SOIL STABILITY AND URBAN DESIGN CASE STUDY

K. Talaganov (I)
D. Aleksovski (II)
Presenting author: K. Talaganov

INTRODUCTION

The Montenegro, Yugoslavia, earthquake of April 15, 1979 had a specific character, causing different types of dynamic soil instabilities observed in many zones. These dynamic soil instabilities affected severely the existing structures producing structural damage or failure. This was the reason for extensive investigations carried out in the post earthquake period with a special emphasize to the analysis of the dynamic soil instability potential expected by future earthquakes. The main objective of these investigations was to prepare the necessary maps and to compile the data required for elaboration of master town plans. The investigations covered several zones. This paper presents only the results for the area of the city of Herceg Novi.

DYNAMIC SOIL INSTABILITIES CAUSED BY THE APRIL 15, 1979 EARTHQUAKE

A detailed prospection of the earthquake effects was carried out in the immediate post-earthquake period. The investigations showed that within the epicentral zone, beside the shaking effect, the damage level was significantly influenced by several types of soil instabilities, which in many cases affected considerably structural stability.

The dynamic soil instability was observed in different geological media within the wider urban area of Herceg Novi. Events of rock-fall, land slide and soil liquefaction have been observed.

Rock-fall events are associated with firm, carbonate rocks, most frequently in the fault zones and steep rock cuts. Several events have been observed in the mountain area.

Land-slide of thin alluvium and deluvium layers from instable slopes with triggering of active landslides was, also, observed. Land-slides were observed in the town area of Herceg Novi and at many steep slopes in its surrounding consisting of flysch sediments and overlaying limestone blocks onto flysch sediments. Events of landslides and sea floor rockfalls of the coast, consisting of contemporary quaternary materials were also characteristic.

Liquefaction was followed by cracks of different size, observed along the sea coast, consisting of contemporary river and sea loose sands, which are most intense at the contact zones of proluvial stream mouths and the sea coast.

The observed dynamic soil instability events are shown in Fig. 1.

(I) Assoc. Professor, Institute of Earthquake Engineering and Engineering Seismology, University "Kiril and Metodij", Skopje

(II) Senior Research Engineer, Institute of Earthquake Engineering and Engineering Seismology, Univ. "Kiril and Metodij", Skopje.

GEOLOGICAL AND SOIL INVESTIGATIONS

For the needs of earthquake damage repair and urbanization of the region extensive geological, engineering-geological, hydrological, soil mechanical, morphological, geophysical, seismological and engineering seismological investigations have been carried out.

According to the obtained results the basic engineering and geological characteristics have been determined as a background for more detailed geological classification of soil media.

Generally considered, the Herceg Novi town area consists of different sediments of mesozoic, tertiary and quaternary age, classified within the basic geotectonic units of the Adriatic-Ionian flysch zone overlayed by the Budva-Bar zone. The intersection of these two zones characterizes the basic gological structure and, at some places, the basic stability properties of the region. The geological structure and space distribution of the observed sediments are shown in Fig. 1.

Within the scope of these investigations the geological conditions for occurrence of dynamic instabilities have been particularly studied. The older mesozoic and tertiary sediment rocks have been analysed separately from the younger quaternary sediments.

In the case of older mesozoic carbonate and tertiary flysch rocks, analysis of the level of rock degrading, the characteristics of the formed surface clayly layer, slope stability, position of the fault contacts and, generally, the inclination of the layers have been carried out.

In the case of quaternary sediments analysis and differentiation of the zones with loose uniform sands and clayly layers of poor strength characteristics have been carried out. The differences in the lithological structure, the structural position of the different lithological units and the instability slopes have been, particularly, analysed.

SEISMOLOGICAL AND ENGINEERING-SEISMOLOGICAL INVESTIGATIONS

For the purpose of seismic hazard assessment of the investigated region extensive regional and local seismo-geological studies have been carried out.

The regional seismological studies enabled determination of the seismic parameters at the bedrock level in terms of maximum expected horizontal ground accelerations for the characteristic return periods.

Based on the local seismo-geological and engineering-seismological studies assessment of the local geological media and analysis of its influence on the expected ground motion under future earthquakes have been carried out. Using the results obtained by the regional and local seismo-geological and engineering seismological studies seismic hazard assessment at ground surface level was carried out in terms of expected maximum ground acceleration (a_{max}) for different return periods, to be used for future zoning and town planning purposes.

For dynamic soil instability analysis maximum expected horizontal ground accelerations, corresponding to a 200 year return period were taken as a dynamic excitation.

INVESTIGATED TYPES OF DYNAMIC SOIL INSTABILITY

The results of the studies, described under Item 3, show that there are geological conditions for occurrence of dynamic soil instabilities due to expected future earthquakes. This conclusion was directly proved by the local soil media behaviour during the April 15, 1979 earthquake, as described in Item 2.

It is estimated that the dynamic instabilities of the younger sediments in terms of landslides, slope instabilities and soil liquefaction are possible to be expected.

In these studies the occurence of landslides has been considered as a relative displacement of the surface layers of younger sediments in respect to the bedrock consisting of solid rock masses. The sliding potential is analysed as a function of the soil strength characteristics, the slope of the bedrock at the contact zone and the dynamic excitation intensity of future earthquakes.

The slope instability is considered as a relative displacement of the soil surface layers along the characteristic sliding surface in the soil mass. The potential for occurrence of this type of dynamic instability is analysed as a function of the soil strength characteristics, the slope of the soil media and the intensity of future earthquakes.

The liquefaction is considered as strength loss of cohesionless, loose water saturated sands, due to increase in pore pressure up to the level of the initial effective stresses. The liquefaction potential is analysed as a function of the relative density in sands, D_r, shear wave propagation velocity V_s, grain size distribution and ground water table.

Also, it was estimated that instability of the older flysch sediments and limestones is possible. This possibility is related to the weathered and weak rock masses.

ZONING ACCORING TO DYNAMIC SOIL INSTABILITY POTENTIAL

The dynamic soil instability potential due to expected future earthquakes is determined based on the results obtained by the previously described studies. However, considering the fact that these studies are carried out for town planning needs, and taking into account the size of the region, the soil instability potential is not possible to be determined on the basis of detailed analysis. Such analyses are directly related to actual micro-locations. Therefore, the soil instability potential is determined based on a more general approach.

The dynamic soil instability potential is a function of the geological conditions and the dynamic effect of earthquakes.

Since seismicity studies described under Item 3 enabled determination of the expected maximum ground accelerations (a_{max}) for different return periods which were later used for zoning purposes, the values of (a_{max}) were adopted as sufficient dynamic excitation parameters of future earthquakes. A return period of 200 years was adopted for evaluation of the dynamic soil instability potential. Considering the characteristics of the closest earthquake origin and earthquake magnitude of $M \geq 7$ corresponds to the value of (a_{max}). By analysing the value of (a_{max}) in which (a_{max}) $\geq$ 0.20g and taking into account the magnitude they refer to, it is concluded that the dynamic excitation of future earthquakes will be sufficiently large to cause soil instabilities under certain geological conditions. This conclusion was proved by the local soil behaviour during the last earthquake of April 15, 1979 when an acceleration of a_{max} = 0.25 g was recorded. Thus, the further analysis was reduced to analysis of the geological conditions loading dynamic soil instability

The analysis of the geological conditions is carried out based on the results obtained by the studies described under Items 3 and 5.

The parameters leading to landslide occurrence have been analysed and they are mainly referred to as strength characteristics of soil layers and the slope of the underlaying bedrock. In case of slope instability, the surface slope and the strength characteristics of the materials have been analysed. The grain size distribution and the relative density of sands together with the ground water table are considered as parameters influencing soil liquefaction occurrence.

For analysis of the geological conditions influencing the occurrence of rockfalls and rockslides, the degradation of the rock mass and its slope was included as the most important parameter.

Based on these results, three principal zones are defined:

- S zone which is dynamically stable
- MP zone with moderate dynamic soil instability potential
- NP zone with high dynamic soil instability potential

In each of these zones some corresponding subzones are distinguished which depend upon the geological conditions and the type of the expected dynamic soil instability.

Table 1 gives the definitions of the zones and subzones, while Fig. 2 presents the microzoning map based on the dynamic soil instability potential of expected future earthquakes.

RECOMMENDATIONS FOR TOWN PLANNING

The main objective of these studies and the microzoning using the parameter of dynamic soil instability was to obtain results to be used for the elaboration of the Master Plan of the region. For this purpose, the recommendations for town planning should be considered as an integral part of the microzoning. These recommendations, are aimed to provide explanation of the meaning of the individual microzones and to direct future detailed studies for the needs of the design as the next stage. In this respect, the following recommendations are given:

- For town planning purposes the S zone, defined as a stable one, should be, generally, considered as a zone with no restrictions from the viewpoint of dynamic soil instability occurrence. Exclusively, limited soil media micro locations, sensitive to instability effects, might be found, which does not impose any town planning restrictions, but only points out that detailed studies for determination of design and construction criteria should be carried out.

- The MP zone, defined as a zone of moderate dynamic soil instability potential, for town planning purposes should be considered as a zone with certain restrictions. It means that there is a possibility for some microlocations to be excluded from construction. It, also, means that special structural solutions will be recommended for some microlocations, this specially referring to the foundation structures. Detailed studies should be carried out for determination of the usability and construction of some microlocations within the investigated zone.

- The HP zone, defined as a zone of high dynamic soil instability potential, for town planning purposes should be considered as unfavourable and with many restrictions. It means that most of the microlocations will be excluded from construction, while for construction of some of them special precaution measures and structural solutions will be applied, which particularly refers to the foundation structures. The feasibility and construction conditions of each microlocation should be defined by separate detailed studies.

CONCLUSIONS

The results of the above presented studies have shown that the dynamic soil instability potential due to expected future earthquakes is of vital importance in some zones having specific soil conditions. In such cases, the dynamic soil instability parameter should, necessarily, be included in the microzoning procedure. For the considered region, the zoning based on this parameter proved to be predominant for microzoning purposes.

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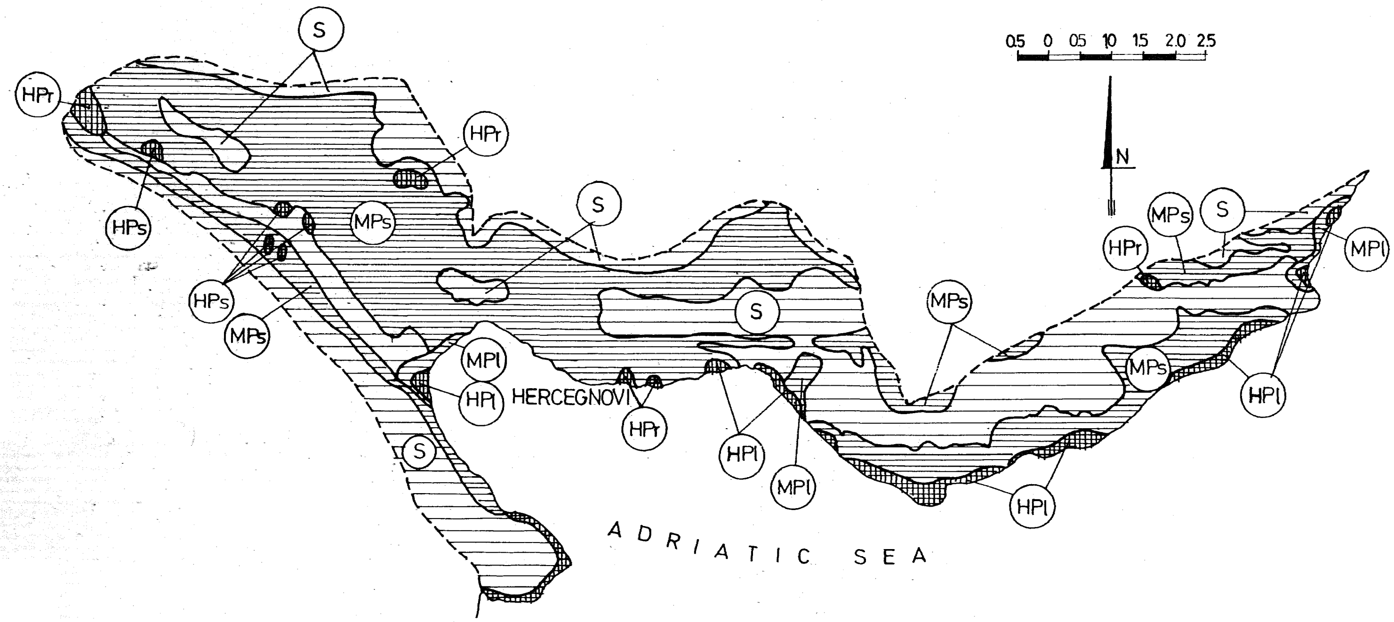

LEGEND :

HP zone of high potential

MP zone of medium potential

S stable zone

l — liquefaction

s — instability of quaternary clayly soils

r — instability of degraded flysch and limestone rocks

Fig. 2. A map of dynamic instability potential of the soil medium for the expected future earthquake