MACROSEISMIC FIELD ANISOTROPY OF THE M_L6.3 (MW6.4) EARTHQUAKE OF 26 NOVEMBER 2019 IN DURRES, ALBANIA

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ABSTRACT

November 26, 2019, ML=6.3 (Mw=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. Macroseismic 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 macroseismic data. Intensity map is created using averaged macroseismic 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 macroseismic intensities and peak ground motion, available PGA values of manually processed strong motion waveforms are collected and implemented in regression analysis.
Keywords**:** macroseismic 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?*" (IGEWE 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 questionaries' responses, the Durresi main shock intensity was defined by the IGEWE 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 Duresi earthquake (M_L6.3 and M_w6.4) 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_L4.4. 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

Macroseismic 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 macroseismic questionnaires. For the reliable estimation of macroseimic 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 questionaries' 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 Instituto Nazionale di Geofisica and Vulcanologia (INGV), Italy. The ESM data that we used, includes Durresi 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 macroseismic 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 macroseismic 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 km^2 (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).

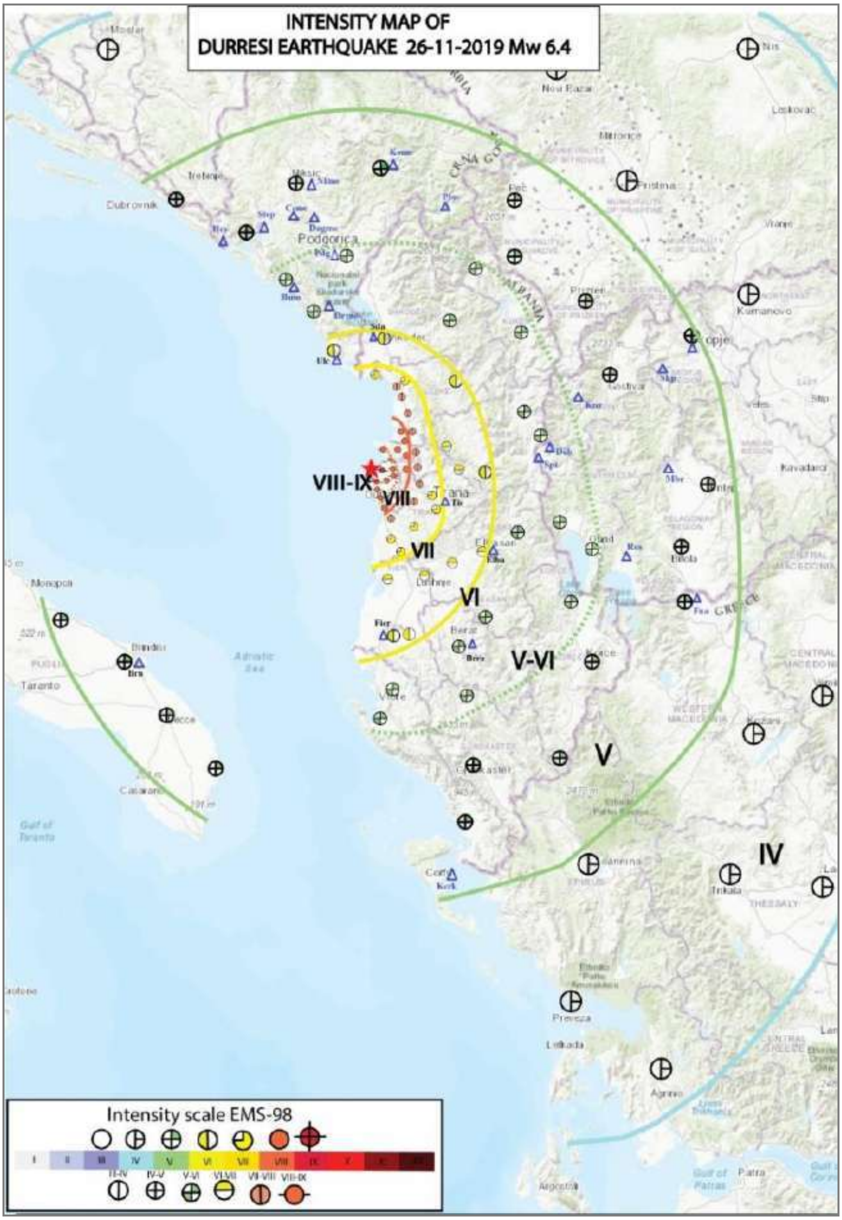

Fig. 1: Municipality and the regional macroseismic field: red star symbol marks the earthquake epicentre; colour scheme of municipal macroseismic intensity (I_m) symbols and isoseismal lines separates the intensity degrees - as indicated in the legend; blue triangle symbols are indicating positions of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

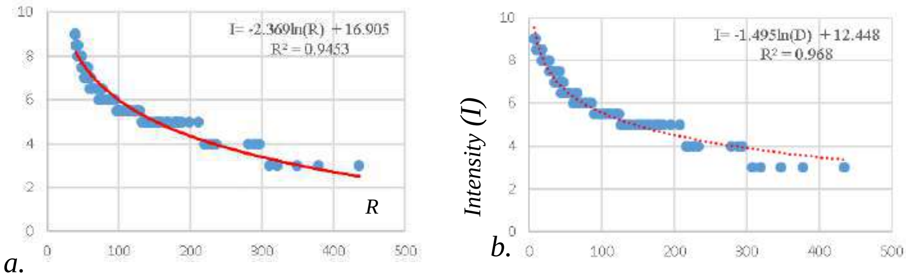

Fig. 2: Decay of Intensity with hypocentral (a) and epicentral distance (b); models are developed on the dataset of 119 points.

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 luck 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.

$$I = 1.816 \log PGA + 3.373 \qquad (I<VII), \qquad (2)$$

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.

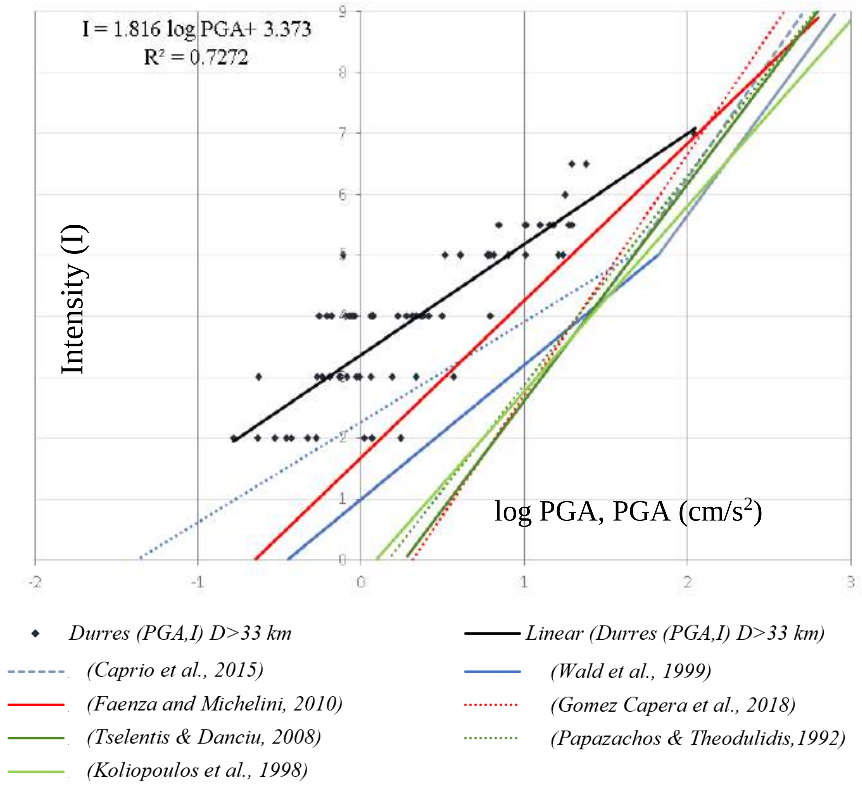

Fig. 3: Collected data and macroseismic intensity vs. PGA model (Eq. 2) (black line) is compared to the regional and worldwide empirical models. Line colours show the empirical model: blue for the world-wide models - Wald *et. al*., 1999 (solid line), Caprio *et.al.*, 2015 (dotted line); red for Italian 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 luck 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≤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.

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