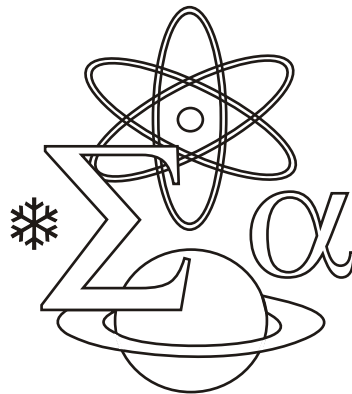


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MONITORING CHANGES IN VLF RADIO SIGNAL PROPAGATION PARAMETERS OF TERRESTRIAL ORIGIN

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ABSTRACT

We monitor changes in Very Low Frequency (VLF 3-30 kHz) radio wave propagation parameters of NWC/19.8 kHz signal, transmitted from H. E. Holt in Australia (21.8° S, 114.16° E) towards Belgrade receiver site (44.85° N, 20.38° E) in Serbia. The VLF data used were from Absolute Phase and Amplitude Logger (AbsPAL) receiving system of Belgrade's Institute of Physics database. Time span encompasses December 2005 to June 2007. We investigate possible relationship between NWC signal amplitude and phase delay characteristics and seismic activity reported by Helmholtz-Zentrum Potsdam - Deutsches GeoForschungs Zentrum GFZ. Main results are presented in this paper.

Keywords: Seismo-ionospheric effect, Ionosphere–lithosphere interactions, Earthquake, VLF propagation

1. INTRODUCTION

Changes in Very Low Frequency (VLF, 3-30kHz) radio signal propagation parameters, primarily in terms of amplitude and phase delay (A&Ph) perturbations, are nowadays widely used as remote sensing tool for exploration of wide range of extraterrestrial and terrestrial causative agents' influences onto Earth's lower ionosphere (e.g. [1] and references therein). D region electron density increasing mechanism related to increased tectonic activity induced by earthquake's preparation period and occurrences is often referred as seismo-ionospheric effect.

Terminator shifting during earthquake activity technique (e.g. [2-3]), was applied on monitored NWC/19.8 kHz signal's propagation parameters in period 2005-2007. Propagating along Great Circle Path (GCP) with 12 mM long trace, from transmitter in Australia (H. E. Holt, 21.8° S, 114.16° E) towards the Absolute Phase and Amplitude Logger (AbsPAL) receiving

system stationed in Serbia (Belgrade, 44.85° N, 20.38° E), this both over-water/over-land signal passes over many seismically active regions, where seismo-ionospheric effect is possible (Indian Ocean including western outskirts of Java and Sumatra Islands, southern Indian subcontinent, Iran, Turkey, Bulgaria, Romania). NWC/19.8 kHz signal propagation path (path_{NWC}) within Earth-Ionosphere wave guide is given in red in Figure 1.



Fig.1: Propagation path NWC along GCP (red line), as transmitted from E. H. Holt (AU) towards Belgrade (SRB)

2. RESULTS AND DISCUSION

Favorable geographical position makes NWC signal receptive for seismo-ionospheric effect analysis, aside the stable and continual emitting features and despite long path_{NWC} [4-6]. In general, NWC signal records in Belgrade are of good quality. A&Ph_{NWC} registrations are of the same form, normally with heavy noise during dawn and especially during dusk conditions, in some cases with completely masked signal. Readings related to dusk conditions are far less reliable, sometimes even impossible. A_{NWC} is

more stable than Ph_{NWC} , which is very susceptible to external effects and thus often gives unreliable or even impossible readings. A and/or Ph_{NWC} readings in cases of intense noise with large scatter in data, were excluded from analysis.

Seasonal dependence of terminator times is easily recognizable on 24h patterns of VLF signal registrations. Dawn or dusk at the receiver site in regular ionospheric conditions is defined by local zenith angle, as characteristic of given season. Deviation from this characteristic scheme is indication that disturbed propagation conditions inside the Earth-ionosphere waveguide took place and is considered as perturbation. Transition from stable nighttime to stable daytime ionospheric conditions and vice versa is dependent of seasonal and solar activity factors. Since very long path $_{NWC}$, it should be noted that at local dawn at Belgrade receiver site, entire trace became sunlit, while during local dusk, trace segments closer to the receiver, gradually enter nocturnal ionospheric conditions.

Survey of NWC signal propagation parameters encompassed period 12-2005 –06-2007. A& Ph_{NWC} showed perturbation that lasted 37 days, which has abruptly started on 30-08-2006, abruptly ended on 05-10-2006, too. Further on, terminator times went back to their normal and expected values. This behavior is more accurate in case of dawn than in case of dusk conditions. Terminator time dependence related to local dawn conditions (terminator $_{ND}$) during analyzed period is shown in Figure 2.

Values of A_{NWC} related to terminator time sat local dawn and dusk conditions (terminator $_{ND\&DN}$) are in Figure 3 given. Critical days of perturbation beginning and end are indicated by dashed black lines, while readings related to perturbed ionospheric conditions are rounded by red ellipse. During analyzed period, only one perturbation appeared on NWC signal propagation parameters, so seismic activity reported by Helmholtz-Zentrum Potsdam - Deutsches GeoForschungs Zentrum GFZ including all regions covered by path $_{NWC}$, within this time frame with few days before and after the disturbance extent, was inspected thoroughly, with some events discussed in more detail (Figures 4 and 5).

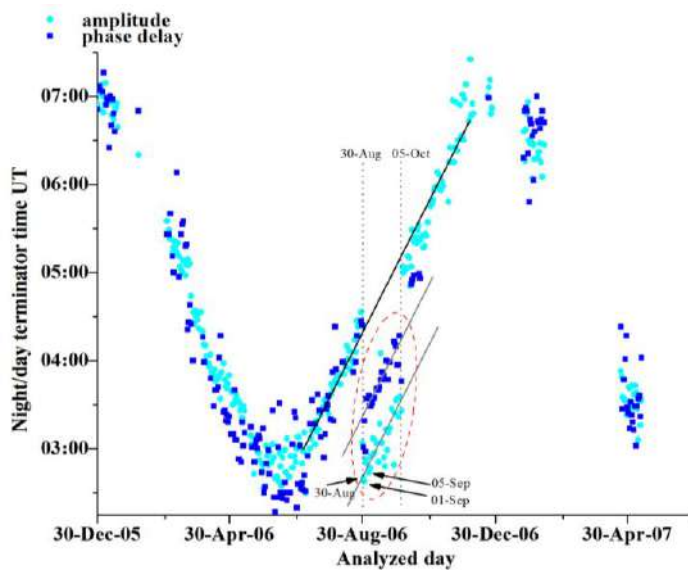


Fig. 2: A&Ph_{NWC} terminator t_{ND} times (dark and light blue, respectively) during analyzed period 12-2005 – 06-2007, with disturbance-related perturbed readings indicated by red oval

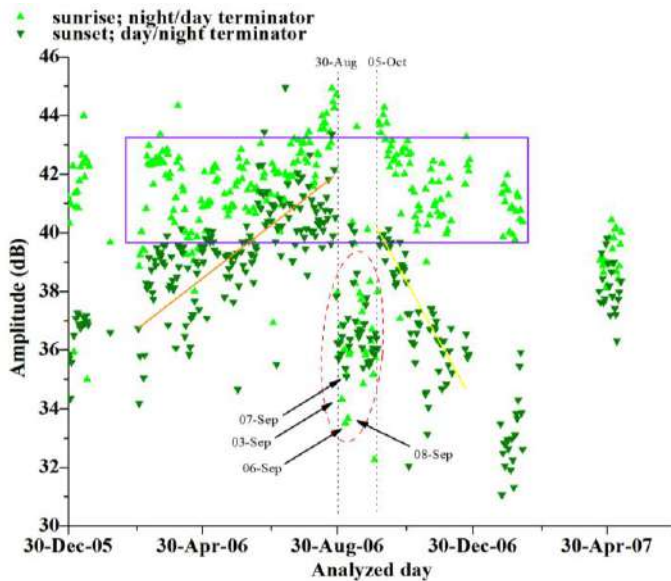


Fig.3: Values of A_{NWC} related to terminator t_{ND} and t_{DN} times (light and dark green, respectively) during analyzed period 12-2005 – 06-2007, with disturbance-related perturbed readings indicated by red oval.

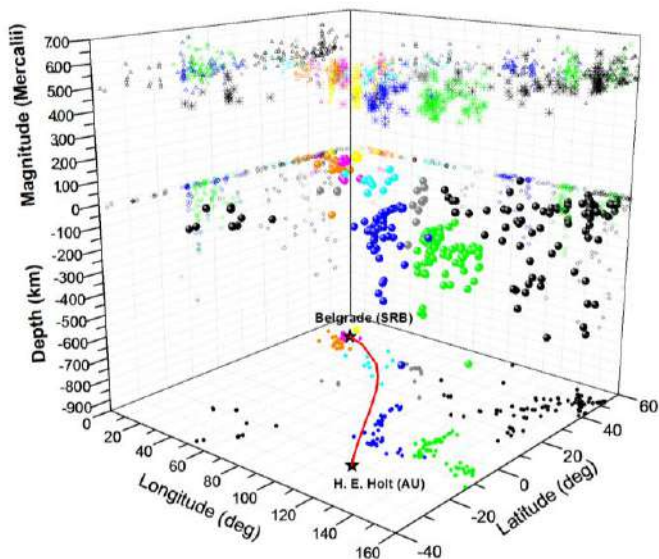


Fig. 4: Reported events' depths and magnitudes according to seismic activity reported by GFZ Potsdam in observed area during inspected period 15-08-2006 – 06-10-2006, enclosing perturbation extent 30-08-2006 – 05-10-2006.

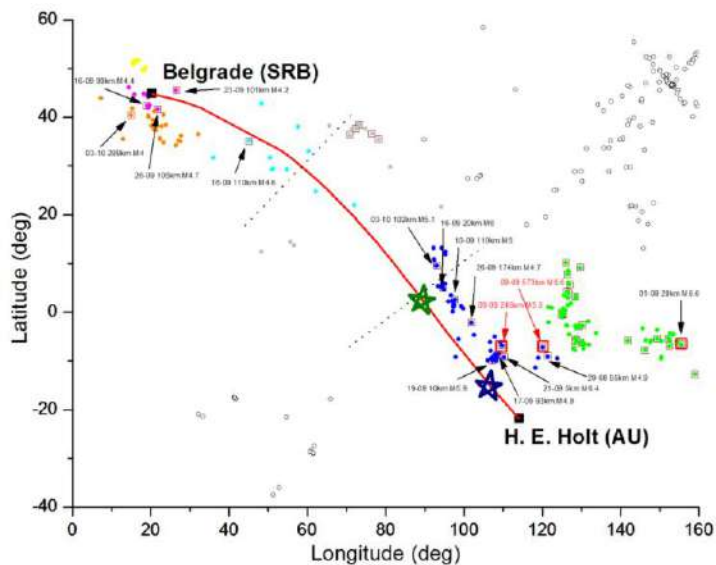


Fig. 5: Discussed events selected from seismic activity data reported by GFZ Potsdam in observed area during inspected period 15-08-2006 – 06-10-2006, enclosing perturbation extent 30-08-2006 – 05-10-2006.

The perturbation is particularly striking at $\text{terminator}_{\text{ND}}$ times trend related to local dawn conditions from A_{NWC} readings (light blue in Figure 2). In case of Ph_{NWC} readings (dark blue in Figure 2), despite some scattering, the disturbance can still be obviously recognized and distinguished from readings on regular trend. The much more distinct and convincing depiction given by A_{NWC} , is a consequence of its significantly lower sensitivity to external influences compared to Ph_{NWC} , as previously mentioned. In both cases during perturbation, it is clearly evident that $\text{terminator}_{\text{ND}}$ times trend was the same, as in pre and post disturbed conditions (solid gray and black lines in Figure 2, respectively), but was just shifted towards earlier times than are expected for that time of season. After perturbation, $\text{terminator}_{\text{ND}}$ times related to local dawn conditions went back to expected values.

The perturbation is also distinct in A_{NWC} values readings related to $\text{terminator}_{\text{ND}}$ times during dawn conditions (light green in Figure 3). In case of $\text{terminator}_{\text{DN}}$ times readings of A_{NWC} values related to dusk conditions (dark green in Figure 3), such dependence is not so clearly observable, although it is still recognizable. During the disturbance, in both cases, A_{NWC} were very similar both in behavior and in values and showed significant decay during disturbance compared to pre disturbance period (shifted downward in Figure 3) and no trend in data. In case of A_{NWC} readings related to $\text{terminator}_{\text{ND}}$ times (light green in Figure 3), even with somewhat higher amount of scattering present, it is clearly visible that after disturbance A_{NWC} went back to values relatively in the same range as they were in pre disturbed conditions (violet rectangle in Figure 2b). Not so regular behaviour is present in A_{NWC} readings related to $\text{terminator}_{\text{DN}}$ times related to local dusk conditions (dark green in Figure 3), where A_{NWC} values after the disturbance stayed somewhat lower compared to pre disturbance period (trend shown in yellow and orange solid lines in Figure 3, respectively).

Perturbation went through its extremum early in September 2006, with minimum round dates 30-08 – 01-09 – 05-09-2006 in case of $\text{terminator}_{\text{DN}}$ times, while round dates 03-09 – 08-09-2006 in case of A_{NWC} values (both indicated by arrows in Figures 2 and 3), showing a good match.

During 2006, within observed area enclosed by longitude (0° E, 160° E) and latitude (40° S, 60° N), according to GFZ Potsdam (more details at <http://geofon.gfz-potsdam.de>), no significantly stronger earthquake occurred. Only 4 relatively stronger events with magnitudes above 6.5 degrees on Mercalli intensity scale were reported, with two occurred during September 2006 (Table 1). In period 15-08-2006 – 06-10-2006 that encloses perturbation, there were 349 earthquakes reported within observed area.

Table 1 –Earthquakes reported by GFZ Potsdam during September 2006, with magnitude greater than 6.5 degrees on Mercalli intensity scale

No.	Date and Time UT	Intensity (M)	Lat. (°)	Long. (°)	Depth (km)	Region
1	01-09-2006; 10:18	6.6	6.7 S	155.5 E	28	Solomon Islands
2	09-09-2006; 04:13	6.6	7.2 S	120.1 E	573	Flores Sea
#	09-09-2006; 17:48	5.3	6.9 S	109.7 E	245	Java, Indonesia

weaker earthquake

Considering very long path_{NWC} and that due to technical reasons observed area had to be of regular shape, the size of analyzed area was very large with longitude (0° E, 160° E) and latitudes (40° S, 60° N). Events reported in far north-east and south-west zones, that were too far away from path_{NWC} (114 events), were manually excluded from analysis (black in Figures 4 and 5). The rest of 235 events were analyzed in detail and manually grouped in several categories according to their locations related to path_{NWC} (presented by different colors in Figures 4 and 5). In region of path_{NWC} close to transmitter (the first third of trace - dashed black line in Figure 5), events relatively close to the path_{NWC} are presented in dark blue, while those far from the path_{NWC} in green. Events relatively close to middle region of trace, are presented in gray and light blue, while in region close to Belgrade receiver (the last third of trace- dashed black line in Figure 5) in orange, pink and yellow.

In block-diagram in Figure 4, reported earthquakes are presented by their projections onto the Earth's surface with filled dots in x-y plane, their hypocenters in lower sector are presented by solid spheres, while magnitudes in upper sector by crosses. On vertical projection planes, depths and magnitudes are presented by hollow diamonds and triangles, respectively. Zero on vertical axis refers to ground level in case of depth, while to no occurrence in case of magnitude. Although the deepest reported earthquake was of 650 km hypocenter depth (in far zone), for the sake of visibility, depths are plotted up to 900 km.

Depending on magnitude and depth, 50 events were analyzed in detail, while 3 events from early September stood out (rounded by brown and red hollow squares in Figure 2d, respectively). Two of them were the strongest reported events with M6.6 (1-2 in Table 1), while two were especially deep (573 km and 254 km) and from the same day 09-09-2006 within ≈18.5h interval (bold 2 and # in Table 1, indicated by red arrows in Figure 5).

Taking into consideration all seismically active regions along path_{NWC}, it can be assumed that observed perturbation is of seismotectonic origin, even though there was no notably strong event reported that could be potentially assumed as indicator of seismic activity and directly brought into the relationship with observed disturbance. It is certain that change in the scheme of terminator time variation of NWC signal in period 30-08-2006 – 05-10-2006 could not be of technical nature and that observed perturbation is related to increased ionization levels within the waveguide alone.

It is possible to correlate reported seismic activity from early September 2006 and observed disturbance on NWC signal propagation parameters, although stating conclusions of any direct relationship is quite uncertain. There is a relative coincidence between somewhat stronger 2 events from early September (Table 1) and disturbance start on one hand and its extremum around September 5th on the other (Table 1, bold), but stating any certain and direct relationship is fairly inconclusive. Particularly, the deep earthquake that occurred near transmitter on September 9th and in relative vicinity to path_{NWC} (precisely the position of regular daily signal's I modal minimum, blue star in Figure 5) should be stressed out.

Nevertheless, constantly present and frequent low and/or mid-level seismic activity with numerous shallow events [7], distributed in relative vicinity of path_{NWC} and especially near locations of regular daily signal's modal minima (blue and green stars in Figure 5, respectively), could impacted ionization state change within the wave guide. However, it cannot be stated with certainty, that this type of earthquakes actually caused such perturbation.

3. CONCLUSIONS

The possible relationship between monitored NWC/19.8 kHz signal propagation parameters changes, as registered by AbsPAL receiving system in Belgrade (Serbia) and seismic activity reported by GFZ Potsdam in period 2005-2007 was investigated. During perturbation detected in period 30-08-2006 – 05-10-2006, lasted 37 days, terminator times related to local dawn and dusk conditions at Belgrade receiver site, have been shifted indicating disturbed ionospheric conditions with increased electron densities. Regardless the long path_{NWC}[4-6], distinct terminator time shifting and amplitude changes cannot be explained by variations in the VLF wave reflection height. Assumption about seismotectonic origin of observed perturbation can be drawn based on data readings. Considerable noise suppression in data, appearing not only at perturbation beginning (suggested as possible new earthquake precursor, [8]), but also during the entire perturbed period, supports this assumption. However, the precise cause and voltage state change location that induced disturbance of such extent and characteristics, cannot be

determined with certainty, due to complex conditions within the waveguide allong path_{NWC}.

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REFERENCES

- [1] **Silber I, Price C. 2017.** On the Use of VLF Narrowband Measurements to Study the Lower Ionosphere and the Mesosphere–Lower Thermosphere. *Surveys in Geophysics*, **38(2)**: 407–441, doi:10.1007/s10712-016-9396-9.
- [2] **Hayakawa M, Molchanov OA, Ondoh T, Kawai E. 1996.** Precursory signature of the Kobe earthquake on VLF subionospheric signal. *Journal of atmospheric electricity*. **16 (3)**: 247-257.
- [3] **Hayakawa M, Molchanov OA. 2004.** NASDA/UEC team, Summary report of NASDA's earthquake remote sensing frontier project. *Physics and Chemistry of the Earth*, **29**: 617–625, DOI: 10.1016/j.pce.2003.08.062.
- [4] **Rodger CJ, Clilverd MA, Thomson NR. 1999.** Modeling of subionospheric VLF signal perturbations associated with earthquakes. *Radio Science*, **34(5)**: 1177-1185, doi: 10.1029/1999RS900061.
- [5] **Clilverd MA, Rodger CJ, Thomson NR. 1999.** Investigating seismoionospheric effects on a long subionospheric path. *Journal Geophysical Research*, **104(A12)**: 28, 171–28,179, <https://doi.org/10.1029/1999JA900285>.
- [6] **Cohen MB, Marshall RA. 2012.** ELF/VLF recordings during the 11 March 2011 Japanese Tohoku earthquake, GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L11804, doi:10.1029/2012GL052123.
- [7] **Singh V, Singh B, Hayakawa M, Kumar M, Kushwah V, Singh OP. 2004.** Nighttime amplitude decrease in 19.8 kHz NWC signals observed at Agra possibly caused by moderate seismic activities along the propagation path. *Journal of atmospheric electricity*, **24**: pp. 1–15.
- [8] **Nina A, Pulinets S, Biagi PF, Nico G, Mitrović ST, Radovanović M, Popović LČ. 2020.** Variation in natural short-period ionospheric noise,

and acoustic and gravity waves revealed by the amplitude analysis of a VLF radio signal on the occasion of the Kraljevo earthquake ($M_w = 5.4$). *Science of The Total Environment*, **710**, 2020, 136406, ISSN 0048-9697, <https://doi.org/10.1016/j.scitotenv.2019.136406>.

RELIABLE SEISMIC HAZARD ASSESSMENT: NDSHA¹

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“You never change things by fighting
the existing reality. To change something,
build a new model that makes
the existing model obsolete.”

- Buckminster Fuller

ABSTRACT

A New Paradigm is now needed for Reliable Seismic Hazard Assessment (RSHA) – one that is intrinsically data-driven and formulated on scientific judgment, unlike current and unreliable risk-analysis models. Neo-Deterministic Seismic Hazard Assessment (NDSHA) integrates earthquake geology, earthquake science, and particularly earthquake physics to finally achieve this New Paradigm for RSHA. Although observations from many recent destructive earthquakes have all confirmed the validity of NDSHA’s approach and application to earthquake hazard forecasting – nevertheless damaging earthquakes still cannot yet be predicted with a *precision* requirement consistent with issuing red alert and evacuation orders to protect civil populations. But now proper integration of both seismological and geodetic information together reliably contributes to a reduction of the geographic extent of alarms – and it therefore defines a New Paradigm for Time-Dependent Hazard Scenarios: Intermediate-Term and Narrow-Range Earthquake Prediction.

Keywords: NDSHA; RSHA; Earthquake prediction.

¹ Invited keynote lecture

1. INTRODUCTION

Since our world-wide experiences (expressed in terms of *unacceptable* human losses) from now over more than half-a-century of equating earthquake risk-analysis models with earthquake hazard (or likelihood of an earthquake) have proven unreliable, a New Paradigm (one that is intrinsically data-driven and formulated on scientific judgment, unlike the current PSHA) is needed for Reliable Seismic Hazard Assessment RSHA.

Neo-Deterministic Seismic Hazard Assessment (NDSHA), fully described in Panza and Bela (2019) and references therein, integrates earthquake geology, earthquake science, and particularly earthquake physics to finally achieve this New Paradigm for RSHA.

Building upon both the familiarity and long experience of successful practice with DSHA and seismic zonation, NDSHA now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves through anelastic media; and then (iii) their combined interactions with site conditions – and thus effectively accounts for the *tensor* nature of earthquake ground motions. In such a way NDSHA computationally copes with the physical fact that so-called “site effects” are not intrinsically stable at any given site (Olsen 2000; Boore 2004; Molchan et al 2011; Panza and Bela 2019), but rather reflect a strong *signature* of earthquake-source properties.

By computationally using all available information about the spatial distribution of large Magnitude earthquake phenomena, including: (a) geological and geophysical data; and (b) Maximum Credible Earthquake (MCE) – M_{design} is effectively set equal to the maximum observed or formally estimated magnitude M_{max} , plus some multiple of its accepted global standard deviation σ_M (Rugarli *et al.*, 2019). Since NDSHA does not rely on *scalar* empirical ground motion attenuation models GMPEs, as these are often both: (a) weakly constrained by available observations and (b) fundamentally unable to account for the tensor nature of earthquake ground motions (Olsen 2000; Molchan *et al* 2011; Panza and Bela 2019) – it provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies. Importantly, these are accomplished without invoking the *chimeric* or illusory and physically-rootless Hazard Curve: annual frequency of earthquakes | earthquake return-period (see Figure 1) – generally depicted as either a “475 yr. earthquake” or the more rare “2475 yr. earthquake.”

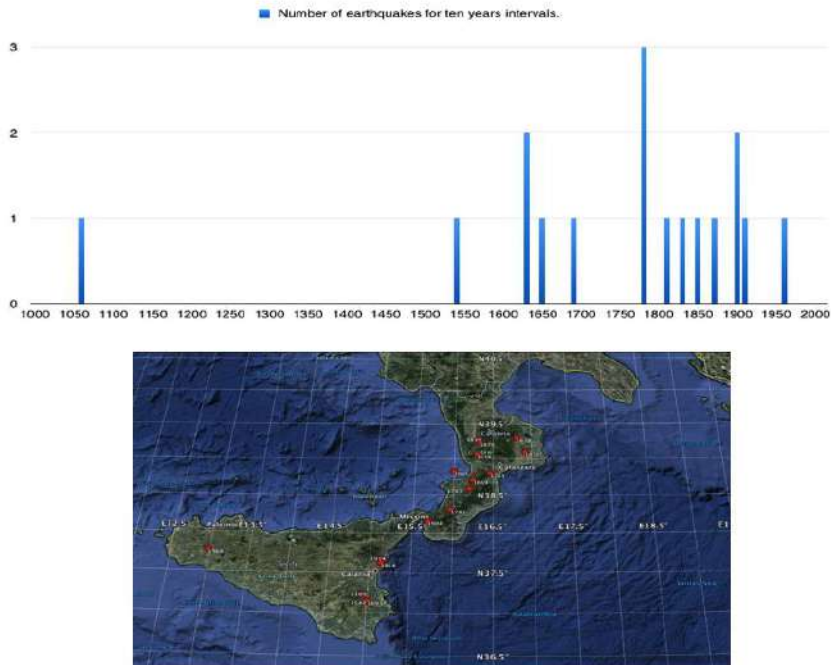


Fig. 1. Earthquakes with $I_{MCS} \geq X$ (Mercalli, Cancani, Sieberg scale), since 1100, in Messina strait area s.l. (Italy): (a) to be conservative all intermediate Intensity values are rounded up to the nearest integer accordingly with Grünthal (1998); (b) the sometimes-clustered sporadic locations of epicentres, in *space-and-time*, threatens at its core the *chimeric* concept of "average return period" or "return time" – the promoted presumed *appropriate* cornerstone for *expressing* seismic risk in PSHA! What is the real *practical value* that an engineering seismic risk analysis should assign to the Messina strait area for the "average return period" or "return time?" – which here we can calculate at about "60 years" for historic events with $I_{MCS} \geq X$ occurring in the last millennium? (courtesy of D. Bisignano).

Earthquake Hazard and Earthquake prediction

Although observations from many recent destructive earthquakes have all confirmed the validity of NDSHA's approach and application to earthquake hazard forecasting — nonetheless damaging earthquakes still unfortunately cannot yet be predicted with a *precision* requirement consistent with issuing red alert and evacuation orders to protect civil populations. However, intermediate-term (several months) and middle-range (few 100s km scale) *predictions* of main shocks above pre-assigned thresholds that are based on seismicity "alarms" generated by interpretative algorithms (Keilis-Borok and Soloviev 2003; Keilis-Borok 2018) – may be properly used for the implementation of low-key preventive safety actions for affected at-risk populations, as recommended by UNESCO in 1977 (Kantorovich and Keilis-

Borok 1977; Molchan 1997). Progressive reduction of prediction uncertainty in both *space-and-time* remains an ongoing and challenging task, and aforementioned CN, M8 and M8S algorithms have now been tested and evaluated for some decades for *intermediate-term* – *middle-range* – earthquake predictions (e.g. Peresan et al 2005).

Through a retrospective analysis of both the 2012 Emilia sequence and also the 2016-2017 Seismic Crisis in Central Italy (Panza *et al.*, 2018, Crespi *et al.*, 2019), space-time precursory features have been already highlighted within both GPS *ground velocities* and instrumentally monitored seismicity. Overall, it is demonstrated now that the proper integration of both seismological and geodetic information can achieve what here is called — *intermediate-term* (several months) – *narrow-range* (few 10s km scale) – earthquake prediction. Therefore, the extent of the alarmed areas, identified (as above) for the strong earthquakes by earthquake prediction algorithms based on seismicity patterns (e.g. Kossobokov and Shebalin 2003), can be significantly reduced from linear dimensions of a few hundred to now a few tens of kilometers, leading to an improved and more specific *implementation* of low-key preventive actions, like those recommended by UNESCO as early as in 1991 (Kantorivic and Keilis-Borok, 1991).

NDSHA in Albania

The NDSHA scenario studies so far performed for Albania are those by Muço *et al.*, (2001; 2002) and Marku *et al.*, (2014). In the area most severely affected by the M 6.4 earthquake of 26 November 2019, the NDSHA DGA (~PGA) value at the bedrock is around 0.3g, which well *envelopes* the observed ground motions reported — <https://earthquake.usgs.gov/earthquakes/eventpage/us70006d0m/shakemap/pga> — with larger values being observed where strong "site effects" are to be expected; and a model (Stein and Sevilgen 2019) shows "amplification" factors of 4 - 5 greater than the shaking that was experienced at bedrock sites. Predicted PSHA values, however, do not exceed 0.18g! (Muço 2013). Marku et al (2021) concluded that, for the reliable assessment of seismic hazard, the most logical procedure to be followed from now on is the NDSHA methodology, which has provided, so far, data that certainly is closer to reality.

Last but not least, the tsunami hazard in the Adriatic Sea had been modeled by Paulatto et al (2007) following NDSHA approach; and their pioneering results were also later confirmed by Tiberti et al (2009). Notwithstanding that both the conservative NDSHA estimates, as well as the subsequent confirmation by Tiberti *et al.*, (2009), *excluded* any significant tsunami generation hazard caused by the M 6.4 earthquake of 26 November 2019 – the Italian Istituto Nazionale di Geofisica e Vulcanologia (INGV)'s

Center for Tsunami issued (7 minutes after the quake) an alert to Civil Protection for tsunami hazard in Albania, Montenegro and Italy. That alert was appropriately rescinded the very following morning of November 27, based on records of tide gauge measurements.
https://www.agi.it/estero/terremoto_albania-6620218/news/2019-11-26/.

2. CONCLUSION

Our world-wide experiences from now more than half-a-century of equating earthquake risk analysis models with earthquake hazard (or likelihood of having an earthquake) have proven unreliable; and they therefore have prompted the development of a New Paradigm (one that is intrinsically data-driven and formulated instead based on scientific judgment, unlike the current PSHA), in order to meet the need for Reliable Seismic Hazard Assessment (RSHA). NDSHA methodology now convolves a comprehensive physical knowledge of: (i) the seismic source process; (ii) the propagation of earthquake waves through anelastic media; and then (iii) their combined interactions with site conditions – and thus effectively accounts for the *tensor* nature of earthquake ground motions.

By computationally using all available information about the spatial distribution of large Magnitude earthquake phenomena, including: (a) geological and geophysical data; and (b) Maximum Credible Earthquake (MCE) – M_{design} is set equal to the maximum observed or formally estimated magnitude M_{max} , plus some multiple of its accepted global standard deviation $\sigma_M \approx 0.2\text{--}0.3$ (Båth 1973, p.111).

NDSHA, since it does not rely on GMPE inputs into so-called Hazard Models, as these inputs are often both: (a) weakly constrained by available observations and (b) fundamentally unable to account for the tensor nature of earthquake ground motions – alternatively provides both robust and safely conservative hazard estimates for engineering design and mitigation decision strategies.

Further examples illustrating the reliability of NDSHA, including detailed updates on NDSHA research and application methodologies in Africa, America, Asia and Europe, that hopefully will encourage responsible people and authorities to seriously employ these more reliable procedures for SHA evaluation, are presented in “Earthquakes and Sustainable Infrastructure: Neo-Deterministic (NDSHA) approach guarantees prevention rather than cure.” Edited by Panza G., Kossobokov V., Laor E. and De Vivo B. (2021, in press) for Elsevier.

REFERENCES

Báth M. 1973. Introduction to Seismology. John Wiley, New York, pp. 395. ISBN 978-0470056608 – [https://doi.org/10.1016/0012-8252\(81\)90014-3](https://doi.org/10.1016/0012-8252(81)90014-3).

Boore DM. 2004. Can site response be predicted? *Journal of Earthquake Engineering*, **8** (SI 1), 1-41. – <https://doi.org/10.1080/13632460409350520>.
http://www.daveboore.com/pubs_online/rose_keynote_je_e_2004.pdf

Crespi M, Kossobokov V, Panza GF, Peresan A. 2019. Space-Time Precursory Features within Ground Velocities and Seismicity in North-Central Italy. *Pure and Applied Geophysics*. – <https://doi.org/10.1007/s00024-019-02297-y>.

Grünthal, G. 1998. European Macroseismic scale 1998. Cahiers du Centre Européen de Géodynamique et de Séismologie. Volume 15, Conseil de l'Europe, Luxembourg.

Kantorovich LV, Keilis-Borok, VI. 1977. Economics of Earthquake Prediction. Proceedings of UNESCO Conference on Seismic Risk, Paris, 1977.

Kantorovich LV, Keilis-Borok, VI. 1991. Earthquake prediction and decision-making: social, economic and civil protection aspects. In: Proc. International Conference on Earthquake Prediction: State-of-the-Art, pp. 586–593 (Scientific-Technical Contributions, CSEM-EMSC, Strasbourg, France, 1991. Based on “Economics of earthquake prediction” (*Proc. UNESCO Conference on Seismic Risk, Paris, 1977*).

Keilis-Borok VI. 2018. Prediction of Extreme events in Nature and Society. A.A. Soloviev (Ed.), Ori Books, pp. 520. ISBN 1940076447 <https://doi.org/10.28935/9781940076447>
<https://www.amazon.com/Prediction-Extreme-Events-Nature-Society/dp/1940076447>.

Keilis-Borok, VI. Soloviev, A.A. (Eds) (2003) Non-linear dynamics of the lithosphere and earthquake prediction. Springer, Heidelberg, Germany, pp. 337. ISBNe 978-3-662-05298-3
<https://www.springer.com/us/book/9783540435280>.

Kossobokov VG, Shebalin, P. 2003. 4. Earthquake Prediction. In: Keilis-Borok, V.I., A.A. Soloviev (Eds). Nonlinear Dynamics of the Lithosphere and Earthquake Prediction, 141-207. Springer Series in Synergetics. Springer, Berlin, Heidelberg. ISBN 978-3-642-07806-4. –https://doi.org/10.1007/978-3-662-05298-3_4 –<https://www.springer.com/us/book/9783540435280>

Marku S, Panza GF, Ormeni R. 2014. The necessity of an anti-seismic law in Albania based on NDSHA method of risk calculation. *Buletini i Shkencave Gjeologjike*. 1/2014 - Special Issue. Proceedings of XX CBGA Congress, Tirana, Albania, 24-26 September 2014, 462-465.

https://www.academia.edu/43151518/Beqiraj_A_Ionescu_C_Christofides_G_Uta_A_Beqiraj_Goga_E_and_Marku_S_Proceedings_XX_Congress_of_the_Carpathian_Balkan_Geological_Association_September_24_26_2014_Tirana_Albania_Special_Issue_Vol_1_2014_Special_Sessions. The full volume with abstracts may be downloaded from: www.fgjm.edu.al/cbga

Marku S, Ormeni R, Panza GF. 2021. Seismic characterization of Tirana - Durrës - Lezha region (northwestern Albania) and analysis effort through NSHDA method. In: "Earthquakes and Sustainable Infrastructure: neodeterministic (NDSHA) approach guarantees prevention rather than cure." Edited by Panza G., Kossobokov V., Laor E. and De Vivo B. for Elsevier.

Molchan GM. 1997. Earthquake prediction as a decision-making problem. *PAGEOPH*, 149, 233–247. – <https://doi.org/10.1007/BF00945169>.

Molchan G, Kronrod T, Panza GF. 2011. Hot/Cold Spots in Italian Macroseismic Data. *Pure and Applied Geophysics*, **168** (3-4): 739-752. <https://doi.org/10.1007/s00024-010-0111-3>.

Muço B. 2013. Probabilistic seismic hazard assessment in Albania. *Ital. J. Geosci.* 132 (f,2), 194-202. – <https://doi.org/10.3301/IJG.2012.33>.

Muço B, Vaccari F, Panza, GF. 2001. Seismic zonation of Albania using a deterministic approach. *The Albanian Journal of Natural & Technical Sciences*, **10**: 5-19.

Muço B, Vaccari F, Panza GF, and Kuka N. 2002. Seismic zonation in Albania using a deterministic approach. *Tectonophysics*, **344** (3): 277-288. [https://doi.org/10.1016/S0040-1951\(01\)00279-7](https://doi.org/10.1016/S0040-1951(01)00279-7).

Olsen KB. 2000. Site Amplification in the Los Angeles Basin from Three-Dimensional Modeling of Ground Motion. *Bulletin of the Seismological Society of America*, **90** (6B), S77-S94. – <https://doi.org/10.1785/0120000506>.

Panza GF, Bela J. 2019. NDSHA: a new paradigm for reliable seismic hazard assessment. *Engineering Geology*, Vol. **275** SI, 20 September 2020, Article 105403, pp 14. – <https://doi.org/10.1016/j.enggeo.2019.105403>.

Panza GF, Peresan A, Sansò F, Crespi M, Mazzoni A, Nascetti A. 2018. How geodesy can contribute to the understanding and prediction of earthquakes. *Rendiconti Lincei. Scienze Fisiche e Naturali*, **29** (Suppl 1): 81-93. <https://doi.org/10.1007/s12210-017-0626-y>.

Paulatto M, Pinat T, Romanelli F. 2007. Tsunami hazard scenarios in the Adriatic Sea domain. *Natural Hazards and Earth System Sciences*, **7** (2): 309–325. <https://doi.org/10.5194/nhess-7-309-2007>.

Peresan A, Kossobokov V, Romashkova L, Panza, GF. 2005. Intermediate-term middle-range earthquake predictions in Italy: a review. *Earth-Science Reviews*, **69** (1-2): 97-132. – <https://doi.org/10.1016/j.earscirev.2004.07.005>.

Rugarli P, Vaccari F, Panza GF. 2019. Seismogenic nodes as a viable alternative to seismogenic zones and observed seismicity for the definition of

seismic hazard at regional scale. *Vietnam Journal of Earth Sciences*, **41 (4)**: 289–304. – <http://dx.doi.org/10.15625/0866-7187/41/4/14233>.

Stein RS, Sevilgen V. 2019. Albania earthquake strikes highest-hazard zone in the Balkans, devastating nearby towns, Temblor. 26 Nov. 2019. <http://doi.org/10.32858/temblor.057>.

Tiberti MM, Lorito S, Basili R, Kastelic V, Piatanesi, A, Valensise G. 2009. Scenarios of Earthquake-Generated Tsunamis for the Italian Coast of the Adriatic Sea. *Pure and Applied Geophysics*, **165**: 2117-2142. <https://doi.org/10.1007/s00024-008-0417-6>.

CURRENT ISSUES IN SEISMIC RISK REDUCTION POLICY IN MONTENEGRO

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ABSTRACT

Seismic risk reduction policy is constituted through plans, rules, expertness, professional practices etc. acting to reduce human casualties, economy losses in case of future earthquake. Seismic risk reduction is a long-term oriented and continuous policy. The proclaimed principle “build back better” (*UNDRR, Sendai Framework for disaster risk reduction 20015-2030*) underlines the importance of learning through past experiences. Current issues in this risk governance are analysed from the point of its view of different constituting aspects: legislative, administrative, technical, economical, societal and political. State of governance in these spheres is influencing the overall success of seismic risk reduction/control policy. The major laws controlling the seismic protection in Montenegro are *Law on spatial planning and construction* (2018), set of European standards adopted by Institute for Standardization of Montenegro (ISME, 2015-2018) and *Law on Protection and Rescue* (2016). Administrative aspect of seismic risk managing in Montenegro is its’ weakest point. Different sectors (e.g. construction, transport, spatial and urban planning etc.) have own missions in the task of controlling/reducing seismic risk in the state, but the level of coordination is insufficient. Additionally, there is a huge gap in capacities on different administrative levels – municipal vs. state. Trend of favouring risk preparedness measures over the preventive actions is highly present. Problems originating in technical aspects of seismic risk reduction policy are analysed from the point of view of the level of present risk specific knowledge, state of seismic hazard assessment, state of vulnerability classification, state of data availability and accessibility and the national state of seismic risk evaluation. Specific emphasize is on the presence of risk drivers e.g. in spatial and urban planning, illegal settlements, construction control. Mono-sectoral economic development, barely existing risk transfer policies are solely few examples seriously influencing consequences of a future earthquake in Montenegro. Although often neglected – societal circumstances such are risk perception and risk awareness, professional ethics, migrations, poverty and vulnerable groups are taking tool on present state of risk reduction. Finally,

political support to candidate and implement seismic risk reduction programs and policies should be clearly prioritized.

Keywords: Risk reduction policy, Law on Spatial Planning and Construction, sectoral coordination, risk assessment, risk drivers, risk transfer

1. INTRODUCTION

Contemporary and historic data are revealing significant examples of losses caused by intensive earthquakes in Montenegro. In 1979, destructive earthquake of magnitude Mw 6,9 caused overall losses approximated to 4 times of national GDP (Pavićević, 2000). Earthquake caused damages to buildings, railway and roads, shipyards and ports, as well as historical towns situated along the Montenegrin coast. National economy, social and cultural settings of the affected region withstand lasting consequences.

Seismic risk reduction (RR) policy is constituted through plans, rules, expertness, professional practices etc. acting to reduce human casualties, economy losses in case of future earthquake. Being long-term oriented and continuous, seismic RR policy should reflect lessons from past experiences – as is proclaimed in the principle “build back better” (UNDRR, Sendai Framework for disaster risk reduction 20015-2030). It should integrate the different sectoral policies, different administrative levels. At the same time, RR policy ought to be public. Some of its aspects involves the particular knowledge and expertise – thus it is important to achieve coordination and understanding between the different stakeholders. Seismic risk should be managed in most economic manner and in synergy with risks’ management caused by other natural and technological hazards - thus deliberately mitigating occurrence of cascading effects and systemic risk.

Seismic risk governance is executed through: creation of policies, planning process and realization of RR activities as schematically presented in the Figure 1. Overall government is conditioned by the existence of sufficient, accurate, available and accessible data. Its’ success is directly linked to interoperability of disaster risk reduction data (Migliorini *et. al*, 2019).

This paper is the outcome of the recent analysis of seismic risk governance which the author carried out for the elaboration of Spatial Plan of Montenegro 2020-2040. Issues in seismic risk governance in Montenegro were analysed from the different perspectives of its governance: legislative, administrative, technical, economical, societal and political.



Fig 1: Seismic risk reduction governance (according to Pavićević, 2000).

LEGISLATIVE ISSUES

Law of general character majorly influencing seismic risk reduction policy in Montenegro is the *Law on Spatial Planning and Construction of Structures* (Off. Gazette ME No. 64/17 and 44/18). Law is stipulating content of the spatial plans of different levels. Location requirements (LR)- a set of data (limitations as well) necessary for the preparation of technical documentation and issuing of the construction permit, are set by this Law as well. General and nonspecific formulation directs that spatial plans should define the guiding principles for seismic RR refers. This is considered to be step backwards in respect to previous versions of this law. For instance, earlier municipal spatial plans were elaborated in accordance to seismic macro-zonation, while on the urban planning level LR reflected and cited seismic micro-zonation studies. At the current, LR do not have to enclose findings of micro-zonation studies, but may/not impose conducting of a particular geophysical study. Such a stipulation is in direct conflict to experts' constant appeals to broaden the extents of micro-zonation studies that were conducted in 1980-es (entitled "for the purpose of urban planning").

Particular chapter of the mentioned Law is referring to the status of illegal building stock (estimation of 100.000). Referring to the *Guidance Book* (Off. Gazette ME No. 84/17), there are two different procedures set to approve the structural stability and seismic safety of illegal building (conditioned by total area of a building). In both cases, a building owner ought to provide the relevant analysis conducted by business entity. If the total building area exceeds 500 m², additional declaration issued by certified review is obligatory. Exceptionally, for the households, a building owner may supply own certified declaration- as a substitute for structural analysis (owner is claiming the responsibility for any damages caused to third parties). This declaration is stated in the households' real estate records. The last stipulation

is questionable from the standpoint of human lives safety, and may have long-lasting harmful effects.

Regarding technical regulations concerning seismic design and safety of structures significant progress in adoption of European standards has been achieved (Table 1). In the time span of 2015-2019, following Parts (with National Annexes) of *Eurocodes 8 Design of structures for earthquake resistance* were standardized:

- *Part 1: General rules, seismic actions and rules for buildings and National Annex (NA),*
- *Part 2: Bridges and NA,*
- *Part 3: Assessment and retrofitting of buildings and NA*
- *Part 4: Silos, tanks and pipelines and NA*
- *Part 5: Foundations, retaining structures and geotechnical aspects and NA*
- *Part 6: Towers, masts and chimneys and NA*

Still, the challenge of training of all engineers and codes' implementation remains.

ADMINISTRATIVE ISSUES

Different sectors (e.g. construction, transport, spatial and urban planning etc.) have own missions in the task of controlling/reducing seismic risk in the state, but the level of coordination is insufficient. Lack of administrative centre (body) to prioritize, guide and synchronize these particular and marginal policies towards efficient management is evident. During the last decade (and in accordance with *Law on Protection and Rescue*, 2016), Directorate for Emergency Management imposed authority in risk management. Due to lack of its own (civil) engineering expertise, risk preparedness took over the preventive actions.

One of the most important problems in Montenegro is competency and capacity of human resources. There is a huge gap in capacities on different administrative levels – municipal vs. state.

ISSUES RELATED TO TECHNICAL ASPECTS

Technical issues might be stated for each of the risk assessment components: seismic hazard, exposure and vulnerability.

New seismic hazard map of Montenegro (IHMS, Glavatovic & Vucic, 2014) has been delivered for definition of the *National Annex Part 1: General rules, seismic actions and rules for buildings of Eurocode 8 (NA)*. Need to

scrutinize the NA statements and seismic action definition is crucial. This refers to:

- Identification of ground types: NA specifies that in cases when $V_{s,30}$ is not determined by the geophysical investigation, soil category might be determined by standard penetration test (NSPT) or soils' undrained shear strength of soil (C_u). When deep geology is unknown, NA recommends the soil classification scheme based on (averaged) results gathered in micro-zonation studies.

Having in mind current stipulations towards LR (and undermining the of micro-zonation studies), it looks that site specific amplification, near-fault effects, potentials for soil sliding and liquefaction etc. can be easily "lost" in current seismic action definition.

- Shape of adopted (recommended) elastic response spectra. Namely, number of available strong motion records for the earthquake Type 1 was small (20). For the earthquake Type 2, a records were dominantly small events ($M < 4.0$); only 10% of analysed records were strong events ($4 < M < 5.8$). No records for the soil types B, C, D and E were available (Janković and Glavatović et al., 2019).

Since the Montenegrin earthquake (1979, M_L 7.0) when 40 000 buildings were inspected, no further earthquake damage was systematically conducted. Recent Plav (2018, $M_{5.1}$) earthquake (Mihaljević *et. al*, 2018) was the first one in almost 40 years to cause damages. Local commission of insufficient engineering competence assessed financial damage. In the absence of methodology and trainings to assess damage, there is a worrisome possibility that potential damage state of the constructions could be under or overestimated – having harmful consequences in both cases. With no systematic efforts to gather data, identify, categorize and research existing vulnerability (classes) of buildings - the overall statement would be that the vulnerability is a weakest link in seismic risk assessment.

Another issue is inefficient sectoral management of data related to exposures. INSPIRE directive implementation will be a huge challenge in Montenegro.

Related to national risk assessment - a national consensus on methodology, acceptable risk level, leading institution and partners involved, technical capacities etc. still had to be determined/assigned.

Important present technical aspects might be classified as underlying risk drivers: intensive urbanization, uncontrolled adaptations and reconstruction of buildings, inadequate transport infrastructure (jam prone), illegal settlements situated on unstable slopes/soil, etc.

OTHER ISSUES

State of risk governance is highly affected by the existing level of economic development. Resources attributed to RR policies are closely connected to political priorities and political will to strengthen the legal aspects of risk governance and to pursue risk control policies.

Some of the most influential economy issues are: a weakened economy, development oriented towards tourism and services (present in coastal area of highest seismic hazard), policy of natural resources management (hydropower plants and hydrocarbon extraction - both with potential to induce seismicity). There are very limited attempts towards risk transfer policy implementation – weak attempts in insurance policy and total absence of funds and incentives for seismic retrofit.

Last but not least, social aspects affect the current state of seismic risk safety. The state of risk perception should be upgraded to risk awareness (of decision-makers, practitioners and citizens). During last decades, Montenegro experienced intensive migrations (many of whom are unconscious of earthquake related risk). Education of specific professions is of utmost importance. The engineering professional ethics should be addressed in educational process, while controlled and verified in every day's practice. Poverty and inequity are the factors highly present in resolving of seismic safety of illegal settlements and buildings. Finally, the occasion of new national census should be taken as opportunity to gather risk-appropriate data (along with geographical one).

2. CONCLUSION

Despite significant efforts to adopt new seismic design norms, common structural practice in Montenegro is showing worrisome examples of neglecting basic seismic design principles: irregularities of mass and stiffness, weak and soft story existence etc. In spite seismic risk prevention guidelines that are part land use planning, soil conditions are often neglected in favour of market demand. Rapid urbanization is present - even on unsuitable terrains. There is no law or economy mechanisms established to strengthen existing buildings.

It is of utmost importance to re-affirm the seismic RR policy as national priority: by re-asserting the tasks of existing stakeholders, strengthening human and technical capacities, redefining legal framework and assigning overall seismic risk government to recognizable national authority.

REFERENCES

Glavatović B, Vučić Lj. 2014. *MEST EN 1998-1, Seizmički hazard u Crnoj Gori, Aneks A (normativ)*, Zavod za hidrometeorologiju i seizmologiju Crne Gore, Sektor za seizmologiju.

Janković S, Glavatović B. et al., 2019, *Baznastudija Elementarne nepogode i rizik od tehničkih incidenata za potrebe izrade Prostornog plana Crne Gore*, MORT.

Mihaljević J, Kaluderović N, Tomanović M. 2018. *Plavski zemljotres od 04.01.2018.* Proceedings of VI International Conference “Earthquake engineering and engineering seismology”, pp 127-136, SGIS, Belgrade.

Migliorini M, Gooijer L, Guha Sapid D, Hagen JS, Meliksetian K, Mihaljević J, Mysiak J, Rossi JL, Siegmund A, Siegmund Z, Thieken A. 2019. *The role of data interoperability in disaster risk reduction: barriers, challenges and regional initiatives.* Contributing Paper to GAR 2019.

Pavićević B. 2000. *Aseizmičko projektovanje i upravljanje seizmičkim rizikom.* Univerzitet Crne Gore i Građevinski fakultet. Podgorica.

SEISMICITY AND SEISMIC MONITORING OF MONTENEGRO

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ABSTRACT

The coastal area encompassing the towns of Ulcinj, Bar, Budva and the entire Boka Bay is the most seismically active area in Montenegro. Going inland, the whole regions of Skadar Lake, Maganik mountain ridge, Polimlje river basin etc. are recognized as seismic sources, as well. In addition, Montenegro is influenced by neighboring seismic active zones in Croatia, eastern Bosnia and Herzegovina, northern Albania and southeast of Serbia. There are many historical evidences of destructions caused by earthquakes on the southern Adriatic coast (XVI c and XVII c). In 1667 earthquake with magnitude 7.4, devastated epicentral area in near vicinity of Dubrovnik, causing huge damages in the whole southern Adriatic - from Boka Bay to Bar and Ulcinj. The most important contemporary event is the earthquake that happened on April 15, 1979 off coast between Bar and Ulcinj. With magnitude 7.0 on Richter scale, this is the strongest earthquake instrumentally recorded in Montenegro. Given the recent earthquakes in Montenegro (Plav, 2018), Albania (Durres, 2019) and in Bosnia and Herzegovina (Nevesinje, 2019), assuming that the seismic activity in the region is on the rise is correct. Tectonics and structural setting of Montenegro is formed by intensive over-thrusting: regional thrusts such as Durmitor, Zeta-Bjelopavlici thrust, as well as the Budva-Cukali zone over-thrusting system. The present paper reviews the results of several major research projects realized in the previous decade characterizing: i) general pattern of the fault plane solutions that are indicating dominant reverse mechanism along coastline, while moving towards inland there is a transition of reverse to active strike-slip to oblique strike-slip faults, ii) recent geodetic data processing as the results of monitoring of active crustal deformations, iii) Seismic Hazard Map of Montenegro issued as the National Annex to new seismic design standards compliant with European norms. Sector of Seismology, Institute of Hydrometeorology and Seismology (IHMS), is the legatee of Seismological Observatory of Montenegro in charge of the national seismic monitoring. In June 2020, Sector conducted the analysis of networks' instrumental capacities, data transmission, station location and ambient noise, data processing, and current maintenance costs. Development goals and objectives were defined, tied up

by its' sustainability analysis. Goals of proposed restructuring are: i) to upgrade capacities for continuous seismic monitoring in line with the modern standards, ii) improve analysis of seismogenic sources, further improve services towards public and authorities in providing reliable earthquake information, and contribute to prevention and mitigation of adverse earthquake effects.

SEISMICITY IN MONTENEGRO

The coastal area encompassing the towns of Ulcinj, Bar, Budva and the entire Boka Bay is the most active part of Montenegro (ME). Going inland, the whole regions of Skadar Lake, Maganik mountain ridge, Polimlje River basin etc. are recognized as seismic sources. The figure 1 depicts the seismic active zones in neighboring countries like Croatia, eastern Bosnia and Herzegovina, northern Albania and south-east of Serbia potentially affecting the relatively small area of Montenegro.

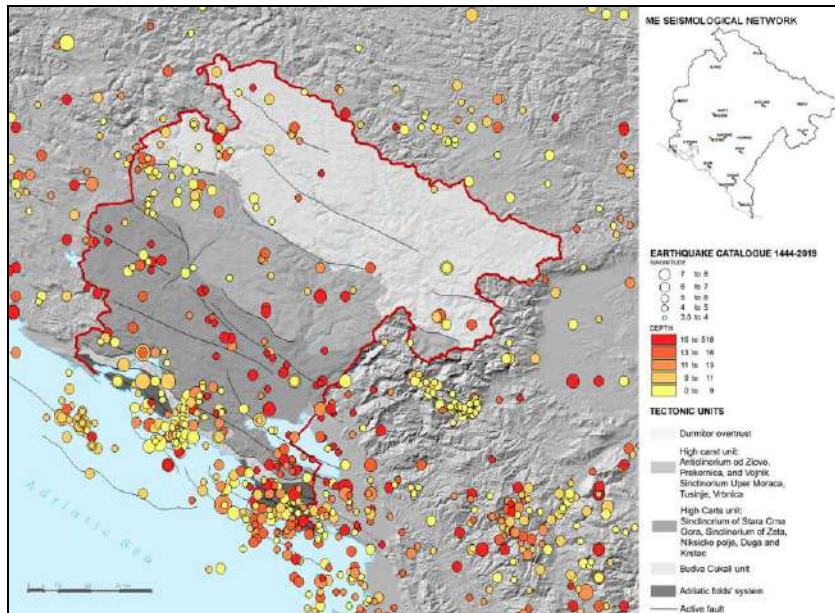


Fig. 1: Positions of tectonic units and major active faults versus national earthquake catalogue data ($M > 3.5$, 1444-2019).

There are historical evidences of destructions caused by earthquakes on the southern Adriatic coast (XVI c and XVII c). In 1667, earthquake with magnitude 7.4 devastated epicentral area in near vicinity of Dubrovnik, causing huge damages in whole southern Adriatic - from Boka Bay to Bar and

Ulcinj. In 1905, destructions in Podgorica caused by Shkoder earthquake were interpreted as the effects of VIII on MCS intensity scale.

The most important contemporary event was the earthquake that happened on April 15, 1979. This event caused disastrous consequences in Montenegro, affecting the area of app. 50.000 km² (including the neighboring Croatia and Albania). With magnitude 7.0 on Richter scale and epicentral intensity X, this is the strongest earthquake instrumentally recorded in Montenegro. Map of national historical and instrumental earthquake data (gathered in ME seismological network) is in the Fig.1 depicted.

On January 4, 2018, an earthquake of magnitude 5.1 struck the vicinity of Plav. Epicentral area belongs to the seismic source zone of Polimlje - characterized by complex seismotectonic settings that is generating strong earthquakes with long return period. In almost 40 years, this was the first earthquake in Montenegro that caused significant (enough) damages.

Given the recent earthquakes (Plav, 2018), Albania (Durres, 2019) and in Bosnia and Herzegovina (Nevesinje, 2019), assuming that the seismic activity in the region is on the rise would be correct.

ACTIVE TECTONICS AND GEOLOGICAL STRUCTURES

The geological structure of Balkans (and Montenegro) is strongly affected by the collision between Adria microplate and the southwestern Eurasia tectonic plate margin. Along the coast of Adriatic Sea and eastern coast of Ionian Sea, the collision between these two tectonic units has led to the build-up of Dinaro-Albanian-Hellenic folded structure. The Dinarides are a thrust and fold belt zone of elevated and deformed sediments stretching along NW-SE. The fold-thrust belt of the Dinarides is subdivided into two tectonic domains of external and internal Dinarides. The External Dinarides encompass the SW-verging thrust belt formed along the Eastern Adria margin and the NE dipping thrusts of the Central Adriatic (Mihaljevic *et al.*, 2017).

Tectonics and structural setting of Montenegro is formed by intensive over-thrusting: such regional thrusts are Durmitor, Zeta - Niksicko polje - Duga - Krstac, as well as the Budva - Cukali zone over-thrusting system. The deformation of these three thrusting systems was possible over the existing flysch zones located at the very base of these thrusts. By its' high plasticity and low resistance to rock movements, flysch layers enabled the intensive sliding of masses to southwest direction (Janković *et al.*, 2019). Along with the Adriatic folds system and submarine fault belt (Fig.1), these units are generating the major part of seismic activity.

As the direction of regional maximal horizontal stress is a good indicator of the dominant tectonic regime in a certain area, regional fault plane

solutions (FPS) database (BSHAP, 2012-2015) was employed for the geodynamic characteristics of the region.

The general pattern of the FPS indicates that the majority of the earthquakes observed along the coastlines of Croatia, Montenegro and Albania have reverse mechanism, correlated to the thrusting in the most part of the External Dinarides and Albanides (Fig. 2a). Majority of the FPS in Montenegro, contain elements of reverse faulting of NW–SE direction, having the low dip angle in the direction towards NE. In general, there is a good agreement between FPS, stated tectonic settings and mapped faults.

Present strike-slip faults are usually perpendicular to the reverse ones, and are characterized by relatively small dimension and steeply dipping fault plane.

In the regions bordering Albania and Bosnia and Herzegovina, and in the Skadar Lake, Lim River basin, Niksic and Pluzine regions, the FPS contain elements of normal faults of NW-SE or N-S direction (Mihaljevic *et al.*, 2017). Focal plane solution of the Plav earthquake 2018, shows that the dominant stress field has been extensional – coinciding with the assumption that active tectonic features of the region are represented by disjunctive and applicative forms (Fig. 2(a)) (Đokić *et al.*, 1968; Živaljević *et al.*, 1979).

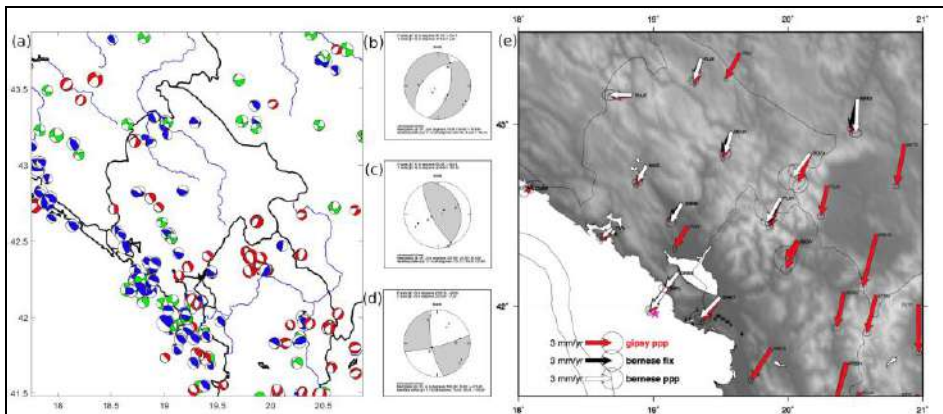


Fig. 2: (a) Integrated presentation of fault plane solutions in IHMS database. Color of beach-ball symbols denotes the FPS for different mechanisms: the blue, red and green symbols stand for the reverse, normal and strike-slip events, respectively. FPS for the mainshocks: Plav 2018 (b) on normal fault, Durrës 2019 (c) on thrust fault and Nevesinje 2019 (d) on strike-slip fault; (e) Insert from the comparison between the station velocities in the Apulia reference frame obtained using Bernese GNSS and Gipsy software (Kaludjerovic and Luzzi, 2018).

The recent studies on fault slip rates show that the most active portion in this region is the south-eastern part of the External Dinarides (offshore

Montenegro and Albania), where the highest average slip rate of 2 mm/yr was calculated (Kastelic and Carafa, 2012).

During the last decade, tectonic movements in region were analyzed on a processed series of continuous GPS measurements (2008-2019) made in 42 stations in the Balkan area, via Bernese GNSS Software and its precise point positioning and double-difference network solutions. In the framework of the ongoing bilateral project with INGV, IHMS has gained experience in GNSS data processing and analyzing. Obtained results are compared to the Gipsy software analysis (N. D'Agostino), showing good coincidence (Fig. 2e) (Kaludjerovic and Luzzi 2018). A velocity profile across the Adriatic shows small internal deformation in Montenegro suggesting that 3-4 mm/yr of convergence occurs mostly offshore. These results are included in a new velocity field and strain rate analyses of the SW Balkans. Clarifying the pattern of rotation and deformation in the SW Balkans (D'Agostino *et al.*, 2020), analysis is based on homogeneously processed continuous GPS measurements from permanent sites in Albania, Bulgaria, Greece, Kosovo and North Macedonia most of which were not included in the previous geodetic studies.

SEISMIC HAZARD MAP

The new seismic hazard map for Montenegro was elaborated after a decade of intense research and a number of scientific projects (BSHAP, SHARE etc.). Map is a part of national standard MEST EN 1998-1: 2015 (*Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings - National Annex*) (Fig. 3). PSHA analysis (Glavatović and Vučić, 2014) was conducted combining two methods in logic tree:

- In one branch, method of distributed seismicity was implemented. Distributed seismicity (Stirling, 2000) is term usually associated to seismicity that cannot be assigned to the particular geologic structure or unknown nature of geologic structures. It may refer to historical earthquakes whose location is not sufficiently precise, as well. As appropriate way to model distributed seismicity, spatially smoothed procedure (Frankel 1995; Lapajne 2003) was implemented.
- The other branch implemented individual modeling of linear seismic sources and EZ Frisk software application.

Seismic hazard calculations (Janković *et al.*, 2019) were based on five different attenuation laws (Glavatović 1998; Berge-Thierry 2003; Akkar and Bommer 2007; Boore and Atkinson 2008 and Cauzzi and Faccioli 2008).

Compared to PSHA conducted in BSHAP project, max hazard values (0.38g at Vladimir, Ulcinj) are approximately the same, while - towards the

inland, calculated PGA values are attenuating at slower rates. The smallest PGA value is 0.07g (Otilovići, Pljevlja).



Fig. 3: Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings - National Annex (Montenegro Seismic Hazard Map - Peak horizontal ground motion a_{gR} (g) on hard rock ($v_s > 800 \text{ m/s}$), Return Period 475 (10% probability exceedance in 50 years), Institute of Hydrometeorology and Seismology of Montenegro – Sector of Seismology.

SEISMIC MONITORING

Sector of Seismology, Institute of Hydrometeorology and Seismology, is the legatee of Seismological Observatory of Montenegro and in charge for the national seismic monitoring (ME seismological network is shown on Fig.1).

Seismic network of Montenegro (Fig. 1) consists of 3 BB seismometers (installed in last decade) and 10 SP one-component seismometers (installed in early 1980-es). From 2008, BB station Podgorica is part of Mediterranean Seismic Network. Steadily growing strong motion network (14 instruments) is still of insufficient coverage. Processing of geodetic data is performed on own

permanent GPS stations (2), stations of Montenegrin Real Estate Agency (9) - in accordance to renewed Memorandum of Understanding (2019) and a number of regional GNSS reference stations.

Monitoring and processing have been upgraded since June 2020 with the support of CTBTO organization in Austria. - are implemented in the SeisComp3 platform was employed for all the weak and strong motion data.

Geographical coverage of seismic stations is showing good performances for earthquake detections and reliable location. Inherited (from 1980s) locations of SP seismic stations are in the buildings or in the nearby shallow volts, owned by semi-state company *Radio Broadcasting Center*. Having high reliability of transmission, quite reliable power supply and safety against vandalisms, major disadvantage of these locations is the presence of man induced seismic noise. The sources of interferences are the vibrations of antenna masts due to wind load, vibrations due to installed equipment in the building /its' surroundings (cooling systems, engine generators of multiple mobile companies etc.), internal sensor noise induced by AC current frequency (power supply or transformer house). Additional problem are the infrastructures that are newly built in the vicinity of existing stations (wind turbines, tunnel).

In June 2020, Sector conducted the analysis of network proposing its' reconstruction. Goals of proposed restructuring are: to upgrade capacities for continuous seismic monitoring in accordance to modern standards, improve analysis of seismogenic sources, improve services towards public and authorities in providing reliable earthquake information, and contribute to prevention and mitigation of adverse earthquake effects. Stated goals and objectives are tied up by sustainability analysis –supported by human resources and maintenance costs analyses. Additionally, *Law on Seismic observations* is drafted - characterizing seismic infrastructure as the critical infrastructure. Human resources are insufficient and there is need to employ young specialists with knowledge of informatics and geophysics.

REFERENCES

Akkar S, Bommer J. 2007. Prediction of elastic displacement response spectra in Europe and the Middle East. *Earthquake Engineering and Structural Dynamics*, **36**: 1275 – 1301.

Berge-Thierry C, Cotton F, Scotti, O. 2003. New Empirical Response Spectral Attenuation Laws for Moderate European Earthquakes. *Journal of Earthquake Engineering*, **7 (2)** : 193-222. Imperial College Press.

Boore DM, Atkinson GM. 2008. Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA

at Spectral Periods between 0.01 s and 10.0 s. *Earthquake Spectra*, **24(1)**: 99-138.

Cauzzi C, Faccioli E. 2008. Broadband (0.05 to 20 s) prediction of displacement response spectra based on worldwide digital records. *Journal of Seismology*, **12(4)**, 453–475.

D'Agostino, N, Métois M, Koci R, Duni LI, Kuka N, Ganas A, Ivan Georgiev I, Jouanne F, Kaludjerovic N, Kandić R. 2020. Active crustal deformation and rotations in the southwestern Balkans from continuous GPS measurements. *Earth and Planetary Science Letters*, Volume **539**. <https://doi.org/10.1016/j.epsl.2020.116246>.

Đokić V, Živaljević M, Perović Z. 1968. *Geološki tumač Osnovne geološke karte - Gusinje*. Zavod za geološka istraživanja Crne Gore, Titograd.

Frankel A. 1995. Mapping Mapping Seismic Hazard in the Central and Eastern United States. *Seismological Research Letters*, **66 (4)**: 8-21.

Glavatović B. 1988. Simultana obrada grupe zemljotresa u južnim Dinaridima – doktorska disertacija. Katedra za geofiziku Rudarsko-geološkog fakulteta Univerziteta u Beogradu.

Glavatović B. 1998. Model seizmogeneze i seizmički hazard južnih Dinarida. Zbornik radova sa I Kongresa geofizičara Jugoslavije, Beograd, 19-20. novembar 1998.

Glavatović B, Vučić Lj. 2014. Determinisanje seizmičkih parametara u crnogorskom nacionalnom aneksu eurokoda MEST EN 1998-1: 2014 (seizmički hazard, spektri odgovora, klasifikacija tla). Institut za standardizaciju Crne Gore.

Janković S, Glavatović B. et al., 2019. Bazna studija Elementarne nepogode i rizik od tehničkih incidenata za potrebe izrade Prostornog plana CrneGore. MORT.

Kaludjerovic N, Luzzi L. 2018. Yearly Project Report. Development of knowledge-based tools for tsunami and seismic risk management. Bilateral Project Italy-Montenegro 2018-2020.

Kastelic V, Carafa MMC. 2012. Fault slip rates for the active External Dinarides thrust-and-fold belt. *Tectonics* **31 (3)**: TC3019. <https://doi.org/10.1029/2011TC003022>.

Lapajne J, Šket Motnikar B, Zupančič P. 2003. Probabilistic Seismic Hazard Assessment Methodology for Distributed Seismicity. *Bulletin of the Seismological Society of America*, **93(6)**:2502-2515. DOI:10.1785/0120020182.

MEST EN 1998-1: 2015. National Annex Part 1: General rules, seismic actions and rules for buildings of Eurocode 8 (NA). Institute for Standardization of Montenegro.

Mihaljević, J, Zupančič P, Kuka N, Kaluđerović N, Koči R, Markušić S, Šalić R, Dushi E, Begu E, Duni LI, Živčić M, Kovačević S, Ivančić I,

Kovačević V, Milutinović Z, Vakilinezhad M, Fiket T, Gülerce Z. 2017. BSHAP seismic source characterization models for the Western Balkan region. *Bulletin of Earthquake Engineering*, **15**: pp 3963–3985. <https://doi.org/10.1007/s10518-017-0143-5>.

Stirling MW. 2000. *A New Seismic Hazard Model for New Zealand*. In Proc of 12 WCEE, Wellington, New Zealand 2362.

Živaljević M, Vujisić P, Miroković M, Đokić V, Čepić M. 1979. *Geološki tumač Osnovne geološke karte - Ivangrad*. Zavod za geološka istraživanja Crne Gore, Titograd.

SURFACE EFFECTS AND ACTIVE GEOTECTONIC REGIME OF THE NOVEMBER 26, 2019, DURRËS EARTHQUAKE

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ABSTRACT

On November 26, 2019, a strong earthquake of M_w 6.4 occurred in central Albania. The epicenter is located about 7 km north of Durrës (epicentre EMSC: 41.38°N, 19.47°E; IGEWE source: 41.46°N, 19.44°E). The fault plane solutions show that the causative fault is reverse, striking NNW-SSE and delineates a low angle thrust. The aftershock sequence supports this trend, while the mainshock displacement has been modeled at *ca.* 1.6 m (

Fig. 1a). The most affected areas were Durrës city and Thumanë town, while damages were also reported in Laç and Fushë-Krujë areas, as well as in Kamëz and Tirana city.

In this paper the surface effects of the earthquake are presented and the geotectonic structure of Albania territory in Durrës broader area examined. Emphasis is given to the active or capable faults of the region, especially on the accretionary wedge which consists of Oligocene-Miocene sediments affected by the Durrës offshore thrust and its accompanying backthrusts. They are part of the compressional fold-and-thrust belt that was developed due to the Adria-Albanides collision, the activity of which is well documented by the seismic activity characterizing the area. The occurrence of a deeper structure is proposed, causing a tectonostratigraphic duplication, within which the last seismic event occurred. Widespread damage was observed in buildings throughout the meioseismic area. The most severe cases were the collapse of hotels and residential buildings in Durrës and Thumanë, which unfortunately led to human loss. Some of the damages were observed in the immediate vicinity of surface effects (mainly liquefaction), indicating a possible association with poor inherent or co-seismic ground conditions.

Keywords: Durrës detachment, seismotectonics, fold-and-thrust systems, liquefaction, lateral spreading

Surface effects

The present paper aims to briefly describe the surface effects of this earthquake and discuss their possible association with the active structures of the meioseismic and broader areas. Surface effects are mainly distributed in three areas of particularly poor geotechnical properties (

Fig. 1b):

1. Area 1: Durrës Beach.
2. Area 2: Rushkull area.
3. Area 3: FushëKuje area.

The following paragraphs summarize in brief the ground effects in each area.

Durrësi beach

The most severe damages around Durrës were observed in the area bordering the beach, SE of the city. Three hotels collapsed (Miramare Hotel, Vila Verde and Lubjana Hotel), and several more buildings were damaged beyond repair. At least one of the cases (Miramare Hotel), the collapse is associated with liquefaction, as is evident from the ejected sand. In this case, damages may be associated with poor geotechnical conditions, as the buildings are built on coastal sand deposits with a very shallow water table. The varied response to the earthquake (i.e. destroyed buildings next to intact ones) is an indication of differentiated build quality, which may also have played a significant role in the distribution of damages.

Rrushkull area

This is a flat area that is controlled by the interaction of the meandering river and the coast. Satellite images show a clear interplay between the river and the coast development. The flat morphology has led to the deposition of loose fine to medium grained alluvial sediments. In these sediments widespread liquefaction was observed, together with lateral spreading along the riverbanks.

This is the area where maximal displacements on the ground were modeled (

Fig. 1a) according to Papadopoulos *et al.*, (2020). Liquefaction was frequently observed along cracks, while in other cases the source of the liquefied sand was not possible to be identified. In any case, the sand was of the same properties, (i.e. grain size, color, etc.), which is consistent with previous geotechnical investigation which had indicated the presence of layers of the fine light gray sand throughout the broader area.

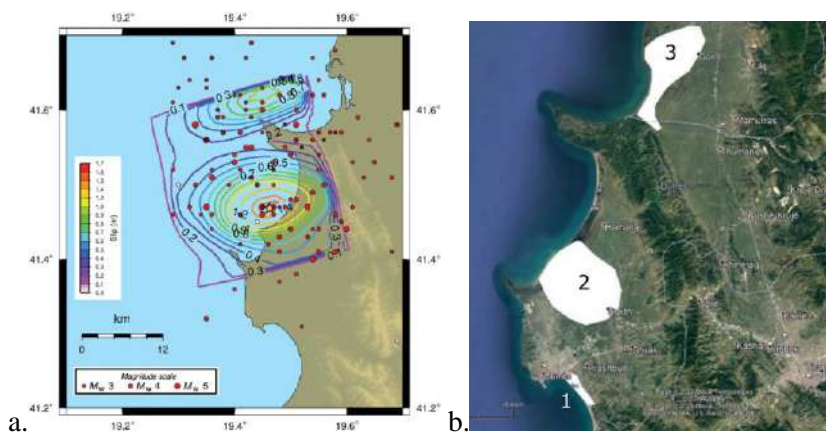


Fig. 1. a. Epicenter location and displacement model of the earthquake sequence (modified from Papadopoulos *et al.* (2020)). b. Generalized location map of the areas in which liquefaction was observed: 1. Durrësi beach, 2: Rrushkull area, 3: Fushë Kuqe area.

Of particular importance in this area are the lateral spreading effects that were observed along the riverbanks. The location of the main ones is shown in

Fig. 2a. They are mostly parallel to the riverbanks and are attributed to local failures due to the shaking during the earthquake. The most prominent of those crack sets is observed at the area close to the estuary (

Fig. 2b), where a complex set of cracks accompanied by liquefied ejecta has been formed (

Fig. 3a).

The cracks had a general trend parallel / subparallel to the riverbank (NE-SW), while the longest (northern branch) show a rather uniform displacement vector towards the NW. A small vertical displacement of up to 15 cm is also evident in some cases along the crack (

Fig. 3b). Similar, smaller-scale, cracks with ejecta were observed in other areas of the flatlands as well.



Fig. 2. a. Location of lateral spreading cracks (yellow lines) along the banks of the river south of Rushkull. Their location is marked with red circles. **b.** Detail of the mapped lateral spreading near the river estuary in area 2. Liquefaction was widespread along the southern branches of the fracture system.

Fushë Kuqe area

This area has many common geological-geotechnical characteristics with the Rushkull one. A shallow water table is developed in alluvial deposits, with the main difference being the existence of gravels that can be seen in a gravel pit next to the river north of Gurëz village. In this area, liquefaction was observed in the fields (e.g.

Fig. 3c), as well as around boreholes (

Fig. 4a). Solely in one particular case, liquefaction caused the ejection of not only sand, but gravel as well (

Fig. 4b).



Fig. 3. a. Part of the southern branches of the lateral spreading near the river estuary. b. Vertical displacement of up to 15 cm was evident in certain places along the crack. c. Detail of sand ejecta along a crack in the area.

Along the coast of Patok Lagoon some limited surface cracks and lateral spreading were also observed, but they are interpreted as secondary features due to poor geotechnical conditions with no direct association with primary earthquake effects. According to some reports from local fishermen, some liquefaction phenomena were also observed at the beach west of Adriatik village; however, these reports were not evidenced, due to very difficult approach to the location, as well as due to time constraints.

The spatial distribution of historical liquefaction occurrences in south Balkans, including Albania, is included in the DALO database, where the empirical relationships between Magnitude (M_s) and maximum epicentral distance (R_e) are also presented (Papathanassiou *et al.*, 2005; Papathanassiou and Pavlides, 2011). The 2019 earthquake liquefied areas are included.

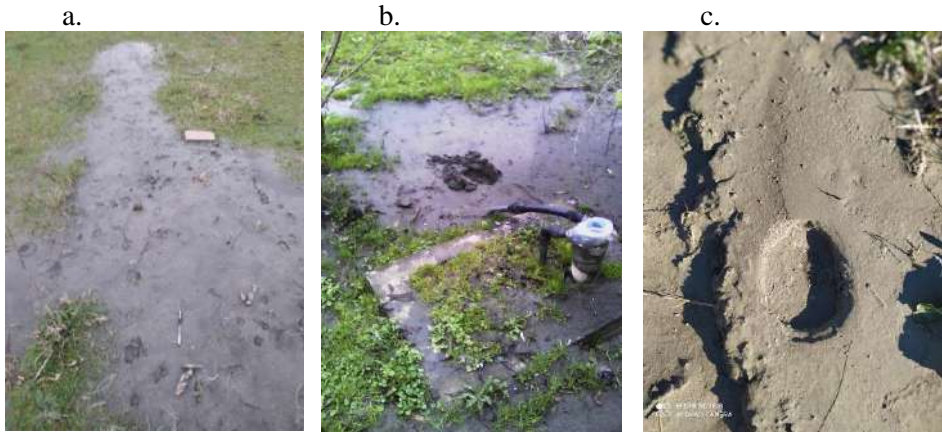


Fig. 4. a. Liquefied sand in Gurëz area. b. According to reports, liquefaction at this site started with gravels that were ejected first, followed by sand. The sampling site is also visible. c. Typical occurrence of a sand boil.

Active geotectonic regime

The region is characterized by compressional tectonics, as it represents the outermost continental thrust belt of the Albanides. The main indication of compression in the area, apart from focal mechanisms, is an array of NW-SE-trending parallel fold axes perpendicular to the inferred active maximum stress axis (σ_1),

Fig. 5a). Crustal deformation is characterized by NNE-SSW to E-W oriented contraction (

Fig. 5b). Thrusting, which also contributes to the area shortening, is represented by typical thrust faults, mostly blind, that occupy the core of the mapped anticlines. Given also that the November 2019 hypocenter was relatively deep, the tectonic structure of the area is consistent with the observed ground effects that are, in their entirety, secondary ones. Primary effects (i.e. fault ruptures) were not observed in the affected area.

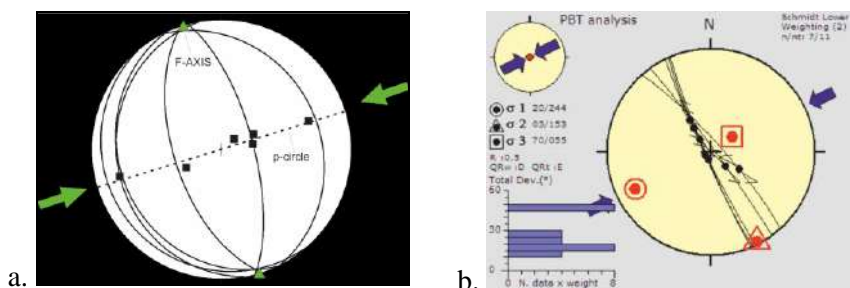


Fig. 5. a. The inferred compressional stress direction in the study areas, using the bedding planes as indicators of folding. b. Kinematic analysis of fault data collected in the broader area. The stress direction, as derived from the calculated σ_1 axis, coincides with the active one in the area, hence the reverse faults associated with the folding are characterized as possibly active. Both diagrams are a result of data collected in the field.

Seismotectonics

The Southern Balkans are characterized by intense seismic activity due to the rapidly deforming broader Eastern Mediterranean area and its complex neotectonic structure. Although the Albanian region has a long record of historical seismicity, available knowledge about co-seismic surface ruptures in the region is limited. The Greek Database of Seismogenic Sources – GreDaSS (Caputo *et al.*, 2012; Sboras *et al.*, 2009) geographically covers the broader Aegean Region including Greece and its neighboring countries, such as Albania. From a long list of published papers and catalogues describing ground co-seismic deformation cases, only few pre-instrumental earthquakes can be directly correlated to a particular fault and even fewer ones contain reliable information about the surface rupture length, the maximum displacement, and the average displacement (Wells and Coppersmith, 1994; Pavlides and Caputo, 2004;). A fundamental problem in all statistical analyses and empirical relationships is the accuracy of the primary data. Fault-associated ground deformation is usually investigated and described by different authors who are not necessarily scientists, especially for old historical events.

Located in a region of high seismic activity, Albania is placed among the most frequently struck countries by damaging earthquakes, along with Turkey, Greece, and Italy (Mihailović, 1951; Sulstarova and Kociu, 1975; Kárník, 1979; Koçiaj and Sulstarova, 1980; Sulstarova, 1986; Papazachos and Papazachou, 2003; Ambraseys, 2009). During the last fifty years alone, Albania was struck many times by destructive earthquakes: 16 events of $M=5.5$ ($I_0=VII$), 3 events of $M=6.0-6.5$ ($I_0=VIII$), and 2 events of $M=6.5-7.0$ ($I_0=IX$). The strongest events occurred on April 15, 1979 ($M=6.8$) in the broader Montenegro-Shkodra area, on June 1, 1905 ($M=6.6$, $I_0=IX$), on

November 30, 1967 ($M=6.6$, $I_0=IX$) in Diber (Sulstarova and Koçiaj, 1980), and on January 9, 1988 ($M=5.4$, $I_0=VII$) in Tirana (Koçiaj and Pitarka, 1989). Strong and destructive historical earthquakes among others are the Butrint AD 368 (Pavlidis *et al.*, 2001), the 1267 and especially the July 14th Durrës earthquakes (Aliaj *et al.*, 2010; Ambraseys, 2009), as well the AD 522 devastating earthquake of Durrës, following the AD 518 extremely destructive Skopje earthquake (Ambraseys, 2009).

Active faults

The active faults of Albania can be classified into three very broad groups, based on their geodynamic characteristics and seismic potential (

Fig. 6a):

1. Eastern Albania mainland faults: these faults are predominantly normal dip-slip to oblique-slip, with length typically ranging from a few to a couple of tens of km. They generate shallow earthquakes with hypocentral depths of no more than 10-15 km (seismogenic layer thickness)
2. Western Albania mainland faults: they consist of mainly reverse faults (thrusts, overthrusts and back-thrusts) and strike slip faults as well.
3. Albanian coastal and offshore faults: according to focal mechanisms, as well as seismic profiles that have been performed along the coastal area, these faults can be of any kind. Depending on kinematics, their length varies from a few to several tens of km.

The active fault zones of Albania have been enumerated and their individual characteristics have been identified (

Fig. 6b). Based on their approximate quantitative characteristics, a number of properties associated with SHA were estimated, including their earthquake potential, maximum expected displacement, slip rate, recurrence interval, etc.

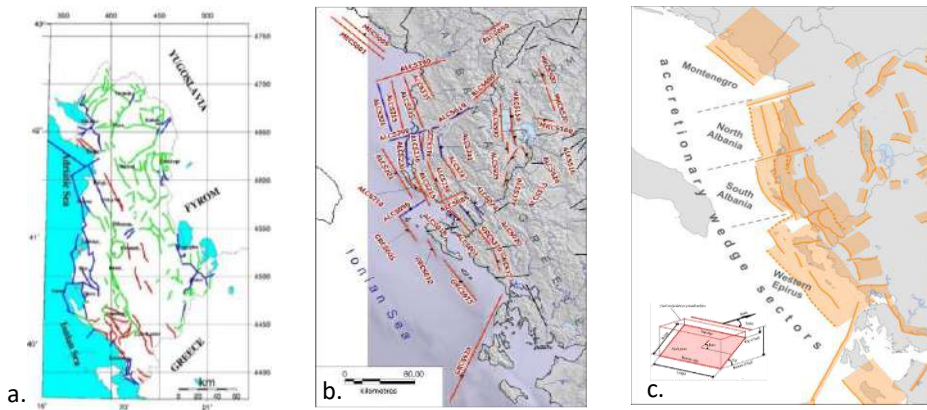


Fig. 6. a. Simplified neotectonic map of Albania (Aliaj et al., 2004). b. Schematic map of the main active fault zones of Albania and the surrounding areas (TAP pipeline design study) c. Schematic projections of the main active fault zones (seismogenic sources) in Albania (modified from GreDaSS, gredass.unife.it). The orogenic thrust system of the accretionary wedge is divided into four sectors. Inset shows the way that the quantitative properties of the fault zones are extrapolated.

The accretionary wedge of Albania

The accretionary wedge represents the most external sector of the Albanian orogene and is formed from sediments that are accreted onto the obducting tectonic plate along the plate boundary. The western sector of the Albanian territory and its nearby offshore area are characterized by a convergent regime, where Adria-Albanides continental plates collision takes place. The occurrence of major faults is well constrained due to the seismic reflection profiles performed for hydrocarbon explorations, while their recent seismogenic activity is documented both historically and instrumentally. The Albanian accretionary wedge is in continuity with the southern one of the Hellenides and the northern one of the Dinarides. It is displaced by major transfer zones which play a crucial role in fault zone segmentation, by reducing the length of thrust systems. Four principal sectors along the accretionary wedge have been recognized separated by such transfer zones; from North to South, these are: Montenegro, North Albania, South Albania and Western Epirus, Greece(

Fig. 6c).

The active Durrës detachment system

Durrës Detachment represents the frontal tectonic structure of the central sector of the Albanides accretionary wedge (Fig.7). It separates the orogenic belt developed in the hanging wall block from the underthrusting units of the Adria plate and is associated with the Albanian Foredeep. This basal detachment is typically low angle, and it is possibly mechanically connected with several thrusts and backthrusts affecting the coastal sector of Albania, like the Durrës Offshore Thrust and the Durrës Backthrust. In instrumental times, seismicity is relatively low in magnitude and diffused, thus not permitting to recognize with enough confidence the causative faults. All regional focal mechanisms though, show almost pure reverse faulting. However, some focal mechanisms obtained from moderate magnitude earthquakes ($5 < M < 6$; Albanian territory), document seismogenic depths of 15-18 km, therefore suggesting the occurrence of a deeper major low-angle east-dipping shear zone (Louvari *et al.*, 2001).

Seismic profiles crossing this offshore area do not have enough details to constrain the geometry of the fault. The problem is on the fact that in the shallowest sector (thin-skin tectonics), Durrës Detachment runs parallel to layering and probably along the stratigraphic-mechanical discontinuity separating the Albanian Foredeep deposits from the carbonate platform units of the underthrusting Adria plate. The overall dimensions of this tectonic structure are certainly important; however, considering all uncertainties and the lack of a clear signature in seismic profiles (at least at shallow depths), Durrës Detachment is probably highly segmented. In any case, the uppermost tip of the fault does not reach the sea bottom (i.e. minimum depth of some kms). A further argument for suggesting the occurrence of Durrës Detachment offshore the Albania coast, is the comparison with both the northern and southern sectors of the Albanian accretionary wedge. Indeed, north of the Shkodra Transfer Fault the basal detachment is clearly active (Montenegro Detachment), while south of the so-called Fieri-Elbasan-Dibra shear zone the Karaburun-Sazan Island Detachment has a clear evidence of recent activity. Focal mechanisms in the broader Durrës area are documenting horizontal E-W-trending P-axes (i.e. compression).

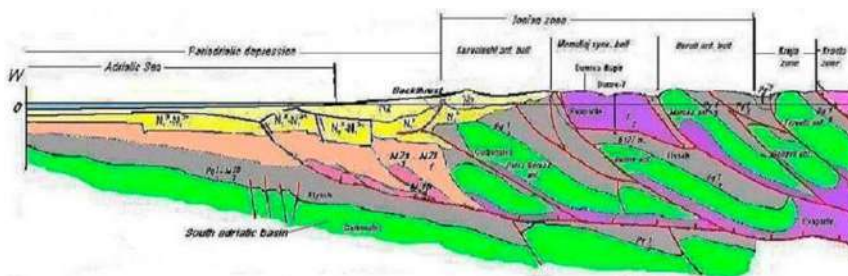


Fig.7. Interpreted seismic profile across the external Albanides (Velaj, 2011).

According to the interpretation of seismic profile by (Velaj, 2011), the most external fault of the accretionary wedge is the Durrës Offshore Thrust. It is characterized by a ramp-flat geometry, generally east-dipping and associated with some secondary structures synthetic splay faults developed in its hanging wall block. The fault does not seem to affect the whole Neogene sedimentary succession. It represents a major structure; however, it is clearly blind (i.e. maximum depth of some km) and any seismogenic reactivation will not directly cut the sea floor. The ramp-flat geometry and the occurrence of several secondary structures likely induce a segmented behavior of this composite seismogenic source. In map view it strikes 300-350° and dip angle 20 to 25°.

Durrës Backthrust is also part of the overall system and is clearly detected in several regional seismic and geological profiles (Velaj, 2011). The fault is also particularly evident in other interpreted profiles (Aliaj, 2006; Skrami, 2001). Based on the interpretation of the seismic profile in (Skrami, 2001), the unconformity between the Quaternary deposits and the Pliocene molassic sediments is formed due to the recent and ongoing activity of the backthrust (Durrës Backthrust- ALCS325 in

Fig. 6b). Thrust faults belonging to this system and associated with the November 26, 2019 epicenter are about 75 km long with slip rates of ~1 mm/yr (Stein and Sevilgen, 2020). It is similar to the Vlore backthrust (ALCS5220 in

Fig. 6b), which has been interpreted as an active backthrust, associated to the low-angle frontal thrust of the Albanides over the Apulian platform. Various seismic profiles of the broader area however, as well as the local stress field, suggest that this is a W-dipping reverse active structure.

Geodynamic model of the area–Conclusions

Based on published seismic interpretations, local geology, and comparative assessment of similar structures in NW Greece, we suggest that the geodynamic model of the area is controlled by a stacking of several (at least two) repetitions of carbonates, which have been accumulated during the Adria obduction (Fig. 8). As a basal weakness zone, it is suggested that it could be consisted of evaporites, which are very often acting as a mechanically weak zone that facilitates large-scale horizontal displacements. In this case, a shortening of at least 70% must be assumed, which is consistent with similar observations in the southern part of this fold and thrust belt (i.e. Epirus, Greece).

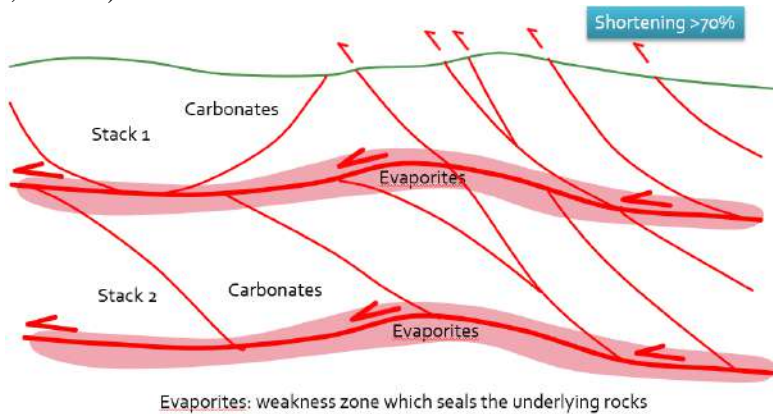


Fig. 8. Indicative sketch of a thin-skinned geodynamic model, that could explain the large hypocentral depth of the November 29, 2019 earthquake.

The 2019 earthquake was a deep-seated event that was likely produced by the reactivation of the backthrust of the basal thrust in the fold-and-thrust belt. It is a blind structure, as suggested by onshore and offshore seismic sections, as well as by field observations. This deep epicentral rupture mitigated the surface effects, causing mainly liquefaction and in certain cases secondary ruptures due to lateral spreading. The pattern of the surface effect distribution however, is consistent with the assumed strike of the causative fault, despite them being rather scattered. The proposed geodynamic model is compatible with both the seismotectonic and the geological data. The properties of this earthquake are also in accordance with the inferred deep structures and the active stress field, as is shown by structural analysis on surface structures, showing thus that there is no differentiation in the stress direction in deeper parts of the crust. Finally, the comparison of the current event structural setting with similar structures along the western Albanian –

NW Greece fold-and-thrust belt shows that the role of backthrusts may be underrated in terms of seismic potential and current activity.

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REFERENCES

Aliaj Sh. 2006. The Albanian orogen: convergence zone between Eurasia and the Adria microplate, in: Pinter, N., Gyula, G., Weber, J., Stein, S., Medak, D. (Eds.), *The Adria Microplate: GPS Geodesy, Tectonics and Hazards SE - 09*, Nato Science Series: IV: Earth and Environmental Sciences. Springer Netherlands, pp. 133–149. https://doi.org/10.1007/1-4020-4235-3_09

Aliaj Sh, Adams J, Halchuk S, Sulstarova E, Peci V, Muco B. 2004. Probabilistic seismic hazard maps for Albania, in: *13th World Conference on Earthquake Engineering*. Vancouver, B.C., Canada, p. 2469. <https://doi.org/10.4095/226354>.

Aliaj S, Kociu S, Muço B, Sulstarova E. 2010. Seismicity, seismotectonics and seismic hazard assessment in Albania. Academy of Sciences of Albania, Tirana.

Ambraseys N. 2009. *Earthquakes in the Mediterranean and Middle East*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9781139195430>.

Caputo R, Chatzipetros A, Pavlides S, Sboras S. 2012. The Greek database of seismogenic sources (GreDaSS): state-of-the-art for northern Greece. *Annals of Geophysics* 55, 859–894. <https://doi.org/10.4401/ag-5168>.

Kárník V. 1979. Large European earthquakes of the 20th century. *Tectonophysics* 53, 159–169. [https://doi.org/10.1016/0040-1951\(79\)90060-X](https://doi.org/10.1016/0040-1951(79)90060-X).

Koçiaj S, Pitarka A. 1989. The earthquake catalogue for earthquakes with $M > 4.0$ for the period 1971–1985 for Albania. Seismological Center, Tirana.

Koćiaj S, Sulstarova E. 1980. The earthquake of June 1, 1905, Shkodra, Albania; Intensity distribution and macroseismic epicentre. *Test. Tectonophysics* **67**: 319–332. [https://doi.org/10.1016/0040-1951\(80\)90272-3](https://doi.org/10.1016/0040-1951(80)90272-3).

Louvari, E, Kiratzi, A, Papazachos B, Hatzidimitriou P. 2001. Fault-plane solutions determined by waveform modeling confirm tectonic collision in the Eastern Adriatic. *Pure and Applied Geophysics* **158**: 1613–1637. <https://doi.org/10.1007/PL00001236>.

Mihailović DJ. 1951. Catalogue des tremblements de terreEpiro-Albanais, Archive Seismologique. Zagreb, Yugoslavia.

Papadopoulos GA, Agalos A, Carydis P, Lekkas E, Mavroulis S, Triantafyllou I. 2020. The 26 November 2019 Mw 6.4 Albania destructive earthquake. *Seismological Research Letters*, **91**: 3129–3138. <https://doi.org/10.1785/0220200207>.

Papathanassiou G, Pavlides S, Christaras B, Pitilakis K. 2005. Liquefaction case histories and empirical relations of earthquake magnitude versus distance from the broader Aegean region. *Journal of Geodynamics*, **40**: 257–278. <https://doi.org/10.1016/j.jog.2005.07.007>.

Papathanassiou G, Pavlides S. 2011. GIS-based database of historical liquefaction occurrences in the broader Aegean region, DALO v1.0. *Quaternary International*, **242**: 115–125. <https://doi.org/10.1016/j.quaint.2011.03.049>.

Papazachos BC., Papazachou, K. 2003. The earthquakes of Greece [in Greek], Second edi. ed. Ziti Editions, Thessaloniki.

Pavlides S, Caputo, R. 2004. Magnitude versus faults' surface parameters: quantitative relationships from the Aegean Region. *Tectonophysics* **380**, 159–188. <https://doi.org/10.1016/j.tecto.2003.09.019>.

Pavlides S, Kociu S, Mukelli P, Hyseni A, Zouros N. 2001. Archaeological evidence for seismic activity in Butrinti (SW Albania) and neotectonics of the area. *Bulletin of the Geological Society of Greece* **34**: 311. <https://doi.org/10.12681/bgsg.17028>.

Sboras S, Caputo R, Pavlides S, Chatzipetros A, Papathanasiou G, Valkaniotis S. 2009. The Greek Database of Seismogenic Sources: state-of-the-art on the northern Greece pilot area, in: EGU General Assembly Conference Abstracts. p. 485.

Skrami J. 2001. Structural and neotectonic features of the Periadriatic depression (Albania) detected by seismic interpretation. *Bulletin of the Geological Society of Greece* **34**: 1601–1609.

Stein R, Sevilgen V. 2020. Albania earthquake strikes highest-hazard zone in the Balkans, devastating nearby towns [WWW Document]. Temblor. <https://doi.org/10.32858/temblor.057>.

Sulstarova E. 1986. The focal mechanism of Albanian earthquakes and the field of actual tectonic stress in Albania. Seismological Center, Tirana.

Sulstarova E, Koçiaj S. 1980. The Dibra (Albania) earthquake of November 30, 1967. *Tectonophysics* **67**: 333–343. [https://doi.org/10.1016/0040-1951\(80\)90273-5](https://doi.org/10.1016/0040-1951(80)90273-5).

Sulstarova E, Kociu S. 1975. The catalogue of Albanian earthquakes.

Velaj T. 2011. Tectonic style in Western Albania thrustbelt and its implication on hydrocarbon exploration. *AAPG Search and Discovery*, 10371.

Wells DL, Coppersmith KJ. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. *Bulletin of the Seismological Society of America* **84**: 974–1002.

MACROSEISMIC FIELD ANISOTROPY OF THE $M_L6.3$ ($M_W6.4$) EARTHQUAKE OF 26 NOVEMBER 2019 IN DURRES, ALBANIA

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ABSTRACT

November 26, 2019, $M_L=6.3$ ($M_W=6.4$) Durres earthquake, Western Albania, was widely felt throughout Albania and in Montenegro, Kosovo, North Macedonia, Greece, Italy, Bosnia and Herzegovina, Croatia, Serbia, and Bulgaria. The present paper shows the intensity isoseismal map for the Durres main shock earthquake. In addition, attenuation function of intensity in respect to recorded peak ground acceleration (PGA) values is derived. Macro seismic investigations about the damages impaired to the constructions and the surface effects of the ground shaking were carried out based on the online web surveys by the Institute of Geosciences, Energy, Water and Environment (IGEWE), Albania, and European-Mediterranean Seismological Centre (EMSC). When assessing epicentral intensity to VIII-IX degrees an EMS scale - states of general panic, large heavy damages in Durres - Tirana-Laci area, as well as the liquefaction phenomena observed in the Durresi beach, Jub-Sukth, Rrushkull and Fushe-Kuqe areas, were considered. Statistical analysis was applied to all collected macro seismic data. Intensity map is created using averaged macro seismic data for each town or village. It identifies two main areas of amplification and de-amplification of earthquake intensity. Significant foci depth (39 km) of this earthquake represents a point of interest for the assessment of Intensity attenuation function. To analyse relationship between observed macro seismic intensities and peak ground motion, available PGA values of manually processed strong motion waveforms are collected and implemented in regression analysis.

Keywords: macro seismic data, intensity, PGA, attenuation.

1. INTRODUCTION

On November 26, 2019 Albania was struck by the Durresi earthquake of magnitude $M_L6.3$. Earthquake was felt all over Western Balkan.

Durres earthquake caused vast damages in the Durresi, Kruja, Tirana, Laci, Lezha etc. regions. The questionnaires “*Did You Feel Earthquake?*” (IGWE and EMSC) were used to collect macroseismic data from a wider area of neighbouring countries - Montenegro, Kosovo, North Macedonia, Greece, Italy, Bosnia and Herzegovina, Croatia, Serbia, and Bulgaria. Based on the field observations and questionnaires’ responses, the Durresi main shock intensity was defined by the IGWE in line with the EMS-98 scale.

The intensity attenuation can be determined from a distribution of intensity values and from isoseismal shapes (Sulstarova 1983; Muco 1992; Bozo *et al.*, 2018). In this paper we described decay of intensity with distance for the Durres main shock earthquake by its Intensity Isoseismal Map and derived attenuation relationships, as well.

Available peak ground acceleration (PGA) values of manually processed strong motion waveforms were collected and implemented in regression analysis to study the empirical relationship between observed macroseismic intensities and recorded peak ground motion.

Assessment of macroseismic intensity is an important task covering a wide range of engineering and seismological applications (Sulstarova *et al.*, 1983; Muco *et al.*, 1992; Aliaj *et al.*, 2010; Bozo *et al.*, 2017).

Earthquake

The main shock of Durresi earthquake ($M_L 6.3$ and $M_w 6.4$) occurred in the Adriatic Sea, about 16 km north of the Durres city, and 35 km NW from Tirana, the capital city (north-western Albania).

Within 6 hours preceding this quake, four shocks rattled the epicentral region - the largest one with $M_L 4.4$. The main shock (with epicentral coordinates of 41.46°N and 19.44°E , and the hypocentral depth $h = 39$ km) happened at 02:54:11 UTC. Earthquake parameters are inferred from Albanian Seismologic Network Monthly Seismological Bulletin (ISNN) (Ormeni *et al.*, 2019). A large number of aftershocks followed – majority of these occurring to the north and east of the epicentre, with depths ranging from 2 to 50 km. Based on the neotectonic mapping and the focal mechanism of the mainshock (strike 143° , dip 70° , rake 82°) it is considered that seismotectonic source which generated this earthquake is related to the NW-SE longitudinal tectonic structures in the Adriatic Sea. The main shock has caused occurrence of soil cracks and fractures, liquefaction phenomena, outflows of pressured water in saturated sands and clays. As estimated, terrain in the epicentral area was elevated for 10 cm, what has been accompanied by a coastline retreat (Hamallaj beach).

Data collection

Macro seismic data were collected through questionnaires available at the website www.geo.edu.al of IGEWE and www.emsc-csem.org of EMSC. A vast number of questionnaires came from Albania and the larger area of Western Balkan, as well. From internet we gathered 1575 macro seismic questionnaires. For the reliable estimation of macro seismic intensity - we solely relied on data coming from (community) locations where at least 3 questionnaires were collected.

In addition, Albanian General Directorate of Civil Emergencies collected information from 107 municipalities which we used to check out and update data collected from internet.

In accordance to EMS-98 scale, field observations and questionnaires' responses were classified into three groups detailing the intensity related information on behaviour of: i) living things, ii) objects and natural environment, and iii) buildings.

Available peak ground acceleration (PGA) values (from the manually processed strong motion waveforms) implemented in this study are collected from several institutes. The majority of PGA values (61) were processed by and collected from the Engineering Strong Motion Data Base (ESM) (Luzi *et al.*, 2020), held by the Istituto Nazionale di Geofisica and Vulcanologia (INGV), Italy. The ESM data that we used, includes Durrresi main shock SM data recorded by seismic networks operated in Italy (Italian National Seismic Network - IV, Irpinia Seismic Network – IX and OTRIONS network – OT), Greece (ITSAK Strong Motion Network - HI, Hellenic Seismological Network, University of Athens, Seismological Laboratory - HA, National Observatory of Athens Seismic Network - HL and University of Patras, Seismological Laboratory network - HP), Bulgaria (National Seismic Network of Bulgaria - BS), Romania (Romanian Seismic Network - RO) and Montenegro (Montenegrin Seismic Network - ME), as well as regional Mediterranean Very Broadband Seismographic Network -MN network. In addition, processed PGA values from SM networks of Albania (Seismological Network of Albania - AC, IGEWE, 4), Montenegro (additional 5 ME SM stations not in ESM data base) and North Macedonia (Institute of Earthquake Engineering and Engineering Seismology - IEES, 13) were collected.

Isoseismal map and attenuation of intensity

The macro seismic intensity represents a classification of the magnitude of ground motion based on observed phenomena in a defined area, e.g. a town (De Rubeis *et al.*, 2016). Therefore, regional macro seismic anomalies could be linked to the efficiency of wave propagation inside the crust-upper mantle system (Sbarra *et al.*, 1998).

The estimation of earthquake intensity applied here is operationalized using the standardized EMS-98 scale (Grünthal 1998). Statistical analysis was applied on collected macroseismic intensity data. The average intensities I_m (where I_m represents the averaged intensities of municipality within width intervals of 4 km epicentral distance), are plotted on Fig. 1. Results are indicating that the earthquake was felt far away from Durres: up to distances of 450 and 400 kilometres – in the directions of southeast and northwest, respectively. Fact that the main shock was generated at a depth of 39km influenced the larger size of felt area, while lowering the damaging effects in the epicentral area. The epicentral intensity is assessed to VIII-IX degrees on EMS-98 scale in an area of app. 250 km² (Ormeni *et al.*, 2019).

Abundance of web-based surveys gave a possibility to detect anomalies in the attenuation of earthquake effects. Two main areas of amplification and de-amplification of earthquake intensity were identified. Field of macroseismic intensity is showing high eastward attenuation as opposed to the low attenuations in the north-south direction relative to Durres. Indicated macroseismic field anomaly is in consent with the fault mechanism solution, the directivity of strike angle, as well as to known crust properties.

The attenuation of Intensity versus hypocentral (R) and epicentral distance (D) were then correlated ($R^2 = 0.9453$ and $R^2=0.968$, respectively) in the models (Eq. 1a and 1b, Fig. 2a and 2b, respectively). For this purpose, we utilized the dataset of 119 points of averaged intensities (I_m) with epicentral distances ranging from 7 to 434 km from the epicentre. Hypocentral distances were calculated using earthquake parameters:

$$I = -2.369 \ln R + 16.905, \quad (1a)$$

$$I = -1.495 \ln D + 12.448, \quad (1b)$$

where, $7 \leq D \leq 434$ and foci depth $h=39$ km (ISSN, Ormeni *et al.*, 2019).



Fig. 1: Municipality and the regional macroseismic field: red star symbol marks the earthquake epicentre; colour scheme of municipal macroseismic intensity (I_m) symbols and isoseismal lines separates the intensity degrees - as indicated in the legend; blue triangle symbols are indicating positions of SM stations in the area of $I > 5$.

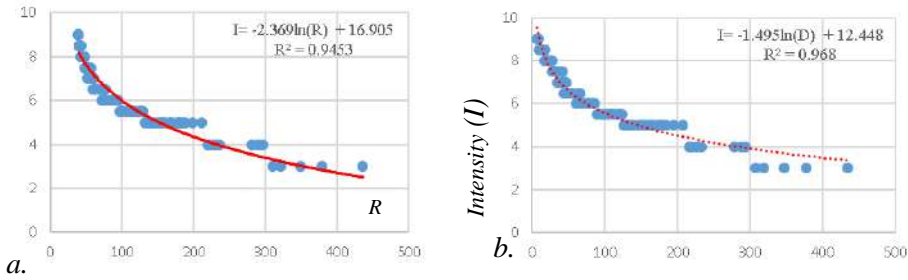


Fig. 2: Decay of Intensity with hypocentral (a) and epicentral distance (b); models are developed on the dataset of 119 points.

Attenuation of intensity in respect to PGA values

The association between macro seismic data observed within an area and local measurements of the ground shaking need a careful check in order to guarantee the similarity in terms of site response (Gomez-Capera *et al.*, 2020). The most reliable procedure would be to correlate recorded PGA values matching to intensity assessed on the location of SM station — a rarely feasible procedure. Even assuming that geology and topography on a particular SM station location is representative for municipality's averaged macroseismic intensity I_m - in our case it was impossible to identify statistically valid number of such geographically close / matching pairs (PGA, I_m) (Fig.1).

Therefore, to capture the general attenuation of intensity in respect to PGA, we correlated recorded PGAs (cm/s^2) values to corresponding intensity inferred from the Intensity isoseismal map (I_i) (Fig.1).

Distance range of collected SM data varies from 33 km (Tirana) to 443 km (Kavala, Greece). Also, there is a significant lack of data describing peak ground motion in the range of the most significant intensities (VII-IX). The nearest SM station that recorded main shock is located in Tirana with Intensity I_i =VII.

Total 75 pairs of PGA and corresponding inferred Intensity values (\log PGA, I_i) were correlated ($R^2 = 0.727$) in attenuation relationship given by the following Eq. 2.

$$I = 1.816 \log \text{PGA} + 3.373 \quad (I < \text{VII}), \quad (2)$$

Slope of linear regression (Eq. 2) is affected by the ratio of farther to closer PGA data (or ultimately luck of the later ones). Fitted attenuation model is failing to predict (reasonable) PGA values in the epicentral area (e.g. for intensities VIII to IX).

Empirical relationships between macroseismic intensity and instrumental ground motion parameters - derived from different data sets (and from multiple earthquakes) and using very different approaches, are showing notable differences. We compared collected data and relationship derived in this study to some of known worldwide empirical models (Wald *et al.*, 1999; Caprio *et al.*, 2015) and regional models developed for the Italy and Greece (Papazachos and Theodulidis 1992; Koliopoulos *et al.*, 1998; Tselentis and Danciu 2008; Fienza and Michelini 2015; Gomez Capera *et al.*, 2018) as depicted in the Figure 3.

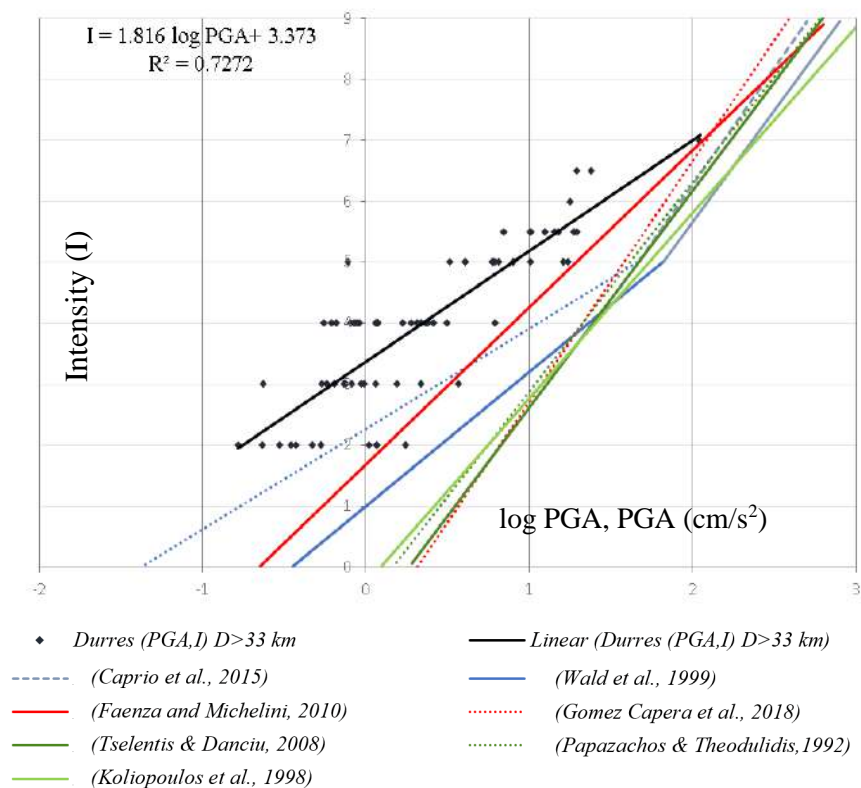


Fig. 3: Collected data and macroseismic intensity vs. PGA model (Eq. 2) (black line) is compared to the regional and worldwide empirical models. Line colours show the empirical model: blue for the world-wide models - Wald *et al.*, 1999 (solid line), Caprio *et al.*, 2015 (dotted line); red for Italian models - Faenza and Michelini, 2010 (solid line), Gomez Capera *et al.*, 2010 (dotted line), and green for Greek models - Tselentis and Danciu, 2008 (solid line), Papazachos and Theodulidis 1992 (dotted line) and Koliopoulos *et al.*, 1998 (light solid line), respectively.

According to Eq. 2 and Fig. 2, the highest PGA recorded at the SM station in Tirana is well correlated to observed intensity VII (and to the other empirical models, as well). In the range of intensities $I \leq 5$, slope of our model is comparable to Caprio *et al.*, 2015 and Wald *et al.*, 1999 (both bi-linear log PGA- I models). This study model has lower slope than majority of single-branch linear empirical models. As already stated, later may be caused by the lack of SM data for higher intensities. We may assume that foci depth of 39 km might have affected this trend, as well.

Due to method which the present study applied, scatter of collected data - caused by geographical, geological and topological conditions, data processing etc., is highly expected. However, it is noticeable that this singular event's data are consistently having positive error in respect to median of presented regional and worldwide relationships. This may be an important observation, worth to take note of and further investigate if it represents specific regional feature.

2. CONCLUSIONS

The citizen-based science of the “*Did you feel an earthquake?*” portals proved to be an unmatched opportunity for interaction between the IGEWE's scientists and the community of Albanian citizens. Implemented statistical analysis of data gathered from Internet has been extended to identifications of macroseismic field anomalies.

Attenuation of intensity in respect to PGA values derived in this study is representative solely for $I \leq VII$. Data set (of recorded PGA and intensities inferred from Intensity isoseismal map of Durres main shock earthquake) used in this study, are consistently showing positive error in respect to median plots of regional and worldwide empirical correlations between macroseismic intensities and peak ground motion. This might be a significant point of interest for the further regional data collection and study – especially because we found limited number of empirical models for the close region of interest.

Intensity map and attenuation models derived in this study are a means to address further civil engineering and seismological studies.

REFERENCES

- Aliaj Sh, Kociu S, Muco B, Sulstarova E. 2010. Seismicity, seismotectonics and seismic hazard assessment in Albania. Published, Academy of Science of Albania, 59-65 pp. Tirane.
- Bozo Rr, Ormeni Rr, Gjuzi O. 2017. Fast information exchange and evaluation of macroseismic field of moderate 2017 Albanian earthquakes.

Journal of International Environmental Application and Science, Selçuk University, Turkey, **12 (2)**: 224-229.

Caprio M, Tarigan B, Worden C, Wiemer S Wald D. 2015. Ground motion to intensity conversion equations (GMICES): A global relationship and evaluation of regional dependency. *Bulletin of the Seismological Society of America*. **105**. 10.1785/0120140286.

Faenza L, Michellini A. 2010. Regression analysis of MCS intensity and ground motion parameters in Italy and its application in ShakeMap. *Geophysical Journal International*, **180 (3)**: 1138–1152, <https://doi.org/10.1111/j.1365-246X.2009.04467.x>

Gomez-Capera A, D'Amico M, Lanzano G, Mario Locati M, Marco Santulin M. 2020. Relationships between ground motion parameters and macroseismic intensity for Italy. *Bulletin of Earthquake Engineering* **18**: 5143–5164 <https://doi.org/10.1007/s10518-020-00905-0/>.

Grünthal G. 1998. *European Macroseismic Scale. (1998) (EMS-98)*. Cahiers du Centre Européen de Géodynamique et de Séismologie 15, Centre Européen de Géodynamique et de Séismologie, Luxembourg, 99 pp.

Koliopoulos PK, Margaritis BN, Klimis, NS. 1998. Duration and energy characteristics of greek strong motion records. *Journal of Earthquake Engineering*, **2(3)**: 391 — 417.

Luzi L, Lanzano G, Felicetta C, D'Amico, MC, Russo E, Sgobba S, Pacor F, and ORFEUS Working Group 5 2020. *Engineering Strong Motion Database (ESM) (Version 2.0)*. Istituto Nazionale di Geofisica e Vulcanologia (INGV). <https://doi.org/10.13127/ESM.2>.

Muço B, Minga P. 1992. Anelastic-attenuation coefficient and the correction of Ao values of Richter magnitude formula for Albania. *Geofizika*, p. 123-132.

Ormeni Rr, Koci R, Dushi E, Minarolli A, Gjuzi O, Hajrullai S, Dushi I. 2019. *Monthly Seismological Bulletin* (ISSN), November 2019. <https://geo.edu.al>.

Sbarra P, Tosi P, De Rubeis, V, Ferrari C. 2010. Web based macroseismic survey of 2009 L'Aquila earthquakes sequence. *News_letter_emsc* 2010, Monteller, France. 7 pp34-36.

Sulstarova E, Muço, B. 1983. *Fusha makrosizimike e tërmetit të 15 prillit 1979*. Tërmeti i prillit, Shtëpia Botuese 8 Nëntori, pp. 167-186 (shqip-anglisht).

Theodulides NP, Papazachos BC. 1992. Dependence of strong ground motion on magnitude-distance, site geology and macroseismic intensity for shallow earthquakes in Greece: I, peak horizontal acceleration, velocity and displacement. *Soil Dynamics and Earthquake Engineering*, **11**: 387-402. doi:10.1016/0267-7261(92)90003-V.

Tselentis A, Danciu L. 2008. Empirical Relationships between Modified Mercalli Intensity and Engineering Ground-Motion Parameters in Greece. *Bulletin of The Seismological Society of America*. **98**. 1863-1875. 10.1785/0120070172.

Wald DJ, Quitoriano V, Heaton TH, Kanamori H. 1999. Relationships between Peak Ground Acceleration, Peak Ground Velocity, and Modified Mercalli Intensity in California. *Earthquake Spectra*, **15(3)**: 557-564. doi:10.1193/1.1586058.

SEISMIC ACTIVITY AND SEISMOTECTONIC CHARACTERISTICS OF THE SEISMIC SOURCE ZONES OF KOSOVO

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ABSTRACT

Kosovo is characterized by a relatively high seismic activity as it is located in the Alpine-Mediterranean seismic belt. The thickness of the seismogenic zone in the Earth's crust plays an important role in seismotectonics, affecting fault-system architecture and relative fault activity, earthquake size and distribution within a fault system, as well as long-term accumulation of tectonic deformation. The very high relief and large depressions make Kosovo a very geomorphologically complex country. The recent geological period is characterized by the neotectonic processes which have conditioned the formation of many structural units that are expressed by intensive uplifting and sinking movements. The territory of Kosovo is divided by a large number of blocks along the faults due to these prevailing movements' tendencies. Contacts between these blocks are expressed through normal faults, along which differentiations of the order of amplitude of about 2000 m, have occurred during the neotectonic phase. Accurate analysis of the hypocenter parameters is essential in understanding the seismotectonic characteristics of Kosovo as the magnitude of the historical earthquakes that have hit the Kosovo are re-evaluated. This study represents basic data of seismicity and neotectonic characteristics for the assessment of seismic hazard of Kosovo.

Keywords: neotectonic structure, seismicity, seismotectonics, seismogenic zones

1. INTRODUCTION

The territory of Kosovo represents from a seismicity point of view a space where indigenous catastrophic earthquakes are expectable along with earthquakes originating from the seismic sources in the bordering regions. In both cases damages are considerable.

There is a long history of earthquakes hitting Kosovo. Here we can mention the earthquake of 1456 that hit the city of Prizren with intensity IX on MSK-64, and the earthquake of 1662 in the Peja district with intensity VIII on MSK-64 scale have caused considerable material damages. In addition, historical earthquakes could be considered the earthquake of 1921 in Gjilan-Viti- Ferizaj region, with epicenter intensity IX on MSK 64 scale. The 1980 Kopaonik earthquake had intensity VIII on MSK-64 scale in the northern part of Kosova. In 2002, region of Gjilan was hit by an earthquake of seismic intensity VII +1/2 on MSK-64 scale. The earthquake of March 2010 hit Istog, with epicentral seismic intensity of VII. Kosovo's territory has been also affected by the strong earthquakes, which epicenters were in the Republic of North Macedonia, Albania, Montenegro and Serbia. This short review of the seismic activity affecting the territory of Kosovo throughout the time, points out that this region should be considered as a region with high seismic hazard potential. There is a growing urbanization process in Kosovo which makes awareness about the seismic hazard necessary. Integrating data from various field such as seismologic, geologic, tectonic data is of great importance for the assessment of seismic hazard.

2. Neotectonic structure of Kosovo

Neotectonic research in the territory of Kosovo is closely related with the studies on the morphostructure units resulting from the neotectonic movements that have occurred during Pliocene and Quaternary, in the so called neotectonic stage. Investigation about the neotectonic activity in Kosovo is closely related to the early recognition of geological structure for the detect of the relation between early tectonic movements and neotectonic.

The neotectonic stage in the territory of Kosovo was characterized by the tectonic processes, which have resulted in formation of new morph-structure units: morph-structure with dominant tendency of uplifting trend and sinking. We emphasize that the grounds noticed with new volcanic activity occupies a special place in Kosovo and with them are related many useful minerals.

2.1. Structures characterized by uplifting trends

In neotectonic map, the areas with dominant uplifting tendency are limited with neotectonic isolines of deformations, where the real value of

vertical rise during Neogen and Quaternary can be observed. Today, remains of past volcanic activity are manifested with termal waters that are common in Kosovo and throughout Balkan region. Areas of Kosovo with dominant uplifting trend are divided into these three separate units: Uplifting, High Intensity, and Low intensity units, fig. 1 (Elezaj).

2.2 Structures characterized by sinking trends

The neotectonic units that represent sinking morphostructure are very much expressed in the territory of Kosovo. These are large lowlands known as Neogen depressions and are characterized by large accumulation of molasic material, and large reserves of coal (fig.2).

The Neogen depressions are: i) Dukagjini Depression which is subdivided into smaller parts such as the Peja, Gjakova, Prizreni and Bellanica Depressions, ii) Drenica Depression, iii) Kosovo Depression which includes the smaller Podujeva and Morava Binçës Depressions, and iv) Krivarekës Depression. The past-volcanics are currently manifested through water thermo-minerals water phenomenon, which proves the existence of expressed geothermal field.

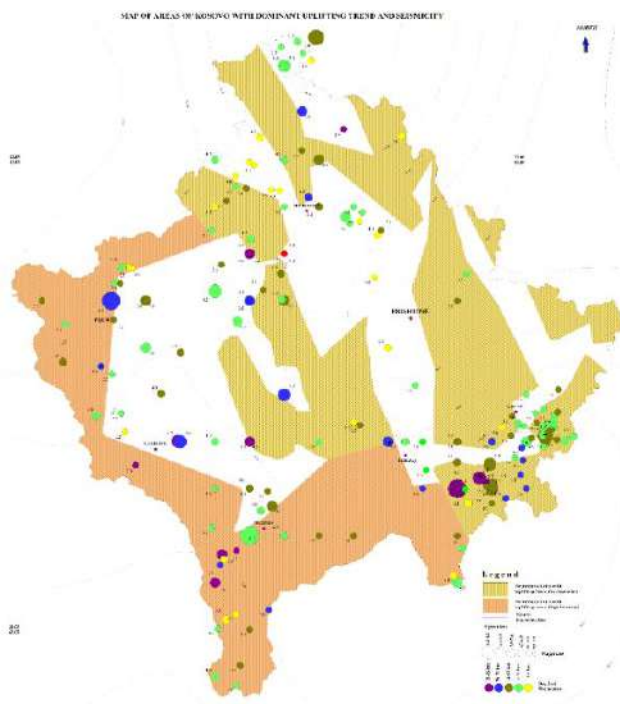


Fig. 9: Map of Kosovo. Neotectonic Units with uplifting trend and neotectonic depression.

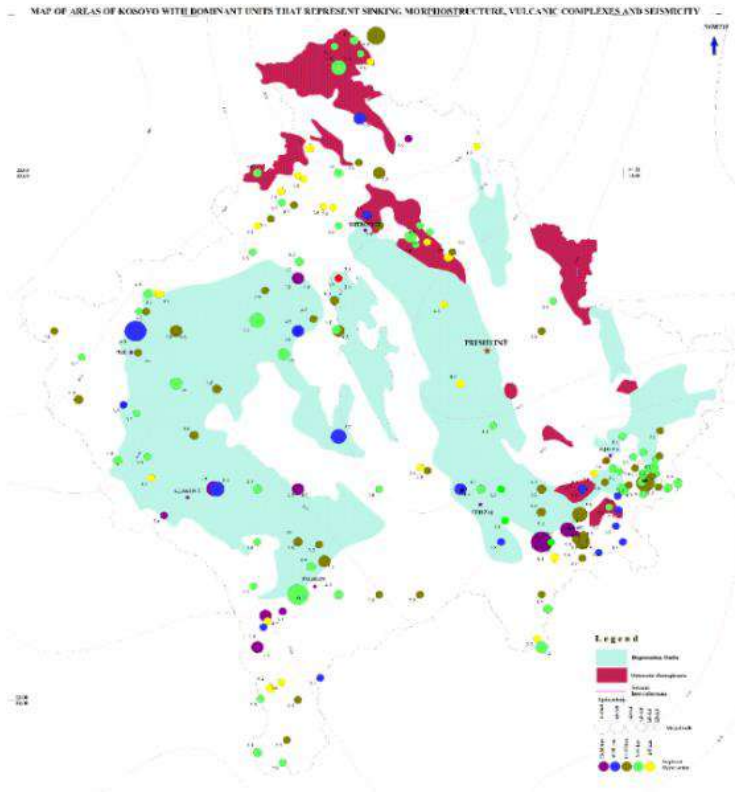


Fig.2: Map of Kosovo. Sinking morphostructure volcanic complexes and seismicity.

3. *Seismicity of the territory of Kosovo*

The earthquake catalogues of Albania, Montenegro, Croatia, Serbia, Macedonia, Greece (Thessaloniki), the earthquake bulletins of the International Seismological Centre (ISC), the southern and southern-eastern European earthquake catalogues were all used for an accurate seismic hazard study.

A new catalogue for the territory Kosovo was compiled illustrating the 156 earthquake events with magnitude $M \geq 3.5$ from 1456 to September 31, 2020.

However, such studies are continuously updated with new information. Kosovo is characterized by high seismic activity. Most of the earthquakes are earthquake foci as they occur within a few tens of kilometers of the surface. They are generated in the Earth's crust, maximum 15-25 km deep underground, tab.1, fig.3. In this case they are classified as *shallow-focus earthquakes*.

Tab.1 Number of earthquakes according to the Magnitude and Intensity

Number of Earthquakes	112	60	22	11	3	3
Magnitude	3.5-3.9	4.0 - 4.4	4.5 - 4.9	5.0 - 5.4	5.5 - 5.9	6.0 - 6.2
Intensity	4.16-4.83	5.0 - 5.66	5.83 - 6.5	6.6 - 7.33	7.5 - 7.6	8.73 – 9.0

Here we can mention: the Prizreni earthquake of June 16, 1456 (MS=6.0; 42.200oN, 20.700oE) epicentral intensity of VIII_{1/2}, the Peja earthquake of November 11, 1662 (MW=6.0; 42.700oN; 20.300oE) epicentral intensity of VIII_{1/2} degree, the Ferizaj-Viti earthquake of August 10, 1921 (ML=6.1; 42.300oN; 21.300oE) epicentral intensity of IX degree, the Viti earthquake of august 15.1921 (MI = 5.4; 42020' N, 21020' E) epicentral intensity of VIII degree, the Gjilan earthquake of September 02.1921 (MI = 5.0; 42024' N, 21030' E) epicentral intensity of VIII degree, the Kaçanik-Viti earthquake of October 03.1921 (MI = 5.6; 42020' N, 21020' E) epicentral intensity of VIII degree, the Gjakova earthquake of September 03.1922 (MI = 5.3; 42025' N, 21025' E) epicentral intensity of VIII_{1/2} degree, the Prizren earthquake of September 26.1945 (MI = 5.0; 42015' N, 21045' E) epicentral intensity of VII degree, the Klina earthquake of February 05.1947 (MI = 5.2; 42030' N, 21045' E) epicentral intensity of VIII degree, the Kopaonik earthquake of May 18, 1980 (MW=5.7; 43.307oN; 20.867oE) epicentral intensity of VIII degree, the Gjilani earthquake of April 24, 2002 (MW=5.7; 42.440°N, 21.590°E), epicentral intensity of VIII degree, the Istog earthquake of march 10, 2010 (MI = 5.2; 42.763440N, 20.628110E) epicentral intensity of VII degree, the Vushtrri earthquake of November 18, 2013 (MI=4,8; 42.9 N; 21.014 E) epicentral intensity of VI degree.

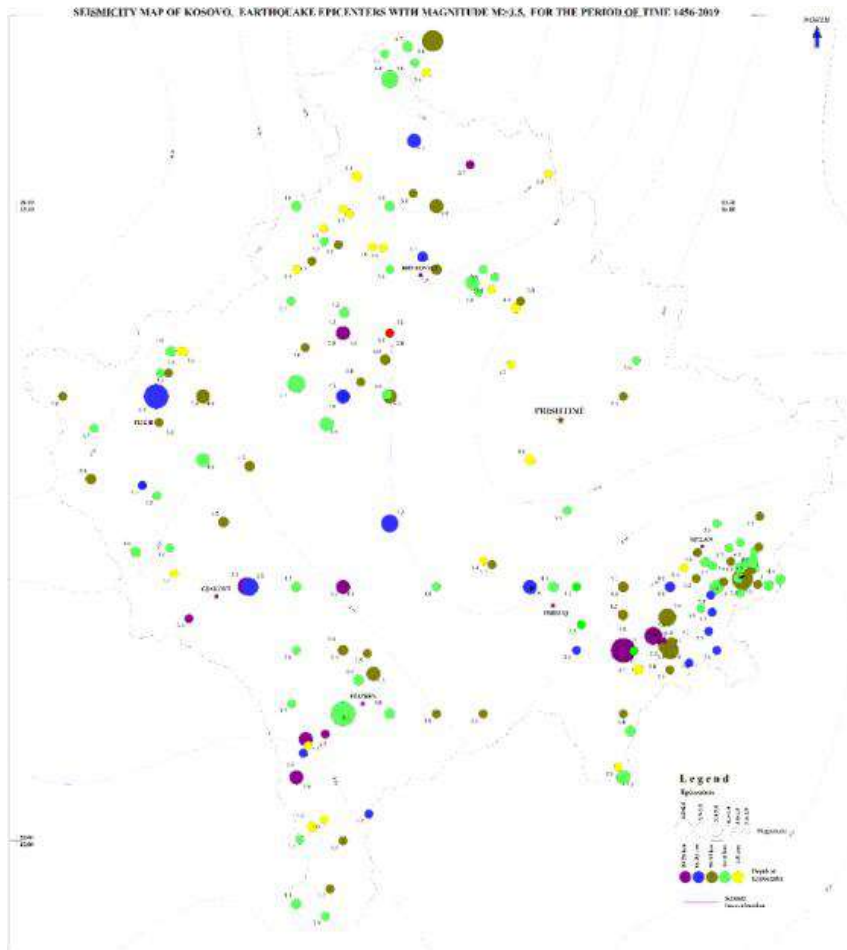


Fig. 3: Map of earthquake epicentres.

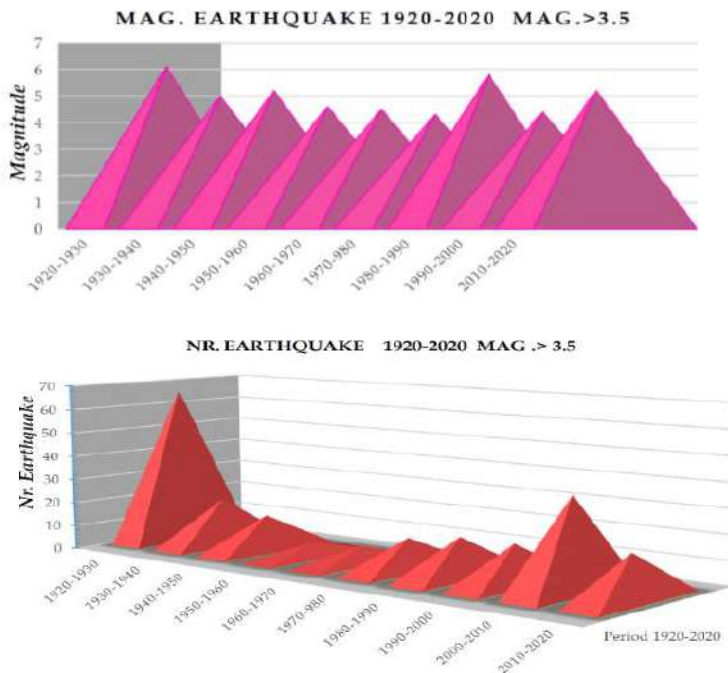


Fig. 4: Chart of Earthquakes' number and magnitude of every decade.

The Figure 4 depicts earthquakes' number and magnitude of every decade.

4. Macroseismic intensity attenuation and PGA attenuation based Earthquakes catalog of Kosovo territory

Seismic attenuation describes the energy loss experienced by seismic waves as they propagate. In this case, three earthquakes with approximate magnitude and with different depths, 7km, 14km and 20 km were considered. They result in different extinction values, where at a distance of 100 km the 7 km depth quake has much higher attenuation values than the 20 km depth quake at a distance of 100 km. Table 2 and figure 5 report the attenuation in 100 km in the territory of Kosovo, reporting one intensity scale difference for the 7 km and 20 km- deep earthquake.

$$I - I_o = -3.227 \log \sqrt{1 + \frac{\Delta^2}{h^2}} - 0.0033 \left(\sqrt{\Delta^2 + h^2} - h \right)$$

Papazachos and Ppaoannou (1977)

$$I_{\max} - I_i = 4.2 \log (R_i/h)$$

Hadzviecki and Pekvski (1975)

Tab.2 Attenuation of Intensity at the distance of 100 km

I 10 = 7.21	I 20 = 6.96	I 30 = 6.65	I 40 = 5.55	I 50 = 6.10	I 60 = 5.85	I 70 = 5.64	I 80 = 5.44	I 90 = 5.25	I 100 = 5.08
I 10 = 6.25	I 20 = 5.53	I 30 = 5.00	I 40 = 4.59	I 50 = 4.26	I 60 = 3.98	I 70 = 3.74	I 80 = 3.52	I 90 = 3.32	I 100 = 3.14
I 10 = 7.06	I 20 = 6.58	I 30 = 6.14	I 40 = 5.77	I 50 = 5.45	I 60 = 5.19	I 70 = 4.90	I 80 = 4.74	I 90 = 4.54	I 100 = 4.37
I 10 = 5.41	I 20 = 4.49	I 30 = 3.90	I 40 = 3.47	I 50 = 3.13	I 60 = 2.84				
I 10 = 5.92	I 20 = 5.16	I 30 = 4.67	I 40 = 4.20	I 50 = 3.87	I 60 = 3.59	I 70 = 3.34			
I 10 = 6.21	I 20 = 5.63	I 30 = =5.14	I 40 = =4.75	I 50 = =4.43	I 60 = 4.15	I 70 = 3.91	I 80 = 3.69	I 90 = 3.50	I 100 = 3.32
I 10 = 6.98	I 20 = 6.73	I 30 = 6.42	I 40 = 5.32	I 50 = 5.87	I 60 = 5.62	I 70 = 5.41	I 80 = 5.21	I 90 = 5.02	I 100 = 4.85
I 10 = 6.43	I 20 = 6.08	I 30 = 5.72	I 40 = =5.39	I 50 = 5.10	I 60 = 4.84	I 70 = 4.61	I 80 = 4.40	I 90 = 4.22	I 100 = 4.04
I 10 = 6.83	I 20 = 6.13	I 30 = 5.71	I 40 = 5.35	I 50 = 5.04	I 60 = 4.77	I 70 = 4.54	I 80 = 4.33	I 90 = 4.13	I 100 = 3.96
I 10 = =5.80	I 20 = 5.00	I 30 = 4.44	I 40 = 4.02	I 50 = 3.68	I 60 = 3.40	I 70 = 3.15	I 80 = 2.93	I 90 = 2.74	I 100 = 2.56
I 10 = 6.04	I 20 = 5.20	I 30 = 4.63	I 40 = 4.21	I 50 = 3.87	I 60 = 3.58	I 70 = 3.33	I 80 = 3.12	I 90 = 2.92	I 100 = 2.74
I 10 = 6.80	I 20 = 6.00	I 30 = 5.44	I 40 = 5.02	I 50 = 4.68	I 60 = 4.40	I 70 = 4.15	I 80 = 3.93	I 90 = 3.74	I 100 = 3.56
I 10 = 7.20	I 20 = 6.68	I 30 = 6.23	I 40 = 5.85	I 50 = 5.53	I 60 = 5.26	I 70 = 5.02	I 80 = 4.81	I 90 = 4.62	I 100 = 4.44
I 10 = 6.85	I 20 = 5.96	I 30 = 5.38	I 40 = 4.95	I 50 = 4.61	I 60 = 4.33	I 70 = 4.08	I 80 = 3.86	I 90 = 3.66	I 100 = 3.48
I 10 = 8.00	I 20 = =7.33	I 30 = 6.81	I 40 = 6.41	I 50 = =6.08	I 60 = 5.80	I 70 = =5.55	I 80 = 5.34	I 90 = 5.14	I 100 = 4.96
I 10 = 8.16	I 20 = 7.81	I 30 = 7.45	I 40 = 7.12	I 50 = 6.83	I 60 = =6.57	I 70 = 6.34	I 80 = 6.13	I 90 = 5.95	I 100 = 5.77
I 10 = 8.33	I 20 = =7.98	I 30 = 7.62	I 40 = 7.29	I 50 = =7.00	I 60 = 6.74	I 70 = =6.51	I 80 = 6.30	I 90 = 6.12	I 100 = 5.94

* Results of macroseismic intensity attenuation, based on Earthquakes catalog of Kosovo

The Graph in the Figure 5 plots the intensity attenuation at a distance of 100km.

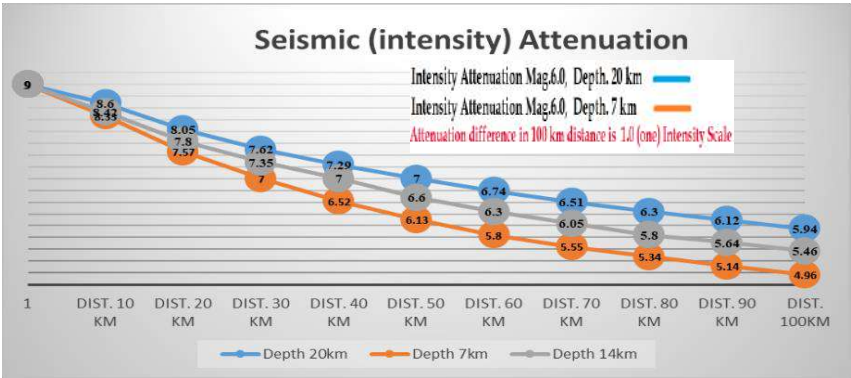


Fig. 5. Intensity attenuation at a distance of 100km.

4.1. Results of PGA attenuation

Attenuation model of PGA which includes magnitude (Mag.6.0) and distance to 100 km, in the Kosovo territory is here reported.

The table 3 and the figure 6 show the Peak ground acceleration attenuation relationships for the European area proposed by Ambraseys:
 $\log(a^*) = -1.39 + 0.266 \log(r) - 0.922 \log(r)$

Tab.3 Attenuation of PGA at a distance of 100 km.

Attenuation PGA In 100 km	PGA 5 =0.3643	PGA 10 =0.197	PGA 20 =0.102	PGA 30 = 0.07	PGA 40 = 0.054
PGA 50 =0.044	PGA 60 = 0.037	PGA 70 = 0.032	PGA 80 = 0.028	PGA 90 = 0.025	PGA 100= 0.023

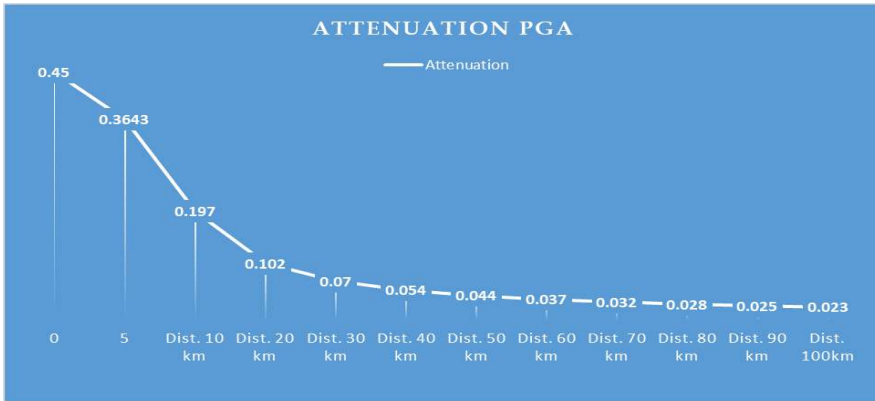


Fig 6: Graphical representation of PGA attenuation at a distance of 100km.

5. Seismotectonic characteristics of Kosovo

Synthesis and analysis of neotectonic data and their correlation with seismological data for the assessment of seismotectonic activity are in the present study made. New tectonic processes, which appear from time to time as seismic phenomena, are the earthquakes generated by active, causal faults of earthquakes, which represent seismic sources. The morphologic study of the faults and their classification based on the seismic risk assessment is of primary importance. The existing seismic data provide information about the tectonic activity of the existing faults for a short historical period. The seismic data of Kosovo provide information about the last century, while some documents inform only about the strong earthquakes of an earlier period.

Seismic activity assessment based on the existing data and the research carried out so far are means to address a more detailed information about the seismotectonic characteristics of Kosovo can be given in more detail than the seismological statistics. Based on the aforementioned seismic parameters, a map with all seismotectonic elements such as active faults, earthquake epicentres and their focal mechanisms, seismic source zones, and geological criteria of seismicity was compiled.

The map in the figure 7 seismogenically illustrates all the seismic parameters.

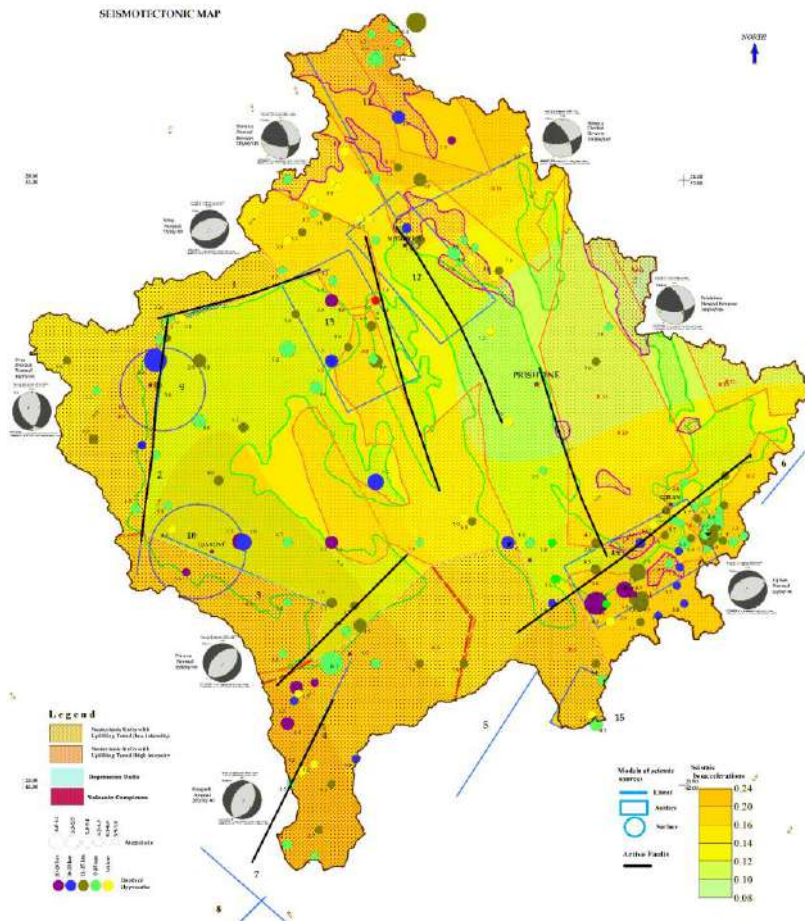


Fig.7: Seismotectonic Map of Kosova.

6. Seismic sources in Kosovo

The definition of seismic sources with respect to the maximum possible expected magnitude of future earthquakes is of a particular importance for the seismic hazard assessment. Delineation of seismic source zones is a fundamental step in probabilistic seismic hazard approach. A description of future earthquakes is based on a combination of the knowledge of the past earthquakes and of the geological features (active faults) along which they occurred (Elezaj 2002; Aliaj *et al.*, 2010).

6.1. Seismic sources in Kosovo and their geometric characteristics

It is already known that the exclusive use of seismological data for does not provide the required results, as other additional, geological, geodetic and

geophysics data would be needed. The general six seismic zones defined for Kosovo were divided into 15 seismic sources capable of generating earthquakes with the maximum magnitude up to 6.5, (Table 1). The earthquakes that are not included in the defined seismic sources are here defined as the background seismicity. The locations of the sources are identified based on the recorded hypocentral position of past earthquakes and the geological and seismological information. The spatial distribution of hypocenters is then divided into different zones based on their shape and seismicity.

Considering the aforementioned information and basing on the existing seismological data, a model of seismic sources of Kosovo involving part of the neighboring countries and consisting of 7 areas and 8 line sources fig.8 which characteristics are in the Table 2 presented was created.

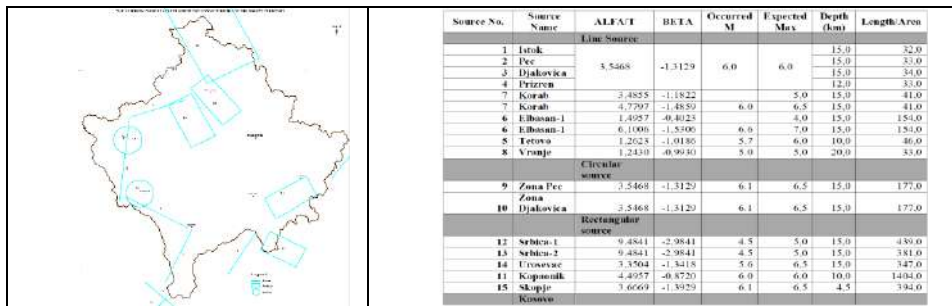


Fig. 8: Seismic sources in Kosovo.

6.2. Seismic Source Zone Model in Kosovo

In geophysics and seismology, the seismogenic layer covers the range of depths within the crust or lithosphere in which most earthquakes originate. A fundamental step in any probabilistic seismic hazard analysis (PSHA) is the delineation of seismic source zones and the identification of seismically active faults (Araya and Der Kiureghian 1988).

The geological criterion is related to the processes that occurred during the neotectonic stage, which marked the main morphostructures formed in the today's relief. These processes are a continuation of the early neotectonic stages and therefore serve as reliable data for the prediction of the location and strength of future earthquakes. Based on the existing data, the Dukagjini region represents the most active seismotectonic area of Kosovo. The Peja-Istog and Peja-Decan faults can be singled out disjointedly as active zones, morphologically notable and of a regional character. This region is prone of strong earthquakes which maximum magnitude is 6.1 - 6.5. The Prizreni and Dragashi faults are the most active faults in the south-western area. Here, the

maximum magnitude of earthquake is 6.3 - 6.5. The South-eastern area is also transverse, which is delineated by the Quaternary Lowland of Morava e Binçës, from Ferizaj to Viti towards Gjilani. The strongest earthquakes have a maximum magnitude of 6.2 -6.5 Richter. The central area, the lateral detachments of the Kosovo Lowland are not morphologically expressed and do not show any tectonic activity. The existing data report that the most active disconnections during the Pliocene epoch were the Sitnica and Çyçavica Drenica disconnections. These two disconnections are morphologically prone to seismic events. Here, the maximum magnitude of earthquakes is 5.5 - 6.0. The Kopaunik region, in the north of Kosovo, where volcanism was typical of the Neogene period, represents the end of the separations of the Vardar direction with the transverse ones. Earthquakes of magnitude between 5.8 and 6.2 are here expectable (fig.9).

The zones of seismic sources are :

1. Prizren-Gjakova-Dragash, maximum magnitude $M = 6.3 - 6.5$ Richter,
 2. Ferizaj-Viti-Gjilan, maximum magnitude $M = 6.2 - 6.5$ Richter,
 3. Istog-Peja-Decan, maximum magnitude $M = 6.1 - 6.5$ Richter,
 4. Kopaonik, maximum magnitude $M = 5.8-6.2$ Richter,
 5. Drenas - Skenderaj, maximum magnitude $M = 5.5 - 6.0$ Richter,
 6. Prishtina-Mitrovica, maximum magnitude $M = 5.5 - 6.0$ Richter,
- These areas prone to strong earthquakes.

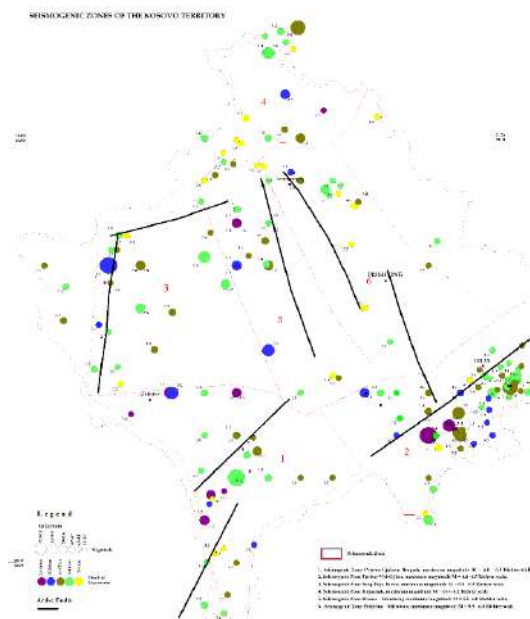


Fig. 9: Seismic Source Zones of Kosovo.

2. CONCLUSIONS AND RECOMMENDATIONS

The aforementioned data show that the major part of the territory of Kosovo can be considered as area with average seismic hazard ($0.10g < PGA < 0.24g$). The Kopaoniku zone in the north of Kosovo, the Prizren- Djakova zone, especially in the east-southeast of Prizreni, close to the Albanian border, the Peja-Istog zone, the Ferizaj-Viti-Gjilan zone, especially in the Skopje direction, the Drenas- Skenderaj zone and the Prishtina-Mitrovica zone can be considered as zones with high seismic hazard.

The seismological monitoring network of Kosovo has been recently created, and the scientific research has already begun.

The seismic hazard maps are frequently updated to include the latest seismologic data at a local, regional and global level. Issues to be addressed to would be: i) further investigation about the hypocenter parameters of the earthquakes in Kosovo and, ii) the re-evaluation of the magnitude of the historical earthquakes in Kosovo.

The results here reported can be improved if: i) further improvement of the seismicity parameters through the updating of the earthquake data base for Kosovo and the surrounding areas are made, ii) a regional seismotectonic model that correlates seismicity with the active tectonic faults, their focal mechanism, etc. is created and, iii) more accurate models for the prediction of ground motion parameters based on regional strong motion records in Kosovo and the surrounding areas are created.

REFERENCES

Akkar S, Bommer J. 2007. Prediction of elastic displacement response spectra in Europe and the Middle East. *Earthquake Engineering and Structural Dynamics*, 36: 1275 – 1301.

Aliaj SH. 1998. Neotectonic structure of Albania. *Albanian Journal of Natural and Technical Sciences*, 4: 15-42

Ambraseys NN, Simpsont KA, Bommer JJ. 1996. Prediction of horizontal response spectra in Europe. *Earthquake Engineering and Structural Dynamics*, Vol. 25: 371-400.

Araya R, Der Kiureghian A. 1988. Seismic hazard analysis: improved models, uncertainties and sensitivities. Report to the National Science Foundation, Earthquake Engineering Research Center 1988. Report No. UCB/EERC-90/11.

Elezaj Z. 2002. Seismotectonic characteristics if Kosovo can have used for its seismic regionalization. PhD thesis.

Eurocode 8. 2003. “Design of structures for earthquake resistance; Part 1: General rules, seismic actions and rules for buildings”, Draft No. 6; Version for translation (Stage 49), Doc CEN/TC250/SC8/N335”, European Committee for Standardization.

Frankel AD, Petersen MD, Mueller CS, Haller KM, Wheeler RL, Leyendecker EV, Wesson RL, Harmsen SC, Cramer CH, Perkins DM, Rukstales KS. 2002. Documentation for the 2002 update of the national seismic hazard maps, USGS Open-File Report 02-420.

Mustafa Sh, Dojcinovski D, Wang G. Elezaj Z. 2017. Modeling of Synthetic Accelerograms for Locations in Kosovo 29-36, Journal International Environmental Application & Science, 12(1): 29-36.

Sulstarova E. 1987. Mekanizmi i vatrave te termeteve ne Shqiperi dhe fusha e sforcimeve tektonike te sotme. Buletini i Shkencave Gjeologjike, 4: 133-170.

RECENT ITALIAN REGULATORY GUIDELINES FOR DAM AND BARRAGES

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ABSTRACT

In June 26, 2014 the Minister of Infrastructure and Transport issued a decree with the new technical regulations for dams and barrages. This decree introduced substantial changes in the existing technical rules, by suggesting a design approach according to latest national regulations. A technical board was set up by the same decree to monitor its effects in the first eighteen months following the issue. This paper, written by one member of that board, reports the activities carried out on the evaluation of the new legislation, highlighting the most innovative aspects as well as the critical issues, and underlining the need for further updating of the legislation.

Keywords. Barrages, dams, seismic design, structural safety, technical regulation.

1. INTRODUCTION

The paper examines the regulatory situation of dams and barrages following the approval of the Decree of the Minister of Infrastructure and Transport "*Technical standards for the design and construction of dam and barrages*" of June 26, 2014 (hereinafter DM2014) [1]. This decree replaces the previous legislation, dating back to 1982, which had to be updated in relation to the changes in the technical standards for the construction sector, such as the Ordinance of the President of the Council of Ministers no. 3274 of March 20, 2003 [2], the Technical Standards for Construction of January 14, 2008 (NTC2008) [3] recently updated on January 17, 2018 (NTC2018) [4]. The regulatory framework proposed in the DM2014 substantially embraced the inspiring criteria of the Eurocodes (already accepted in the NTC2008 and NTC2018), overcoming the previous legislation, which remained substantially

based on the allowable stress design method. However, this update has led to some uncertainties and criticalities which will be described below.

Historical Evolution of the Italian DAM STANDARDS

This section presents some technical standards of particular interest. More detailed references can be found in the recent report of the ICOLD European Club Report [5] and, in the website maintained by L.A. Ghinami [6] where a very accurate collection of rules and regulations can be found. To these regulations must be added the guidelines issued by the Italian Dams Register (*Registro Italiano Dighe*), currently the Directorate General for Dams (*Direzione Generale Dighe*) of the Ministry of Infrastructures and Transport (see, for example, the recent Instructions for the application of the Technical Regulations) [7] and, possibly, regional laws. More information can be found in [8].

1. Decree of the Ministry of Public Works n. 481 of April 2, 1921: *General rules for the projects and construction of dams for reservoirs and artificial lakes* [9]. It is the first Italian law to regulate the technical provisions on dams. This standard defined the documents necessary for the preparation of the final project and proposed a classification of the works that will also be maintained in the following regulations. Further indications concerned the definition of the stresses, the calculation methods, the safety loads of the materials and some recommendations to be followed during the construction phase.

2. Royal Decree no. 2540 of December 31, 1925: *Regulations for the projects, construction and operation of retaining dams* [10]. This is the standard written by the Technical Commission in charge of analyzing the Italian dams following the failure of the Gleno dam. This standard introduced stricter control of the work in the design phase and accurate control of the quality of materials and construction techniques. It established that, in the testing phase and during the entire period of operation, the dam had to be continuously monitored by personnel residing in the immediate vicinity of the dam itself. It established that the measurements of the deformations of the structure were carried out according to the reservoir levels and the leaks through the dam body. In the static calculation of the dam it required to take into account, in addition to self-weight of the masonry, water pressure and embankments, the possible existence of uplift pressures and, for the dams in the Alpine regions, the pressure exerted by the ice.

3. Royal Decree no. 1370 of October, 1st 1931: *Regulations for the projects, construction and operation of the retaining dams* [11]. It defined the scope of the regulation to dams with a height larger than 10 m, whatever the relative reservoir, or which determined a reservoir greater than 100000 m³.

For gravity dams, this regulation made some changes to RD n. 2540 with regard to the definition of safety loads for construction materials, introducing more restrictive conditions and prescribing the use of a concrete conglomerate with superior mechanical characteristics of resistance. This provision also provided for the “filtering task” of the Dams Service (*Servizio Dighe*, evolution of the "special department" provided for by the 1921 regulation), interposed between the Civil Engineering Offices (*Ufficio del Genio Civile*) and the Higher Council of Public Works (*Consiglio Superiore dei Lavori Pubblici*). For the examination of the projects and related condition documents; the Dams Service was also entrusted with the examination of the non-substantial variants and construction features proposed in the executive phase and their possible approval, as well as the approval of the particular precautions to be followed in the case of construction in periods of freezing weather, as well as any abbreviation of the terms established in the regulation for partial reservoirs of earth dams.

4. Decree of the President of the Republic n. 1363 of November 1st, 1959: *Regulations for the compilation of projects, construction and operation of the retaining dams (dams and barrages)* [12]. The legislation introduced the seismic load in the calculation of dams. In zones with high seismicity, dams had to be calculated taking into account, in addition to the static loads of weight and water, the corresponding loads in seismic conditions. With regard to gravity dams, the method of calculating the uplift pressures was changed, taking into account the possible presence of drainages in the foundation rock. In case of empty reservoir, the presence of tensile stresses on the edges not exceeding 300 kPa was allowed; with a full reservoir, wherever the stresses on the edges had to be compressive.

5. Decree of the Ministry of Public Works of March 24, 1982: *Technical standards for the design and construction of barrage dams* [13]. It was promulgated according to the Law no. 64 of February 2, 1974 "*Provisions for constructions with special requirements for seismic areas*", which in art. 1 required the issue of specific technical standards for the design, execution and testing of special works, including dams. The law updated the lists of seismic zones and attributed to these areas different values of the degree of seismicity to be taken as a basis for the determination of the corresponding loads. For gravity dams, the safety checks were to be performed for the foundation section at the lowest elevation and for the sections at various elevations in the structure, taking into account self-weight, hydrostatic pressure, uplift pressures and, if applicable, forces due to ice and seismic loads. In general, among the loads to be considered, the constraints of thermal origin and shrinkage were cited, however not taken into account in the calculation of gravity dams but in the calculation for vaulted dams, as already indicated in all the previous regulations. Tensile stresses should not exceed 300 kPa or 500

kPa if the exceeding of 300 kPa was induced solely by seismic loads.

6. Decree of the Ministry of Infrastructure and Transport of June 26, 2014: *Technical standards for the design and construction of restraint barriers (dams and barrages)* [1]. It will be described in detail in the following sections.

The chronological sequence of the Italian rules shows how the DPR 1363 of 1959 represents the last unitary measure referring to procedural regulations and technical standards, to which two distinct parts are dedicated.

From 1982 to today, the national regulatory technical framework has undergone important changes starting with the Ordinance of the President of the Council of Ministers no. 3274 of March 20, 2003 [2] which profoundly innovated the technical standards in the field of construction, adopting solutions consistent with the European regulatory system of Eurocodes (in particular Eurocode 8) and abandoning the purely prescriptive character in favor of a performance-based approach. Since 2008, the technical standards for constructions moved to the semiprobabilistic method and limit states, while the regulations on dams, which were still in 1982, referred to the allowable stress design method no longer in use. These technical standards were updated in January 2018. This succession of technical standards has resulted in the misalignment of the DM1982 with respect to the construction regulations and has determined the need for its profound renewal with the current legislation of June 26, 2014.

DECREE OF JUNE 26, 2014

The decree introduces, for the first time in Italy, the semiprobabilistic limit state method for dams and establishes the Monitoring Board for the exam of its first application at the Higher Council of Public Works. It also introduces the distinction between dams of normal importance and dams of strategic importance, and refers to NTC2008 for what concerns the partial safety, combination and concomitance coefficients.

This legislation applies to all dams and barrages in the national territory. For dams whose height does not exceed 10 m or which determine a reservoir volume not exceeding 100000 m³, the Administration responsible for security supervision will decide on a case-by-case basis and, in relation to the characteristics of the dam, which rules are to be applied. It also requires that the design and construction of the works and interventions covered by the standard must comply with the current Technical Standards for Construction referred to in NTC2008, in compliance with the special provisions indicated below.

An aspect of particular importance concerns the existing dams that will have to be subjected to safety assessment of the entire structure or parts of it,

when the general conditions established by the NTC2008 (now replaced by the NTC2018) are fulfilled.

Finally, it should be emphasized that the DM2014 is particularly advanced since, to the knowledge of the author, one of the only three regulations on dams based on the semiprobabilistic method at limit states, even if it should be noted that the other two are the French Recommendations [14] and Chinese standards [15], which do not have the mandatory character that characterizes the technical standards in Italy.

The NTC2008 in §4.1 write: "*with the exception of those works for which there is a specific regulation of a particular nature*" and in §6.8 "*the embankment dams materials are subject to specific legislation*", suggesting that the dams are excluded from these rules. This is perhaps the starting point of the critical issues of the DM2014, which constantly refers to the technical standards of the buildings from which, however, the dams seem to be excluded. Eurocode 8 itself writes "*Special structures, such as nuclear power plants, offshore structures and large dams, are excluded from the scope and scope of EN 1998.*" This provision disappears in the revision of the Eurocodes in progress, as it has now been clarified that the Eurocodes can be used for the verification of any engineering work although it will be necessary to use specially prepared supplementary standards for dams, as for other special works.

From the point of view of the application of the standard, in particular for existing dams, the main issues concern the use of criteria and coefficients defined for ordinary civil works with partial safety coefficients, combinations and concomitances with the values envisaged by the NTC2008 and not instead, as it should be (see the aforementioned French guidelines) tailored *ad hoc*. These coefficients lead to inconsistencies in the design and verification phase. The direct link between DM2014 and NTC2008, explicitly referred to in the first section (*Generalità*) of the Decree, makes today even more critical the choice of standardizing criteria and partial safety coefficients for the project and verification of the barrier works to those of ordinary constructions as, the recent revision of the NTC (the NTC2018) has introduced substantial changes both to the verification criteria and to the values of the partial factors, following the experiences acquired with the application of the standard.

The adoption of the verification methodologies provided for civil works is therefore a cause of inconsistencies and uncertainties on the results. An example is the case of existing gravity dams for which ENEL, a prominent Italian dam manager, produced in 2014 several comparisons between the dimensions of the dam obtained by applying the DM2014 and the previous DM1982. The study shows that not all load combinations and design approaches of DM2014 lead to acceptable results, as the current sizing may be

less restrictive and therefore less safe than those obtained with the previous legislation in some conditions.

It is therefore clear that the procedure of analysis for dams cannot simply be taken up by the NTCs and that it is necessary to address the issue of safety from a more systemic perspective in which, in addition to the limit states already envisaged for the dam, a series of other possible critical issues concerning the entire plant are considered, with the hydraulic works, the control and monitoring systems of the work and the upstream and downstream area of the basin, the mechanical devices whose functioning is the critical element for the general safety of the plant.

All this is more evident by the specific examination of some substantial points: the substantial differences between the loads in dams and other constructions are neglected (for example the weight of the structures, which for dams assumes a stabilizing character) and great importance is given to the seismic aspect, which is considered more relevant than the hydrological/hydraulic aspect (while the greater vulnerability of dams with respect to hydraulic aspects is known, such as flood events). See the work of the ITCOLD (Italian National Committee of Large Dams) Working Group "*Behavior of dams subjected to earthquakes*" [16] for a discussion on the effects of earthquakes on Italian dams. In fact, it should be noted that the NTCs follow an approach mainly oriented towards buildings, with particular attention to their behavior in seismic conditions.

Furthermore, some of the limit states are not easily distinguishable, for example, the Limit State of Safeguarding Life (*Stato Limite di Salvaguardia della Vita*) and the Limit State of Collapse (*Stato Limite di Collasso*), the classification of dams based on the intended use is under discussion, the safety margin on the resistance of the soil is expressed through identical partial coefficients for cohesion and the tangent of the friction angle, an aspect that is not found in other regulations, while it would be appropriate to express this margin on the overall resistance, without necessarily binding the standard to the use of a specific criterion of collapse. The seismic combination at the Ultimate Limit State, for small seismic events, is less critical than the fundamental combination at the maximum regulation level. An important novelty is the zero tensile strength for some combinations at the Limit State of immediate Operation (*Stato Limite di immediata Operatività*), acceptable for cracking control purposes in reinforced concrete structures with relatively small geometric dimensions, but which leads to excessive structural dimensions in the case of dams.

The standard also lacks indications on the structure factor, an index of the ductility of the structure, which is thus left to the arbitrariness of those who perform the analyses, although in the past, other regulations suggested the possible values to be adopted. In this sense, the proposal of the Italian

National Committee of Large Dams [17] allowed to scale the elastic spectrum with a factor of two for concrete works and four for embankment dams.

The main problematic aspects of DM2014 for gravity dams are related to the use of partial safety coefficients, combinations and concomitance with the values set by the NTC2008 (as already mentioned above) and the null tensile strength of the material (the previous legislation allowed values of tensile stresses less than 300 kPa or 500 kPa in case of seismic events). This limitation leads to an oversizing of the structures with respect to DM1982. Furthermore, the thermal load generally leads to incompatible tensile stresses with the condition of null tensile stresses. It should be noted that the verification for thermal loads was not required by the previous legislation, which increases the difficulty of these verifications for existing dams.

Finally, the verification of the tangential stresses leads to unrealistic results due to the limits imposed on the reference stress and the lack of stress limits in the presence of seismic loads should be corrected. The problem concerning the absence of traction also concerns vaulted dams, where the stresses due to thermal loads are of particular importance.

Few indications are given for earth dams, however rather generic, just as generic information is given for rolled concrete and rockfill dams with concrete mantle, two types particularly used in recent years.

4 MONITORING BOARD

The decree of June 26, 2014 established the Monitoring Board which "*... within 12 months of the entry into force of the technical standards, prepares a report on the results of the monitoring activity and a proposal to update the standards themselves. In the following 6 months, the updating of the aforementioned rules is issued*".

The Monitoring Board for the period of first application of the Technical Standards for the design and construction of the dam works (dams and barrages) referred to in Ministerial Decree of June 26, 2014 was established in accordance with the provisions of the same decree with expert components that they also have an institutional profile in relation to the subjects who have designated them [8]. The members were designated, in addition to the Ministry of Infrastructure, the Ministry of the Interior, the Department for Civil Protection, the Conference of the Regions and the National Association of Italian Municipalities (ANCI). The composition of the Board arose from a precise indication that emerged during the consultation phase and agreement for the issuance of the new rules. It should be remembered that the preparation of the proposal and the subsequent preparatory phase were characterized by a variety of positions that were confronted on multiple occasions and contexts, giving rise to discrepancies of views which were also

a reason for forms of dissent. The innovative nature of the new standard was, especially in the past, a reason for uncertainty about the sharing and acceptance of the proposed rules.

The Board, established by the Minister's Decree in December 2015, operated for approximately 15 months until February 2017, in accordance with the terms set out in the Ministerial Decree 2014 for the issue of the new regulations. In view of the expiry of the terms, the Board proposed a request for an extension of its mandate, to be fixed by law, which was not recognized at the time.

The Board, which met periodically in Rome at the headquarters of the Ministry of Infrastructures, initially consulted the stakeholders involved in the application of the rules, namely the managers, the National Association of Land Reclamation Irrigation Improvements (ANBI), the National Association of Electric Companies (Assoelettrica), the Italian National Committee for Large Dams, consulted the Dams General Management, promoted three meetings with the Universities and proceeded to update the text of the DM2014. In this phase it was intended to carry out an organic recognition of the application experiences of the standards developed by the stakeholders, which also included all the very detailed observations formulated since 2007, when the original text of the proposal to update the technical standards for the barrage works, which remained almost unchanged in the 2014 version. The observations collected were jointly examined by the Board during frequent meetings where the following main conclusions were reached:

- The limit state formulation is confirmed.
- An autonomous formulation with respect to the technical standards for constructions is required although inspired by the same principles. Full autonomy from the NTC is motivated by the specific nature of the dam works, whose structural composition and consequent behavior are different from those of the buildings referred to in the NTC.
- The selection of the limit states should arise from the examination of different scenarios that characterize the element to be analyzed. These scenarios should be identified in order to take into account, in addition to the dam, the ancillary and complementary works, whose functionality and efficiency is also relevant for safety purposes (sealing system, gates, maneuverable mechanical parts, etc.).
- The actual regulations contains widespread, although necessary, numerical references for conducting the checks and developing the calculation models. The engineering, design and construction aspects of the barriers are to be treated in a more explicit and widespread way to balance the formal setting of the regulatory text that appears unbalanced towards numerical and computational aspects.
- The application of the rules will be almost exclusively related to

existing dams, often in operation for decades. These dams are, in a large part, characterized by a well-documented behavior in normal operating conditions and in exceptional conditions, such as for seismic phenomena and hydrological flood events.

The evaluation of the past behavior is an essential prerequisite for the verification of the real condition taking into account the aging of the materials and the re-evaluation of external conditions (earthquakes and floods).

- Like other areas of civil engineering, the levels of knowledge should be codified for each situation considered. According to the levels of knowledge, the partial factors (of uncertainty) that intervene in the numerical checks should be differentiated.

- The stakeholders interviewed reported the need to provide for a differentiation of the formal extension of the verifications according to predefined dimensional classes of the barrier works, in analogy to the provisions of other international regulations.

- The barrages, which present as specificity the prevalence of the mechanical devices that can be maneuvered, are also considered.

During the course of the works, the text of the Ministerial Decree was progressively updated and a series of changes were proposed. The Board has considered and planned the following developments.

- Return consultation with the stakeholders who have formulated the proposed changes, by organizing a special meeting day extended to those who have formulated proposals and observations.

- Comparison with the experiences acquired in relation to the seismic events that, starting from August 2016, have affected the territories on the border between the regions of Abruzzo, Lazio, Umbria and Marche, which include numerous barrage and reservoirs.

- Comparison with the updates of the NTC of the Ministerial Decree of January 17, 2018.

The proposed changes therefore confirmed the limit state approach and the need of a fully independent regulation with respect to NTC2008 (in force at the time). The definitions of the limit states were revised and the need to treat the dam and ancillary works and plants as a single system was highlighted. It is therefore necessary to consider the complementary and ancillary works such as the guard house, the control room, the road system (walkways and bridges), the hydraulic sealing system of the dam body and the drainage system, the electrical equipment (lighting, surveillance, transformers, generators) and mechanical (hydraulic, oleodynamic). The outlet and intake works, penstocks, tunnels and passages, the possible sedimentation affecting the intake works, spillways, energy dissipation tanks and gates must be

checked. The slopes that insist on the banks of the reservoirs and any embankments must be analyzed to verify their stability conditions.

Particular attention was paid to existing dams. A paragraph concerning barrages was then added and the updates of the NTC2008, which became final in 2018, considered in the draft.

Due to the lack of extension of the legal deadlines that established the Monitoring Board, it was not possible to consult back with the subjects who formulated proposals for modification and to compare with the experiences acquired following the damage induced by the seismic sequences of Abruzzo, Lazio, Umbria and Marche. For the same reason it was not possible to carry out an experiment to assess the adequacy of the safety factors, combinations and concomitances necessary to ensure the safety margins and functionality of the plants, as necessary.

6 SOME POSSIBLE SOLUTIONS

The critical issues highlighted in the previous paragraphs suggest difficulties in the application of the standard, especially in the case of static and seismic analysis of existing dams. However, it should be emphasized that the Italian dams have an average age of about 60 years [18] so even the use of the DM1982 could lead to problematic situations for many plants.

To overcome these difficulties, while awaiting an update of the rules, reference can be made to a series of documents prepared by the various subjects operating in the field of dam research. The Directorate General for dams of the Ministry of Infrastructures and Transport has prepared the aforementioned Instructions for the application of the Technical Regulations [7] which should allow designers to overcome the most difficult aspects in the application of the DM2014 and can be compared to the Instructions of the NTC2008 and 2018. A similar publication concerns the ancillary works, which in order to consider the dam and ancillary works as a system, must be subjected to verification as well as the dam [19]. On the subject of ancillary works, the ITCOLD report [20] should also be mentioned.

The National Institute of Geophysics and Volcanology published in 2017 a guide for the preparation of the seismotectonic study, prescribed to evaluate certain seismic loads [21].

Finally, it should be noted that documentation of particular interest for dams and ancillary works can be consulted on the websites of the International Commission On Large Dams (Bulletin and others) [22], of the Federal Guidelines for Dam Safety [23], of the US Army Corps of Engineers [24] and the US Bureau of Reclamation [25]. Many other countries (European and non-European) have their own legislation on dams that can certainly be

useful to consult, together with those just mentioned, to fill the gaps in the Italian one on specific aspects [6].

7 CONCLUSIONS

The previous paragraphs described the current regulatory framework for dams and the regulatory evolution that inspired the principles contained therein. The innovative aspects and the most problematic aspects for the verifications were briefly presented in order to allow a conscious application of the standards, and in order to allow a future commission, possibly in charge of drafting a new version of the standards, to have useful information on the major criticalities that emerged during the activity of the Monitoring Board.

REFERENCES

- [1] Decreto del Ministero delle Infrastrutture e dei Trasporti, 2014. *Norme tecniche per la progettazione e la costruzione degli sbarramenti di ritenuta (dighe e traverse)*. 26/06/2014.
- [2] Ordinanza del Presidente del Consiglio dei Ministri n. 3274, 2003. *Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica*. 20/03/2003.
- [3] Decreto del Ministero dei Lavori Pubblici, 2008. *Norme tecniche per le costruzioni*. 14/01/2008.
- [4] Decreto del Ministero dei Lavori Pubblici, 2018. *Norme tecniche per le costruzioni*. 17/01/2018.
- [5] ICOLD European Club Report, *Dam Legislation*, 12/2017.
Link: <http://cnpgb.apambiente.pt/IcoldClub/index.htm>
- [6] Ghinami L.A. *dighe.eu - informazioni, riferimenti e normativa su dighe e traverse*. Link: <https://www.dighe.eu/normativa.htm>
- [7] Lanzi A., Paoliani P. 2019. *Istruzioni per l'applicazione della Normativa Tecnica di cui al D.M. 26.06.2014 (NTD14) e al D.M. 17.01.2018 (NTC18)*, Divisione VI Strutture e Geotecnica, Ministero delle Infrastrutture e dei Trasporti, 2019.
- [8] **Barpi F., Pascucci V., Ricciardi C., Salandin P., Scarpelli G. 2020.** *Latest Italian technical rules for dams and barrages*, L'Acqua - Rivista dell'Associazione Idrotecnica Italiana, 6.
- [9] Decreto del Ministero dei Lavori Pubblici, *Norme generali per i progetti e per la costruzione di dighe di sbarramento per serbatoi e laghi artificiali*. 2/04/1921.
- [10] Regio Decreto 31 dicembre 1925, n. 2540, *Regolamento per i*

progetti, la costruzione e l'esercizio delle dighe di ritenuta. 31/12/1925.

[11] Regio Decreto 1 ottobre 1931, n. 1370, *Regolamento per la compilazione dei progetti, la costruzione e l'esercizio delle dighe di ritenuta*. 1/10/1931.

[12] Decreto del Presidente della Repubblica, *Regolamento per la compilazione dei progetti, la costruzione e l'esercizio delle dighe di ritenuta*. 1/11/1959.

[13] Decreto del Ministero dei Lavori Pubblici, *Norme tecniche per la progettazione e la costruzione delle dighe di sbarramento*. 24/03/1982.

[14] Comité Français des Barrages et Réservoirs, *Recommandations pour la justification de la stabilité des barrages- poids*, 2012. Link: <http://www.barrages-cfbr.eu/>

[15] **Zongliang C., Chonghui L. 2020.** *The Standards Compilation of Water Power in China*. A cura di "The Department of Standardization China Electricity Council". 2000. Link: <http://www.cepp.com.cn>

[16] **Catalano A., Caruana R., Del Gizzi F., De Sortis A. 2013.** *Observed behaviour of Italian dams under historical earthquakes*, Working Group ITCOLD "Behaviour of dams subjected to earthquakes".

[17] Comitato Nazionale Italiano delle Grandi Dighe, *Bozza di norme tecniche per la progettazione e costruzione di dighe di sbarramento*, 2000.

[18] **Fornari F., 2016.** *La manutenzione e riabilitazione delle dighe ed opere idrauliche associate*, Geomedia, 2016.

[19] Ufficio strutture e geotecnica dell'Ufficio tecnico dighe di Napoli, 2016. *Verifiche di sicurezza sismica degli scarichi e delle opere accessorie e complementari - Riferimenti per l'istruttoria* (04/04/2016).

[20] **Zinetti F.** (coordinatore) 2012, *Opere idrauliche associate alle dighe*. Comitato Nazionale Italiano delle Grandi Dighe, 2012. Link: <http://www.itcold.it>

[21] **Basili R. D'Amico V. Meletti C. Valensise G. 2017.** *Linee-guida per la redazione e le istruttorie degli studi sismotettonici relativi alle grandi dighe*. Istituto Nazionale di Geofisica e Vulcanologia, 27/09/.

[22] International Commission On Large Dams. Link: <https://www.icold-cigb.org/>

[23] Federal Guidelines for Dam Safety (FEMA). Link: <https://www.fema.gov/>

[24] U.S. Army Corps of Engineers (USACE). Link: <https://www.usace.army.mil/>

[25] U.S. Bureau of Reclamation (USBR). Link: <https://www.usbr.gov/>

EARTHQUAKE-RESISTANT CITIES IN ALBANIA: SEISMIC MICROZONATION STUDIES (SM) AND LIMIT CONDITION IN EMERGENCY (LCE) INTEGRATED APPROACH

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ABSTRACT

This work aims to highlight the indispensable significance of the seismic microzonation studies (SM) and the Limit Condition in Emergency (LCE) at the level of primary decision-making in urban planning studies and to help resolve a range of problems connected to seismic risk assessment in Albania. Following the 1979 Montenegro seismic sequence, the Albanian government implemented a 'National Plan for Seismic Prevention', which funded the SM of some of the biggest cities in Albania. Unfortunately, the seismic risk prevention activities were halted after the renewal of the national codes for design in 1989. Located next to the most active fault in Albania, the main cities of the country have experienced seventeen (17) seismic

events with magnitudes varying from 5.4 to 6.6 in the last 114 years. The most recent earthquakes that hit Albania on September 21st, 2019 of Mw 5.4 and November 26th, 2019 of Mw 6.2 severely damaged the cities of Durrës, Thumanë, Tirana, Vora, Shijak and the villages around. The main event of the 26th November caused the deaths of 51 persons and the damaging of hundreds of buildings. The degree of damages produced by these earthquakes has been, in some cases, significantly enhanced by the characteristics of the earthquake ground motion affected by the local subsurface soil structure of the cities. The seismic events of 2019 evidenced the crucial importance of earthquake risk reduction and mitigation. For this purpose, a multidisciplinary research activity was carried out to define the SM of two archaeological cities in Albania: Durrës and Gjirokastër. Based on the SM, the LCE were applied in both cities. In the process of creating earthquake-resistant cities, the SM and the LCE could be the best tools for a better seismic hazard mitigation and prevention in Albania.

Keywords: seismic microzonation studies, Limit Condition in Emergency, Durrës earthquakes, seismic mitigation, seismic prevention.

1. INTRODUCTION

Albania is a Balkan country characterized by a very high seismic activity. It is rather geologically and seismo-tectonically complicated region. The country is characterized by obvious micro-seismicity (a high number of small earthquakes), sparse medium-sized earthquakes (magnitude M from 5.5 to 5.9), and rare large earthquakes with magnitude $M > 6$. The strongest Albanian earthquakes have occurred along three well-defined seismic belts: i) the Ionian-Adriatic coastal belt extending northwest to southeast and coinciding with the boundary between the European plate and the Adria microplate; ii) the Peshkopia-Korça belt (the so called Drini belt), extending north-south in the eastern part of the country and iii) the Elbasani-Dibra-Tetova transverse belt, extending southwest to northeast across the former two belts. During the last 114 years, along these seismic belts seventeen (17) seismic events have been occurred with magnitude from 5.4 to 6.6. These earthquakes caused 407 victims and hundreds of thousands injured. One of the most destructive earthquakes in Albania has been the seismic event of 1979 in Montenegro. Following this seismic event, the Albanian government implemented a "National Plan for the seismic prevention" funding the seismic microzonation (hereafter SM) studies of some of the biggest cities in Albania. Unfortunately, the seismic risk prevention activities were halted after the implementation of the renewed national codes for design in 1989.

Fifty one people died and hundreds of buildings were damaged in Durrës, Thumanë, Tirana, Vora, Shijak and their villages due to the earthquake of November 26, 2019. In some cases the damages caused by these earthquakes

have significantly worsened by the characteristics of the earthquake ground motion affected by the local subsurface soil structure of the cities [9].

In the process of creating earthquake-resistant cities, the geophysical and engineering-geological methods, which take into account the geological and geomorphological characteristics of the local subsoil, for an effective SM, could be fundamental.

The integrated studies of the SM with the Limit Condition in Emergency (hereafter LCE) could be the best tools for a better seismic hazard mitigation and prevention in Albania.

For this purpose, a multidisciplinary research activity that integrated the existing geotechnical and geophysical data with original geophysical surveys was carried out to define the SM of two archaeological cities in Albania: Durrës and Gjirokastrë. Based on the SM, the LCE were applied in both cities.

The integrated SM-LCE approach studies can help decision-makers to identify the strategic buildings, structural blocks, emergency areas and the strategic paths for a successful emergency plan at a municipality level.

1st level of SM of the Durrës and Gjirokastra municipalities

SM studies are important tools in the suitable urban planning and in the prospective of seismic hazards mitigation and prevention. The main goal of the SM is to delineate areas, within a municipality level, with homogenous seismic response in terms of stratigraphic and topographic amplification, as well as areas of earthquake-induced phenomena such as landslides, liquefaction and sinkholes.

On a local scale, the SM identifies the areas that manifest a homogeneous seismic behavior during an earthquake event. According to the Italian guidelines (firstly proposed from the International Society for Soil Mechanics and Geotechnical Engineering ISSMGE in 1999), a municipality territory could be characterized in accordance with three types of areas: i) stable areas, ii) stable areas susceptible to local seismic amplification and iii) areas susceptible to instability (e.g. earthquake-induced landslides, soil liquefaction and surface fractures and faulting). Three levels of SM are considered in these guidelines. The 1st level is based on the collection of the existing data and the distribution of the new surveys, in such a way as to acquire the most in-depth information possible for the municipality territory. This level identifies the areas with the same seismic behavior, based on the three typologies described above. The results are shown on the Seismically Homogeneous Microzones Map (SHMM) (in 1:5000 or 1:10000 scales) and the databases of the investigations are then uploaded into a geographic information system. The 1st level process is totally based on the detailed engineering-geological and geophysical models of the subsoil. The target of the 2nd and 3rd levels is the

evaluation of the local seismic response and seismic amplification factors of the entire territory of the municipalities. The municipalities involved in the process are those with the highest values of peak ground acceleration on rocks, a_{gR} , corresponding to the reference probability of exceedance (PNCR) of 10% in a nominal lifespan of 50 years, equivalently to a reference return period of 475 years [11]. One and two-dimensional numerical modeling analyses based on the modification of the reference seismic signal due to the specific site conditions is needed to quantify the local amplification and to perform the dynamic analysis of slope instability and the liquefaction susceptibility [10].

Based on these criteria, two different ancient cities in Albania were chosen for the 1st level of SM, specifically, the cities of Durrës and Gjirokastra.

Located next to the most active fault in Albania, these cities have experienced several strong earthquakes in the past, sometimes exceeding the magnitude of 6. The seismic event of October 10th, 1858, destroyed many buildings in the city of Gjirokastra. Historians claim that it had a huge impact on the economic life of this archaeological city [12].

The ancient city of Dyrrachium (modern name: Durrës) is not new at seismic risk and has been severely destroyed by a series of earthquakes. The most important ones on record are: the earthquake of 177 B.C., May 1st or 2nd, then in 58 A.D., 334, 345, 506 (that almost destroyed the entire ancient city), March 1st, 1273, 1279, 1869, 1870 and December 17th, 1926 of Ms 6.2 and seismic intensity of IX (MSK-64 scale) [1].

The last earthquake sequence started in September 21st, 2019 with a ML 5.4 and a relatively deep hypocenter (around 17 km referring to cnt.rm.ingv.it). The main event occurred on November 26th, 2019 with Mw 6.2 causing 51 victims and extensive damage to hundreds of buildings in the cities of Durrës, Thumanë, Tiranë, Vorë, Shijak and many others. The earthquake sequence included 8 strong seismic events with magnitude larger than 5. The activation of the reverse faulting system produced many phenomena connected to the local soil conditions such as: seismic stratigraphic amplification, soil liquefaction, surface fractures and earthquake-induced landslides [4].

The city of Durrës is located along the Adriatic coast in the central part of Albania, in the lowland of the Periadriatic Depression.

In the process of collecting existing data, the engineering-geological map of the city of Durrës [3] was taken into account, alongside data obtained through laboratory testing regarding the geotechnical parameters of the clayey formation of Lower Pliocene at Durrës Hill, thus determining their key role in the generation of landslides [5 & 6]. These results were incorporated in the geological map at the scale 1:10.000, the previous microzonation map of the city [1], the bedrock map [2] and the private engineering-geological reports

and studies conducted on the city of Durrës. All the collected data were integrated into a detailed Gis-database for the SM activities.

In order to make a better assessment of the local seismic hazard at the historical center of the city of Durrës and determine the distribution of Quaternary deposits, a series of different geophysical investigations were carried out. Twenty-two single-station noise measurements, processed through the Horizontal/Vertical Spectral Ratio technique, two (Multichannel Analysis of Surface Waves surveys and two 2D array measurements were performed to cover an area of around 3 km² of the historical center of Durrës (Figure1) [4]. The fundamental frequencies of resonance f_0 , were determined for each HVSr curve from noise measurements. Afterwards, the corresponding fundamental periods T_0 as $1/f_0$ were computed. Four different groups of T_0 ranges were obtained: i) one group shows no peak; ii) another group highlighted the presence of very thin surficial layers (i.e., top few meters) prone to amplification; iii) the third group shows a predominant peak period in the range of 0.7 - 1.1s and iv) the last group shows the presence of the highest fundamental periods T_0 (higher than 1.1s) indicating a deep bedrock interface [4].

The fundamental frequencies of resonance f_0 were used to estimate the thickness (h) of the Quaternary deposits overlaying the Messinian-Pliocene bedrock [4].

The Figure 2 depicts the city of Gjirokastra located in the southern part of Albania. The first stage of the SM of the city of Gjirokastra consisted in the reconstruction of the engineering-geological model of the subsoil, with the aim of defining the geometrical setting of soil deposits and their geotechnical and geophysical properties. For this purpose, the available geological, geotechnical, and geophysical data, together with engineering-geological reports and studies from private subjects were collected and analyzed. All the collected data were integrated into a detailed Gis-database for the SM activities. Based on the geological survey and the previous data, it was possible to reproduce the Engineering-Geological Map at the scale 1:10.000, the Slope Map (at the scale 1:10.000) and the Digital Elevation Model Map (at the scale 1:10.000 scale) for the city of Gjirokastra.

In order to define the stable areas, the stable areas susceptible to local seismic amplification and the areas susceptible to instability for the entire territory of the city of Gjirokastra, a research approach that integrated different geophysical methods were performed. To this purpose, 25 ambient vibration measurements were carried out for the most important buildings and across the historical center of the city and recent settlements (Figure 2). Six 2D array and six MASW measurements were performed to provide useful elements for a geophysical subsoil characterization [9].

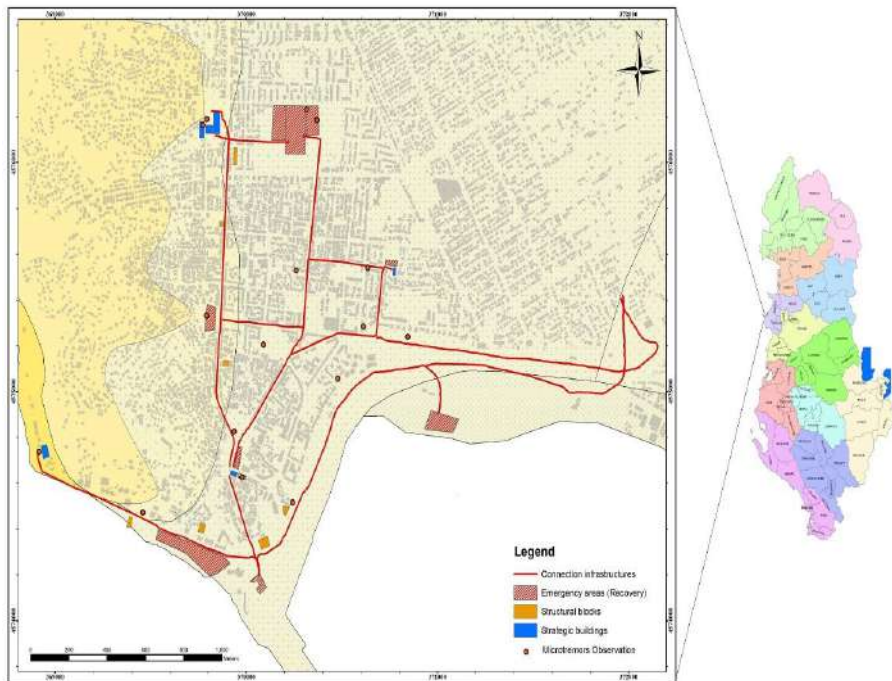


Fig. 10. Shows the integrated approach of the SM [4&9] and the LCE for the center of the city of Durrës.

Based on the data obtained, the municipality of Gjirokastra was divided into six zones of susceptibility to local ground amplification and two zones of geological instability. Due to the different geological, engineering-geological, geophysical and geomorphological settings that characterize the subsoil of the city, the earthquake-induced phenomena that could be manifested during the seismic events might vary significantly. The city of Gjirokastra is subject to extensive landslides and earthquake-induced landslides on the fractured calcareous and siliciclastic rocks and on the turbidity units. Due to the presence of the buried narrow valleys and isolated narrow ridges, this area is prone to a stratigraphic and topographic amplification of the seismic motion [9].

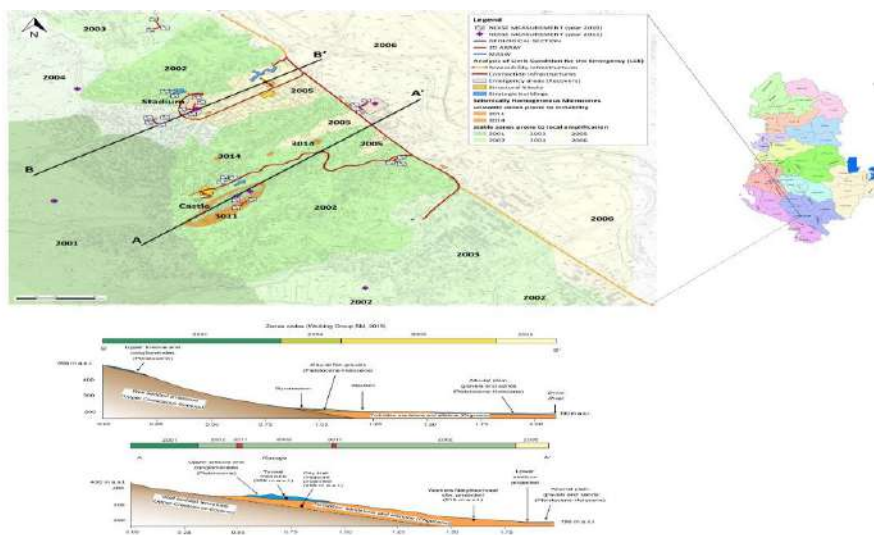


Fig. 2. The conjugate approach of the SM and the LCE of the city of Gjirokastra, allows the systematic association of strictly geological information with the strategic elements functional to emergency management [9].

The Limit Condition in Emergency - LCE

The LCE - Limit Condition in Emergency, is the condition whereby, following a seismic event, the urban settlement as a whole suffers physical and functional damage resulting in the interruption of almost all urban functions, including residency. However, the urban settlement preserves the functionality of most of the strategic functions for the emergency and their accessibility and connection to the territorial context.

The analysis involves: i) the identification of the buildings and areas that guarantee strategic functions for the emergency; ii) the identification of the infrastructures for accessibility and connection with the territorial context and, iii) the identification of structural elements and individual structural units that may interfere with accessibility infrastructures and connection with the territorial context.

By spatially superimposing the elements of LCE on the microzones identified by the SM studies, criteria and guidelines can be defined that are more targeted to the choices of ordinary planning of the territory: i) orienting the choices for the new settlements; ii) defining the eligible interventions in a given area; iii) establishing methods and priorities for intervention in urbanized areas.

An absolute ranking of seismic hazard should include the regional seismic hazard and the amplification due to the geological and geophysical setting [7].

Realizing these kinds of studies before an earthquake occurs can help decision-makers to highlight priority intervention areas and to define the best practice for existing structures where higher overall seismic hazard values are expected.

For both cities, the LCE was conducted in conjunction with SM (Figure 1 and 2).

2. CONCLUSIONS

This work aims to highlight the indispensable significance of the SM and the LCE at the level of primary decision-making at urban planning studies and to help resolving a range of problems connected to seismic risk assessment.

The first level of SM in Durrës is still in process, but considering the high seismic activity of the region, the Peak Ground Acceleration value of 0.268 corresponding to the reference probability of exceedance $P_{NCR}=10\%$ in $TL=50$ years or equivalently to a reference return period of $T_{NCR}\approx 475$ years. [1], the high seismic vulnerability of the buildings and the many uncertainties about the thickness of the Quaternary deposits and the geometry of the depression, the authors strongly recommend the beginning, as soon as possible, of the third level of the SM for the entire municipality of Durrës. Furthermore, the studies of the local seismic response for all the important and strategic buildings of the city of Durrës must be obligatory.

Preliminary results from 2D arrays fixed the maximum depth that could be investigated and fully described the site effects in the city of Durrës. Detailed engineering-geological and geophysical investigations are needed for the third level of SM. In order to determine the distribution and the thickness of the Quaternary deposits, and to provide an image of the buried morphology for a 3D bedrock modeling for the entire municipality, an accurate array of the gravity survey together with further noise measurements could be the most economic and strategic choice [8].

The authors of this paper emphasize that the studies for the first level of the seismic microzonation for all the cities in Albania are long overdue. They would provide the basis for the third level of SM in the cities with higher values of peak ground acceleration, a_{gR} , such as Durrës, Tirana, Shkodra, Vlora, Saranda, Berat, Gjirokastra, Korça, Pogradeci etc., before the next earthquake hits.

The following step would have to be an analysis of the Emergency Limit Condition – ELC for civil protection planning.

REFERENCES

- [1] **Aliaj Sh, Koçiu, S, Muço B, Sulstarova, E. 2010.** Sizmiciteti, sizmotektonika dhe vleresimi I rrezikut sizmik në Shqipëri. *Akademia e Shkencave e Shqipërisë*, Tirana.
- [2] **Koçiu, S. 2004.** Induced Seismic Impacts Observed in Coastal Area of Albania: Case Studies. *Proceedings of Fifth Int. Conf. on case histories in Geotech. Eng.*, New York, NY, April 13-17.
- [3] **Konomi, N. 1980.** Harta rajonizimit gjeologo-inxhinierik e zonës sëDurrësit. Shkalla 1:10000.
- [4] **Mancini M, Skrame K, Simionato M, Muçi, R, Gaudiosi I, Moscatelli M, DajaSh. 2021.** Site characterization in Durrës (Albania) in a seismic microzonation perspective. *Bollettino di Geofisica Teorica e Applicata* (doi: 10.4430/bgta0344).
- [5] **Muçi R, Skrame K, Mancini, M, Gaudiosi I, Simionato M. 2021.** Effect of cement and fly-ash on the geotechnical properties of expansive clay soils. *Italian Journal of Geosciences*, **140** (1) pp., 26 figs., 3 tabs.
- [6] **Muçi R, Fociro O, Skrame K. 2018.** The effect of lime as a stabilizing agent in plastic clayey soils in Vila hill, Durres, Albania. *Muzeul Olteniei Craiova. Oltenia. Studii și comunicări. Științele Naturii. Tom. 34, (2).*
- [7] **MoriF, Gaudiosi I, Tarquini E, Bramerini F, Castenetto S, Naso G, Spina, D. 2019.** HSM – a synthetic damage-constrained seismic hazard parameter. *Bulletin of Earthquake Engineering*, 1-24.
- [8] **Skrame K, Di Filippo M. 2015.** The importance of the geophysical methods for the determination of the urban subsurface structures. *Rendiconti online della Società Geologica Italiana*, **33**: 92-95.
- [9] **Skrame K, Muçi R, Simionato M, Benigni MS, Gaudiosi I, Giuffrè M, Mancini M, Moscatelli M. 2020.** New seismic microzonation studies in Albania: from the past to the future. *First Break*, **38, (8)**: 39-45.
- [10] **SM Working Group. 2015.** Guidelines for Seismic Microzonation, Conference of Regions and Autonomous Provinces of Italy – Civil Protection Department, Rome, ()
- [11] **Solomos G, Pinto, A, Dimova S. 2008.** A review of the seismic hazard zonation in national building codes in the context of eurocode 8. Support to the implementation, harmonization and further development of the Eurocodes.
- [12] **UNDP Albania (2003):** Disaster Risk Assessment in Albania – Executive Summary Report. United Nations Development Programme, Albania, Disaster Management and Emergency Preparedness Project, Department for International Development (DFID, UK), Tirana, 105 pp.

Instructions to Authors

Submission of papers

Contributions should be sent to the Journal address (see inside front cover). The manuscript and copies of figures should be submitted in triplicate, together with one set of good quality figure material for production of the printed figures. Papers should not exceed ten pages. Short contributions of less than four pages may be published as Short Communications, Discussions, Book Reviews, Announcements in a shorter time than regular articles and the proofs will normally be corrected by the publisher. Manuscripts should therefore be prepared with the greatest care.

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Manuscripts should be written in good English. They should be typed throughout with double line spacing and wide margins on numbered, single, column pages.

Articles should contain the following sections: title page, abstract, introduction, main results, applications, discussion and/or conclusions, references, tables and/or figures (if any), legends to figures, numbered consecutively in this order.

The title page(s) should contain the article title, author(s) names and affiliations, the text of related footnotes and the text of the abstract. The author to whom the proofs should be sent must be indicated with her/his full postal address, telephone number and fax number.

Tables should be typed on separate sheets at the end of the manuscript. In addition to its serial number, each table should have a sufficiently detailed caption to explain the data displayed in it.

Figures should be numbered and their captions listed together at the end of the manuscript.

References in the text to other publications should be listed together at the end of the text.

The reference list should be in alphabetical order.

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