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Soil Liquefaction Susceptibility Assessment of Mozdok City (North Ossetia, Russia)

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Abstract*—Urban areas lying in the alluvial soil are usually prone to a threat of liquefaction even during moderate earthquakes. Liquefaction is the measure of vulnerability of saturated sediment to thickening (compaction) during earthquake and thus to pore water pressures generation (formation) sufficient to cause possible ground instability or failure. The buildings which are constructed over the liquefiable soil are more vulnerable to the vibrations of a potential earthquake. The territory of the North Caucasus is characterized by high density of population and a high level of seismic hazard. Liquefied soils are also presented here. But the earthquake effect depends on the water table and level of seismic loadings. Despite the absence of historical data on liquefaction on this territory, there are soil conditions in new regions with a possible liquefaction behavior during strong earthquakes. Mozdok city with seismic potential M=5.0 for Mozdok Eastern seismic fault is considered in the paper. The major part of the Mozdok city covered by the Recent Alluvial soil with a shallow water table, which is more vulnerable during earthquake shaking and quiet enough to trigger liquefaction. In this regard, a study carried out to understand the liquefaction susceptibility of soil in the cities using geotechnical data. A liquefaction susceptibility assessment method was adopted for Mozdok city. Seismic refraction survey is widely used in Russia rather than SPT, and calculations were made on the basis size of shear velocity Vs. As a result, about 90% of the territory of Mozdok city is liquefiable. The present study can be an eye-opening for urban planners and decision-makers and emergency responders for future developmental planning activity.

Keywords—liquefaction; urban areas; susceptibility; shear wave velocity

I. INTRODUCTION

The study of liquefaction of soil will be an important input to assess the seismic hazards in built-up areas. Liquefaction is one of the most important seismic hazards which plays a major role in urban disasters as most of the urban areas nowadays deal with the construction of tall buildings due to limited space. Soil liquefaction has been a major cause of damage to soil structures, lifeline facilities and building foundations in past earthquakes and undoubtedly poses a significant threat to the integrity of structures and facilities during a future earthquake [1]. Buildings in zones of liquefaction are particularly vulnerable to differential ground movements, which is caused by the heterogeneity of stratigraphy and soil properties [2].

Many researches from all over the world carried out studies on liquefaction assessment on the basis of different methods [1-23].

The territory of the North Caucasus is characterized by high density of population and a high level of seismic hazard. Liquefied soils are also presented here. But earthquake effect depends on the water table and level of seismic loadings. Despite the absence of historical data on liquefaction on this territory, there are soil conditions in new regions with possible liquefaction during strong earthquakes.

Mozdok city is located in the Mozdok Eastern seismic fault zone with seismic potential M=5.0 [24-26]. The major part of the town is covered by the recent alluvium with a shallow water table, which is more vulnerable during earthquake impact and is quite enough to trigger liquefaction.

The shallow geological subsurface provides a physical environment that supplies people with the natural resources for extraction (for example, minerals, groundwater and ground source heat) as well as for waste deposit. It also provides facilities to support the construction of engineering constructions and the installation of underground utilities and underground operation.

II. Study Area and Its Baseline Information

2.1 Lithology

Mozdok city is located in the southern part of the Priterechnaya plain, slightly inclined to the southeast (on the third left-bank terrace of the river Terek). In the geological structure of the region, sedimentary rocks represented by the terrigenous-carbonate Pliocene strata are involved, the roof of which in the plain most deeper part of the Priterechnyi forward trough is covered everywhere by a thick mass (up to 250 m) of Pleistocene alluvial and deluvial-proluvial deposits, as well as alluvial formations (Fig. 1).

2.2 Depth to the Water Table and Water Level Fluctuation

The territory of Mozdok city is underlied by the south-western part of the extensive Tersko-Kumskiy artesian basin (of the III order), which is part of the East Ciscaucasian Artesian Basin, characterized by the presence of aquifers. Water-bearing rocks are represented by sands, less often by pebbles, gravel with thin interlayers and lenses of loam, sandy loam and rarely by clay. The total thickness of these deposits varies from 28 to 40 m, and the thickness of the aquifer does not exceed 20–35 m. It is separated from the underlying low-pressure aquifer of the Middle Low-Quaternary alluvial horizon, by a rather coarse intercalation of clayey waterproof rocks up to 15 m.

The depth of the groundwater level in the territory of Mozdok city varies from south to north from 1–2 to 5 m, which is caused by the geomorphological structure of the territory, i.e. by the presence of the above-floodplain terraces and complexes in Quaternary formations and deposits of the Pliocene Holocene.

2.3 Geomorphology

The main elements of the relief forms of Mozdok city are the floodplain and the terrace above the floodplain of the river Terek, laying from west to east.

2.4 Seismic hazard assessment

The earthquake magnitude is an important parameter to trigger the liquefaction. Mozdok city is located in the Mozdok Eastern seismic fault with seismic potential M = 5.0. The lithological section of Mozdok city territory is represented by sands, gravel, loams, sandy loams and Quaternary clays. According to seismic properties, these soils belong to the III category. Soils are watered everywhere. So the territory of Mozdok is referred to a 9-intensity zone according to the MSK-64.

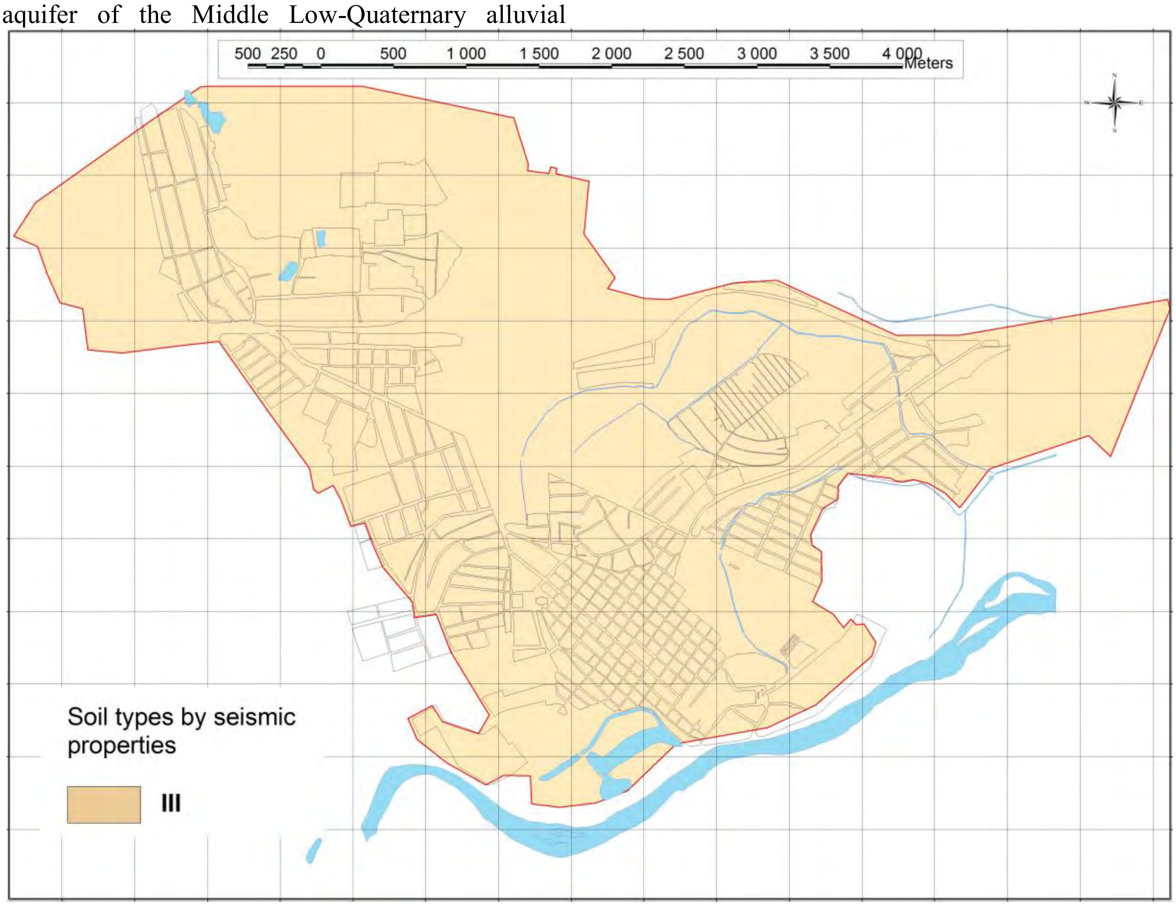

Fig. 1. Geological maps of Mozdok city

III. Methodology

Zoning of soil liquefaction potential can be done with the help of various methods like i) a method based on pre-existing data from available published resources, ii) estimation of liquefaction susceptibility based on existing data viz. Geological & geomorphological criteria and Liquefaction Severity Index (LSI), in-situ liquefaction susceptibility based on Standard Penetration Test and Cone Penetration Test [2, 13]. In the present study, a simple approach used to calculate the factor of safety in term of liquefaction susceptibility by using geotechnical details from shear seismic waves velocities. The methodology used for the present study is given in Fig. 2.

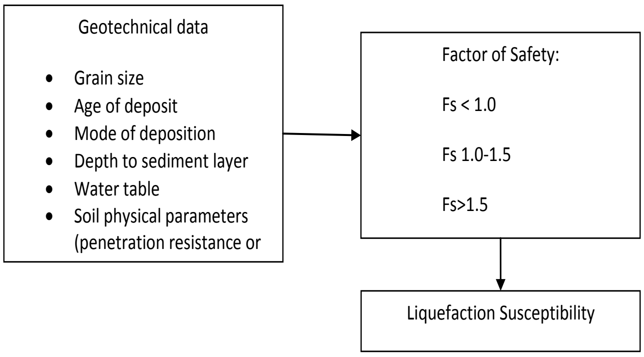

Fig. 2. Methodology used to produce liquefaction susceptibility map

IV. Estimation of Liquefaction Susceptibility

Standard Penetration Test (SPT) is not commonly used in Russia. For Vladikavkaz city, the factor of safety was calculated on the basis of shear wave velocity Vs. The use of Vs as a field index of liquefaction resistance is justified because both VS and CRR are similarly influenced by void ratio, effective confining stresses, stress history and geologic age [23]. One of the most advantages is that VS measurements are possible in soils that are difficult to penetrate with CPT and SPT or to extract undisturbed samples, such as gravelly soils.

The CRR ratio was calculated by Andrus and Stokoe approach [23]:

$$CRR = 0.03(V_{Sl}/100)^2 + 0.9/(V_{Slc} - V_{Sl}) - 0.9/V_{Slc}, \quad (1)$$

where V_{Sl} is normalized V_S by Robertson et al. (1992):

$$V_{Sl} = V_S (P_a / \sigma'_{vo})^{0.25} \quad (2)$$

V_{Slc} – critical value of V_{Sl}, which separates contractive and dilative behavior of granular soils at large strains.

For magnitude 7.5 earthquakes Andrus and Stokoe determined the following best-fit values for V_{Slc}:

V_{Slc}= 220 m/s for sands and gravels with fines contents less than 5%,

V_{Slc}= 210 m/s for sands and gravels with fines contents of about 20%,

V_{Slc}= 200 m/s for sands and gravels with fines contents greater than 35%.

The uniform cyclic shear stress amplitude for level (or gently sloping) sites can also be estimated from the simplified procedure [17]:

$$CSR = 0.65(a_{max}/g)\cdot(\sigma_{VO}/\sigma_{VO'})\cdot r_d \quad (3)$$

where a_{max} - peak ground horizontal acceleration at the surface generated by earthquake.

σ_{VO} ,$\sigma_{VO'}$ - total and effective vertical stresses

r_d – stress reduction coefficient, which is a function of depth and rigidity of a soil column:

$$\begin{aligned} r_d &= 1.0 - 0.00765z, && \text{for } z <= 9.15 \text{ m} \\ r_d &= 1.174 - 0.0267z, && \text{for } 9.15 \text{ m} < z <= 23 \text{ m} \end{aligned} \quad (4)$$

z – depth below the ground surface in meters

For Mozdok a_{max}=0.4g value was used, which corresponds to 9 intensity according to the MSK 64 scale [27].

The Factor of safety is calculated using CSR, CRR and MSF values. The factor of safety values ranging from 0.1 to 2.5 for the study area. The Factor of safety classified into three categories, 0 to <1, 1 to 1.5, and > 1.5 based on the susceptibility to liquefaction of the soil. The values 0 to <1 means the soils are highly susceptible to liquefy, 1 to 1.5 means liquefaction may be likelihood chances and > 1.5 will be no chance of liquefaction of soil for given magnitude and water table. The factor of safety values is used in the spatial analyst tool to prepare the Liquefaction susceptibility map.

Example of factor of safety calculation for one of the sites of Mozdok city is presented in Fig. 3 and the outcome liquefaction susceptibility map in Fig. 4. As a result, about 90% of the territory of Mozdok city is liquefiable (Fig. 4).

V. Discussion and Conclusions

Based on the analysis the areas are divided into three zones of Liquefaction susceptibility: susceptible to liquefy, liquefaction likely and liquefaction unlikely.

The scenario of liquefaction will be different for the different magnitude earthquakes. Also, the present study purely based on available data collected from different sources and it is only a spatially covered area. However, the liquefaction susceptible map will be changed if more data are used with minor geological information.

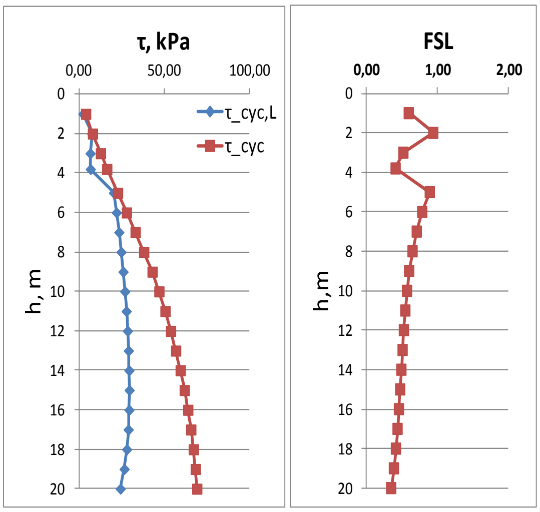

Fig. 3 An example of the factor of safety calculation, site 6

The present study can be used as first-hand information for planning new settlements, a lifeline structure for future development within the city. Also, the tall buildings within the liquefaction susceptible areas are should have detailed site-specific study for the safety of the buildings. Usage of factor of safety makes a more detailed gradation of soils conditions of Mozdok city (Fig. 4), the seismicity of which is uniform 9 according to the MSK-64 scale for all the territory on the basis of geological zonation map (Fig. 1). It makes a more real seismic risk assessment for this territory possible.

Acknowledgments

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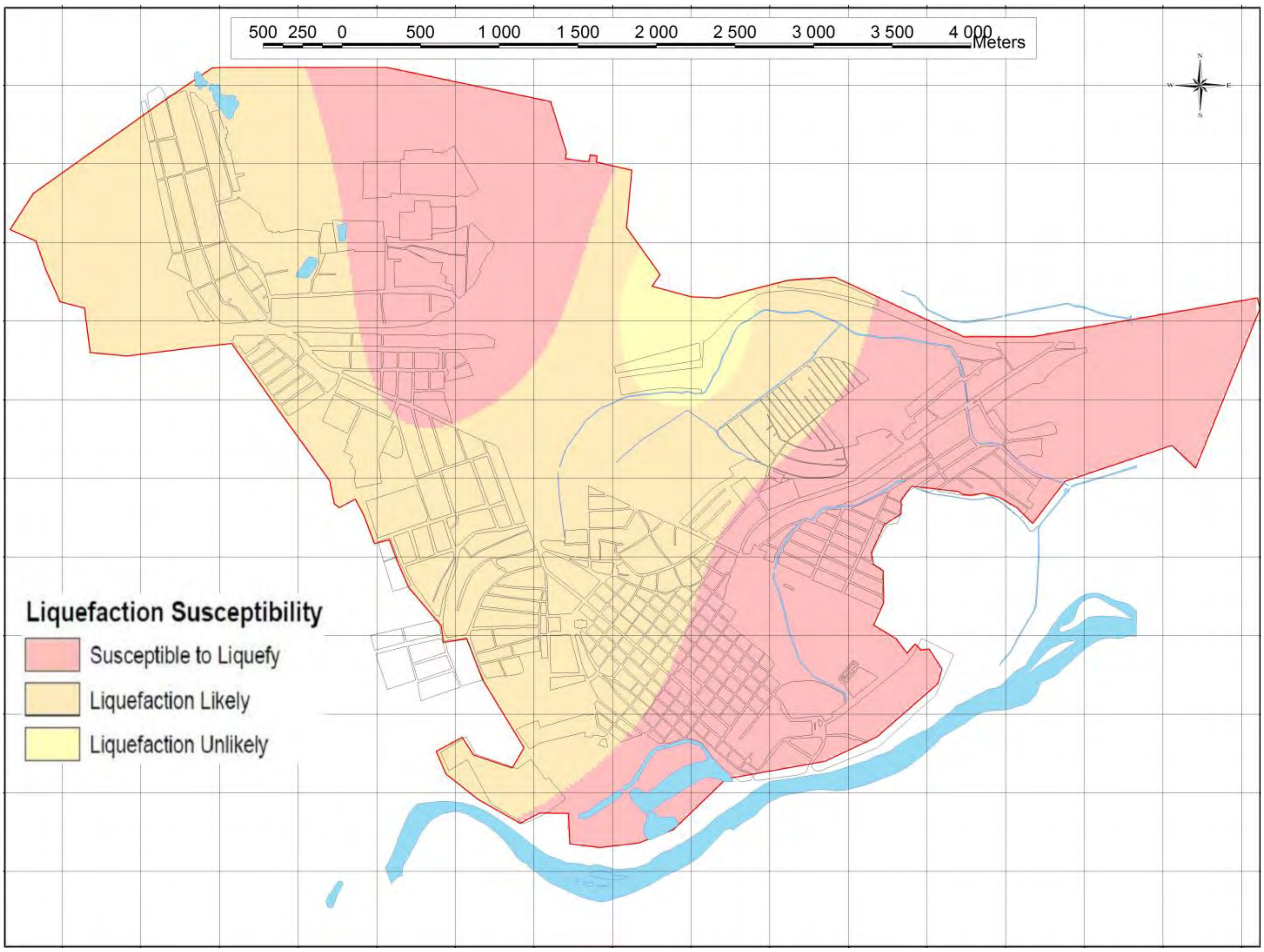

Fig. 4. Liquefaction susceptibility maps of Mozdok city

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