RECENT ACHIEVEMENTS IN SEISMIC HAZARD ASSESSMENT IN ALBANIA

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SUMMARY

Presented are the different approaches used for the assessment of seismic hazard that threatens the territory of the country carried out recently in the Seismological Institute of Academy of Sciences of Albania. Except the actually in force seismic hazard map of Albania that expresses the seismic hazard in terms of seismic intensity, efforts are being made to present the seismic hazard in terms of PGA, using both deterministic and probabilistic procedures. As far as probabilistic method is concerned, both classical "zone method" according Cornell (1968) methodology and "zoneless method" according to Frankel approach (1995) are briefly described.

1. INTRODUCTION

Although Albania is a country with mainly moderate-size seismicity, different large and moderate earthquakes devastate many of its towns and rural areas from time to time.

The history of instrumental monitoring of seismicity in Albania started in 1968 with installation of the first seismographic station in Tirana and more

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effectively, after the beginning of the operation of the Albanian Seismological Network, in 1976.

As the first step, the seismic hazard in Albania has been assessed mostly in terms of macroseismic intensity [14]. The current practice in Albania for assigning the earthquake load in regard to the design of structures is to utilize the seismic zonation map of Albania [14] and various maps compiled during the microzonation studies recently carried out for seven largest towns of the country.

Albania is geologically and seismotectonically a rather complicated region. The country is characterized by obvious microseismicity (a high number of small earthquakes), sparse medium-sized earthquakes (magnitude M 5.5-5.9), and rather small number of large earthquakes (magnitude M>6.5). Most strong earthquakes have been occurred along three well-defined seismic belts:

- the Ionian-Adriatic coastal belt, extending northwest to north-northwest and coinciding with the boundary between the European plate and the Adria microplate.
- the Peshkopi-Korça belt, extending north-south in the eastern part of the country, and
- the Elbasani-Dibra-Tetova transverse belt, extending southwest-northeast across the former two belts.

Several attempts have been made to express the seismic hazard in terms of ground acceleration, velocity and displacement following both deterministic and probabilistic approaches [2, 6, 8, 9, 10, 11, 12, 14]. Below, presented are some of the recent achievements in seismic hazard assessment in Albania, using both methods.

2. SEISMIC HAZARD ASSESSMENT OF ALBANIA USING THE DETERMINISTIC APPROACH

This work has been carried out under the Agreement between the Seismological Institute of Tirana and the University of Trieste.

The almost total absence of strong motion data leads us to carry out the seismic zonation of the country following a deterministic approach, based on the computation of the synthetic seismograms [9].

Based on seismotectonic criteria and on the spatial distribution of earthquakes, eight seismogenic zones are identified in Albania.

Two velocity models M1 and M2 are used. The construction of seismic model M1 is based taking into consideration the structural differences of two domains in Albania. The different sub models for each of these domains are used: a depth of

30 km for the Moho discontinuity is assumed for the outer domain, whereas for the inner domain the Moho discontinuity is fixed at 40 km.

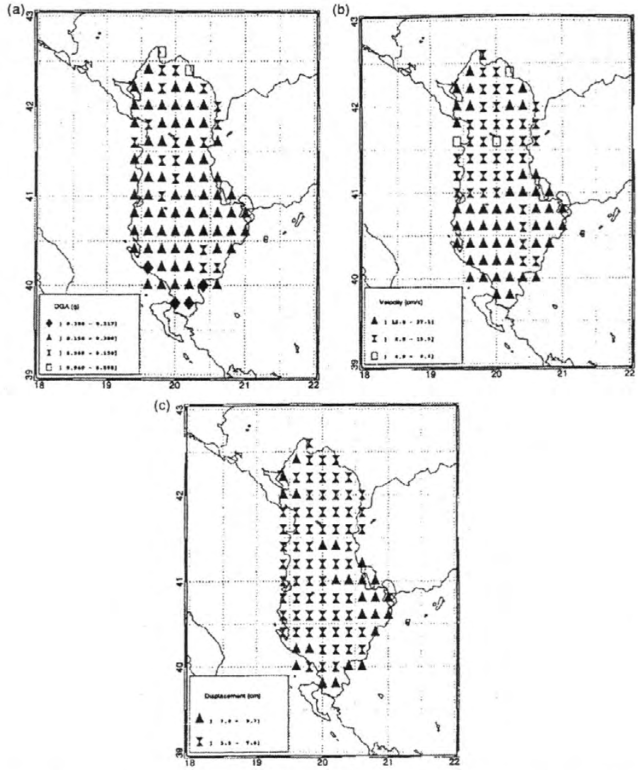


Figure1*. The values of ground motion parameters: (a) design ground acceleration, (b) velocity and (c) displacement*

The results of the computation using the velocity model M1 is shown in Figure 1. The DGA values for Albania are in the range of 68-311 cm/s^2. The area with the largest values is a small one in the very south of Albania, at the border with Greece (DGA over 300 cm/s^2). The second zone covers 80% of Albanian territory (DGA between 150 and 300 cm/s^2). The third zone (DGA between 80 and 150 cm/s^2) is distributed throughout the Albanian territory, from north to south. The last zone is continued in the northernmost part of Albania (DGA between 40 and 80 cm/s^2).

The velocity values can be separated mostly in two zones, the first zone (V between 15 and 27.1 cm/s) covers most of the south and southeast parts of Albania and the second (V between 8 and 15 cm/s) covers most of the central and northern parts of the country. Some small spots with V between 4 and 8 cm/s in the northern part of Albania have been also obtained.

As far as displacement values are concerned, they are distributed mainly in two zones: one in the very south of Albania, in eastern part and in northwestern part (*D* between 7 and 9.7 cm) and another in more than 80% of the country (*D* between 3.5 and 7 cm).

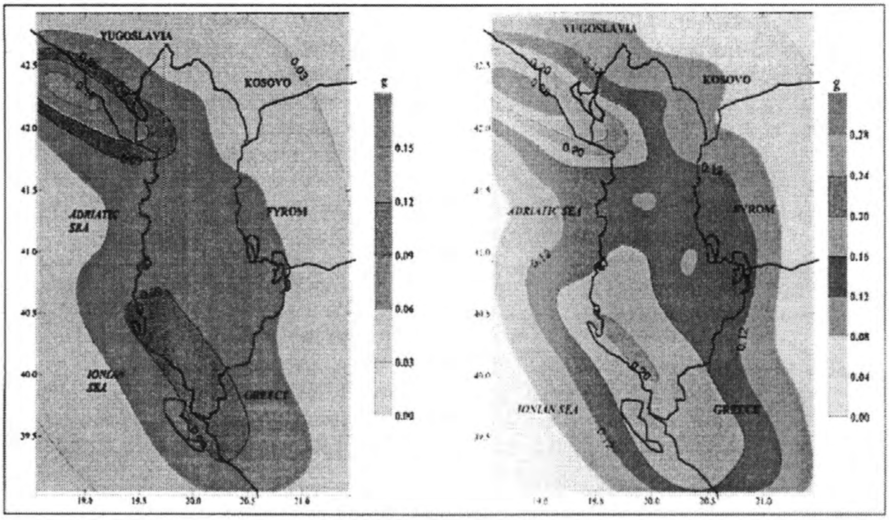
Discretizing the *V*p slopes discussed above, every 5 km and getting the *V*s from *V*p/1,73 have constructed another velocity model M2 to be alternatively used. In this model, the Moho discontinuity is assumed at 35 km for the first sub model and 40 km for the second one. The use of this velocity model M2 provided only small changes in the general picture of DGA distribution.

3. PROBABILISTIC EVALUATION OF SEISMIC HAZARD APPLYING FRANKEL METHODOLOGY

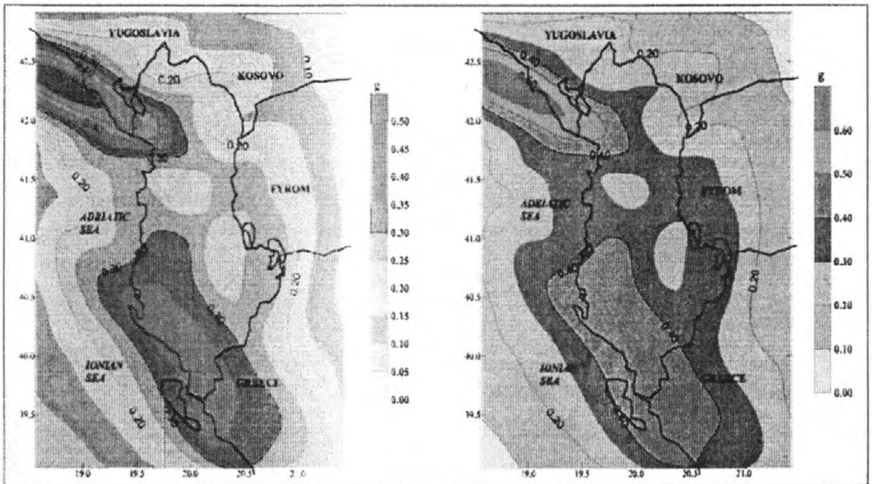
3.1 SFP Project "Seis-Albania"

This work has been carried out into the framework of the NATO Science for Peace project SfP- 972342 "Seis-Albania" [11]. The "zoneless" method according the Frankel (1995) approach is used for PGA evaluations for the entire territory of the country. This methodology still follows the basic approach of Cornell, but no delineation of seismic sources is needed. The observed area is divided into grid cells, and in each cell the activity rate is calculated and then spatially smoothed. Smoothing is carried out in two stages: the first, a two-dimensional Gaussian smoothing due to inaccuracy of the epicenters location; and the second, a fault rupture-oriented elliptical smoothing, according to the orientations of seismogenic faults in different tectonic regions. The radius of circular Gaussian smoothing is defined in a more objective way from the error of epicenter location and from the presupposed subsurface fault rupture length corresponding to the upper bound magnitude. The annual rate of exceedance of the specified values for a given strong motion parameter, and finally its value for a given return period are calculated. The incorporation of seismotectonic data allows the use of ground motion models based on the shortest distance to fault ruptures and not only to epicenters.

PGA are obtained for 4 different return periods: 100, 475, 2375 and 4746 years, that is mean for 60%, 90%, 98% and 99% of non-exceedance of PGA values in 50 years, for rock soil conditions. The most useful for the civil engineers and designers is the map of PGA values for 90% of non-exceedance in 50 years. The results are presented in the maps of Figure 2 (a, b, c, d).



PGA distribution for 60% of nonexceedance on 50 years; b. PGA distribution for 90% of nonexceedance on 50 years.



PGA distribution for 98% of non-exceedance on 50 years and d. PGA distribution for 99% of non-exceedance on 50 years.

Figure 2. *Maps of PGA for different return periods: 100, 475, 2375 and 4746 years*

On the map of PGA values for a return period of 475 years and for rock soil condition, 5 zones with different distribution of PGA values are distinguished. The zone with PGA (0.24-0.28 g), which covers 1.6% of Albanian territory, the zone with PGA (0.20-0.24 g), 7.2% of the territory, the zone with PGA (0.16-0.20 g)

32.4% of the territory, the zone with PGA (0.12-0.16 g), 47.5% of the territory, and the zone with PGA (0.08-0.12 g), 11.3% of the territory. As is seen from the maps produced, the highest PGA values are concentrated along the Albanian orogen thrust front, precisely in the Montenegro-Albania border region, in the zone of Vlora and Tepelena, and in the southern part of the country.

3.2 UNDP Project "Evaluation of risks in Albania"

The assessment of seismic hazard of Albania has been performed also into the framework of the UNDP Project "Evaluation of risks in Albania" [6, 16].

As seismological database, in this study we used a homogeneous catalogue, compiled by Sulstarova *et al.* (2002), which contains 530 earthquakes with magnitudes greater or equal to 4.5. It covers a time span of 1943 years (58-2000), and an area between *18.5-21.5°E* and *39-43°N*. The size of the earthquakes is given in terms of surface-wave magnitude M_s. After investigating the completeness of the earthquake catalogue and declustering it from aftershocks and foreshocks, the parameters of the magnitude-frequency relation were estimated by the maximum likelihood method, considering only the independent events of the complete part of the catalogue [6, 16]. Then, the double-truncated exponential recurrence relationships with b value equal to $b = 0.9$ and $M_{max} = 7.2$ is further used in the seismic hazard computations. To include the seismotectonic characteristics in the hazard computations, a seismotectonic file has been prepared for the territory of Albania which tents to describe the seismotectonic information in a quantitative way [1].

Since historical data records are incomplete, it is important that the probabilistic model accounts for this deficiency. The definition and application of several completeness intervals, the use of different observation periods and magnitude ranges gives an estimate of the variations of the modeled parameters, which is important for successful hazard estimation. Thus, five alternative models of the spatial seismic activity were investigated because it was believed that the accuracy and certainty of data related to more recent periods is higher, while a comparison of different models may be relevant.

In the first two models, the activity rate is counted while foreshocks and aftershocks were removed from the calculations in order to follow a Poissonian earthquake process. Model *M1c* is based on the complete part of the catalogue, 1920-2000. The maximum epicenter location error for this period is estimated about 30 km, so the corresponding smoothing correlations distance c=10 km is used.

Model *M2c* is based on large earthquakes with $M_s \geq 6.0$ for the period 1550-2000. There are 76 such events and the maximum observed magnitude is 7.2. As for the smoothing correlation distance, we used c=12.5 km.

Due to the requirement that sub-catalogues should be complete, no earthquakes before 1550 have been considered yet. However, to emphasize earthquakes with large seismic energy, the alternative seismic activity rate is calculated from released seismic energy from earthquakes including foreshocks and aftershocks [7]. Thus, three additional models *M1e*, *M2e*, and *M3e* are also investigated. Models *M1e* and *M2e* are based on the same data as models *M1c* and *M2c*, respectively. Model *M3e* use the whole earthquake catalogue for the period 58-2000, with a correlation distance c=15 km.

The upper bound magnitude M_{max} for the all models was set to 7.2, because this is the highest magnitude observed historically. On the other hand, the maximum observed magnitude since 1920 is 6.9, so the value 7.2 for the maximum expected magnitude seems to be reliable, keeping in mind the long return periods of the large events.

All models of seismic activity were then smoothed in a two-stage procedure. They were also normalized, so that the total activity rate in the observed area to be the same in all models. Normalizing of the activity rate of each model to M_{1c} model is performed multiplying it by the ratio of the expected and actual annual activity rates. The main characteristics of the five spatial seismic activity models are shown in Table 1.

Table 1. Main characteristics of the spatial seismic activity models

Model	M_{1C}	M_{2C}	M_{1E}	M_{2E}	M_{3E}
Number of events *with* $M_S \geq M_{min}$	240	76	382	89	532
Span period (years)	1920-2000	1550-2000	1920-2000	1550-2000	58-2000
Maximum location error (km)	30.0	37.5	30.0	37.5	45.0
Correlation distance	10.0	12.5	10.0	12.5	15.0
Decay rate, *b*	0.90	0.90	0.90	0.90	0.90
Lower bound magnitude M_{min}	4.5	6.0	4.5	6.0	4.5
Upper bound magnitude M_{max}	7.2	7.2	7.2	7.2	7.2
Normalization factor	1.0	0.71	1.10	0.93	3.89
Weight of the model	0.30	0.20	0.20	0.12	0.18

The PGA hazard maps have been computed for a 10% exceedance probability in 50 years, corresponding to a return period of 475 years. All calculations are performed making it use the computer code OHAZ [18].

The weighted mean map of the five models by Sabetta & Pugliese (1996) attenuation model is given in Figure 3. The seismic hazard assessment results indicate that very few areas can be considered safe, part of Northern Albania, where values lass than 0.15 g are expected. The northwestern and the southern parts of the country, as well as the Lushnja-Elbasani-Dibra area, are represented with the highest hazard up to 0.3 g. Acceleration ranges from 0.2 g approximately in all the territory.

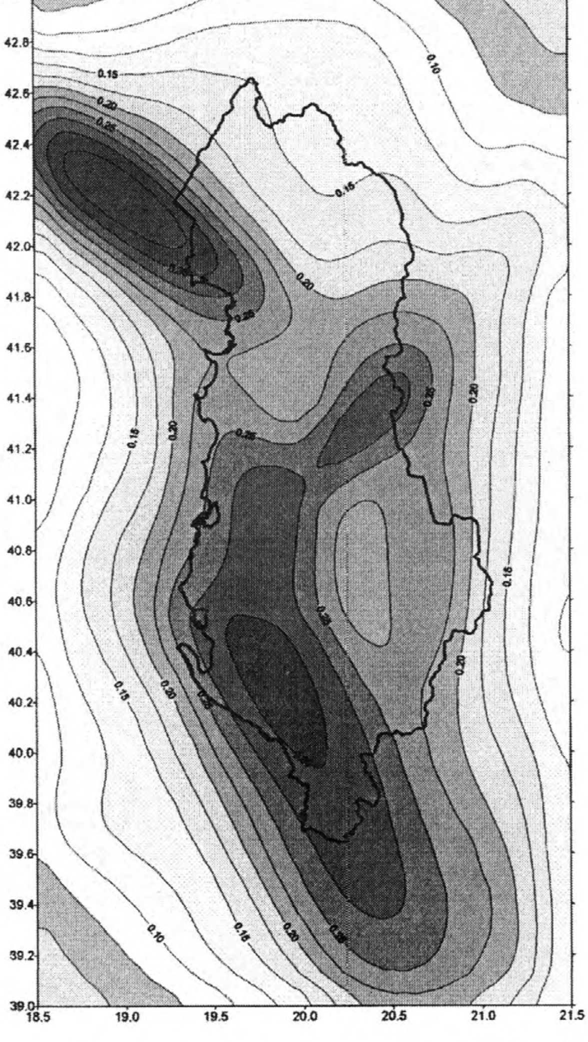


Figure 3. *Map of PGA acceleration 475-years RP. Sabetta and Pugliese -stiff soil*

4. PROBABILISTIC SEISMIC HAZARD MAPS APPLYING CORNELL-MCGUIRE METHODOLOGY

Probabilistic seismic hazard maps have been produced in the framework of the Agreement between the Geological Survey of Canada, National Earthquake Hazard Program and the Seismological Institute of Tirana.

Cornell-McGuire methodology is here applied. The seismic source zones in the absence of detailed information about the activity rate of specific faults in

Albania were used. A single probabilistic seismic hazard model was created for Albania. It comprises ten seismic source zones. In contrast to the PGA values used in KTP-N.2-89, the first 5% damped horizontal spectral acceleration values for the 0.2, 0.5, 1.0, and 2.0 second periods are used to generate Uniform Hazard Spectra for the range of periods important for common engineered structures. PGA values in % g are presented too. A single suite of strong motion relations will suffice for Albania. Is recommended that hazard be depicted for a "rock" condition. We used the 10% chance of non-exceedence in 50 years, equivalent to 475 year return period [2].

The revised catalogue of Albanian earthquakes forms the basis of this study. The subset of the catalogue used for the hazard calculation includes earthquakes with magnitude Ms=>4.5 occurred between 58 and 2000 A.D.

Earthquake source zones were determined from consideration of the present-day tectonic regime of the region, the subset of the Albanian catalogue, and the full catalogue for small earthquakes from 1964-2000. From these considerations, the regional seismicity of concern to Albania was divided into 10 seismic sources (Figure 4).

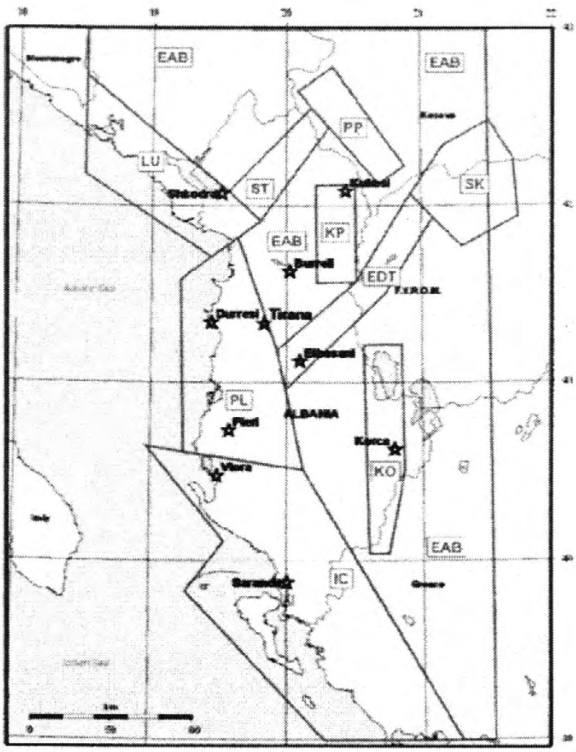


Figure 4. *Seismic source zones used for the hazard maps. EAB encompasses all interior regions not in a named source*

Parameters used for the probabilistic seismicity model are given in Table 2.

Table 2. Parameters for the ten seismic source zones

Zone name/Code	Zone area (km^2)	Earthq used	Beta	Alpha (No)	Mx	Rate of M>6 p.a.	Rate density
Ohrid-Korça	2760	44	1.44	242	6.9	0.0315	11.4
Kukësi-Peshkopia, KP	1480	21	1.75	481	6.9	0.0104	7.0
Ionian Coast, IC	16600	151	1.40	692	7.0	0.115	6.9
Elbasani-Dibra-Tetova, EDT	2660	46	1.99	3142	6.9	0.0167	6.3
Periadriatic Lowland, PL	7460	75	1.61	914	7.0	0.0458	6.1
Lezha-Ulqini, LU	5140	39	1.52	293	7.2	0.0272	5.3
Skopje, SK	3300	5	2.08	2541	7.2	0.00913	2.8
Shkodra-Tropoja, ST	1570	11	1.99	778	6.9	0.00418	2.7
Peja-Prizreni, PP	1740	5	2.03F	418	6.8	0.00173	1.0
Eastern Albanian Backg. EAB	57200	75	2.03F	6075	6.5	0.0199	0.35

Notes: Skopje values adopted from Talaganov et al. (2003). "Rate density" is 10^6 times annual rate for M≥6 per km^2. F=slope fixed as discussed in text.

Earthquakes with epicenters within each source zone were selected from the subset of the Albanian Catalogue. Completeness years were established for all Albania as follows: Magnitude=>4.5 complete since 1901, M=>6 since 1800, and M=>7 complete since 1200. The maximum likelihood method used to compute the magnitude recurrence parameters.

The hazard is strongly affected by the choice of upper-bound magnitude. Estimates of upper-bound magnitude were made for each source zone by considering the largest observed earthquake in the zone, the size of past Albanian earthquakes in related belts, the tectonic reasonableness of large earthquakes, and in a conservative fashion by considering upper-bound magnitudes assigned in more stable environments such as Canada. There was a conscious attempt to avoid linking activity rate to upper-bound magnitude chosen (which often suggests that large earthquakes cannot happen in low activity areas) or to adding a simple 0.5 units to the size of the largest earthquake (which often has a similar effect).

A reasonable default depth for Albanian earthquakes is 10 km. Ambraseys *et al.* (1996) strong motion attenuation relation chosen to compute the ground motions for rock site condition (average V_S velocity >750 m/s).

Seismic hazard values were calculated and used to create national contour maps for the five ground motion parameters chosen (Figures 5 and 6).

The four spectral values were used to construct Uniform Hazard Spectra for some important cities to illustrate the range and period dependence of seismic hazard across Albania. The hazard values for some selected cities and towns are given in Table 3.

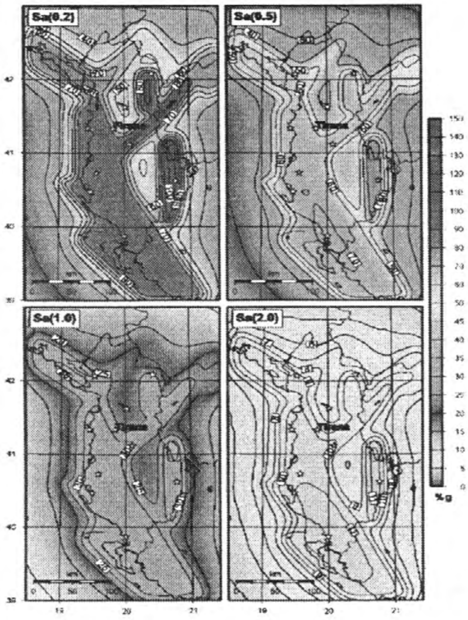


Figure 5 *Seismic hazard on rock for Sa(0.2), Sa(0.5), Sa(1.0) and Sa(2.0), for a probability of 10% /50 years (units=% g).*

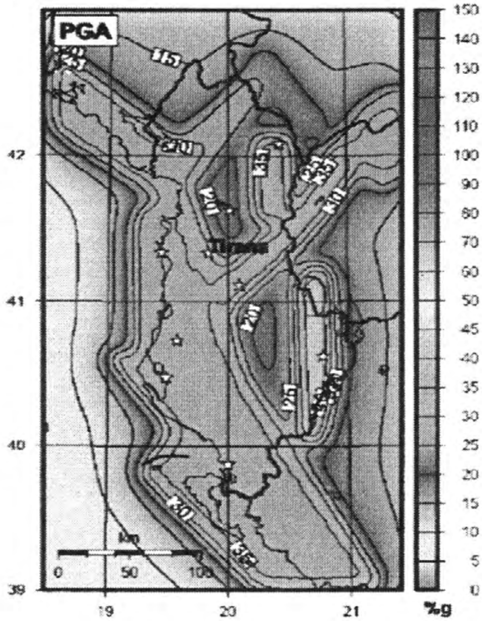


Figure 6 *PGA hazard on rock for a probability of 10%/50year (units=% g)*

Table 3. Hazard at 10% in 50 year probability for selected Albanian cities and towns (%g)

City	Lat N	Lon W	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	PGA
Tirana	41.33	19.83	77	58	28	9.6	32
Durrësi	41.34	19.44	86	66	31	10.3	35
Elbasani	41.12	20.09	90	66	30	10.1	38
Shkodra	42.07	19.52	75	57	28	9.3	30
Vlora	40.47	19.48	88	69	33	11.0	36
Fieri	40.73	19.57	86	68	32	10.8	35
Korça	40.62	20.79	99	75	34	11.0	41
Kukësi	42.08	20.43	81	58	26	8.6	34
Bureli	41.63	20.02	48	40	20	7.6	18

The seismic hazard maps reveal that the region of highest hazard is the Korça-Ohrid zone. Hazard is high to moderate in the coastal regions and near the interior seismic zones. In other places the hazard is relatively low, as in central and northern Albania.

5. CONCLUSIONS

1. The deterministic and probabilistic approaches are used for seismic hazard assessment in Albania. The technology developed at the Department of Earth Sciences of the University of Trieste, Italy, has been used for the deterministic analysis. Methods used for Canada as well as spatially smoothed seismicity, using the OHAZ computer code, developed by Geophysical Survey of Slovenia are adopted for probabilistic analysis.

2. The results obtained by different approaches need to be evaluated. We think that the probabilistic approach is the best one for seismic hazard analysis in Albania, now when we are adopting the Eurocode 8.

3. Regarding the probabilistic approach described in this paper, we think that both "zone" [4] and "zoneless" [5] approaches should be used in order to have a better judgment of their results.

4. We think that for an appropriate seismic hazard assessment in each of Balkan countries the best way is to undertake a joint regional project.

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