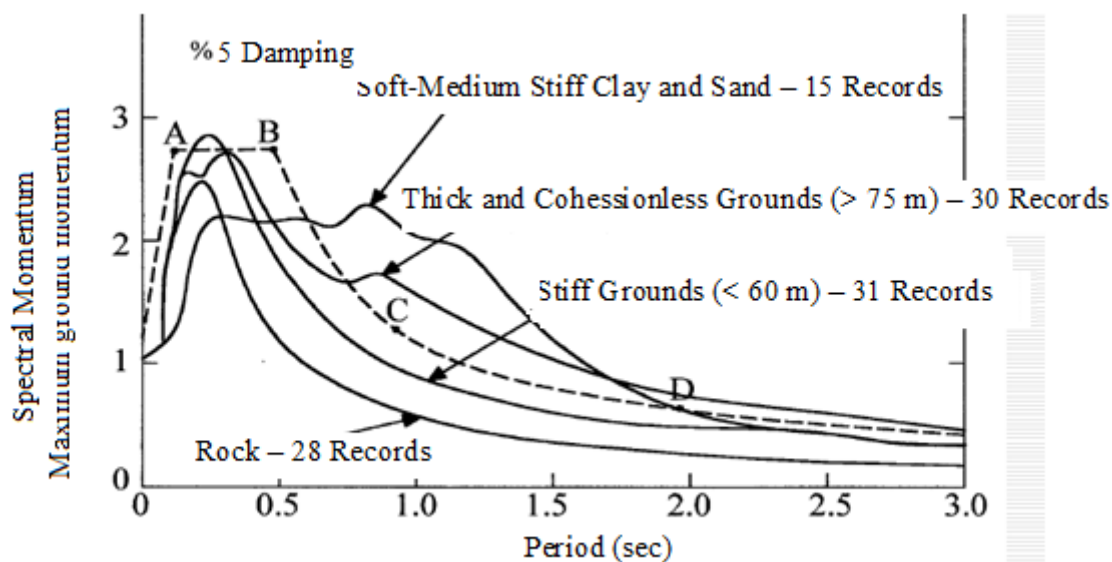


Figure 2. Average Momentum Spectra for Different Soil Conditions (Seed H.B and Idriss I,M, 1983)

Moreover, buildings may sink, rotate, tilt or overturn as a result of the loss in bearing capacity of foundation grounds (liquefaction in sands, softening in clay) (Figure 3).

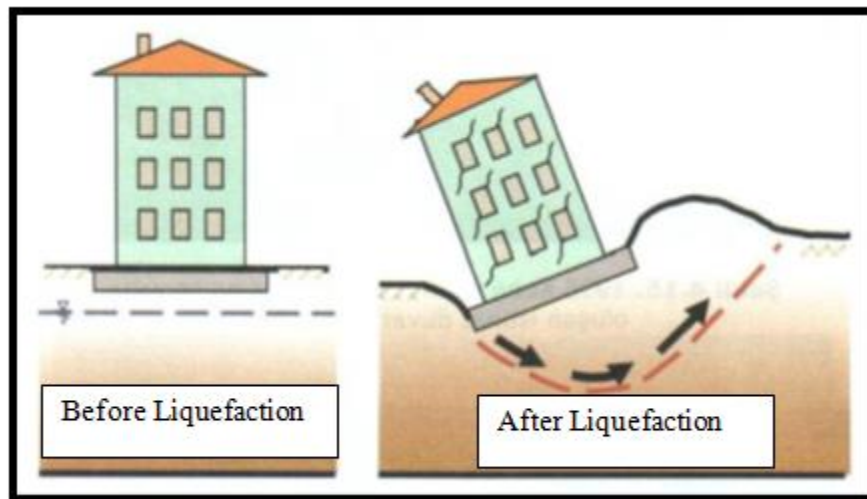


Figure 3. Bearing capacity loss failure type (Mollamahmutoğlu, M., Babuçcu, F. 2006)

Figure 4 shows buildings that overturned due to liquefaction in Adapazarı Province during Turkey's 1999 earthquake.



Figure 4. Buildings overturned by liquefaction, during Turkey's 1999 earthquake in Adapazarı Province (Source: <http://www.jeofizik.org.tr>)

4. ANALYSIS OF SOIL LIQUEFACTION POTENTIAL THROUGH DOBRY METHODS (INITIAL MOMENTUM METHOD)

Soils with liquefaction risks are generally soft, thin and medium grained granular soils (silts and sands) and those where ground water level is relatively high. Based on the velocity of seismic shear wave, liquefaction potential can be analysed by the equation given below (Dobry et al., 1981).

For the factor of safety in threshold momentum criterion (F_a);

$$F_a = 1.6 \ a_t/a_{max}$$

$$a_t = (N_t * (G_{enb}/G_{max}) (V_s^2 (z * rd)$$

For F_a which is the factor of safety in threshold momentum criterion; a_t ; initial (threshold) momentum which is essential for liquefaction, N_t ; distortion of threshold segment, G ; shear resistance of the liquefiable soil (kg/cm^2); G_{enb} ; flexible shear resistance for the cohesive layer below the liquefiable ground (kg/cm^2), V_s ; shear wave velocity of the liquefiable ground (m/sec), z ; depth of the liquefiable ground from the surface; a_{max} ; maximum potential momentum that could be caused by the earthquake.

$$rd = 1 - 0.0015 \ xz$$

Here, rd represents the stress reduction coefficient that may change based on the depth (Figure 5).

N_t = Distortion of threshold segment. This magnitude is based on $(G_{enb}/G_{max})_t$ ratio and N_t could be taken as 0,0001 which is equal to 0,8.

If $F_a < 1$, liquefaction potential is accepted as high while it is considered as high-low when $F_a > 1$.

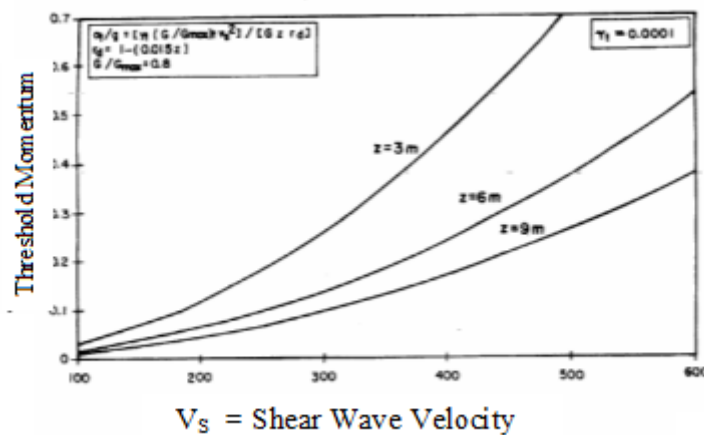


Figure 5. Suggestion on initial momentum values

4.1. Liquefaction analysis of Batman province

This study focuses on liquefaction mechanisms in alluvial grounds and evaluation of soil liquefaction potential. There are a lot of empirical relations, analyses and methods in the evaluation process of soil liquefaction potential. Within the scope of this study, liquefaction analyses were made in an area with alluvial ground strata in Batman Province, Gultepe District, considering seismic shear wave velocities and using Initial Momentum Method (Dobry et al., 1981), which is one of the basic methods that examine liquefaction potential.

4.1.1. General Geological Characteristics and Soil Structure of Batman Province

Batman city is geologically founded on Şelmo Formation and Quaternary units formed by upper Miocene-Pliocene mudstone, sandstone and conglomerate. Şelmo formation is composed of thin-medium-thick strata containing red, brown, grey, light grey conglomerate, silt stones, mudstones, mud, sand, gravels and graveled-sandy mud. White-colored gypsum partly dominates the strata (Eren, Y ,et al., 2012).

The dominant lithology is clay and this structure also contains silt stones, sandstones and various strata in a lentoid shape. The limestone and dolomitic limestone surfacing West Raman Mountain forms the Hoya Formation. The age of this 228-meter-thick unit between Batman and Hasankeyf is Early Eocene-Early Oligocene (Yılmaz and Duran, 1997). The unit formed by limestone, gypsum and shale seen in north-west slope of the West Raman Mountain forms the Germik Formation. This formation is composed of partial silty and sandy dolomites, calcareous shale and white-colored gypsum intercalation (Figure 6).

Soil characteristics of Batman Province show substantial changes in horizontal and vertical directions. For this reason, a number of drilling works and geophysical methods (electric, seismic) have been applied in different times and areas in order to understand soil properties of the city. Thickness of the soil composition that spreads over a wide area in Batman city centrum and north part of the city changes between 300 and 800 meters but evolves into a different thickness and sequence throughout Southeastern Region of Anatolia. Today, dominant composition in eastern part of the city is composed of Pliocene sediments that are loosely based on Şelmo Formation and contains predominantly conglomerate and sandstones. There exist old and probably Pliocene-Quaternary fluvial sediments that contain sandstones and conglomerate, in southern part of Esentepe District.

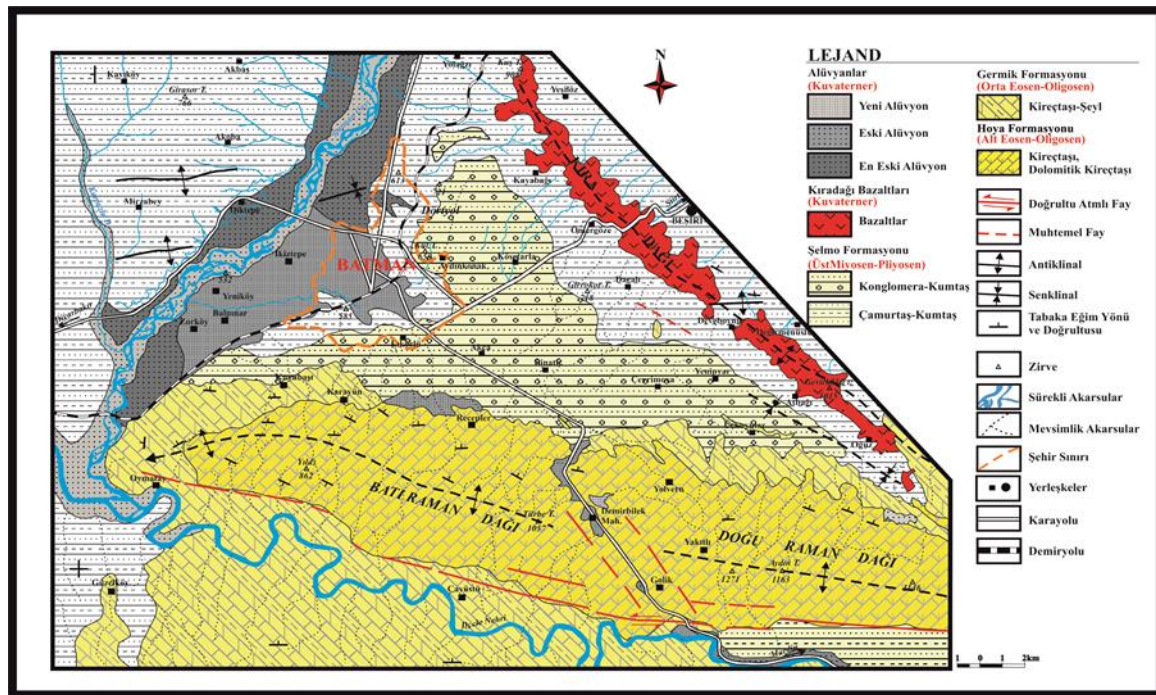


Figure 6. Geological map of “Batman” Province (Prepared by modifying MTA’s 1:500.000 scale geology map).

4.1.2. Seismicity of Batman Province

Batman city is settled in a second-degree seismic zone and a location very close to the first-degree seismic zones. This fact and its proximity to highly active faults place it in a risky position in terms of earthquakes. According to Chart 1, a 100-km-radius circle near the center of Batman city has experienced frequent earthquakes with magnitude values over 4. This indicates that the region is fairly vibrant and significant in terms of seismic movements.

Chart 1. Earthquakes with magnitudes values of 4-9 that occurred in a 100-km-radius circle in Batman city center, between 1950 and 2006 (Kandilli Observatory and Earthquake Research Institute).
<http://www.koeri.boun.edu.tr/sismo/mudim/katalog.asp>

SN	Date	Time	Latitude	Longitude	Depth (km)	Moment magnitude (Mw)
1	21.02.1960	09:29:23.3	38.49	41.52	40	4.9
2	19.03.1960	14:53:53.6	36.64	41.27	10	4.7
3	19.09.1964	16:57:01	37.50	40.00	30	4.7
4	28.06.1965	23:27:2.9	38.00	41.30	33	5.4
5	19.08.1966	21:38:56	38.40	41.20	172	4.7
6	06.09.1975	10:52:16.6	38.46	40.82	47	5.4
7	06.09.1975	12:10:43.1	38.33	40.56	2	5.1
8	06.09.1975	12:24:2.1	38.44	40.48	44	4.5
9	06.09.1975	13:20:52	38.42	40.90	31	4.3
10	06.09.1975	22:42:51.5	38.38	40.42	32	4.4

4.1.3. Seismic Analyses Conducted within the Area of Investigation

According to the seismic analyses conducted within the area of investigation; the strata detected by 2-D MASW profiles, in a large proportion of the area, contain very loose and loose (alluvial) units and have a low shear wave (V_s) velocity. Figure 5 shows 2-D MASW profiles of 1-3-6 numbered samples examined within the area of investigation. For the 1st, 2nd and 6th profiles obtained by the seismic analyses conducted in parallel areas; there exist loose and water-saturated units in each profile which is between 5-10 meters for the 1st profile according to the V_s velocity values of 2-D MASW graphs, between 4-11 meters for the 3rd profile according to the V_s velocity values of 2-D MASW graphs and between 4-11 meters at the beginning and 2-7 meters at the end of the 6th profile (Figure 7).

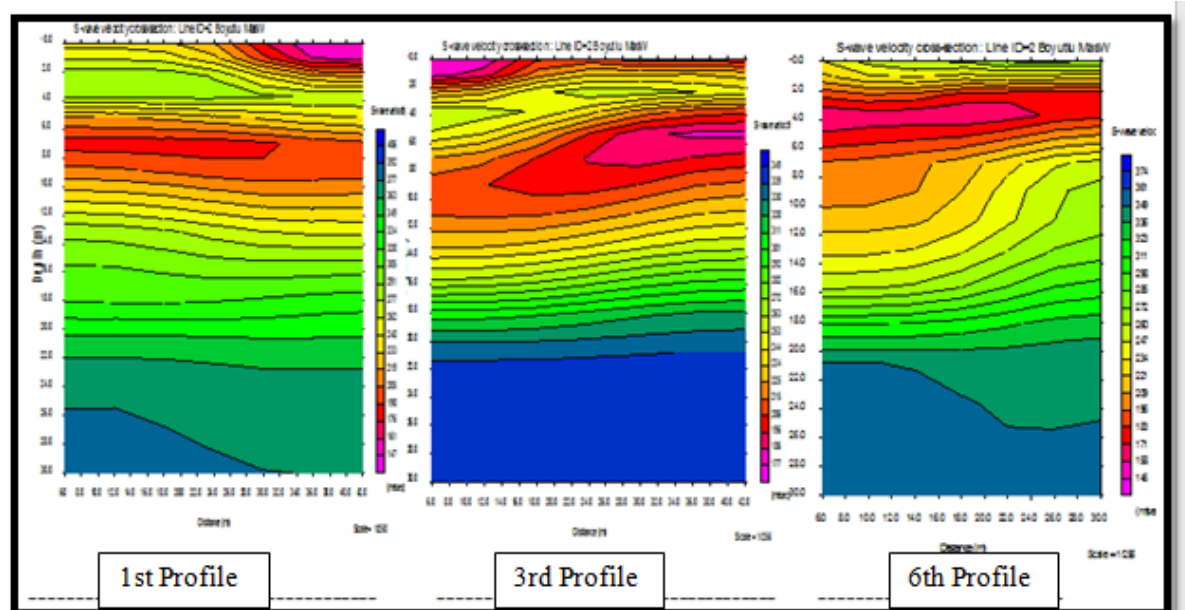


Figure 7. 2-D seismic MASW profiles obtained in certain points within the area of investigation

As a result of the seismic studies conducted in Batman Province, Gultepe District; according to the F_a value measured by the liquefaction analyses based on seismic shear wave velocity, there is a liquefaction risk in the city.

Chart 2. F_a values measured by the seismic profiles obtained within the area of investigation

Profile	G	G_{max}	V_s	z	a_{max}	at	F_a
2nd Profile	555	1143	185	13	0,4	0,158800175	0,6352007
3rd Profile	502	1267	177	7	0,4	0,198131058	0,7925242
4nd Profile	610	1064	193	11	0,4	0,232500379	0,9300015
9nd Profile	429	1035	165	7	0,4	0,180120754	0,7204830

5. CONCLUSION

The phenomenon of soil liquefaction, which is caused by soft soil strata, is one of the most significant factors of earthquakes' destructiveness. Particularly soil compositions that predominantly contain alluvial ingredients create the most problematic grounds in terms of housing. It is getting more important to conduct detailed analyses on alluvial soil compositions of (especially) areas with newly-built settlements. Prior to a housing work on alluvial grounds; liquefaction risk, bearing capacity and resistance criteria should be analysed. The liquefaction mechanism in different types and conditions of grounds and some geological areas is still being argued. Studies in the recent years have analysed the phenomenon of liquefaction in areas with dense housing projects and liquefaction analyses and measurements have gained more importance as a result.

Batman Province, Gultepe District sample of the study has alluvial strata that change according to the depth. The velocities are found to be less than 200 m/sec up to 7-11-13 meters according to 2-D MASW profiles obtained through seismic analyses. The fact that seismic shear wave is less than 200 m/sec shows existence of loose (alluvial) and watery units. According to the F_a value obtained through the liquefaction analyses based on seismic shear wave velocity, a liquefaction risk is anticipated for the area. In conclusion, this study reveals that soil liquefaction does not only occur in cohesionless and clean sands but may occur in alluvial type of soils as well.

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