International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1981 - First International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

28 Apr 1981, 9:00 am - 12:30 pm

Soil Liquefaction Seismic Risk Analysis Based on Post 1979 Earthquake Observations in Montenegro

K. Talaganov
Institute of Earthquake Engineering and Engineering Seismology, Yugoslavia

J. Petrovski
Institute of Earthquake Engineering and Engineering Seismology, Yugoslavia

V. Mihailov
Institute of Earthquake Engineering and Engineering Seismology, Yugoslavia

Recommended Citation

Talaganov, K.; Petrovski, J.; and Mihailov, V., "Soil Liquefaction Seismic Risk Analysis Based on Post 1979 Earthquake Observations in Montenegro" (1981). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 20.
https://scholarsmine.mst.edu/icrageesd/01icrageesd/session02/20

Proceedings: First International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 26 - May 3, 1981, St. Louis, Missouri

Soil Liquefaction Seismic Risk Analysis Based on Post 1979 Earthquake Observations in Montenegro

K. Talaganov, Associate Professor
J. Petrovski, Professor and Director
V. Mihailov, Professor
Institute of Earthquake Engineering and Engineering Seismology, Skopje, Yugoslavia

SUMMARY The scale and consequences of soil liquefaction during April 15, 1979 Montenegro earthquake rose a problem of explanation of this phenomena and assesment of the ground behaviour during future earthquakes. The analysis, the detailes and results presented in this paper is divided into two parts: The first part comprises soil liquefaction during April 15 1979 earthquake inclusing the analysis of both geotechnical conditions and excitation potential inducing them. In order to realise the scale and the properties of the phenomenon, distribution of the locations with manifestations likely to have been induced by soil liquefaction, as observed on the ground surface and on civil engineering structures, has been given and described. To identify the presence of conditions inducing soil liquefaction the geotechnical soil properties for several typical locations have been analysed. Analysis of the characteristic ground surface horizonatl acceleration records obtained by the earthquake from the aspect of their potential to cause liquefaction have been also carried out. To determine the liquefaction potential of the considered earthquake detailed analysis of typical geotechnical model of a site have been performed.

In the second part is presented the seismic risk analysis beckground for soil liquefaction aimed at explanation of the essential problems concerning the evaliation of geotechnical media comprising of loose sand under the effect of future earthquakes. At the same time, the complexity of the problems which have to be dealt with during the seismic risk investigations has been pointed out concerning the necessity of investigation in this sense. It is necessary to make some assumptions and simplifications for solving some of these problems. Applying the results of the analysis from the first part as well as the assumptions and simplifications, an assesment of the seismic risk for soil liquefaction analysed in details in the first part applying one of the possible methodologies, has been carried out.

PART I - ANALYSIS OF SOIL LIQUEFACTION DURING 1979 MONTENEGRO EARTHQUAKE - DESCRIPTION OF LIQUEFACTION

Soil liquefaction was one of the characteristic phenomenon induced by the April 15, 1979 Montenegro earthquake. Visible manifestations on the ground surface and on structures, probable to have been caused by liquefaction, have bee observed at several placed within the Boka Kotorska bay area and along the Bojana river in Ulcinj. It is characteristic that liquefaction was found within relatively limited areas, particularly in the Boka Kotorska bay area, where a narrow belt of sand deposits along the sea coast was found. Liquefaction cases along the Bojana river in Ulcinj have been also observed within a smaller limited area while the major part of the Ulcinj valley, characterized by thick sand deposits, did not exibit considerable ground manifestations of liquefaction. However, no visible cases of soil liquefaction have been observed in the 100 km long coastal belt from Ulcinj in the south to Boka Kotorska in the north.

The sites with typical and very intensive soil liquefaction, as observed on the ground surface, are shown in Fig. 1

Ground surface faulting, ranging from slight cracks to trenches of over 1 meter width, vertical settlements and warping deformations, sinking of parts of the coastal belt under the sea water and similar phenomena have been observed on the ground surface at these locations. There were frequent cases of outbursts of fine uniform sand with high water jets from the ground. Large quantities of sand covered the areas along new-formed trentches, while traces of water were obvious on the walls of the structures. The ground floors of some buildings were covered with sand.

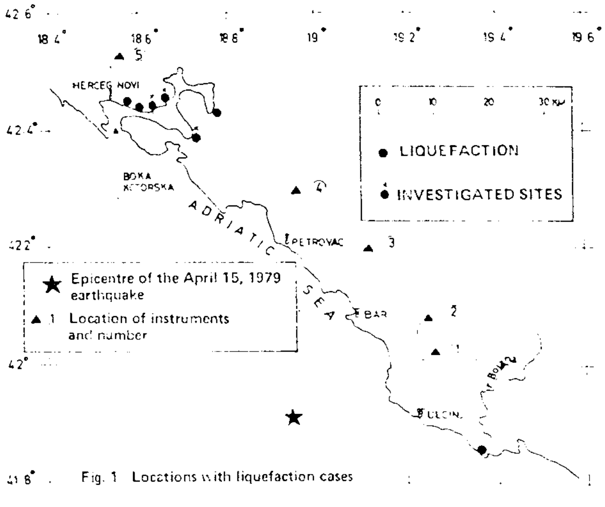


Fig. 1 Locations with liquefaction cases

These processes in the ground itself and on the ground surface had direct influence to structures and induced settlement and horizontal displacement of foundations which combined with rotation caused structural damage of diverse intensity ranging from cracks to collapse. There were several cases of sinking of structures for several centimeters.

Typical examples of liquefaction in the ground and on structures are illustrated in Figs.2,3,4,5.

Fig. 2 Typical ground surface manifestations of soil liquefaction

Fig. 3 Soil liquefaction consequencies observed on the hotel and swimming pool structures

Fig. 4 Damage due to liquefaction: sinking of house and soil, house floor and its surrounding covered with outbursted sand, cracks in the walls

Fig. 5 Damage due to liquefaction: cracks in the soil and the concrete platform, sand outbursts, rotated lighthouse

ANALYSIS OF GEOTECHNICAL PROPERTIES OF THE SITES

Soil liquefaction was identified based on the ground surface manifestations observed at the sites. These manifestations point to the high probability to have been caused by soil liquefaction. The explain them it is necessary to define the geotechnical properties of the soil at considered site, since soil properties and the seismic force potential are the basic factors constituting the conditions for liquefaction occurrence. The lack of detailed pre-earthquake information obtained by geotechnical investigation of the considered locations did not allow definition of the geotechnical soil properties. On the other hand, due to their volume, the required post earthquake geotechnical investigations were not possible to be completed within a short time. Therefore, the presented geotechnical soil property analysis cannot be considered as a complete one, and covers only several locations. It has been carried out according to the results from previous investigations, field observations, laboratory test analysis of soil samples taken from the sites and outbursted during the earthquake, as well as on the basis of investigation of the soil profile after the earth quake.

Three characteristic sites, specially marked on Fig.1 have been analysed. The analysis showed their soils to be of quarternary sediments with average depth of 15 to 20 meters and frequent uniformly granulated sand layers. These sediments are overlying flysch, or marlstone rocks. Underground water level is rather high, from 0.5 to 1.5 meters of the ground level, and equal to the sea level, since all the sites are in the vicinity of the sea coast.

The grain size distribution of the samples taken from the three sites is presented in Fig.6. Analysis could show that they are uniformly granulated sands with coefficients of non-uniformity (D_{60}/D_{10}) from 2.5 to 3.0 and average diameter (D_{50}) from 0.15 to 0.45 mm. These grain size characteristics classify them in the category of sands typical for soil liquefaction.

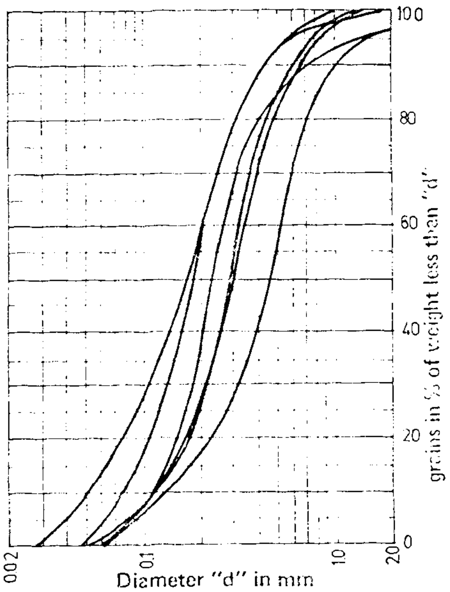


Fig. 6 Grain size distribution for 6 types of sand taken from three investigated sites, as outbursted during the earthquake

More intensive geotechnical investigations have been performed after the earthquake for one of the considered sites. A typical geotechnical soil profile, determined by geotechnical boreholes in the zone of intensive liquefactions is presented in Fig.7. The grain size distribution in the sand layer up to 13.7 m depth compiles with the sands shown in Fig.6 but the coefficient of non-uniformity is somewhat higher. The blow counts of standardpenetration have shown that the major part of the layer is loose with average relative density (Dr) from about 30% to about 50%. It should be mentioned that the presented results correspond to the post earthquake state and due to lack of pre-earthquake information no comparison was possible to be performed. The results obtained by several boreholes in the surrounding area are similar to those shown in Fig.7.

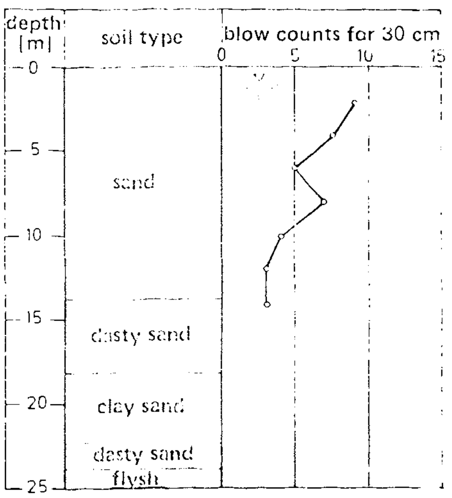


Fig. 7 Typical soil profile of sites investigated after the earthquake

Considering the results of the geotechnical soil property analysis it can be concluded that in view to soil properties the required conditions for soil liquefaction occurrence existed.

ANALYSIS OF EARTHQUAKE DYNAMIC EXCITATION

The Montenegro April 15, 1979 earthquake has magnitude of 7.0 degrees. The ground acceleration due to the earthquake was recorded by five three-componental instruments for recording of strong earthquakes installed at various sites of the coastal area. Fig.1 shows the instrument locations.

The basic data on the instrument locations and the horizonatl component records are shown in Table 1. By comparison of the data from Fig.1 and Table 1 it can be concluded that the records in Table 1, numerated 1,2 and 5 correspond mostly to the sites with the most expressive surface soil liquefaction manifestations. Table 1 also hows the results of the preliminary analysis of the number of different peak values (αa_{max}) as compared to the maximum acceleration (a_{max}) of each record. The analysis was aimed at evaluation of the earthquake excitation from the viewpoint of its potential to induce liquefaction. In determination of the excitation potential by record analysis, especially for the records under 2 and 5, it should be taken into account that they are obtained on bedrock, thus when converted to sites where soil liquefaction was observed some amplifications of their peak values due to site soil influence should be considered.

TABLE 1 BASIC INFORMATION AND DATA ON THE RECORDS

No.	Location of instrument	Geotechnical medium	Component	Max. Acc. a_{max} (g)	Number of peak values of αa_{max}													
					α													
					1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	[illegible]
1	Olimp.	Deposit	N. S	0.29	1	-	2	1		1	2	2	7	4	5	6	.	6
	Ulcinj		W. E	0.24	1				1	3	3	5	3	-	5	3	7	9
2	Albatros	Rock	N. S	0.19	1	1	1	2	4	3	2	5	4	9	5	7	[illegible]	.
	Ulcinj		W. S	0.26	1	1			2		2		2	1	4	5	3	[illegible]
3	Bar	Deposit	N. S	0.37	1		1	1			1	.	1			5	[illegible]	.
			W. E	0.37	1	1	1			2	1	1	3	3	1	4	5	[illegible]
4	[illegible]	Deposit	N. S	0.46	2		2	1	2	1	4		3	3	4	3	.	3
	Petrovac		W. E	0.30	1	1	3	1	.	1	3	1	4	4	3	2	10	[illegible]
5	Herceg	Rock	N. S	[illegible]	1	1			3	2	1	1		3	4	5	6	2
	Novi		W. S	[illegible]	1	1			1				1	2	1	2	.	

To present the excitation potential expressed by the records in a form suitable for comparison with excitations applicable in a laboratory testing of soil liquefaction conditions the records have been converted to equivalent uniform cyclic series. Conversion was performed based upon the results from Table 1 and a wide range of laboratory results obtained by many investigators, as shown in Fig.8. In the range of results illustrated in Fig.8 are also the results obtained by dynamic three-axial testing of sand samples taken from the considered sites.

The conversion results are presented in Table 2.

In summary of the performed analysis it can be concluded that the excitation potential of each

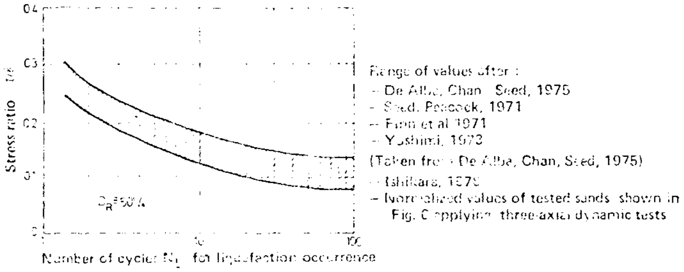


Fig. 8 Range of values for soil liquefaction occurrence, as obtained by laboratory testing

TABLE 2 RESULTS OF THE ANALYSIS OF RECORDS - EQUIVALENT NUMBER OF CYCLES WITH AMPLITUDE $0.65 a_{max}$

No.	Location of instrument	Geotechnical medium	Komponent	Max Acc. a_{max} (g)	a_e $0.65\ a_{max}$ (g)	Equivalent number of cycles Ne	Mean value of the number of cycles Ne
1	Olimpic	Deposit	N-S	0.29	0.19	14.6	11
	Ulcinj		W-E	0.24	0.16	15.7	
2	Albatros	Rock	N-S	[illegible]	0.12	15.6	
	Ulcinj		W-E	0.25	[illegible]	5.6	
3	Bar	[illegible]	N-S	0.37	[illegible]	5.0	
			W-E	0.37	0.24	9.4	
4	Ulcinj	Deposit	N-S	[illegible]	[illegible]	[illegible]	
	Petrovac		W-E	[illegible]	[illegible]	[illegible]	
5	[illegible]	[illegible]	N-S	[illegible]	[illegible]	[illegible]	
	[illegible]		W-E	[illegible]	[illegible]	[illegible]	

component was sufficient to induce soil liquefaction under adequate geotechnical conditions. If both components are taken simultaneously, which is a logical step, especially considering their close peak values, the excitation potential even increases.

ESTIMATION OF LIQUEFACTION POTENTIAL OF THE SITE

A simplified analysis of the estimation of the soil liquefaction potential in the post earthquake conditions was performed for the site with geotechnical profile shown in Fig.7. The geotechnical profile characteristics were considered to be the same during the earthquake.

Estimation of the soil liquefaction potential was performed by comparison of the equivalent cyclic shear stresses due to the earthquake and the estimated cyclic shear stresses which could induce soil liquefaction along the profile. Earthquake stresses are taken according to the record obtained at Herceg Novi (No.5) which is closest to the site, without implification, and with 20% amplification. Two cases were analysed: excitation due to only one component, and excitation due to both components. In both cases conversion to an equivalent number of uniform cycles N=10 have been carried out. Cyclic stresses which could induce liquefaction in 10 cycles are obtained applying the values in Fig.8 and they correspond to the relative density of the sample with D_R equal approximately 50%. For analysis convenience the density of the sand layer up to 14 m depth was taken to be uniform and equal to 50%.

The results obtained from estimation of the soil liquefaction potential are presented in Fig.9.

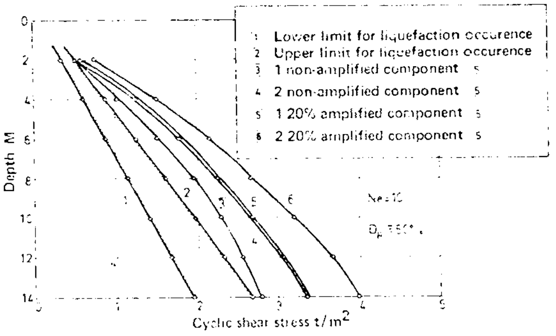


Fig. 9 Results from the analysis of the profile in Fig. 7 to assess liquefaction potential

By their analysis it can be concluded that for the major part of the soil profile the cyclic shear stresses induced by even only one non-amplified record exceed the stree potential which could induce soil liquefaction, i.e. loil liquefaction is higher than 1. Considering the fact that the geotechnical properties of the profile refer to the post earthquake condition it is clear that the soil even at present has same liquefaction potential for similar earthquake excitation. Assuming that certain soil densification might have occurred, as compared to the pre-earthquake state, it can be further concluded that the liquefaction potential could have been even higher during the earthquake.

CONCLUSION

The analysis of the geotechnical soil properties of the considered sites, and the dynamic escitation potential induced by the earthquake proved soil liquefaction conditions to exist in them. It further means that the manifestations observed on the ground surface at the sites were caused by liquefaction.

The results obtained by detailed analysis of liquefaction potential of the characteristic site showed satisfactory correlation with soil behaviour during the earthquake and thus proved the suitability for application of this method of analysis.

PART II - SOIL LIQUEFACTION SEISMIC RISK ANALYSIS

1. BASIC ANALYSIS

The soil liquefaction analysis described in the first part of this paper comprises definition of the geotechnical characteristics of the soil in which liquefaction occurred, as well as definition of the seismic potential which induced it, refers to the April 15, 1979 Montenegro earthquake. Considering the fact that geotechnical soil characteristics may be taken as constant values, i.e. they can be sufficiently defined, and since the mentioned analysis was associated with a definite seismic escitation, the conducted analysis proved to be a deterministic one. However, earthquakes are events of random character. Based upon the statement that geotechnical soil properties can be defined as relatively constant values, and setting forth the problem of soil liquefaction potential tu future earthquakes, the need for probabilistic approach to the problem is imposed considering the random character of the excitation. Thusm definition of the probability for occurrence of an earthquake of certain potential is required. "Potential" here stands for the combination of the peak excitation intensity and their number during the time.

In principle, solving of the problem would consist of several stages of analysis.

The first and initial stage, which should be related to some geotechnical medium, comprises definition of the medium and the conditions for soil liquefaction occurrence in it. The conditions for soil liquefaction occurrence should be the minimum dynamic excitation potential inducing soil liquefaction. The state of liquefaction development in the geotechnical medium should be also defined. Usually, the event developed in only one ground layer is considered as liquefaction, however, it can be also defined developed, exp. in two, three or more layers, which depends upon the geotechnical properties of the medium and the consequences which should be induced by soil liquefaction in some ground layers.

The second phase of the analysis would refer to definition of the seismic risk for occurrence of a certain potential earthquake. Taking into account the importance of the excitation potential in the analysis of soil liquefaction potential assessment, in this investigation stage it is necessary to define not only the expected maximum amplitude of the earthquake excitations and the probability for their occurrence, but also the number of different level amplitudes representing the duration of excitation, which, in terns can be related to the earthquake magnitudes and source mechanisms.

The third and final investigation stage would include the definition of the seismic risk for soil liquefaction by comparison of results obtained from previous analysis. The comparison should result in assessment of the seismic risk for soil liquefaction as related to earthquake occurrence probability, with dynamic excitation potential along the profile depth higher then the minimum excitation potential which could induce soil liquefaction.

The described methodology is of global character. It sets forth problems, especially for definition of the seismic excitation, which cannot be considered completely solvable. They can only be solved through some simplification and under some assumptions. In order to associate it with solution of practical problems it will be applied to some actual conditions using one of the possible solutions.

2. ASSESSMENT OF THE SEISMIC RISK FOR SOIL LIQUEFACTION OF A CHARACTERISTIC SITE

A simplified analysis for assessing the seismic risk for soil liquefaction will be carried out for the site analysed in the first part of this paper, which has geotechnical characteristics as given in Fig.7. To simplify the procedure, the whole sand layer up to 14,0 m depth will be considered to have uniform density of $D_R=50\%$, as in the first part. Then to perform the analysis, using the definition that soil liquefaction developed if being found in only one layer of the ground, the sand layer will be divided into sublayers of 2 m depth. Finally, a more favourable limit of cyclic shear stresses inducing liquefaction along the depth of, the profile will be taken, which is represented as line 2 in Fig.9.

Analysing the soil liquefaction potential results of the site for the April 15, 1979 earthquake given in Fig.9 of the first part, it is obvious that even lower dynamic excitation could induce soil liquefaction of the analysed geotechnical medium. This imposes the need for definition of the minimum earthquake excitation which could induce soil liquefaction at least in some depth of the medium. To define this minimum value the sublayer 3 has been considered as the most unfavourable one.

By an adequate analysis, which is not going to be described in details herewith, based upon balancing of excitation and the dynamic strength of the sublayer

$$\frac{0,65\ a_{max} \cdot r_d \cdot \alpha}{g\ \bar{\sigma}} = (\frac{\tau}{\bar{\sigma}}) \qquad .....(1)$$

where σ and $\bar{\sigma}$ are the normal vertical stresses and the normal effective vertical stresses, r_d is the factor of acceleration attenuation along the depth, and $(\tau / \bar{\sigma})$ the dynamic strength, it was obtained that an earthquake with maximum horizontal acceleration on the ground surface

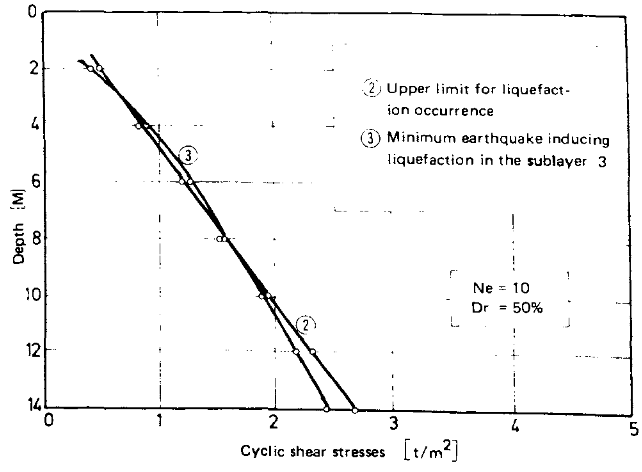
$$(a_{max})\ \text{minimum} = (a)_{min} = 0.186\ g$$

taking into account only one larger component, would induce soil liquefaction in the sublayer 3. The accelerogram of this earthquake should have the equivalent number of cycles Ne = 10, and an equivalent amplitude

$$(a)_{min} = 0.65\ (a)_{min} = 0.121\ g$$

The stress state of the profile, as induced by the described earthquake, is presented in Fig.10.

In other words, by the applied procedure, the further analysis presents definition of the seismic risk for occurrence of an earthquake with given characteritics on the site. So, since in equation (1) (a_{max}) is the only value of random character it is necessary to define the probability



Type of soil	Dr	Sub-layer
Sand	50%	1
		2
		3
		4
		5
		6
		7

Fig. 10 Results of the soil liquefaction potential analysis for the profile in Fig. 7 for the effect of the minimum earthquake inducing liquefaction

for it to take values higher than $(a)_{min}=0.186$ g. Thus, the probability for soil liquefaction occurrence in the sublayer 3 would be:

P [soil liquefaction in the sublayer 3 in the period t]

= P [occurrence of $a_{max} \geq 0.186$ g in period t]..(2)

taking account also of the time duration of the earthquake, i.e. the number of the peak values of different intensity. The problem will be further simplified by considering only one earthquake source which is typical for the given site, having in mind that the same procedure can be equally applied to several sources which could produce earthquakes that could be manifested on the site as the previously defined minimum earthquake.

In the further analysis the source which generated the April 15, 1979 earthquake will be given consideration. The analysis of the seismic risk for occurrence of earthquakes of various amplitudes, i.e. maximum accelerations, as well as accelerogram characteristics and their relationship is a unique problem which could not be presented herewith in details. However, as it has been already analysed for a selected earthquake source the results obtained from analysis will be further used.

Illustrated in Fig.11 are the functions of cumulative distributions of the probability for occurrence of a_{max} on the site with return period of 50 and 100 years, selected as representative ones from the results of the mentioned analysis.

They are obtained by combination of the parameters defining: (1) seismic sources, (2) dependence of earthquake frequence, (3) maximum acceleration attenuation with increase in focal distance and magnitude level, and (4) possible models for earthquake generation. In our case the problem was solved applying a linear and a plane seismic source model, the logarithmic-linear relationships

$$\ln N(M) = \alpha + \beta M \qquad \ldots(3)$$

for earthquake frequencies, the empirical expression of L.Esteva

$$a = \frac{5000 \cdot \exp(0.8M)}{R_h + 40^2} \qquad \ldots(4)$$

as equations for maximum acceleration attenuation with decrease in focal distance and the Poisson's model

$$P_n(t) = \frac{e^{-\lambda t} \cdot (\lambda t)^n}{n} \qquad \ldots(5)$$

as probabilistic model for earthquake generation. Due to the lack of definition of some parameters of earthquake generation mechanism and earthquake characteristics, which due to nonavailability of data could not be sufficiently studies, the obtained results are of preliminary character and in such a manner used in the further investigation.

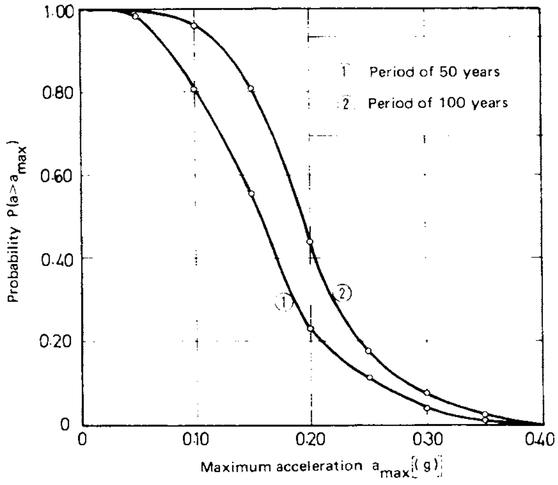


Fig. 11 Function of the cumulative distribution of the probability for occurence of maximum acceleration for periods of 50 and 100

Considering the previously discussed dynamic potential, i.e. that the dynamic strength for the sublayer 3 were carried out for an equivalent number of cycles $N_e = 10$, correlation between the so defined acceleration a_{max}, the earthquake magnitude M and Ne is required.

The correlation between a_{max} and M defined by the mentioned seismic risk analysis for earthquake occurrence is presented in Fig.12.

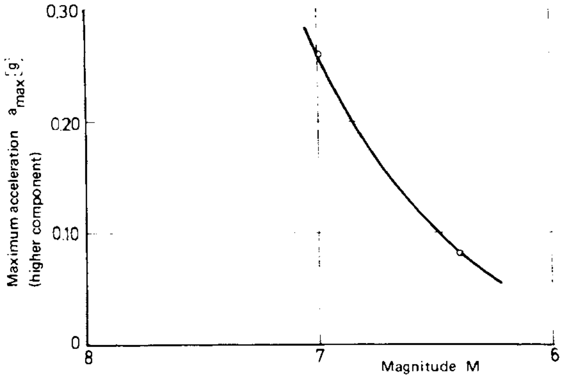


Fig. 12 Maximum acceleration to magnitude relation

Without detailing regarding the analysis it will be mentioned that the correlation between M and a_{max} is obtained using data of the April 15, 1979 and the May 24, 1979 earthquakes with an earthquake source close to the investigated site and the L.Esteva equation for the a_{max} and the focal distance relation. Considering the insufficient number of data on the earthquake generation mechanism of the investigated source more realistic definition of the M and a_{max} relations, as presented in Fig.12, was not possible in this investigation stage, they have been applied in order to explain the application of the methodology for assessment of the seismic risk for occurrence of soil liquefaction.

Applying the results from Fig.12, under the condition

$$a_{max} \geq (a_{max}) \text{ minimum} \qquad \ldots(6)$$

the corresponding minimum magnitude $M_{minimum}$ = 6.8 is obtained.

To set up the correlation between M and N_e the results obtained by Seed (ref.3) will be applied, which were obtained on the basis of analysis of several earthquakes, presented in Fig.13. The results of the analysis of the April 15, 1979 earthquake records from the first part of this paper are also presented in Fig.13, where it should be mentioned that they are well correlated.

Using the middle function from this figure it is obtained than an equivalent number of cycles $N_e = 8$, which is different from $N_e = 10$, correspond to the $M_{min} = 6.8$.

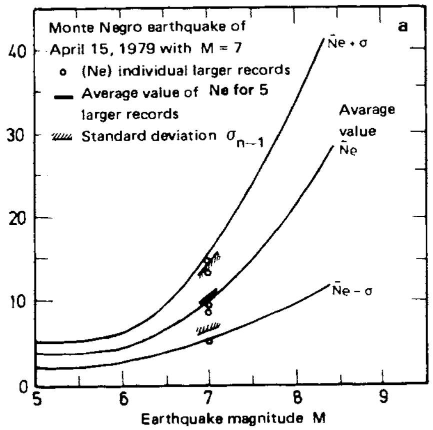
To achieve complete correlation between (a_{max}) minimum, the $(M)_{minimum}$ and $N_e = 10$, the procedure was repeated in several cycles to obtain the final result.

$$(a_{max}) \text{ minimum} = 0.20 \text{ g}$$

with a probability of occurrence

$$P_{50 \text{ years}} = 23\% \quad \text{and} \quad P_{100 \text{ years}} = 44\%$$

Therefore, the conclusion would be that the probability for occurrence of soil liquefaction in the sublayer 3 due to the influence of the investigated earthquake source is 23% and 44% for a period of 50 and 100 years, respectively.



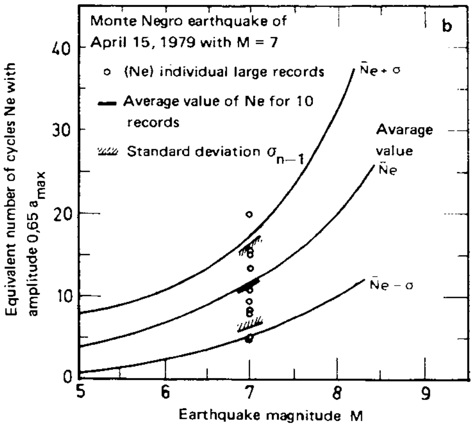


Fig. 13 Equivalent number of cycles N_e for several earthquakes (after Seed et al. 1975) with results obtained by analysis of the records of April 15, 1979 earthquake: (a) based upon larger components, (b) based upon all the components

3. CONCLUSIONS

The complexity of the problem of seismic risk assessment for soil liquefaction due to the effect of further earthquakes imposes the need for further investigations. Beside the definition of the probability for occurrence of earthquakes with some a_{max} and their relationshop with the magnitudes the probabilistic characteristics of the other parameters such as the amplitude-frequency properties of the accelerograms, which in this analysis are presented in terms of equivalent numbers of uniform cycles N_e, properties of the geological medium and so on, should be taken into consideration.

In conclusion of the results obtained by the simplified analysis of the seismic risk for occurrence of liquefaction of the analysed geotechnical medium, carried out in order to apply the described methodology, it can be stated that it may be considered acceptable for solving practical problems.

REFERENCES

Cvijanovic, D., Zivcic, M., "Cataloque of earthquakes with epicentres in the Montenegro coastal area", (in Serbo-Croat) Geophysical Inst., Zagreb 1979.

De Alba,P., Chan,C.,Seed,B.,"Determination of soil liquefaction characteristics by large-scale laboratory tests", EERC 75-14,Berkeley, Cal.1975

Seed H.B., Idriss,I.,Makdisi,F.,Banerjee,N.,"Representation of irregular stress time histories by equivalent uniform stress series in liquefaction analysis". EERC 75-29, Berkeley 1975

Talaganov,K.,Petrovski,J.,Galbov,S.,"Soil liquefaction analysis of the Montenegro coastal area induced by April 15,1979 earthquake"(in Serbo-Croat) Yugoslav Symposium on the Montenegro earthquake, Herceg Novi, 1980.

Petrovski,J,.Talaganov,K.,"Soil liquefaction of water saturated cohesionless soils due to seismic effect",Institute of Earthquake Engineering and Engineering Seismology, No.IZIIS 78-55 (in Macedonian), Skopje 1978.