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LIQUEFACTION MANIFESTATION DURING KRALJEVO 2010 EARTHQUAKE

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Abstract

Moderate earthquake with M=5.4 trembled central part of Serbia on November 3, 2010 at 01:56:55 (local time). The epicenter of the quake was near the city of Kraljevo, 120 km south of Belgrade on the Balkan Peninsula. Apart from structural damages this earthquake had developed interesting geological manifestations. Manifestation of soil liquefaction was observed in the epicentral area, at sites near small villages of Sirca and Oplanici. Typical liquefaction features like: ground cracks, sand boils, ejected sand in wells were reported after the earthquake by the Seismological Survey of Serbia (2010). Most of these manifestations appeared in the agriculture area in the vicinity of West Morava River. Kraljevo 2010 earthquake is one of the rare case histories where soil liquefaction took place under magnitude smaller than six, M<5.5. However, soil liquefaction during Kraljevo 2010 earthquake didn't developed any damages to buildings but its occurrence has risen attention among engineering and scientific community since there are very limited documented case histories of liquefaction in this part of South East Europe. Comprehensive laboratory investigation has been performed on soil samples collected from three sites where liquefaction was observed. A series of cyclic simple shear and cyclic triaxial tests on soils collected from sites which exhibited liquefaction during the Kraljevo 2010 earthquake were used to investigate the key features of liquefaction. The CSR was parameter which was varied during the tests in order to evaluate the dependence of liquefaction resistance curves on level of the seismic exposure. The terrain where samples were collected belongs to quaternary alluvial river deposits from West Morava valley. Such quaternary alluvial deposits are typical for many river valleys in the region and wider on the Balkan Peninsula. Geological conditions and grain size distribution curves are in favor for triggering the liquefaction of the sandy soils layering the river terraces next to West Morava River. The results showed that the number of cycles less than 10, NL<10 are necessary to trigger liquefaction for CSR > 0.125. This study emphasis the importance of liquefaction studies on larger scale for this part of South Eastern Europe in order to developed zoning maps where liquefaction risk can be clearly indicate. It will be contribution toward safer urban development and efficient earthquake preparedness of these regions.

Keywords: Liquefaction, Triaxial test, Cyclic simple shear test.

1. Introduction

Cental part of Serbia was struck by earthquake M=5.4 followed by several hundred aftershocks with magnitudes less than 4. Maximum recorded peak ground acceleration was PGA=0.161 g observed at CACA station, nearly 20 km from the epicenter, Seismological Survey of Serbia [3]. Although not so strong earthquake two people lost their lives and almost 100 million Euros loss has been reported as total damages to area. Most damages occurred on old traditional low rise adobe houses while the newly constructed buildings preserve with minor cracks or not damages at all. Few cases of soil liquefaction were observed in the epicentral area, at sites near small villages of Sirca and Oplanici, Fig. 1. These sites according to Seismological Survey of Serbia were classified as sites with intensity 7 based on European Macroseismic Scale (EMS98).

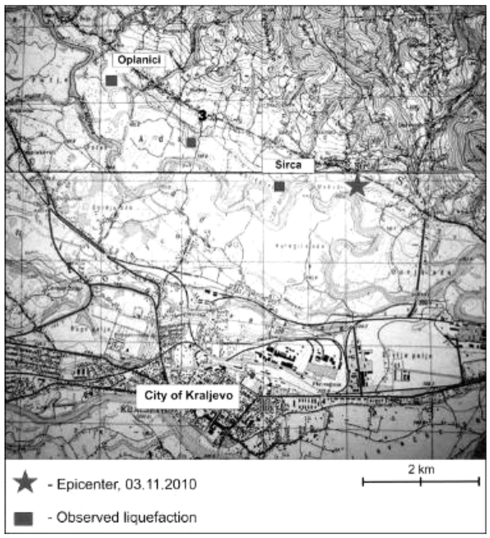


Fig. 1 – Sites where liquefaction was observed during Kraljevo 2010 Earthquake

Fig. 2 –Liquefaction manifestation - Kraljevo 2010 Earthquake

The study focused on experimental investigation on liquefaction potential on soil material collected from the sites where liquefaction was manifested during Kraljevo 2010 earthquake. Cyclic simple shear tests and cyclic and monotonic triaxial tests on soils collected from sites which liquefaction took place during the Kraljevo 2010 earthquake were used to investigate the key features of liquefaction. The CSR was parameter which was varied during the tests in order to evaluate the dependence of liquefaction resistance curves on level of the seismic exposure.

2. Experimental Program

Experimental program consists of cyclic tests performed on Cyclic Simple Shear Apparatus (CSSA) and Dynamic Triaxial Apparatus (DTA) at the Laboratory for dynamics of soils and foundation at IZIIS, Skopje, Macedonia.

2.1. Selection of the material

The selection of the tested materials was made by careful examination of the quality of the received samples. Depending on the type, nature and conditions upon arrival at the laboratory the soil samples were tested as reconstituted samples. The identification markings of all samples were verified immediately upon their arrival at the laboratory. The velocity of pouring rate, height of pouring and tapping energy were parameters which were applied during the preparation process to re-produce as close as possible in-situ stress state [1].

The grain size distribution of investigated soil material is given in Fig.3. As it can be seen the grain size distribution curves show high susceptibility for liquefaction. Also the vertical like shape of presented grain curves clearly shown that the selected soil material has high potential for soil liquefaction. Maximum and minimum void ratios were also determined: soil material from Sirca site , e_{max}=0.98 and e_{min}=0.66; Opalici site , e_{max}=0.99 and e_{min}=0.63; Oplanici site , e_{max}=1.10 and e_{min}=0.65.

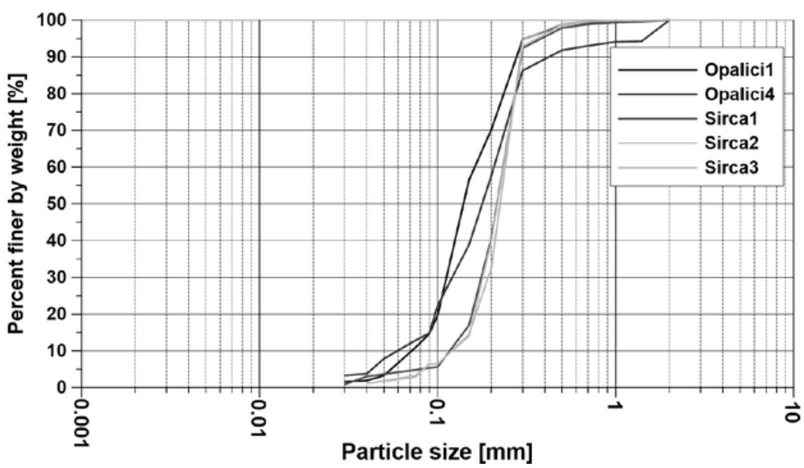


Fig. 3 –Grain size distribution curves of collected soil material

2.2 Cyclic simple shear tests (CSST)

Cyclic Simple Shear Apparatus, CSSA [2] was used to perform the cyclic shearing on soil samples. Several design features contribute to performance of the apparatus: a dual-sample concept which eliminates the frictional problems associated with bearing supported loading platens, dynamic loading system, custom designed for small displacement and high force applications uses a novel system of roiling diaphragms and flexural supports to achieve smooth high load performance and the control system which optimize dynamic range both in measurements and control of force and displacement. Two cylindrical samples both rigidly confined in the vertical and radial direction are simultaneously tested. The schematic view of the apparatus is given in Fig.4.

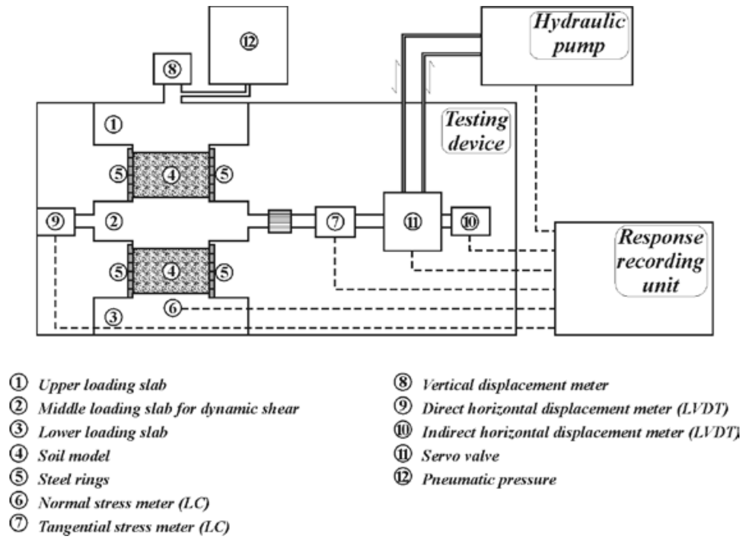


Fig. 4 – Schematic view of the cyclic simple shear apparatus CSSA

A series of strain controlled cyclic simple shear tests have been carried out on dry soil samples ranging from small-medium to large shear strain levels and the nonlinear stress-strain relationships were established. The CSSA enables cyclic shear tests with constant volume and strain control; cyclic shear tests under constant vertical load with control of shear strains and cyclic shear tests with load control. The cyclic simple shear tests on soil samples were performed in 7 series. Performed within each series were at least two to four experiments under equal loading and dynamic excitation conditions. Dynamic excitation was applied in the form of short series of cyclic simple shear loads with frequency of 0.1 Hz by controlling the shear strains (strain control). The excitation was applied step-by-step, with variation of the maximum amplitude of shear strains.

Stable hysteresis curves from the tests, Fig.5 enable clear definition of G/G_{max}-γ and D-γ curves which describe the apparent reduction of the shear modulus G, and the variation of damping ratio D of the investigated soil samples within the shear strain range of interest. Typical test results are presented in Fig.5 and Fig.6. G/G_{max}-γ and D-γ curves were used as input data for site response analysis effective stress approach, which is not part of this paper.

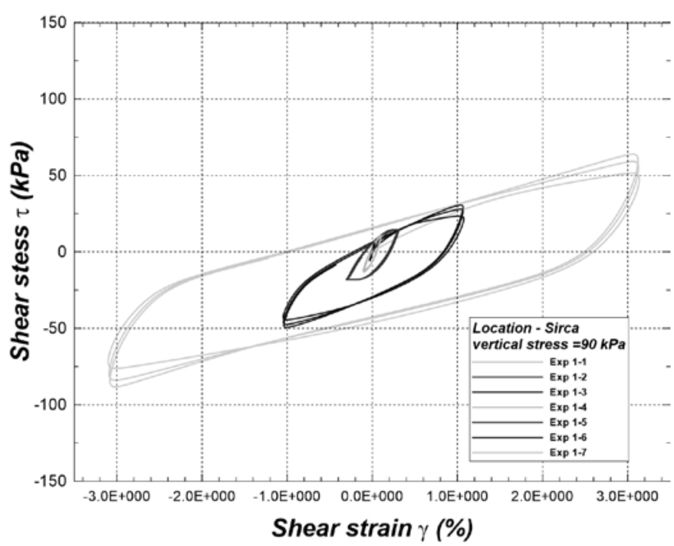


Fig. 5 – Shear stress-strain relationships for different strain levels location Sirca

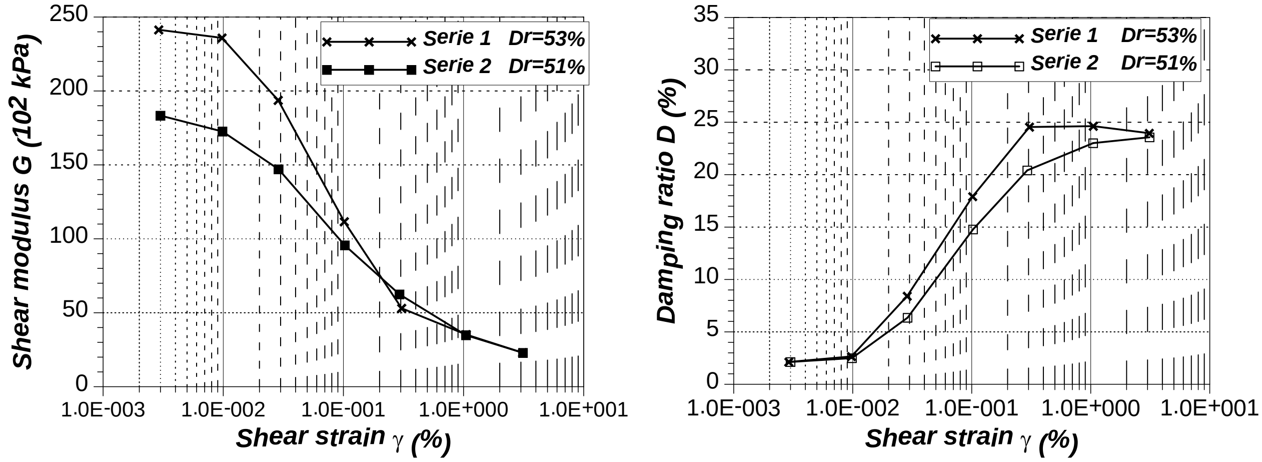


Fig. 6 – Shear modulus and damping curves versus shear strain - location Sirca

Liquefaction tests were performed on CSSA using the approach of constant volume with strain control, [4]. Such approach allows to investigate liquefaction potential on dry sandy samples. Fig.7 presents characteristic results from liquefaction test on soil sample from Sirca site. After several cycles of shearing under constant volume condition effective stress in soil sample starts to decrease, as shearing continues effective stress also continue to drop down to almost zero value, 16 cycles of shearing. It means that liquefaction took place in soil sample and the test is finished.

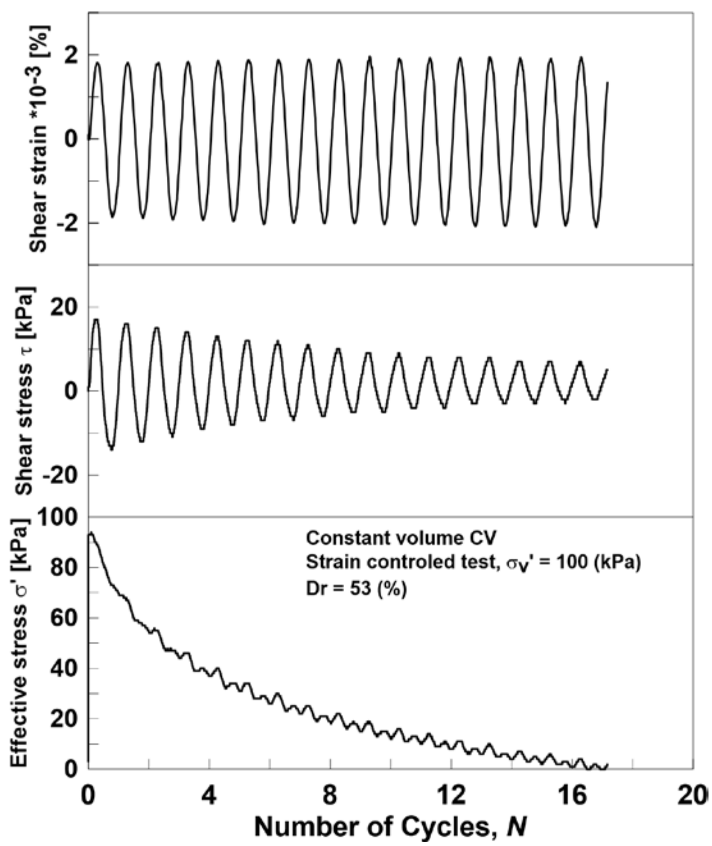


Fig. 7 – Liquefaction during cyclic simple shear tests - location Sirca

2.3 Cyclic triaxial undrained tests (CTUT)

Triaxial test specimens of about 70 mm diameter and 140 mm height were reconstituted by moist tamping method. It was necessary to obtain high degree of reproducibility of specimens since the soil material collected from liquefiable sites was limited. Applied moist tamping procedure have proven satisfactory results, [1]. For each site, three to five specimens were prepared at a nearly similar relative density (Dr=50-60%) representing as much as possible geological conditions. All specimens were isotropically consolidated to an initial mean effective stress of p' =100 kPa and were subjected to cyclic stresses at different cyclic stress ratios (CSR). Cyclic stress ratio is calculated as $CSR=\sigma_d / 2\sigma_3'$, where σ_d is deviator stress and σ_3' is initial confining effective stress. The testing procedure fully complied with ASTM 5311, Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil [5]. Fig.5 show typical results for effective stress path and pore water pressure curve recorded in one of the cyclic tests, site Oplanici.

Liquefaction resistance curves, where the cyclic stress ratio (CSR) is plotted against the number of cycles required to cause liquefaction (N_L) were generated for each considered site, Fig.6. Results in Fig.6 show that sandy soils investigated from Opalici site has slightly higher resistivity to liquefaction than Sirca and Oplanici sites. These are valuable results which will be upgraded with numerical effective stress analyses (ongoing) and there will be enough data to produce zonation of liquefaction risk at wider area of Kraljevo city.

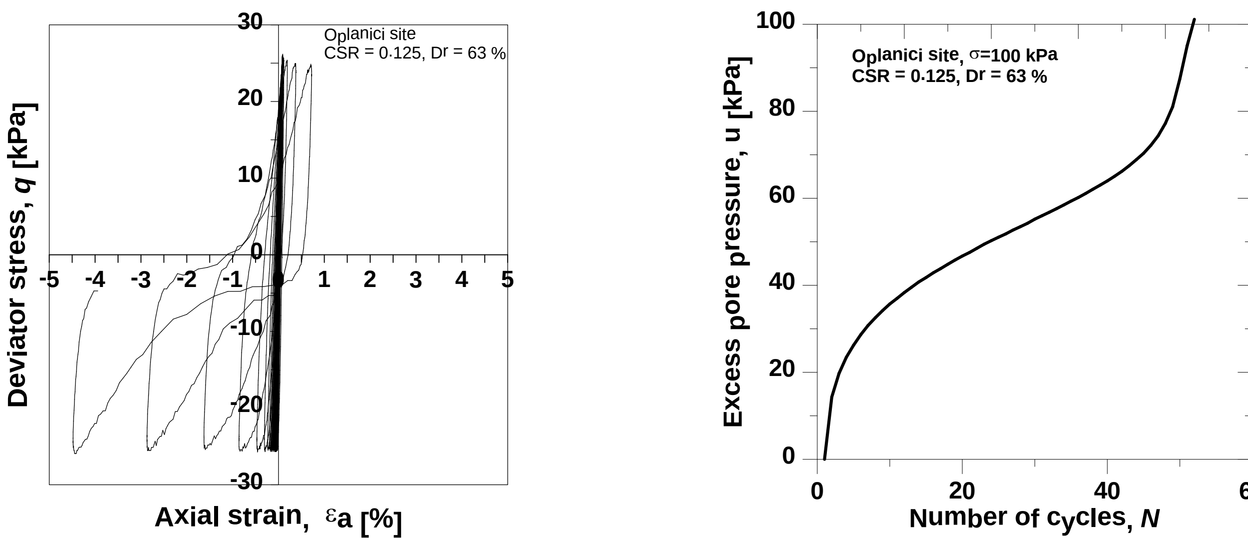


Fig. 8 – Typical results from cyclic triaxial undrained tests, CSR=0.125, σ'=100 kPa, Dr=63%

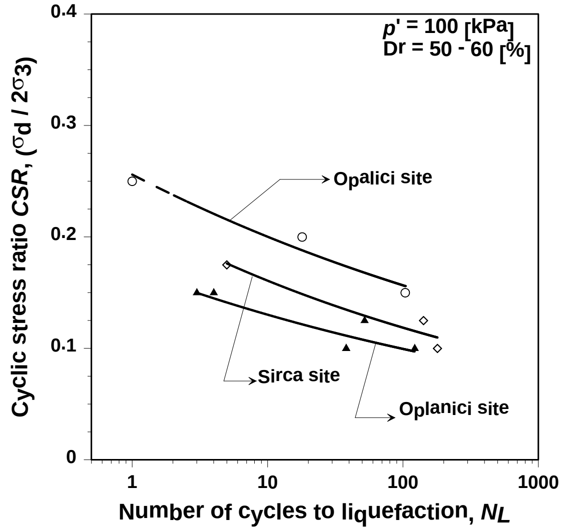
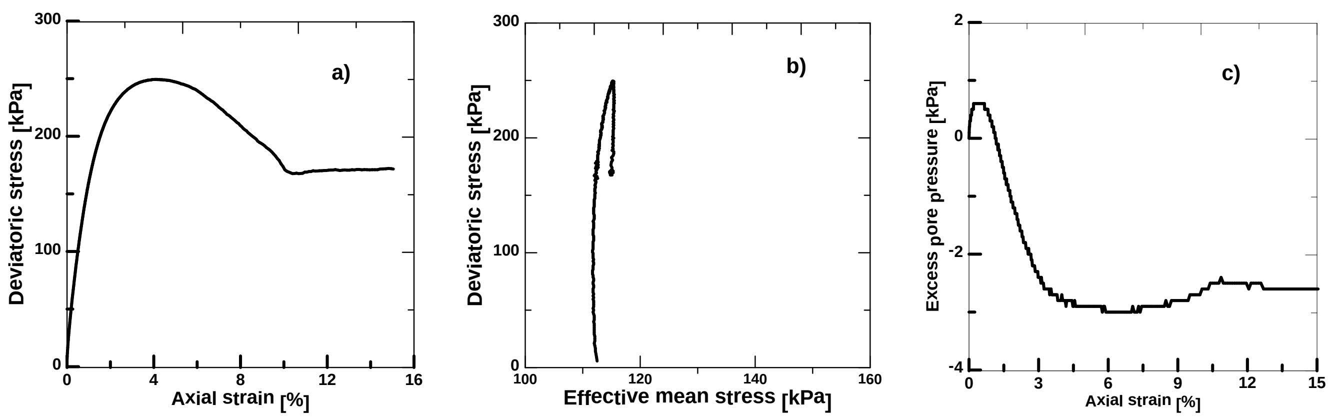


Fig. 9 – Liquefaction resistance curves for investigated sites

2.4 Monotonic undrained tests

The initiation of liquefaction for sites of interest was also investigated by monotonically increasing stresses in undrained condition. Such approach is very useful for proper evaluation of the behavior of liquefiable soils during and after earthquake shaking which was one of the primary interest for this study.

The undrained triaxial compression tests on specimens are carried out by using the triaxial machine at initial confining pressure of 100kPa at constant strain rate of 0.2% per minute. The sample was subjected to maximum axial strain of 15 %. Results for monotonic undrained response of soil sample taken from Sirca site are presented in Fig.10.



a) stress-strain curve b) effective stress path c) excess pore pressure response

Fig. 10 – Undrained triaxial test, Dr=60 %, σ_0'=100 kPa.

As can be observed the soil behavior indicates a peak deviator stress at 4% axial deformation followed by decreasing of deviator stress up to 10% axial deformation and then it is stabilized to a constant value. It seems that response is contractive at first stage at low strains and then dilative entering into intermediate strains. Such behavior of soil sample can be described as limited liquefaction [6]. More monotonic undrained tests on soils samples from the affected area ongoing in order to get much better knowledge about liquefaction susceptibility.

3. Conclusion

The conclusion can be summarized as follows:

- Relatively low magnitude M=5.4 (which can be treated as bottom level of magnitudes causing liquefaction) produced several cases of liquefaction manifestation in the epicentral area without any reported direct damages to building environment.
- Geological conditions and grain size distribution curves are in favor for triggering the liquefaction of the sandy soils layering the river terraces next to Zapadna Morava River
- A series of cyclic simple shear and cyclic triaxial tests on soils collected from sites which exhibited liquefaction during the Kraljevo 2010 earthquake were used to investigate the key features of liquefaction. The CSR was parameter which was varied during the tests in order to evaluate the dependence of liquefaction resistance curves on level of the seismic exposure. The results showed that the number of cycles less than 10, NL<10 are necessary to trigger liquefaction for CSR > 0125.
- More monotonic undrained tests are ongoing in order to get better insight to behavior of liquefiable soils at affected area during and after earthquake shaking.
- Further liquefaction studies of larger scale for this part of South Eastern Europe are necessary to be performed in order to developed zoning maps where liquefaction risk can be clearly indicate. It will be contribution toward safer urban development and efficient earthquake preparedness of these regions.

4. References

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