Evaluation of the Liquefaction Potential by In-situ Tests and Laboratory Experiments In Complex Geological Conditions

V. Sesov, K. Edip & J. Cvetanovska
University Ss. Cyril and Methodius, Institute of Earthquake Engineering and Engineering Seismology-Skopje, Macedonia

SUMMARY:
The study presents the investigations and results on the evaluation of the potential of liquefiable soil layers at location where new industrial complex is planned to be built in southern part of Republic of Macedonia. Investigations combine the results from different in-situ methods, site response analysis and laboratory cyclic triaxial undrained tests. Results from the performed tests and experiments provide valuable data regarding the assessment of liquefaction hazard at the location with medium to high seismicity and heterogeneous soil condition. Methodology applied in this study pointed out the necessity of attention and precaution to draw the final conclusions for potential of liquefaction in complex geological condition with high degree of soil heterogeneity.

Keywords: Liquefaction, triaxial tests, SPT, CPT

1. INTRODUCTION

Assessment of the likelihood of initiation of liquefaction is the necessary first step of most projects involving potential seismically induced liquefaction. Concerning the liquefaction as one of the geotechnical instabilities which increased the damages during the strong earthquakes there are different approaches and methods available for the evaluation and assessment of its potential. Two general types of approaches available for this exist: (1) use of empirical relationships based on correlation of observed field behavior with various in-situ “index” tests (2) use of laboratory testing of samples. In-situ tests namely SPT and CPT with appropriate empirical formulas are very good starting point for estimation of the liquefaction potential in quite short period. For the purpose of the new industrial complex which is planned to be built at first preliminary evaluation of the liquefaction potential is done with SPT and CPT methods. Results indicated the soil layers which cyclic resistance ration is lower than the expected cyclic stress ratio and might behave as liquefiable. The geological condition and especially soil heterogeneity of the site were very complicated to rely only on the SPT and CPT tests since there is not clearly presence soil layers with clean sands and stratification of the sandy soil layers were far from regular. Therefore extensive laboratory tests were conducted at the Laboratory for dynamics of soils and foundations, Department for Geotechnics and special structures, at the Institute for Earthquake Engineering and Engineering Seismology. Soil samples were taken from the boreholes of the site and cyclic undrained triaxial tests were done. Results from the performed tests and experiments provide valuable data regarding the assessment of liquefaction hazard at the location with medium to high seismicity and non-homogenous soil condition. Methodology applied in this study which combines the results from different in-situ and also laboratory tests pointed out the necessity of attention and precaution to draw the final conclusions for potential of liquefaction in complex geological condition with high degree of soil heterogeneity.

2. SITE CONDITIONS

The site is located near the city of Bitola in the Southwestern part of Macedonia. The industrial complex includes one industrial hall, an associated administrative and support buildings and access platforms and roads (Figure 1).

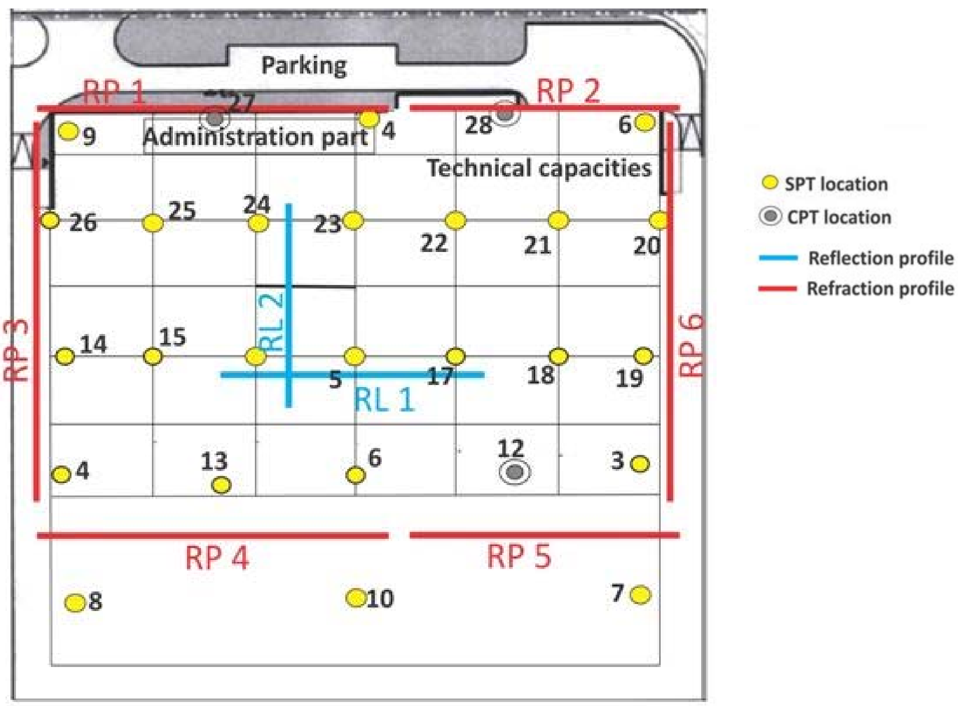

Figure 1. Plan of the site and site location

The field investigations, which are presented in figure 1, for the project included boreholes, seismic cone penetration testing (CPT), standard penetration test (SPT) and in order to define the subsurface amplification soil layers parameters (H-height, Vs- seismis shear wave velocity and T- predominant periods) seismic refraction and seismic reflexion testing is performed. Figure 2 shows a simplified soil profile and a summary of the site conditions located on the analyzed industrial complex.
In general the soil has heterogeneous structure. The location consists of silty and clayey sand; then clayey and silty sand to different depths, but the most at the depth >10-11.0m to the investigation depth. The underground water is noticed on two, three and four water bearing levels and makes aquifers with intergranular porosity and subarterian character. Underground water level has been encountered in all boreholes on the depth of 1.3 to 1.8m.
Based on the results of the field investigation, the proposed facility is located on a site with complex soil conditions, consisting of around 30 metres of alluvial deposits – predominantly layers of medium-dense sand and soft, low-plasticity silt. Significant portions of soil deposits are compressible and there are zones within the upper part that are estimated to be liquefiable. The bedrock elevation (Figure 3) was assumed, as it was not encountered during the field exploration to around 30 metres depth.

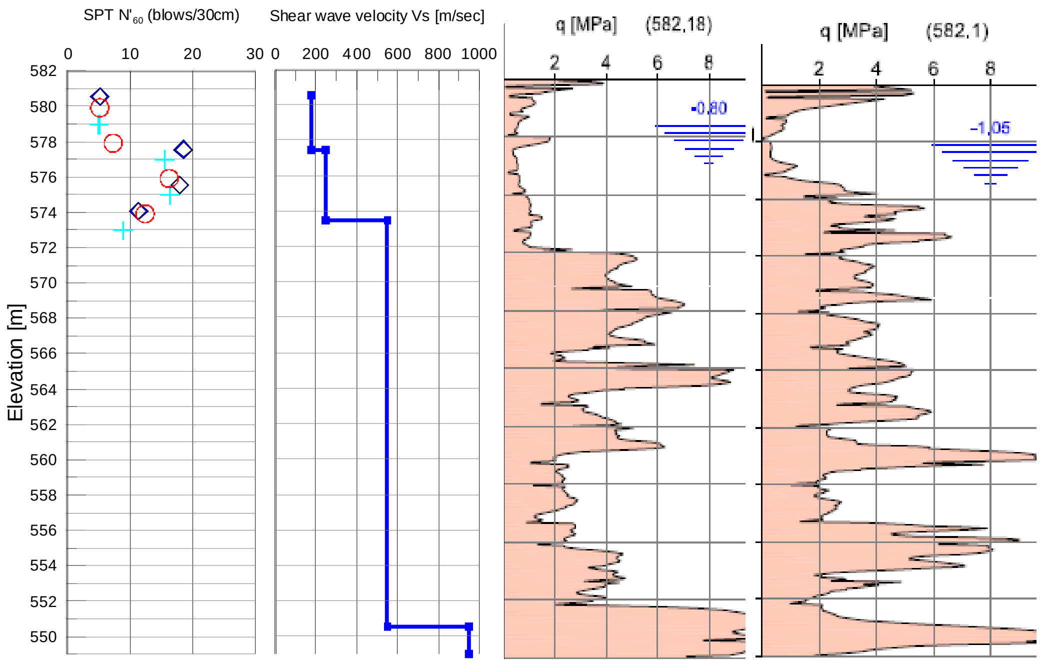

Figure 2. Summary Site Soil Profile

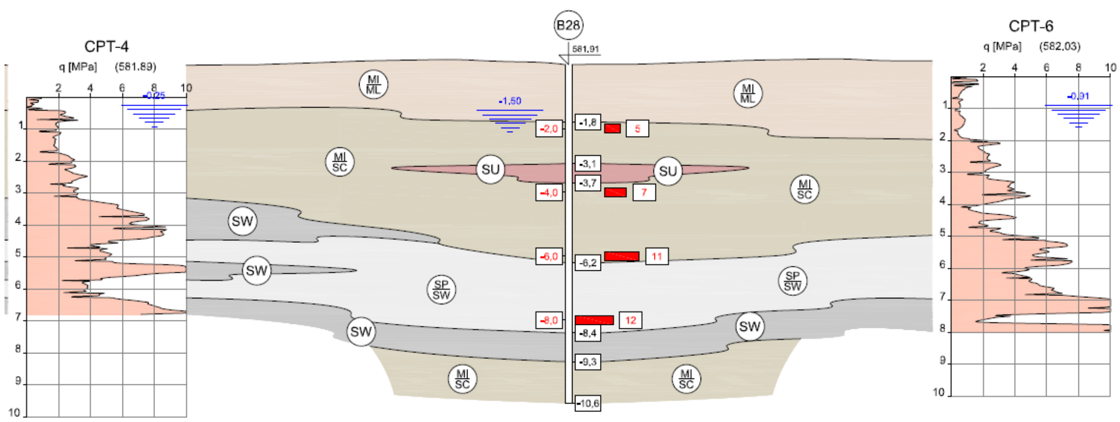

Figure 3. Soil profile formed on the basis of boreholes and CPT data

Given that the site is underlain by more than 30 metres of predominantly soft aluvial materials and the strong ground motions, the industrial complex is designed to be supported by pile foundations with round improvement in the upper 3-5 metres below the ground surface.

3. SEISMIC SITE RESPONSE

The region where this industrial complex is planned is characterized with medium to high seismicity. A site-specific seismic hazard study estimated bedrock peak ground accelerations for different return periods and for near and far earthquake events respectively (Table 1).

Table 1: Peak ground accelerations at bedrock

Earthquake events	Return period (years)				
	50	100	200	475	1000
Near events	0.095	0.121	0.141	0.150	0.160
Far events	0.074	0.084	0.095	0.105	0.110
Together	0.100	0.124	0.150	0.160	0.170

Results based on site response analysis of two representative geodynamic models show value of predominant period of the site in the range between T=0.32 s to 0.36 s. Figure 4 presents the maximum acceleration values versus depths for site response analysis with 10 representative earthquakes for the region. With input acceleration on the bedrock of a_{max}=0.15g (return period of 200 years), respectively for model 1 and 2.

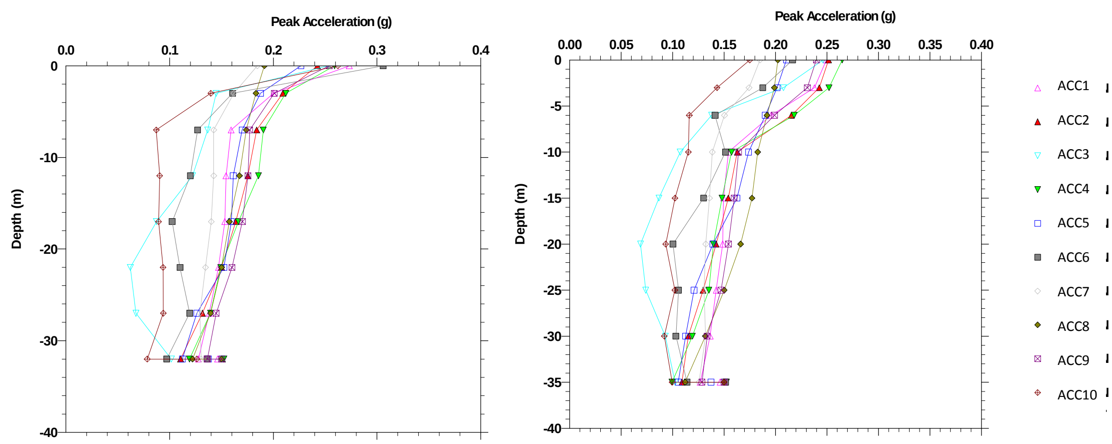

Figure 4. Maximum accelerations versus depth model 1(left) and model 2 (right)

4. EVALUATION OF THE LIQUEFACTION POTENTIAL

4.1. SPT and CPT procedure method

First preliminary analysis for the liquefaction potential using the SPT and CPT procedures explained in Youd et al. (2001) are done and results in format of CSR (Cyclic strength ratio) versus CRR (Cyclic resistance ratio) are given in Figure 5. On the basis of these analyses, it can
be noticed that the majority of the zone between 6-8 meters depth is potentially liquefiable.
In the area between 6- 8 meters, the standard penetration test (SPT) corrected blow counts (N'60) values calculated for the site indicate that the majority of the values are around 12. The grain size distribution of these sandy materials show fines content value of around 10 %.
Given the large heterogeneity of the soil profile, the high level of water table, an in-depth site-response and seismic performance evaluation was conducted for these layers using cyclic triaxial laboratory testing.
This evaluation was particularly connected for this project and the seismic performance requirements for the pile foundations.

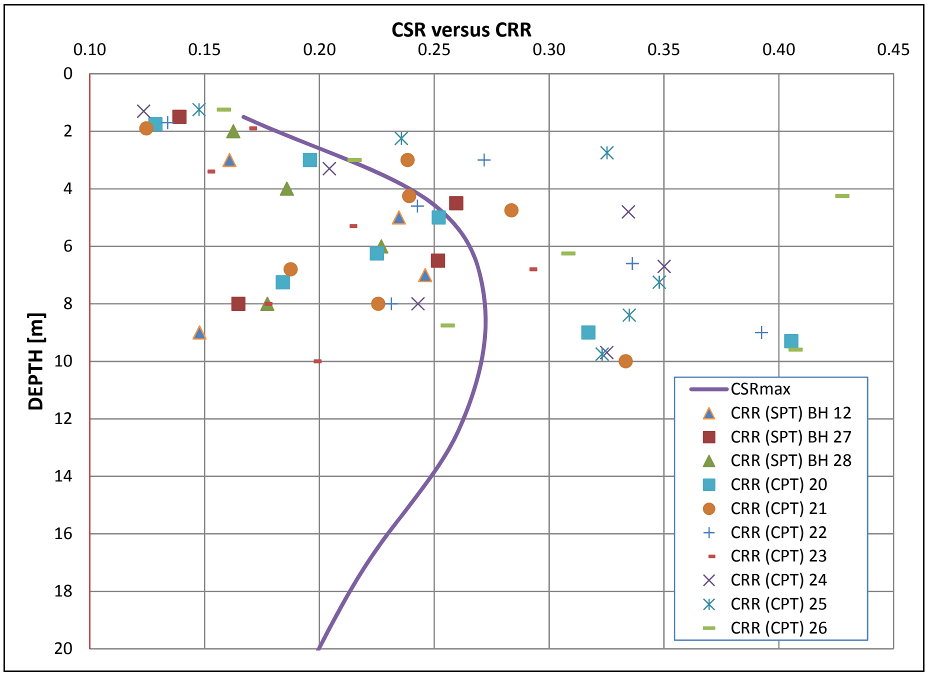

Figure 5. Liquefaction potential by SPT and CPT method (Youd et. Al., 2001)

4.2. Laboratory testing – dynamic triaxial tests

Liquefaction potential for the observed soil layers was evaluated cyclic liquefaction triaxial tests in the laboratory for geotechnics and special structures at IZIIS. Samples from two boreholes were tested on different levels of cyclic stress ratio in order to define the liquefaction versus number of cycles. The samples were cyclically loaded at 0.5 hertz. The sample test conditions are presented in table 2. Results from liquefaction test to cyclic stress ratio of 0.10 are given below.

Table 2. Sample test conditions

Borehole	Depth	Test No.	Initial density [%]	Confining ratio [kPa]	CSR
BH 28	6.2-8.4	1	44.0	100	0.08
		2	41.8	100	0.10
		3	39.8	100	0.15
BH 12	5.0-8.0	1	41.8	100	0.08
		2	40.1	100	0.10
		3	40.5	100	0.15

In order to give more insight of the liquefaction potential of the site the following figure shows the dependence of the cyclic stress ratio CSR to number of cycles necessary to initiate liquefaction. As can be seen from the Figure 6 the number of cycles necessary to initiate liquefaction at both boreholes of BH12 and BH28 is quite small.

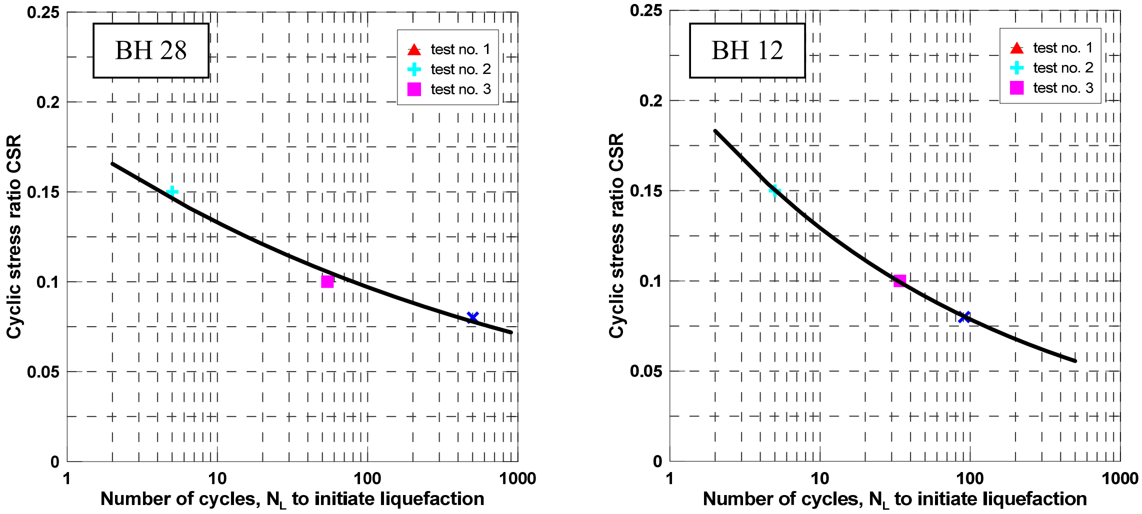

Figure 6. Cyclic stress ratio CSR versus number of cycles to initiate liquefaction

To validate the methodology, next the deviatoric stress and mean stress behavior in relation to the strain percentage is taken into consideration.

As can be seen from the diagrams in Figure 7 and Figure 8 the mean stress reduces from its initial value which proves the liquefaction initiation. On the other hand, the stress strain diagram shows that at the couple of first cycles the slope of the diagram is quite bigger than zero while at the last cycle the slope of the diagram has approached a straight line increasing the strain value enormously. As can be seen from both figures the liquefaction initiation is present even at low cyclic stress ratio such as CSR=0.1 thus pointing out that the liquefaction phenomenon should be taken into the analysis in the evaluation of the site.

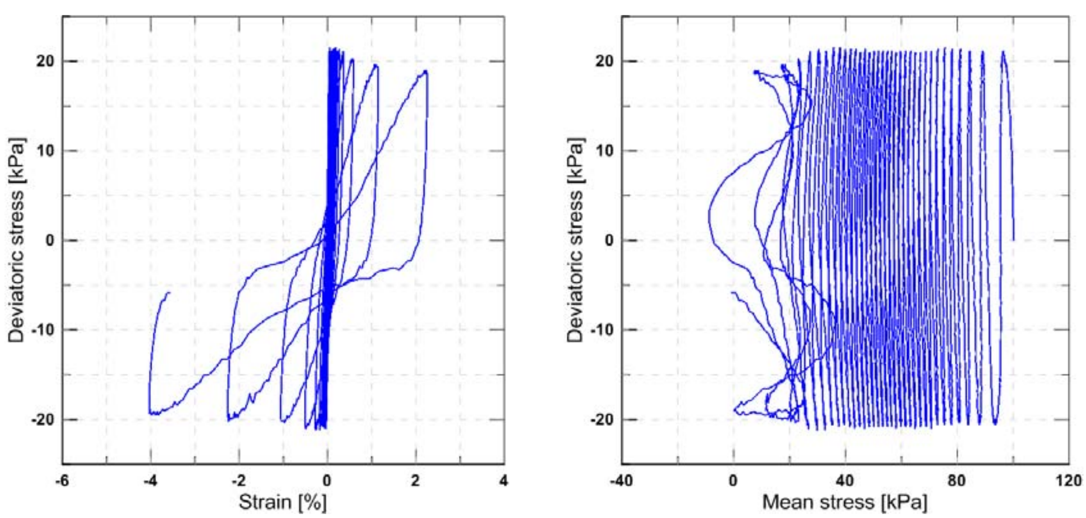

Figure 7. Deviatoric stress vs Strain and Mean stress vs Deviratoric stress diagrams of CSR=0.1 of BH12

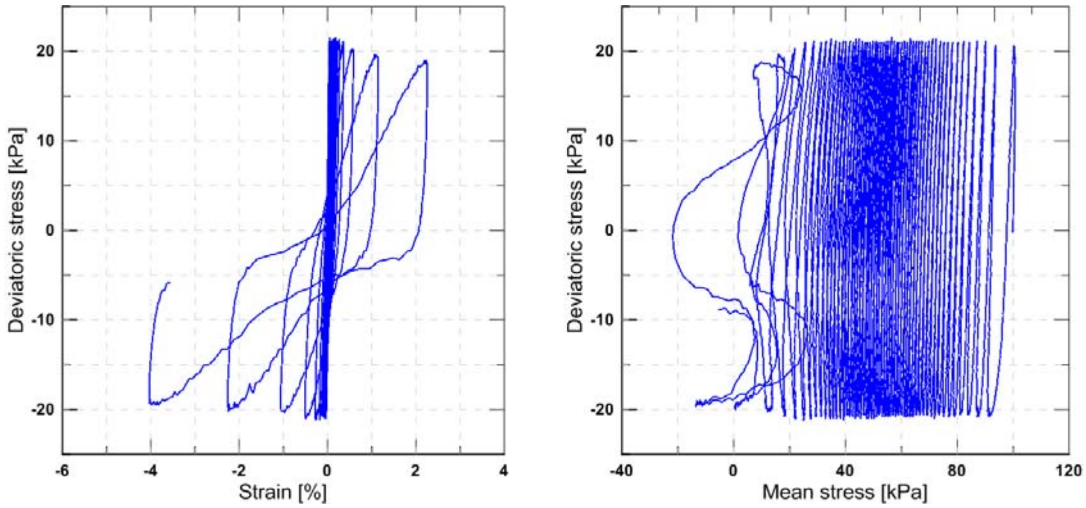

Figure 8. Deviatoric stress vs Strain and Meand stress vs Deviratoric stress diagrams of CSR=0.1 of BH28

5. CONCLUSIONS AND RECOMENDATIONS

The liquefaction potential is an important issue which should be considered in soil site investigation. The present study deals with the investigations and results on the evaluation of the potential of liquefiable soil layers at location where new industrial complex is planned to be built in southern part of Republic of Macedonia. The methodology applied in this study pointed out that at locations with high degree of soil heterogeneity the potential of liquefaction needs special attention to be considered. In this work, two general types of approaches available for this exist: (1) use of empirical relationships based on correlation of observed field behavior with various in-situ “index” tests (2) use of laboratory testing of samples.

In-situ tests namely SPT and CPT with appropriate empirical formulas are very good starting point for estimation of the liquefaction potential in quite short period. For the purpose of the new industrial complex which is planned to be built at first preliminary evaluation of the liquefaction potential is done with SPT and CPT methods. Results indicated the soil layers which cyclic resistance ration is lower than the expected cyclic stress ratio and might behave as liquefiable. Soil samples were taken from the boreholes of the site and cyclic undrained triaxial tests were done. The results of undrained triaxial experiments reveal the fact that the soil can behave liquefiable considering the low cyclic stress ratio needed to initiate liquefaction as it is shown in the figures above. Further investigation is needed in order to study the evaluation of possible liquefaction occurrence at the site.

REFERENCES

Cullough, N.J. et al., (2009). Seismic Site Response for an LNG Facility – Analyses and Lessons Learned. *TCLEE 2009: Lifeline Earthquake Engineering in a Multihazard Environment ©2009 ASCE*

Geoing (2011) Geomechanical report on the location for construction “warehouse for storage cables for cars” Zhabeni-bitola. (in Macedonian)

Sesov et al. (2011) Definition of design seismic paramteres for the Industrial complex Zhabani, Bitola. IZIIS Report No. 2011/40

Youd, T. L. and I. M. Idriss (2001). "Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils." Journal of Geotechnical and Geoenvironmental Engineering 127(Compendex): 297-313.

Kramer, Steven L. (1996). Geotechnical Earthquake Engineering. Prentice Hall

Ishihara, K. (1996). Soil Behaviour in Earthquake Geotechnics”, Oxford University Press, New York.