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The November 26, 2019 Mw 6.4 Durrës (Albania) earthquake

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About

Non-periodic publication of the Post-graduate Studies Program “Environmental Disasters & Crises Management Strategies" of the National & Kapodistrian University of Athens, issued after significant events for the immediate information of the scientific community and the general public. The publication includes also scientific data from various research teams from universities, organizations and research institutes.

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Scientific Mission

Of the National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Department of Dynamic Tectonic Applied Geology

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THE NOVEMBER 26, 2019, Mw 6.4 DURRËS EARTHQUAKE

On November 26, 2019, an earthquake struck the central western part of Albania. It was assessed as Mw 6.4. Its epicenter was located offshore northwestern Durrës, in a distance of about 7 km north of the city and 30 km west from the capital city of Tirana. Its focal depth was about 10 km. Based on the focal plane solutions provided by several seismological institutes and observations, the mainshock was generated by the activation of a NW-SE striking reverse fault. The main shock was felt in the neighboring Montenegro, Italy and Greece, especially in Corfu Island.

The aftershock sequence until 30 November included hundreds of aftershocks, 22 with magnitude larger than M=4.0 and 4 with magnitude larger than M=5.0 (aftershocks by USGS until December 1, 2019).

The most earthquake-affected areas are the city of Durrës and the town of Thumanë at the central-western Albania. More specifically, Durrës city is located along the coastal part of the central-western Albania in a distance of 30 km west from the capital city of Tirana, while inland Thumanë in a distance of about 25 km northwest from the capital city of Tirana. Damage was also reported in Laç town, Fushë-Krujë town, Kamëz and Tirana city.

Unfortunately, the earthquake claimed the lives of 51 people. The number of injured are large reaching more than 750. More than 900 families have been evacuated from the affected areas and were in post-earthquake shelters and assembly areas including stadiums, not-affected hotels and other public facilities for the first days of the emergency phase.

Based on the emergency report of the International Federation of Red Cross and Red Crescent Societies, displaced people in Durrës have been moved from the tent camp that was initially set up in a stadium and are now accommodated in hotels in Vlora. Approximately 400 people still remain in camps in Thumanë and in Laç, a new tent camp is being set up, where approximately 200 are accommodated. Based on this report, the total number of people affected in terms of damage in property is estimated to be 80000-100000.

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Few hours after the mainshock, the authors visited the earthquake affected areas in order to assist the local authorities and civil protection agencies and to offer scientific and technical assistance not only to the authorities of the affected country but also to search and rescue teams that have arrived from several countries to assist Albania's efforts to rescue and recover.

Moreover, they conducted a field macroseismic survey and geological reconnaissance in order to assess the earthquake impact on the natural environment and the building stock of the most affected areas including Durrës city and Thumanë town.

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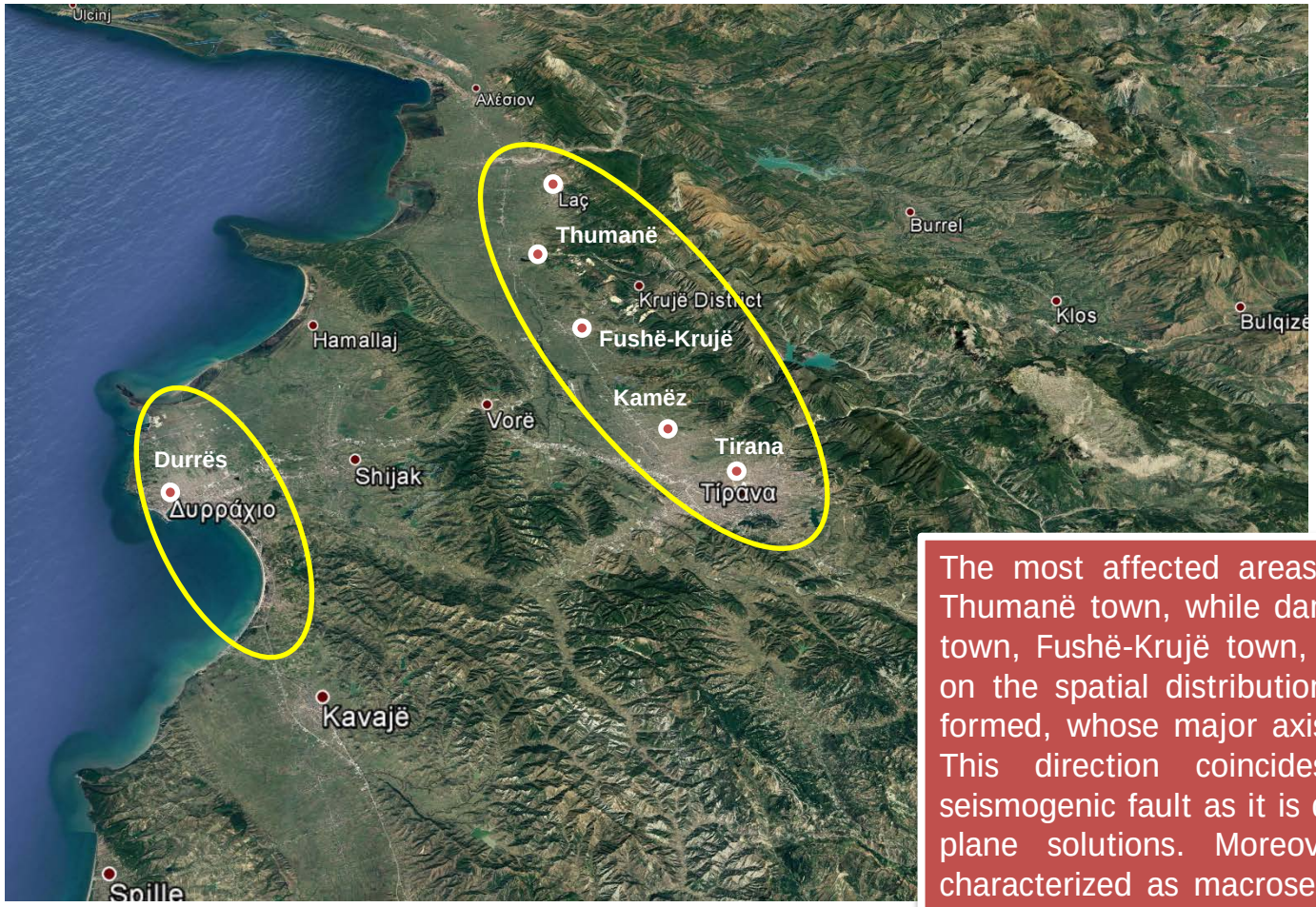
THE NOVEMBER 26, 2019, Mw 6.4 DURRËS EARTHQUAKE-AFFECTED AREA



The most affected areas are the Durrës city and the Thumanë town, while damage was also reported in Laç town, Fushë-Krujë town, Kamëz and Tirana city. Based on the spatial distribution of damage, two ellipses are formed, whose major axis is oriented generally NW-SE. This direction coincides with the strike of the seismogenic fault as it is derived from the provided fault plane solutions. Moreover, these ellipses could be characterized as macroseismic epicenters as a result of the interaction between the seismotectonic setting and the soil conditions and as the outcome of various reflections, refractions, conventions, directivity phenomena of seismic waves and resonance resulting in destruction in the earthquake-affected area.

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THE SEPTEMBER 21, 2019, Mw 5.6 DURRËS EARTHQUAKE

The same area has been recently affected by the Mw 5.6 Durrës earthquake generated on September 21, 2019. Its epicenter was located offshore Durrës and its focal depth was about 18 km. An Mw 5.1 aftershock generated 10 minutes after the main shock.

Based on the field survey conducted by the authors shortly after the September 21, 2019, Mw 5.6 Durrës earthquake (*Lekkas et al., 2019*), it is concluded that only secondary effects were observed comprising slope movements and liquefaction phenomena. Landslides were induced at slopes along the road leading from Durrës to Kavaje (Shkembi i Kavajes) resulting in temporary traffic disruption. Liquefaction phenomena were detected in the area east of Durrës port and were indicated by ejected sand and water on pavements and small scale subsidence.

Based on the field survey conducted by the authors shortly after the September 21, 2019, Mw 5.6 Durrës earthquake, the following conclusions can be drawn:

- As regards the impact on the building stock, the mainshock induced damage to buildings of Durrës, Tirana and several settlements of the broader area.

- The dominant building types in the affected area comprise unreinforced structures with load-bearing masonry walls and buildings with reinforced-concrete (RC) framing system and infill baked clay and/or concrete walls. Moreover, mixed types were also observed. The majority of recent buildings have been constructed according to the KTPs – Albanian Technical Codes, which were first issued and implemented in 1963 and last updated in 1989.

- Non-structural damage was observed to buildings with reinforced concrete frame comprising mainly detachment of plaster pieces from the unreinforced masonry infill wall, pounding phenomena between adjacent buildings, separation cracks between RC framing members and infill walls, damage of non-bearing elements supported by RC cantilevers.

- The unreinforced structures with the load-bearing masonry walls suffered the most by the earthquake due to reasons comprising old construction age, poor quality of construction, poor workmanship, interventions made by people, the design code of the time - if ever was applied - lack of maintenance and inadequate repair after previous damaging seismic events. This type suffered not only non-structural damage but also structural damage including partial or total collapse of the load-bearing masonry walls.

THE SEPTEMBER 21, 2019, Mw 5.6 DURRËS EARTHQUAKE

Significant details for the earthquake affected Tirana - Durrës area as well as the wider study area have already presented in the 13th issue of the Newsletter of Environmental, Disaster and Crises Management Strategies published by *Lekkas et al. (2019)*.

These details refer to the location of Albania in the Alpine Hymalayan belt, the geology of Albanides, the neotectonic structure and neotectonic zonation of Albania, the active faults and fault zones of the affected area, the seismicity and the seismic hazard of the affected area among others. For this reason, these topics are only briefly discussed in this issue for the November 26, 2019 earthquake.

Lekkas et al. (2019), available at:
https://edcm.edu.gr/images/docs/newsletters/Newsletter_13_2019_Albania_EQ.pdf

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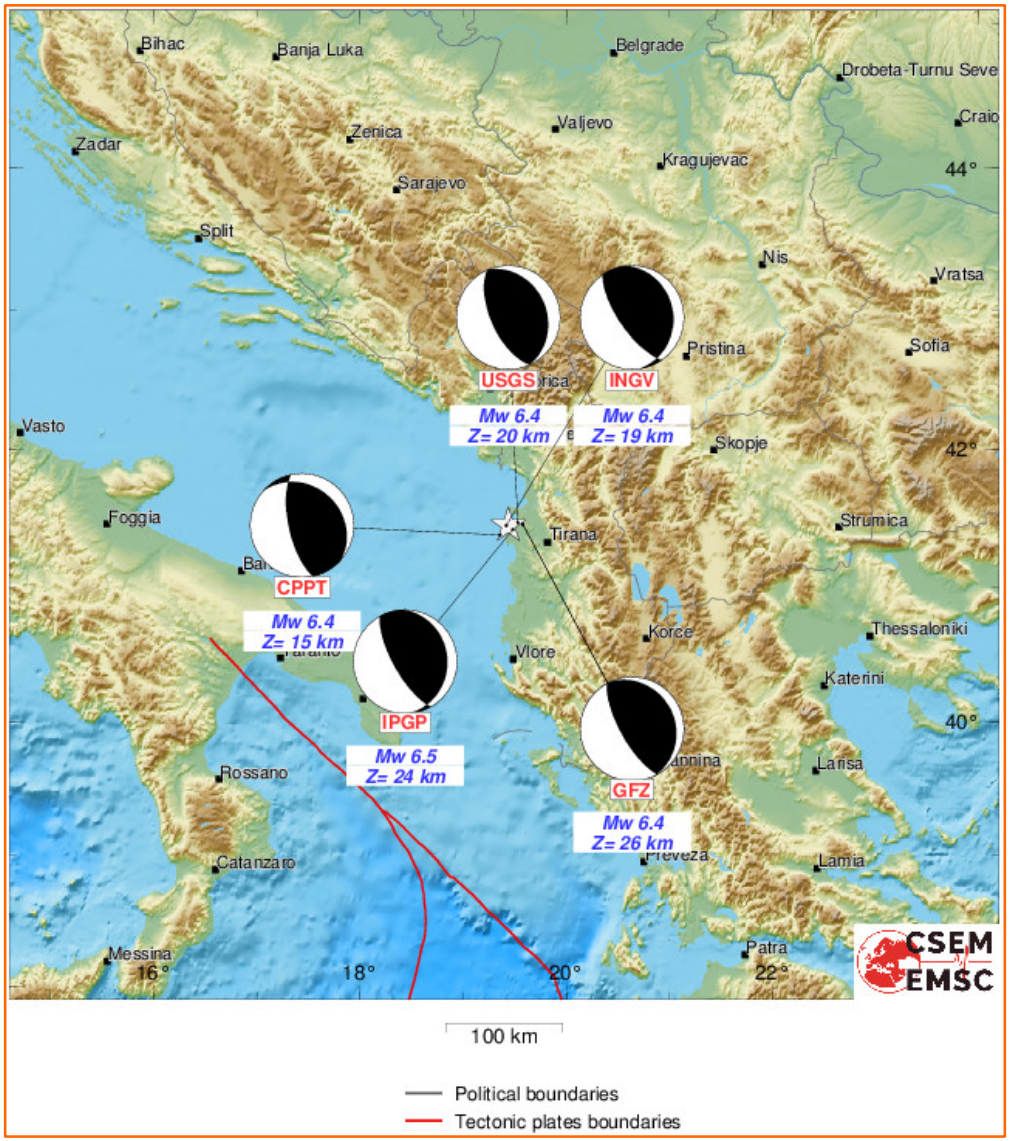
QUICK SOLUTIONS AND REGIONAL MOMENT TENSORS FOR THE NOVEMBER 26, 2019 EARTHQUAKE



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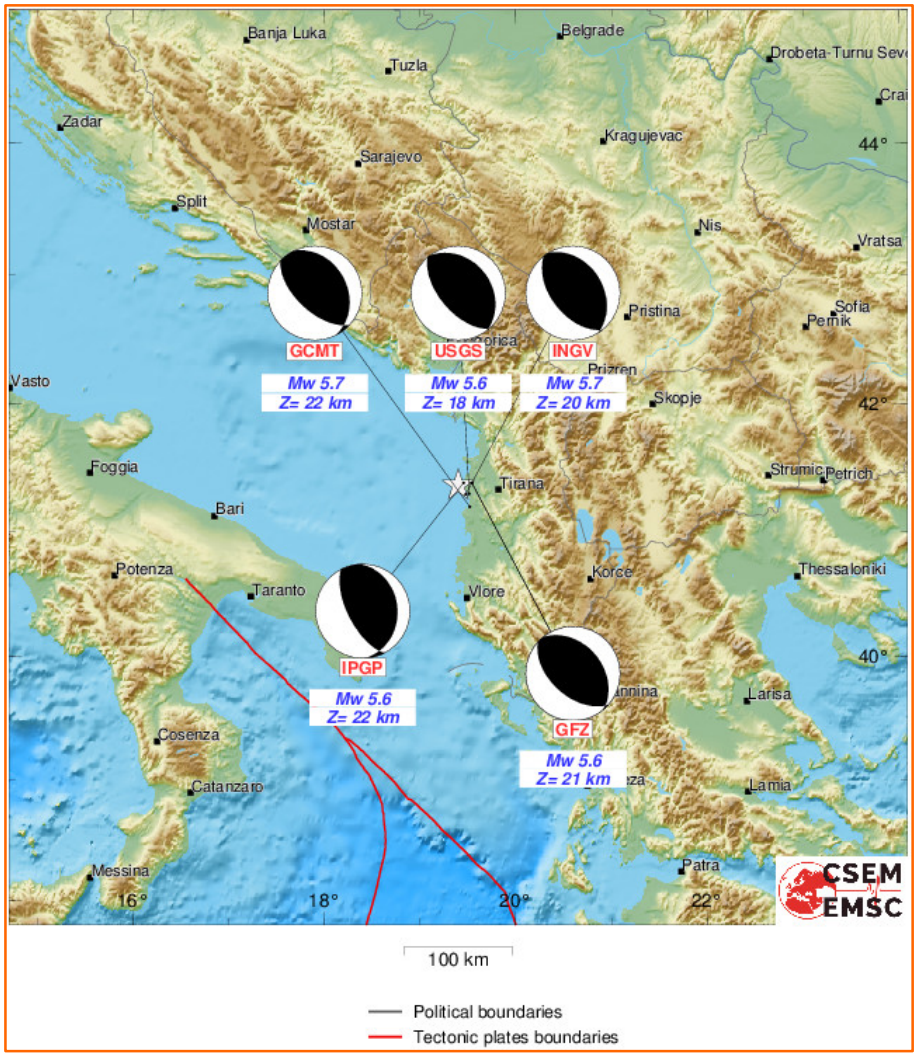
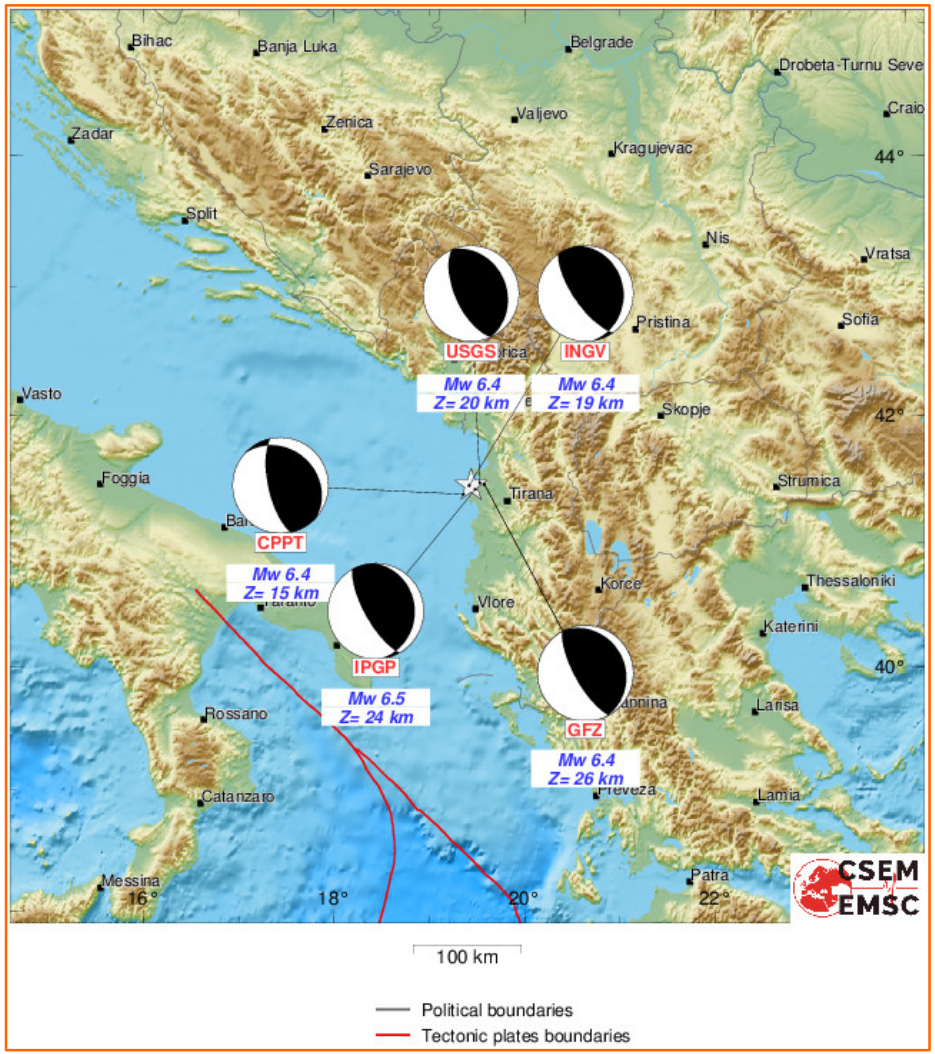
QUICK SOLUTIONS AND REGIONAL MOMENT TENSORS FOR THE SEPTEMBER 21 AND NOVEMBER 26, 2019 DURRËS EARTHQUAKES



September 21, 2019



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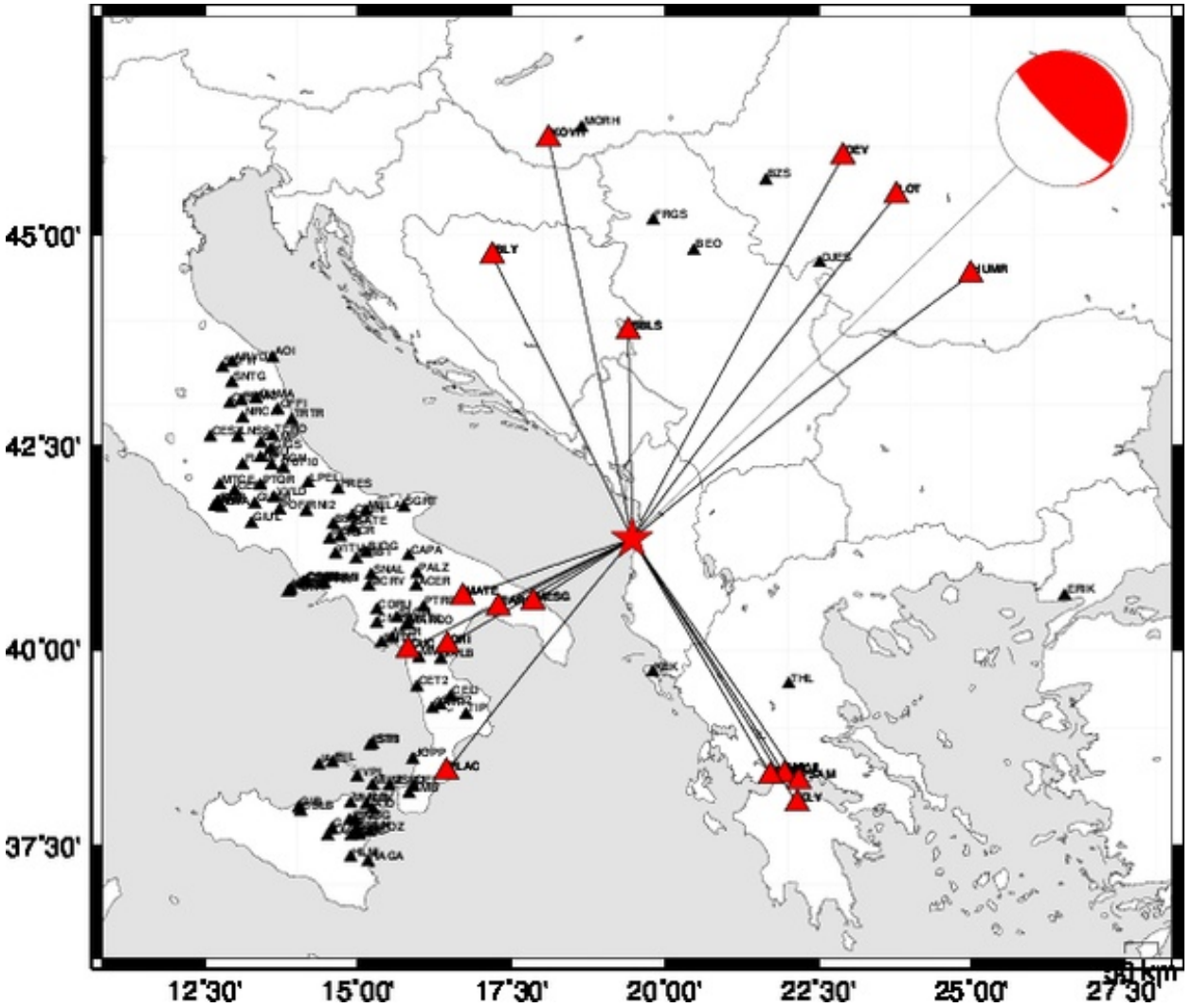
FOCAL MECHANISM
FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



http://webservices.ingv.it/webservices/ingv_ws_map/data/tdmt/15191/74019941_302_tdmt_reviewer_solution.pdf

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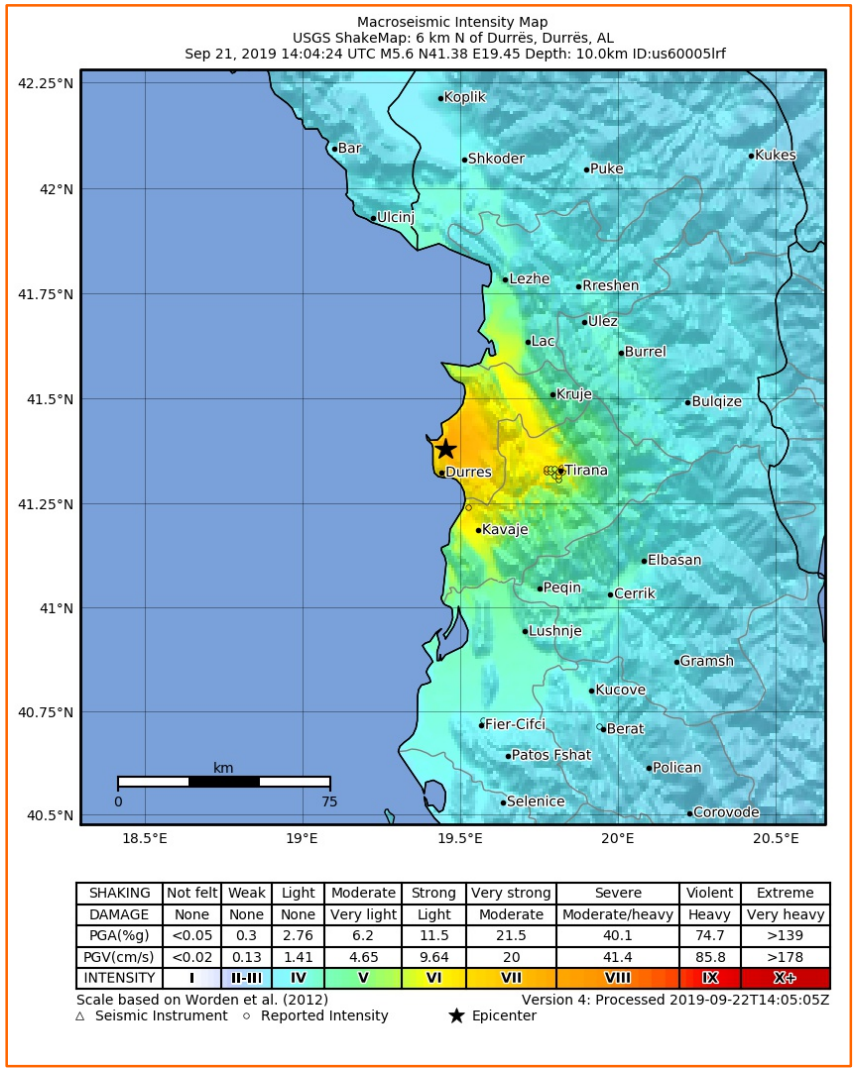
INTENSITY MAPS FOR THE SEPTEMBER 21 AND NOVEMBER 26 DURRËS EARTHQUAKES



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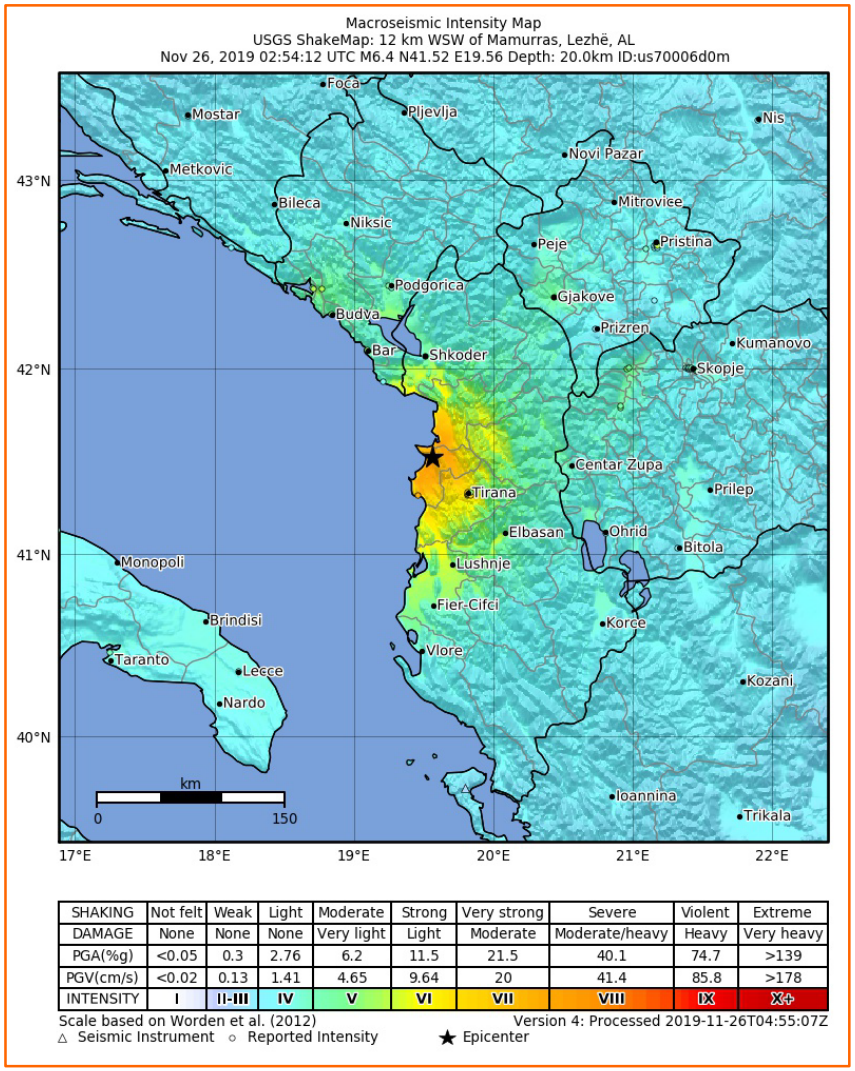

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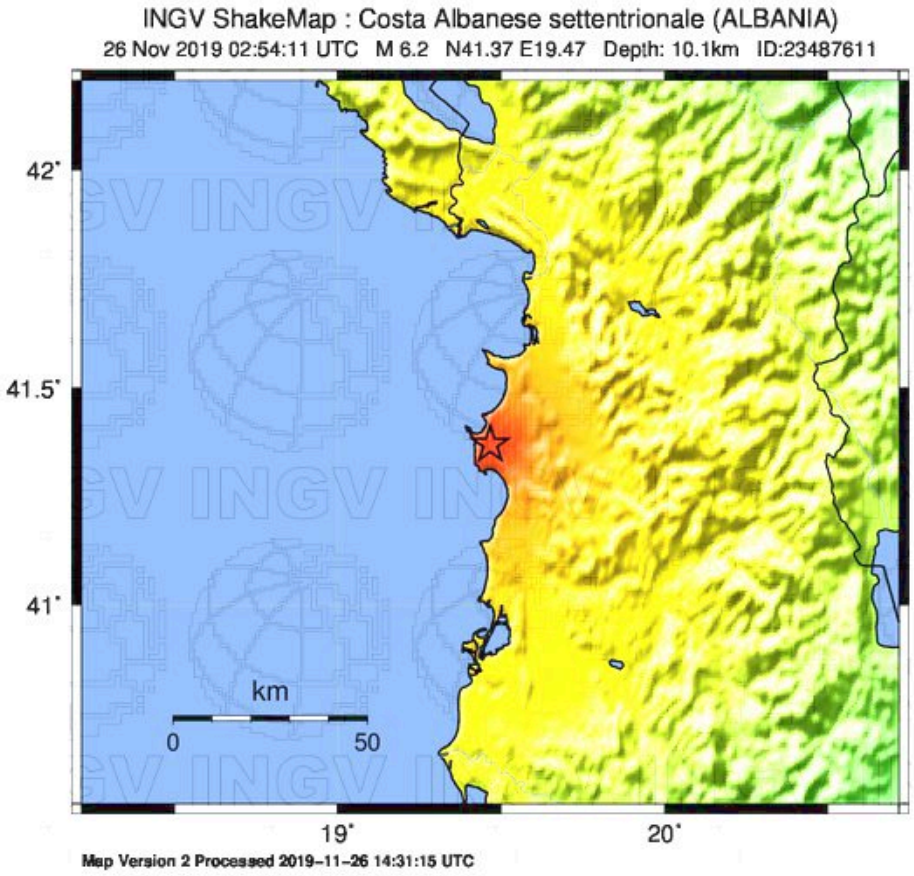
INTENSITY MAP
FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.06	0.2	0.8	2.0	4.8	12	29	70	>171
PEAK VEL.(cm/s)	*<0.02*	*0.08*	*0.3*	*0.9*	*2.4*	*6.4*	*17*	*45*	*>120*
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Faenza and Michelini, 2010, 2011

This map shows the distribution of instrumental intensities. The scale used is the Modified Mercalli Scale (MMI - Modified Mercalli Intensity) and is based on the recorded values of effective ground shaking in terms of ground acceleration and speed. In general, the Mercalli intensity scale is based on the effects that the shaking induces and which is reported by an observer.

http://terremoti.ingv.it/event/23487611
http://shakemap.rm.ingv.it/shake/23487611/intensity.html

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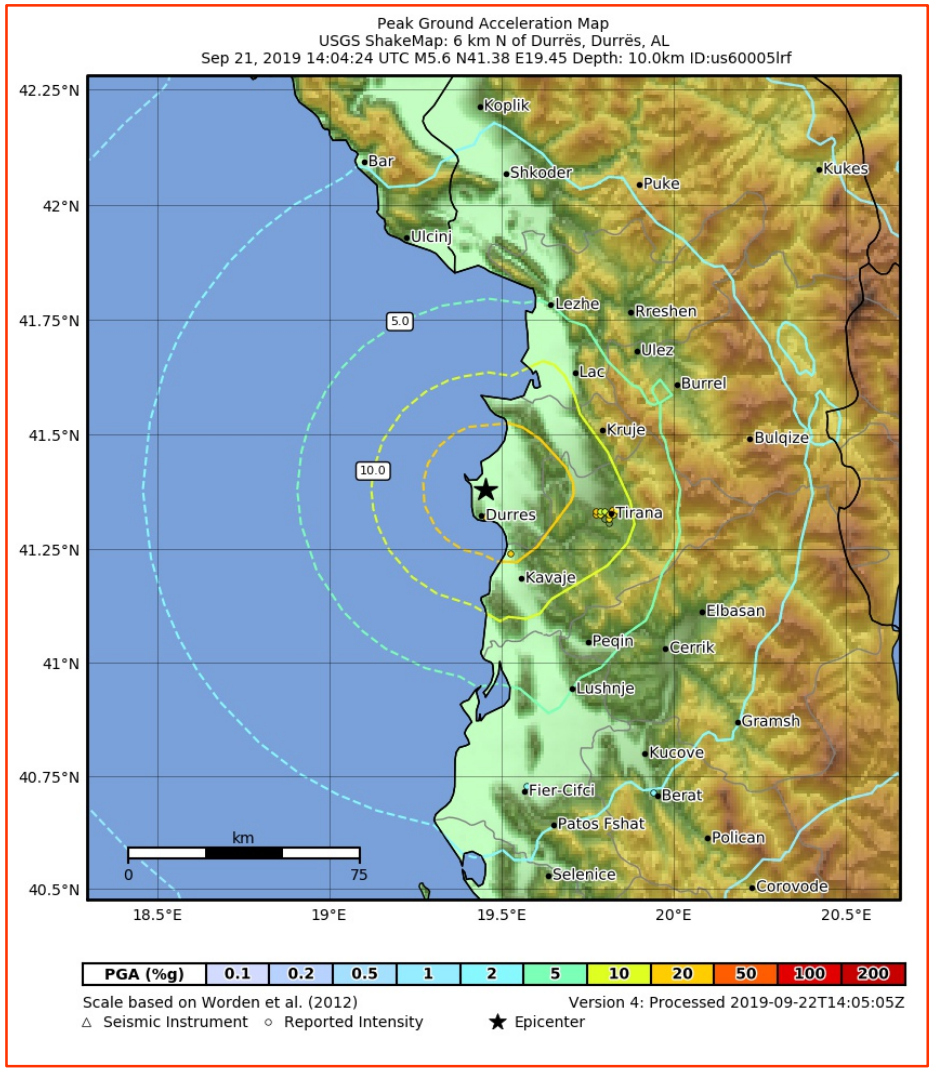
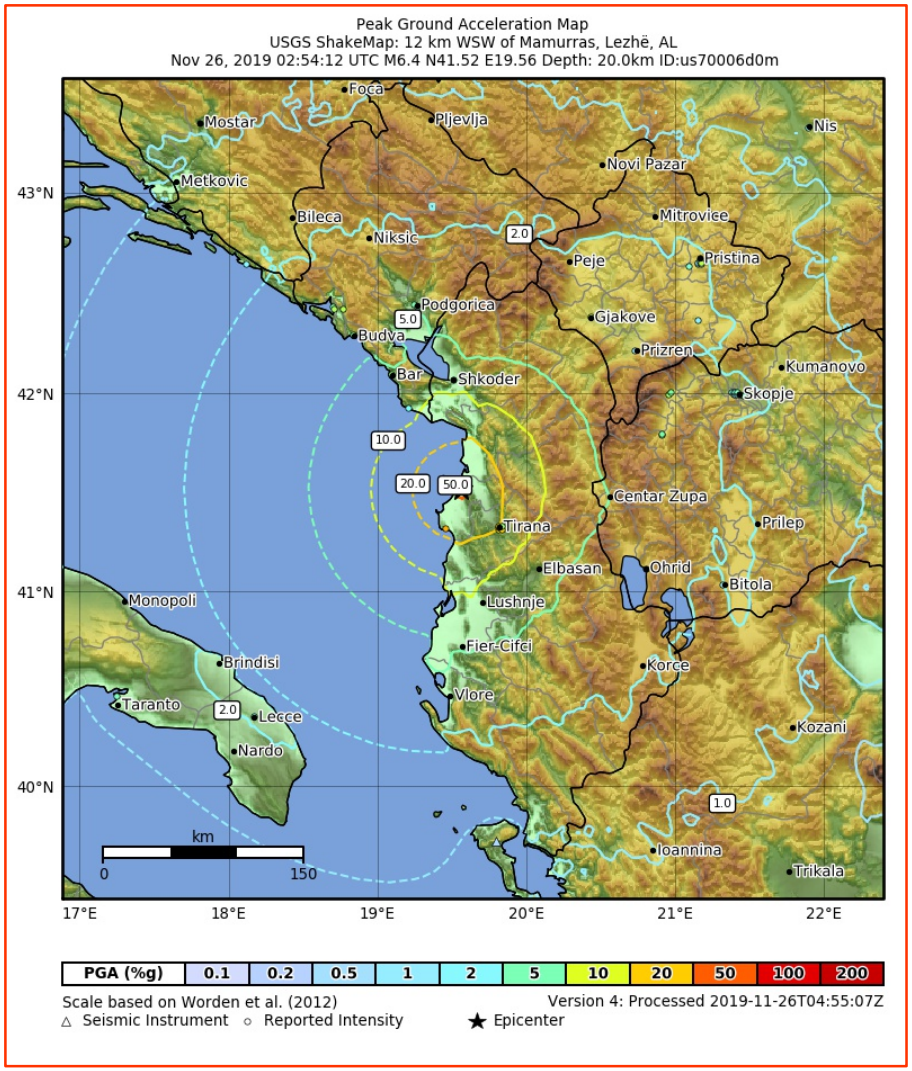
PEAK GROUND ACCELERATION MAPS FOR THE SEPTEMBER 21 AND NOVEMBER 26 DURRËS EARTHQUAKES



September 21, 2019



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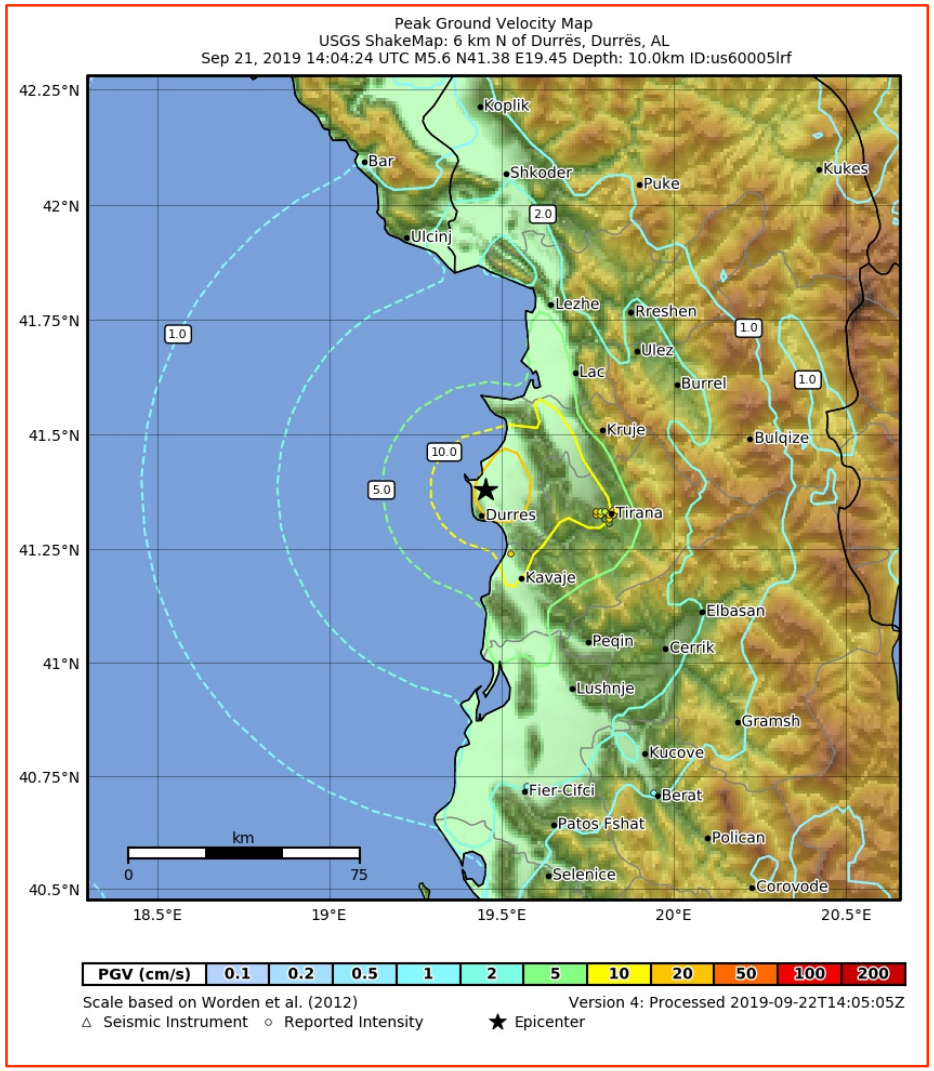
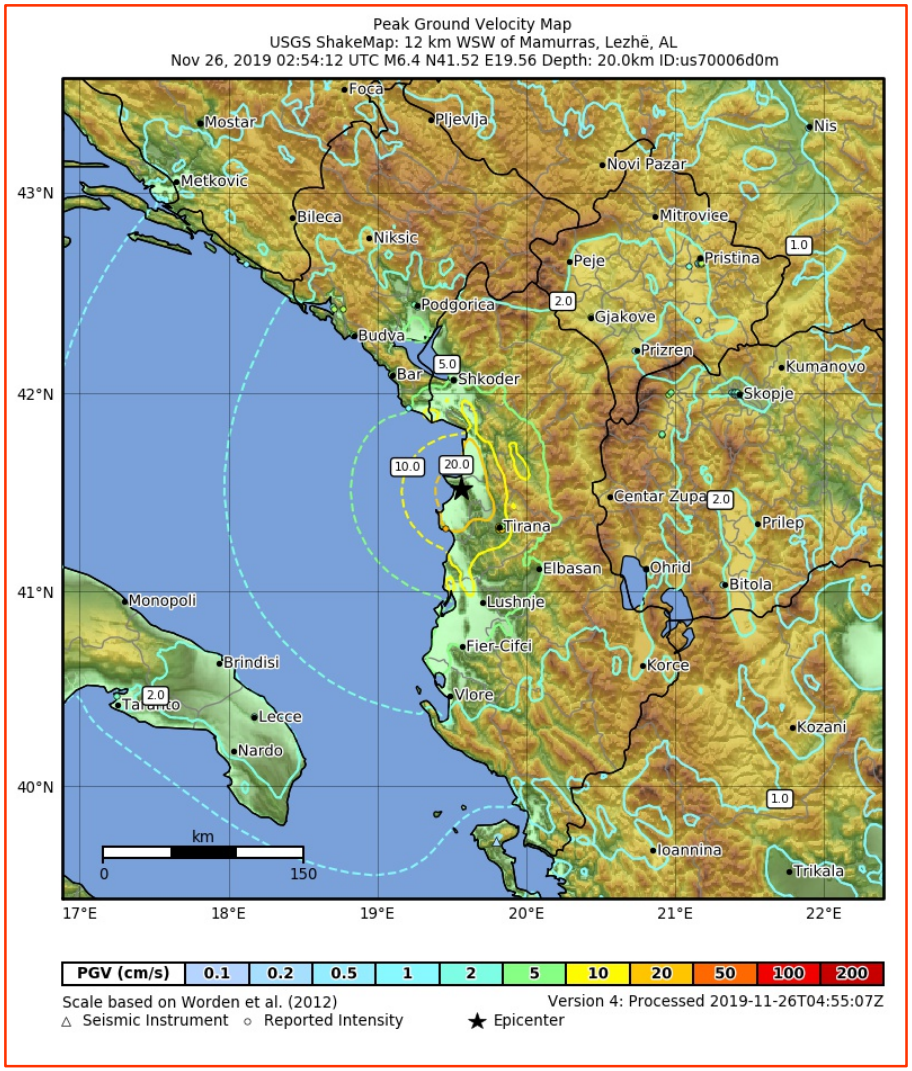
PEAK GROUND VELOCITY MAPS FOR THE SEPTEMBER 21 AND NOVEMBER 26 DURRËS EARTHQUAKES





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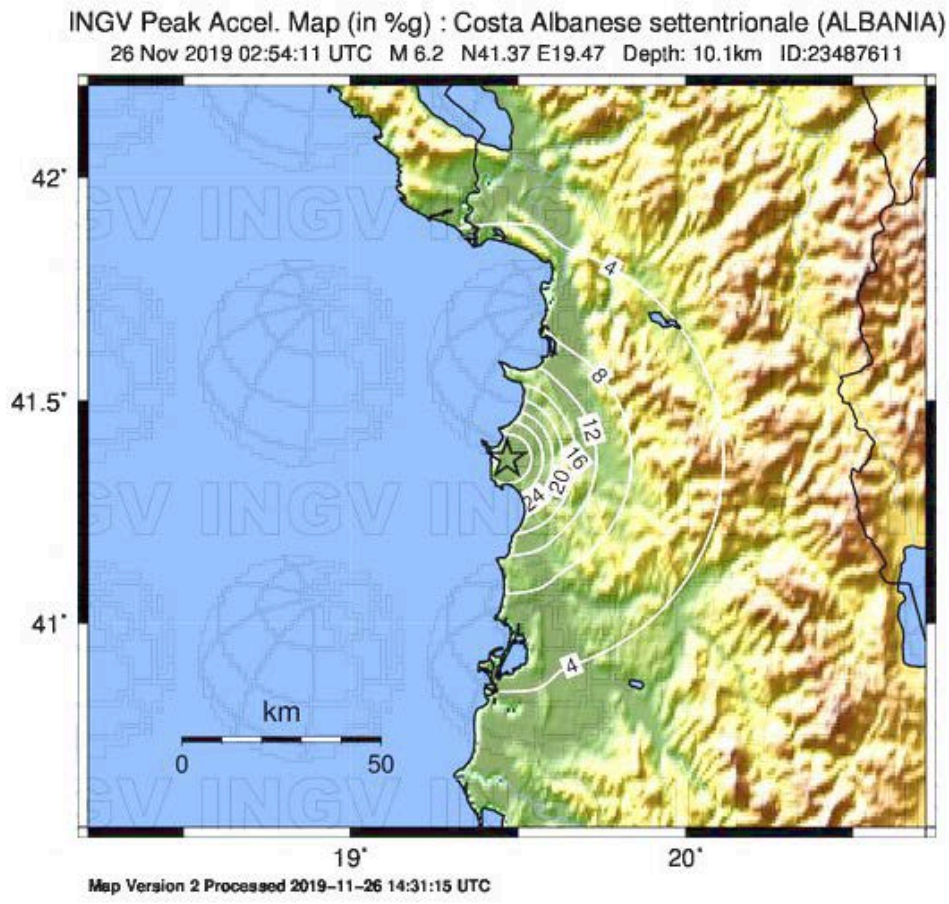
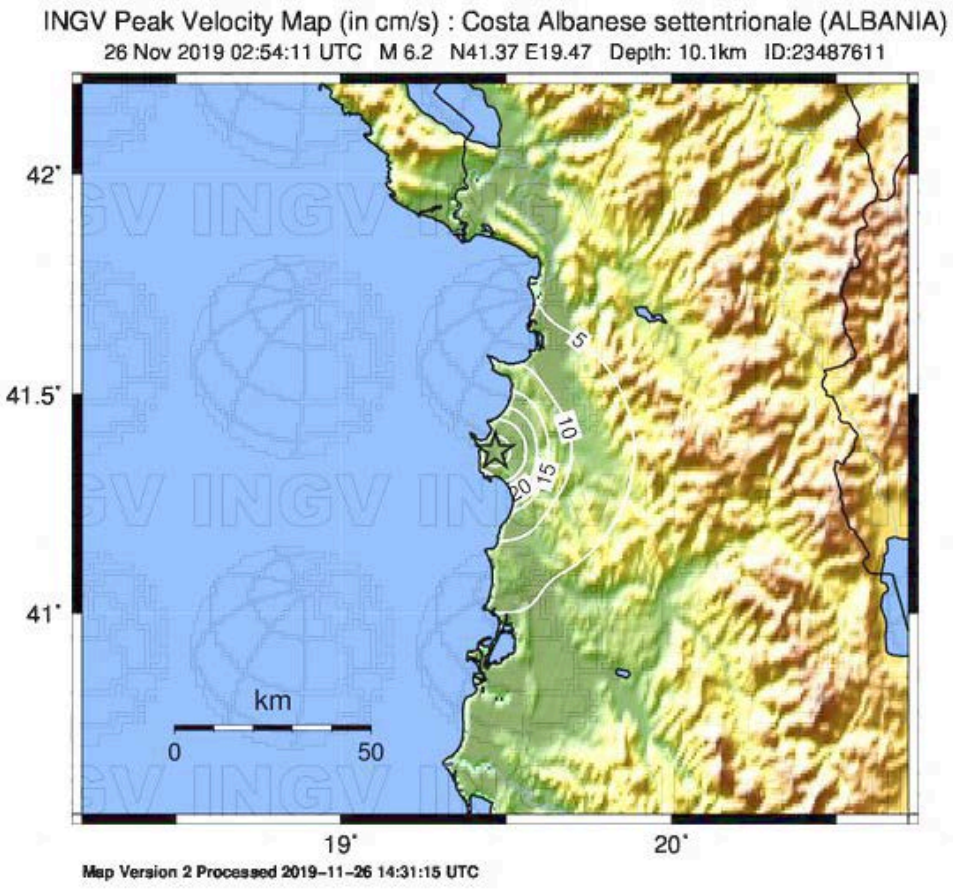
PEAK GROUND ACCELERATION AND VELOCITY MAPS FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE





http://shakemap.rm.ingv.it/shake/23487611/pga.html

http://shakemap.rm.ingv.it/shake/23487611/pgv.html

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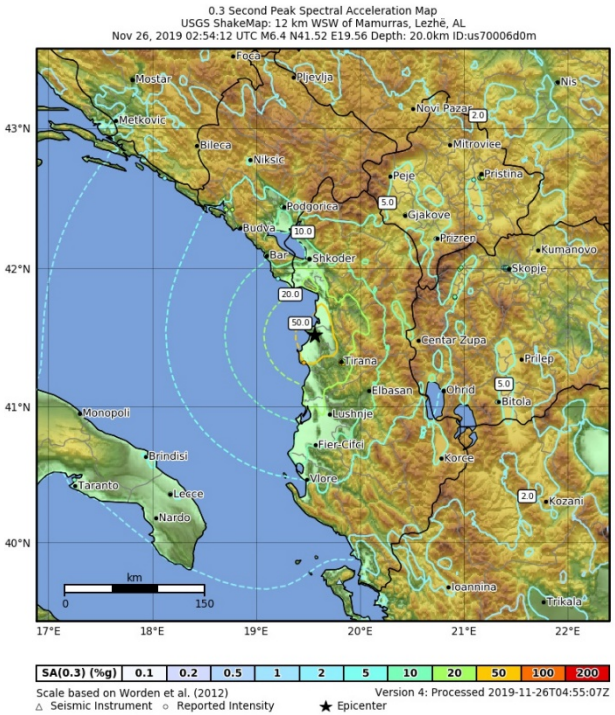
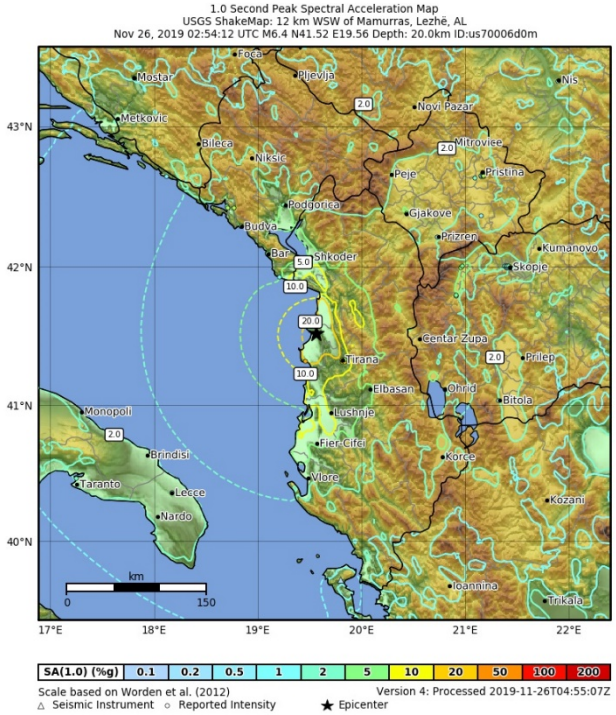
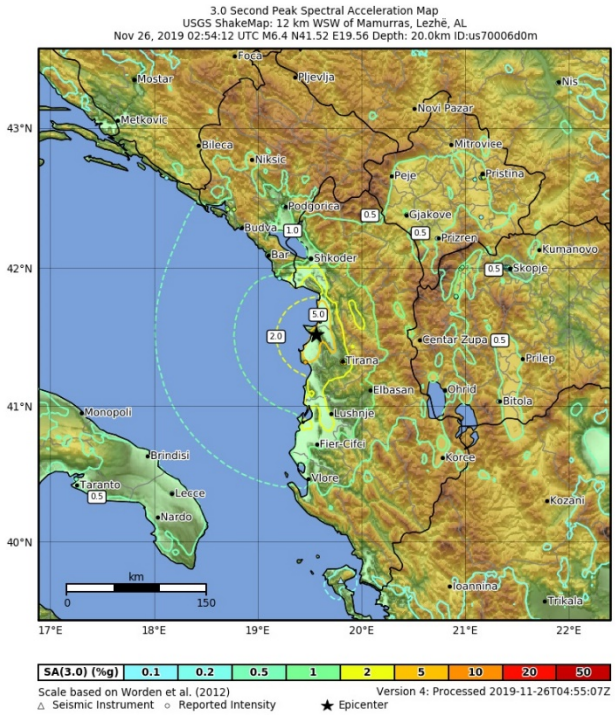
SPECTRAL RESPONSE FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE

USGS science for a changing world







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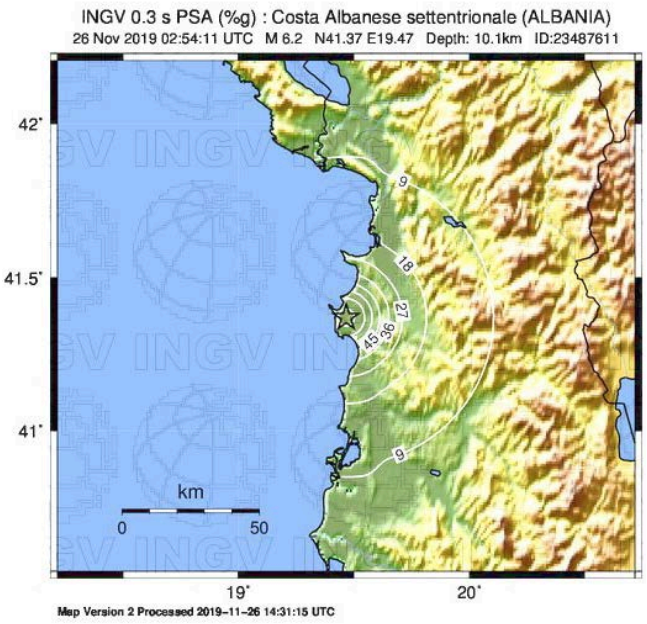
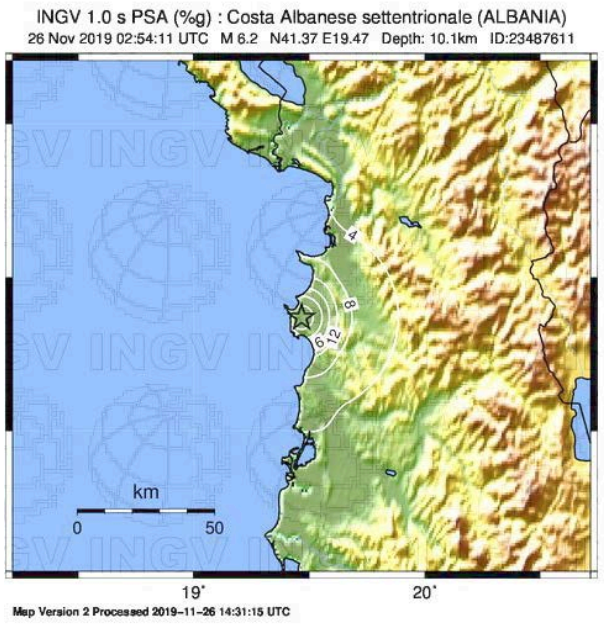
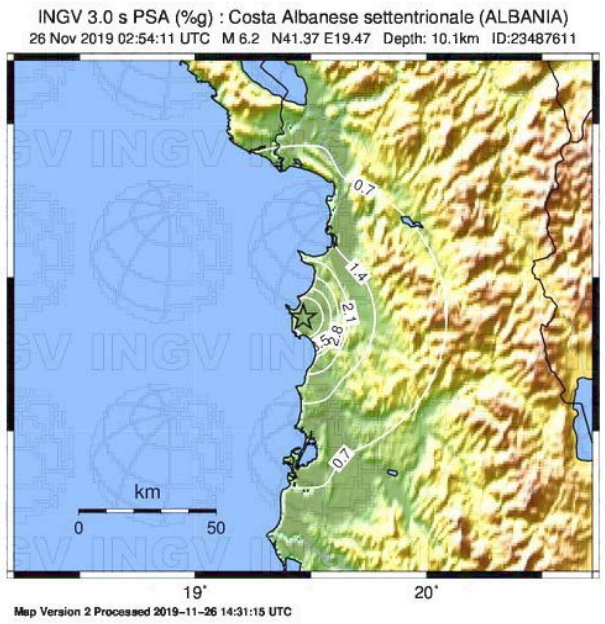
SPECTRAL RESPONSE
FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE







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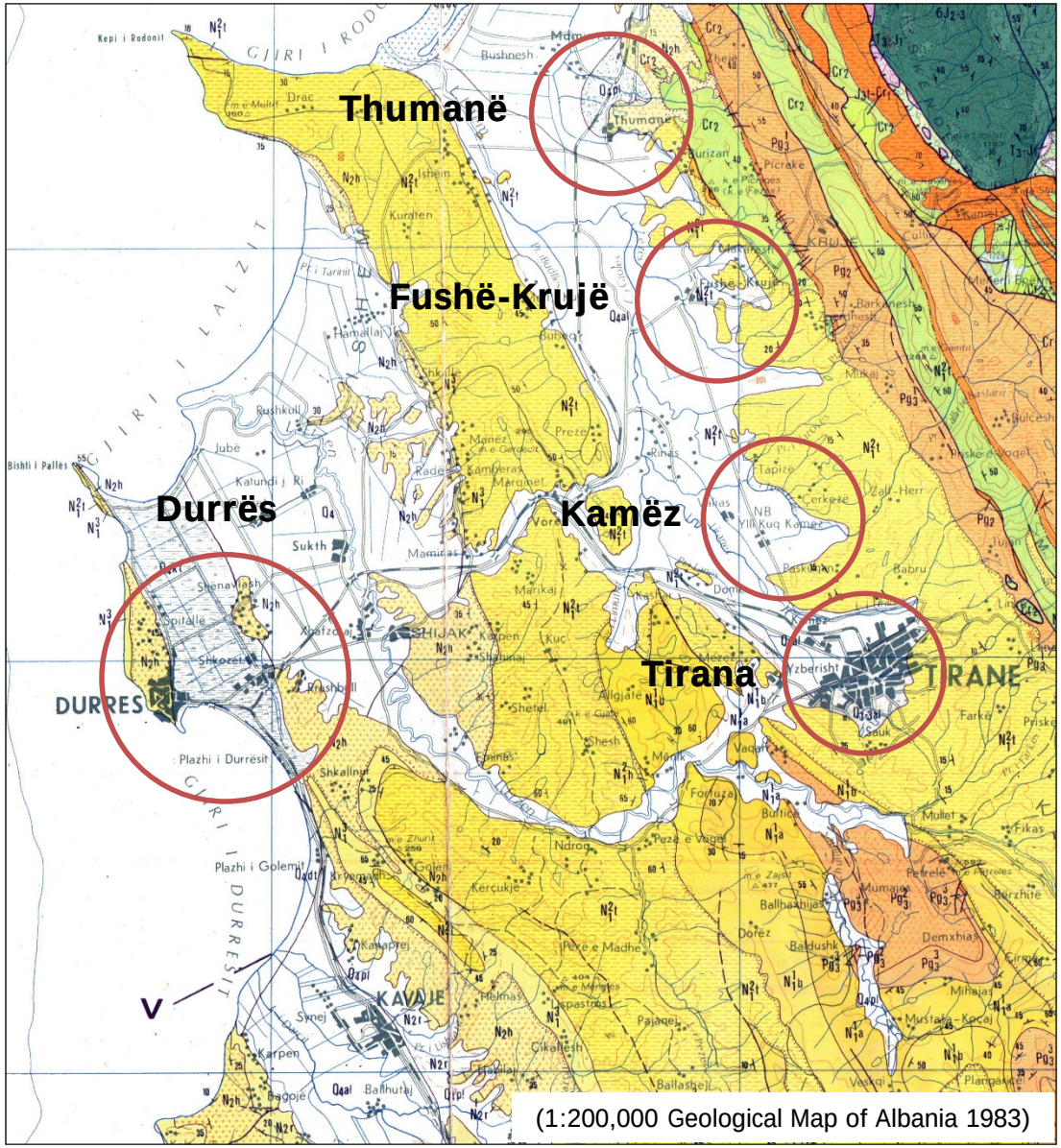
GEOLOGY OF THE NOVEMBER 2019 EARTHQUAKE-AFFECTED AREA



(1:200,000 Geological Map of Albania 1983)

Q_4^{al}	Holocene alluvial deposits with gravels, sand etc
Q_4^{kt}	Holocene marshy deposits, clays, sands and peat
Q_4	Holocene mixed deposits including alluvial and marshy deposits etc
N_2^h	Pliocene clays
N_1^{2t}	Tortonian sandstones, clays and conglomerates
N_1^3	Messinian sandstones, clays and gypsum
N_1^{1b}	Burdigalian marls, clays and limestones
N_1^{1aq}	Lower Aquitanian. Gray marine clays, moraines and coal
Pg_3^3	Upper Oligocene clay-sandstone with limestone, massive sands, clays and coal
Pg_3^2	Middle Oligocene flysch with clays and sandstone, conglomerates, limestone, coals and charcoal.
Pg_3^1	Lower Oligocene flysch with clay and sandstone.

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GEOLOGY OF THE NOVEMBER 2019 EARTHQUAKE-AFFECTED AREA

The geology of the area affected by the September 21 and November 26, 2019 Durrës earthquakes comprise recent deposits. Their age ranges from Oligocene to present based on the *geological map of Albania (scale 1:200.000, 1983)* and *Shallo et al. (2002).* These formations constitute a large part of the Tirana depression, which is located at the northeastern side of the wider Periadriatic depression.

The Oligocene formations comprise flysch with clays and sandstones, limestone, coal and charcoal.

The Miocene formations include:
(i) gray marine clays, moraines and coals of Lower Aquitanian,
(ii) marls, clays and limestones of Burdigalian
(iii) sandstones, clays and gypsum of Messinian and
(iv) sandstones, clays and conglomerates of Tortonian age.

The Pliocene is represented by clays.

The Quaternary deposits comprise Holocene marshy deposits, clays, sands and peat as well as Pleistocene and Holocene alluvial deposits with gravels and sands and proluvial deposits with boulders and clays.

The city of Durrës is composed of Pliocene clays and Holocene marshy deposits including clays, sands and peat. It is significant to note that one of the most affected parts of Durrës with many severely damaged buildings is composed of marshy deposits. The geological structure of this area is also revealed by its name (Keneta in the Albanian language means marshes).

The town of Thumanë, where the majority of the fatalities were reported, is composed of Pleistocene and Holocene alluvial deposits with gravels and sands and proluvial deposits with boulders and clays as well as Pliocene clays.

The towns of Fushë-Krujë and Kamëz present geological setting similar to Thumanë. They are founded on Holocene marine deposits comprising mainly sand, on Pleistocene and Holocene alluvial and prolouvial deposits and Pliocene sandstones, clays and conglomerates.

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GEOLOGY OF THE NOVEMBER 2019 EARTHQUAKE-AFFECTED AREA

As regards the earthquake-affected areas of Laç town, Thumanë town, Fushë-Krujë town, Kamëz and Tirana city, they are located along the eastern margins of the Tirana depression. The alpine basement of the eastern margin comprises Oligocene flysch and Upper Cretaceous limestone, while Miocene formations are overlying the alpine basement. The Miocene formations dip westwards and southwestwards. More specifically, they dip 15° to the W in Thumanë, 15°-30° to the SW in Fushë-Krujë, 5°-15° to the SW in Kamëz and 10°-15° to the SW in Tirana area. Pliocene, Pleistocene and Holocene deposits are overlying Miocene formations. The most affected towns along the eastern margin of the Tirana depression are founded mainly on Holocene deposits.

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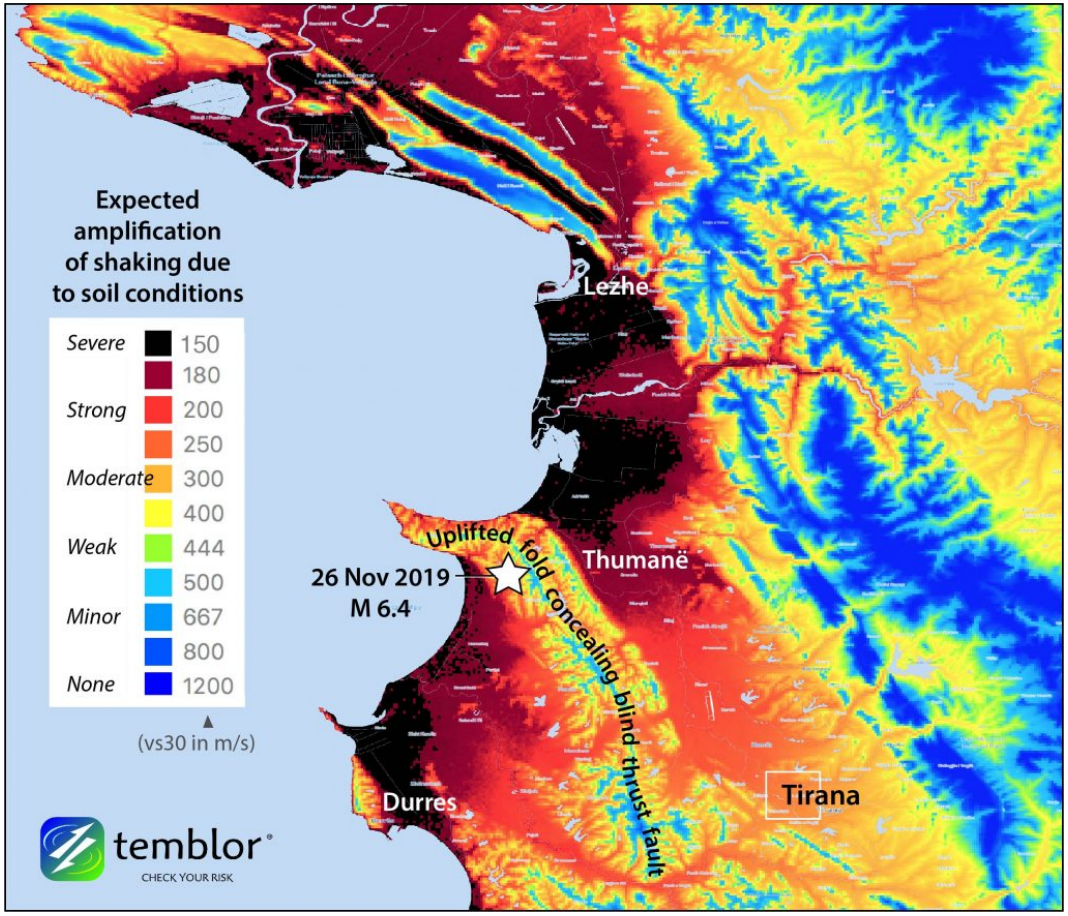
EFFECT OF THE GEOLOGY ON THE AMPLIFICATION OF SHAKING PRODUCED BY THE NOVEMBER 26, 2019 EARTHQUAKE



The shaking produced by the Mag. 6.4 shock was almost certainly amplified in the weak, unconsolidated basins and coastal estuaries surrounding the epicenter
(from *Stein and Sevilgen, 2019*; https://temblor.net/earthquake-insights/albania-earthquake-strikes-highest-hazard-zone-in-the-balkans-devastating-nearby-towns-10153/)

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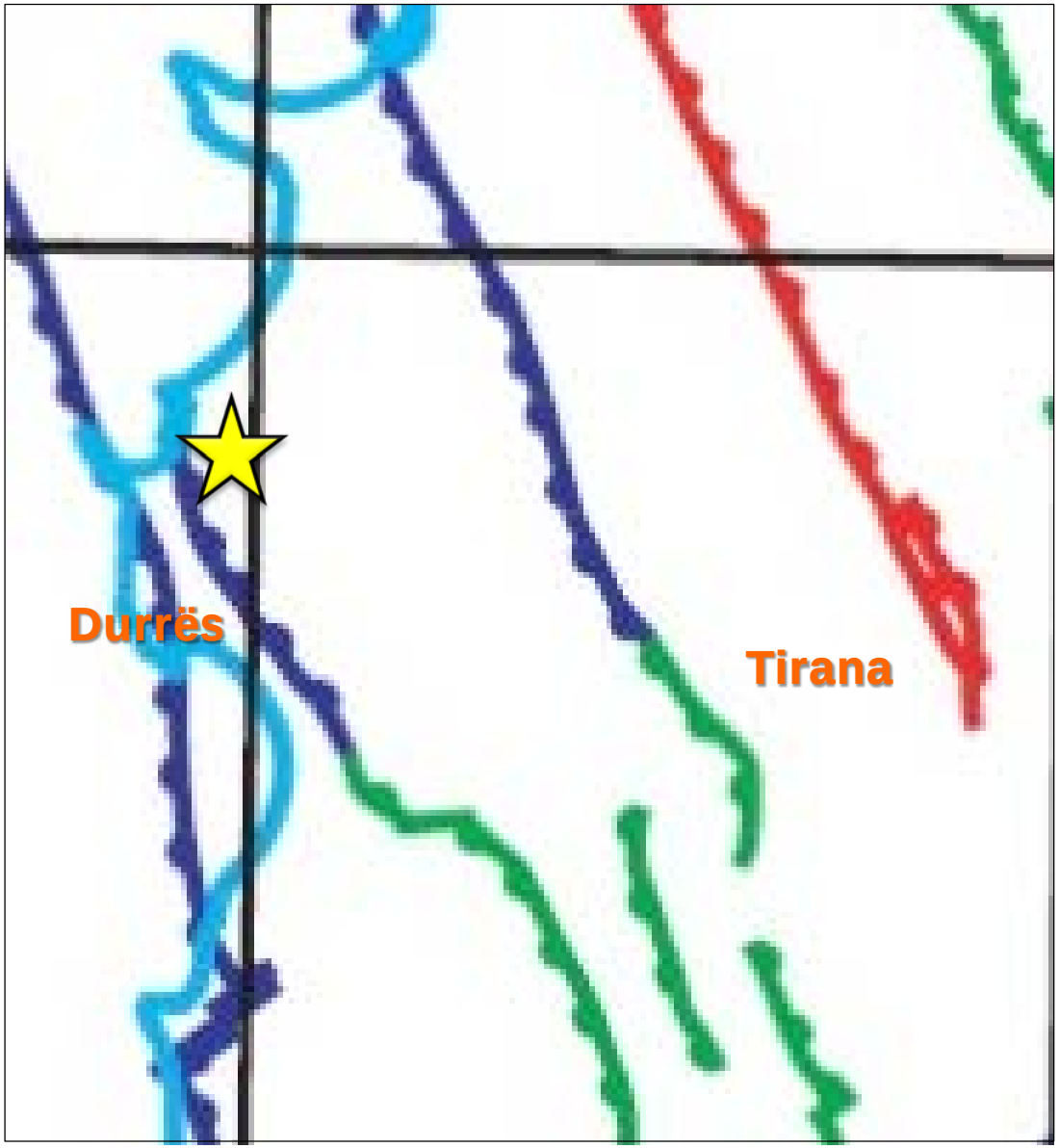
ACTIVE FAULT ZONES AND FAULTS OF THE NOVEMBER 26, 2019 EARTHQUAKE-AFFECTED AREA



The 2019 earthquake affected area is dominated by NW-SE striking reverse active faults.

Blue lines correspond to faults activated during Middle Pleistocene - Holocene (or Quaternary), the green lines to faults activated during Pliocene - Lower Pleistocene and the red lines to faults activated during Pre-Pliocene period.

The star corresponds to the epicenter of the Mw 6.4 Durrës earthquake occurred in November 26, 2019.

Based on the tectonic structure of the earthquake-affected area and the fault plane solutions of the November 26, 2019 Durrës earthquake, it is concluded that there is consistency between fault plane solutions and field geological data.

From *Aliaj (2000)*

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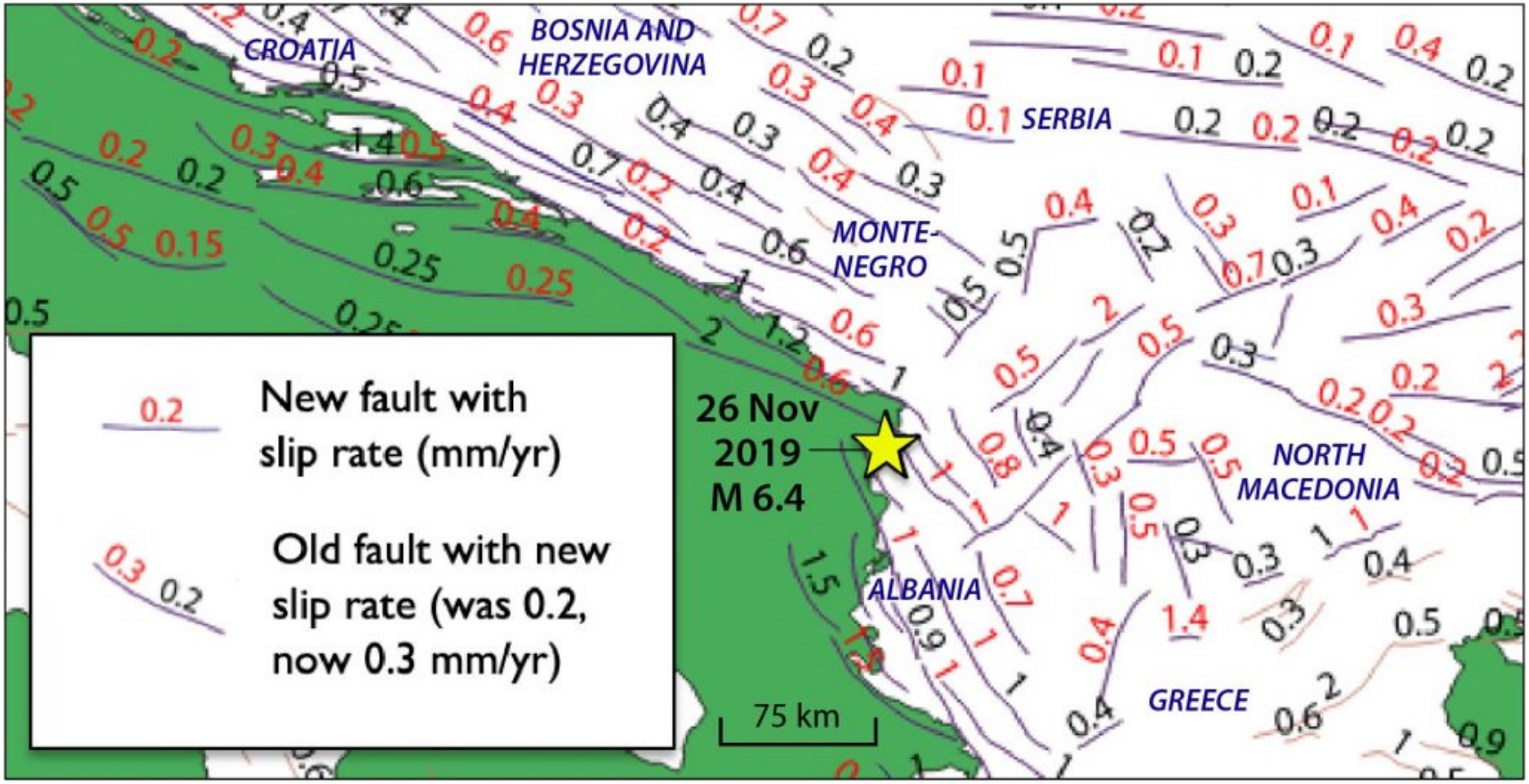
ACTIVE FAULTS AND SLIP RATES OF THE NOVEMBER 26, 2019 EARTHQUAKE-AFFECTED AREA



Active faults in the region for the European SHARE project using satellite imagery and field mapping (with inferred fault slip rates in black numerals by *Koci et al., 2011*, *Kastelic et al., 2016*) and revised fault slip rates (in red numerals by *Sevilgen et al., 2014*). Thrust faults near the November 26, 2019 epicenter are about 75 km long with slip rates of ~1 mm/yr (from *Stein and Sevilgen, 2019*; https://temblor.net/earthquake-insights/albania-earthquake-strikes-highest-hazard-zone-in-the-balkans-devastating-nearby-towns-10153/)

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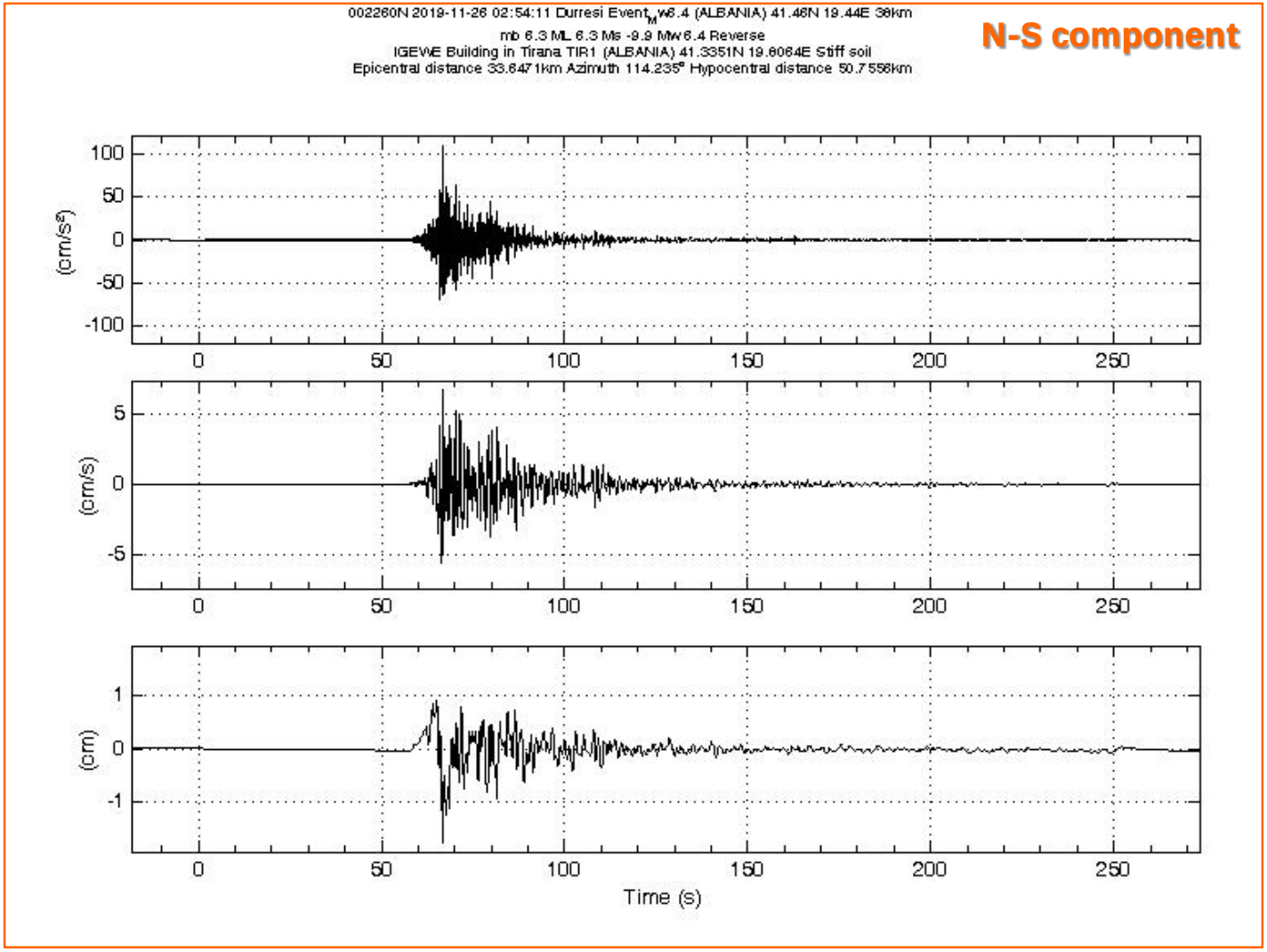
STRONG MOTION RECORDS FOR THE NOVEMBER 26, 2019 EARTHQUAKE



http://www.geo.edu.al/tirana_record/

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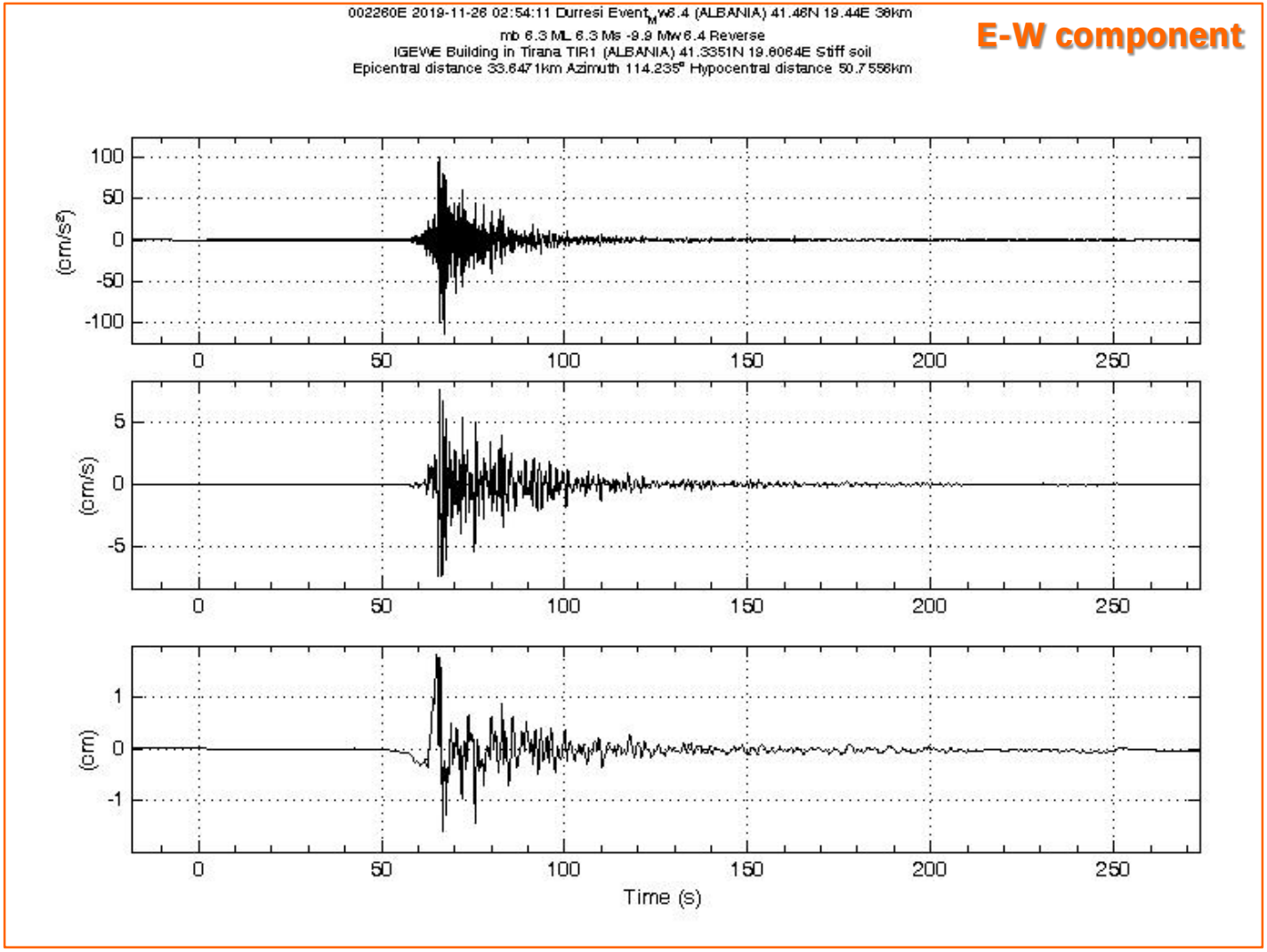
STRONG MOTION RECORDS FOR THE NOVEMBER 26, 2019 EARTHQUAKE



http://www.geo.edu.al/tirana_record/

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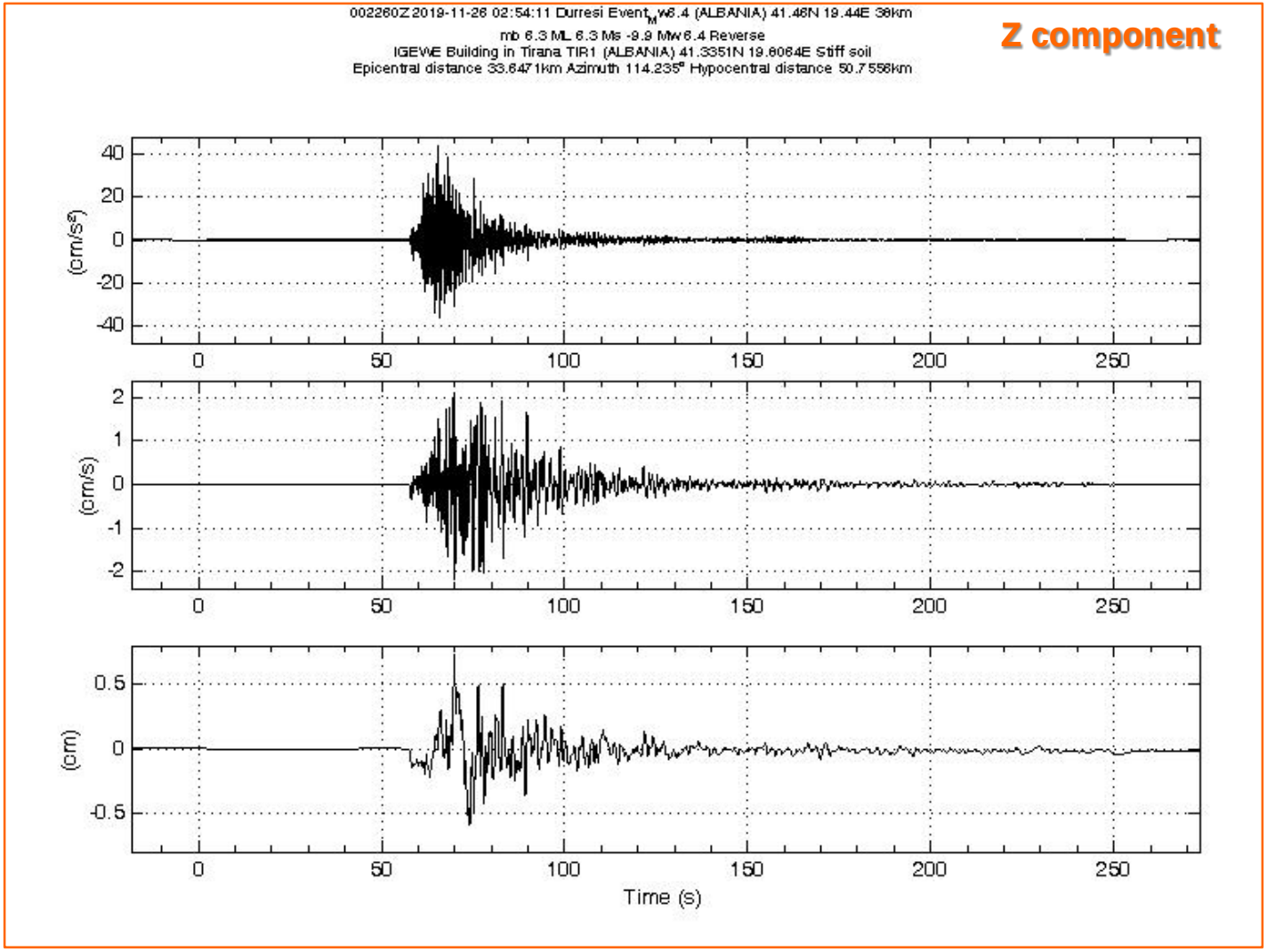
STRONG MOTION RECORDS FOR THE NOVEMBER 26, 2019 EARTHQUAKE



http://www.geo.edu.al/tirana_record/

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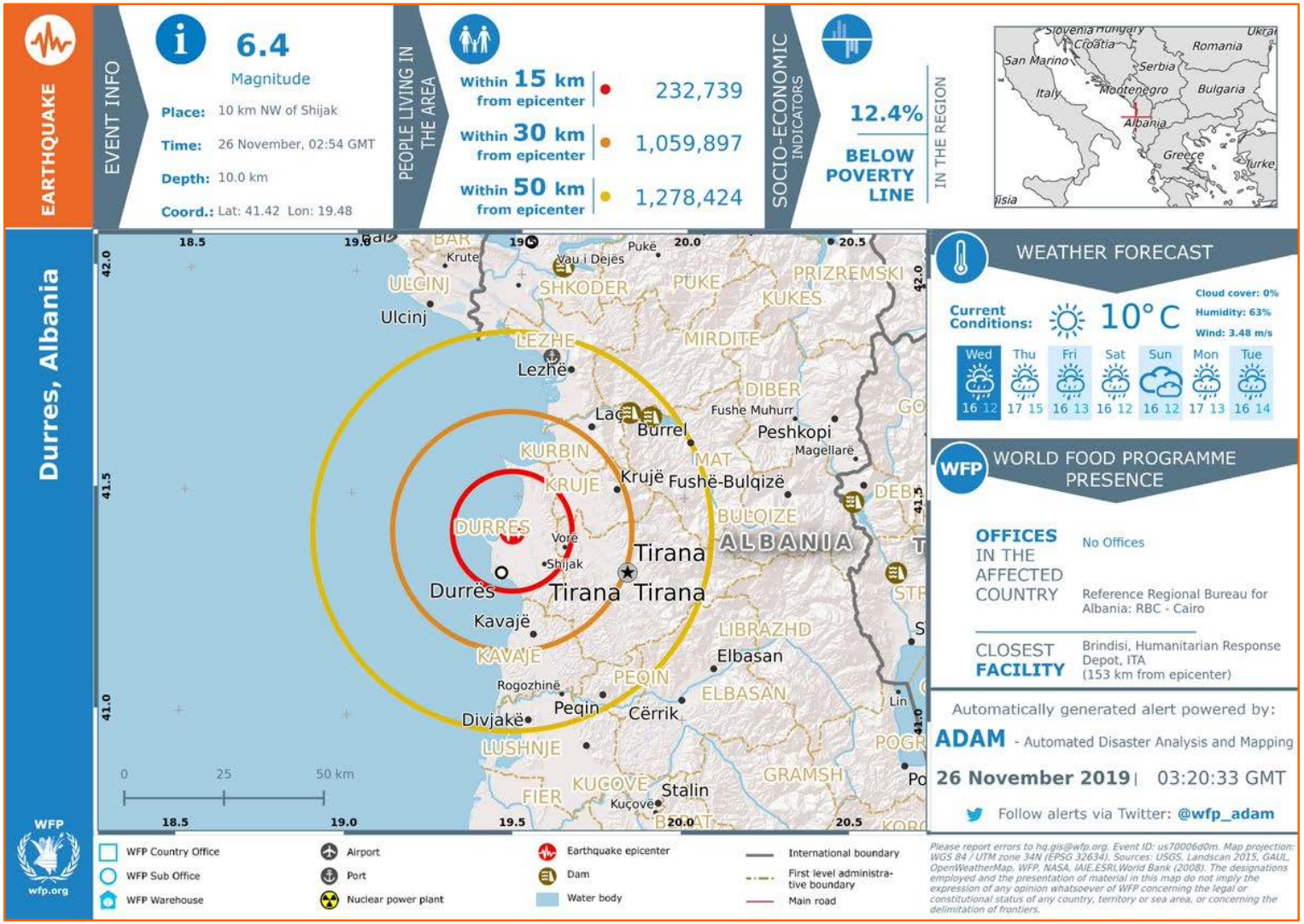
AUTOMATICALLY GENERATED DISASTER ALERT
FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



Automatic Disaster Analysis and Mapping (ADAM) Disaster Alerts: https://twitter.com/WFP_ADAM

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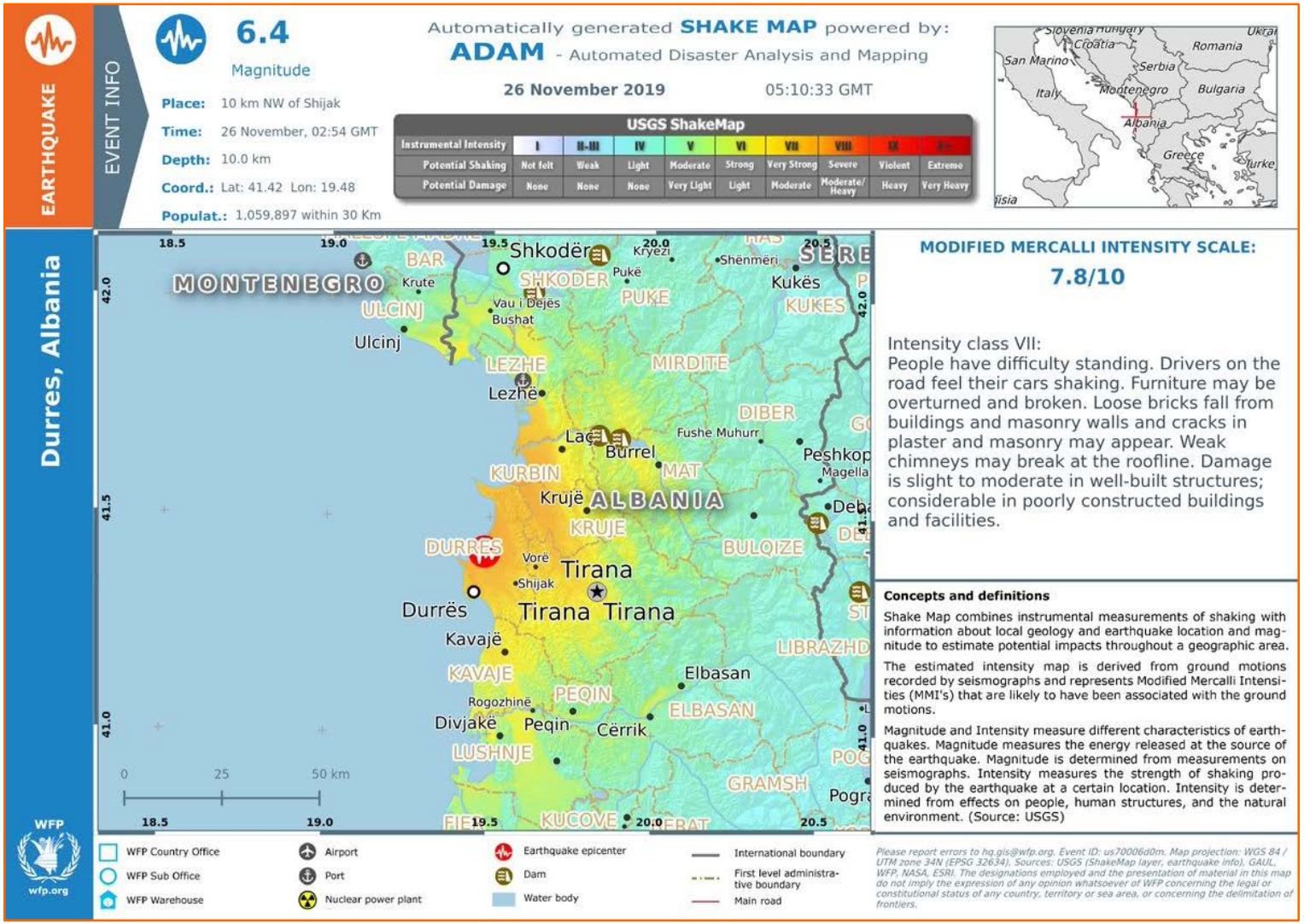
AUTOMATICALLY GENERATED SHAKE MAP
FOR THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



Automatic Disaster Analysis and Mapping (ADAM) Disaster Alerts: https://twitter.com/WFP_ADAM

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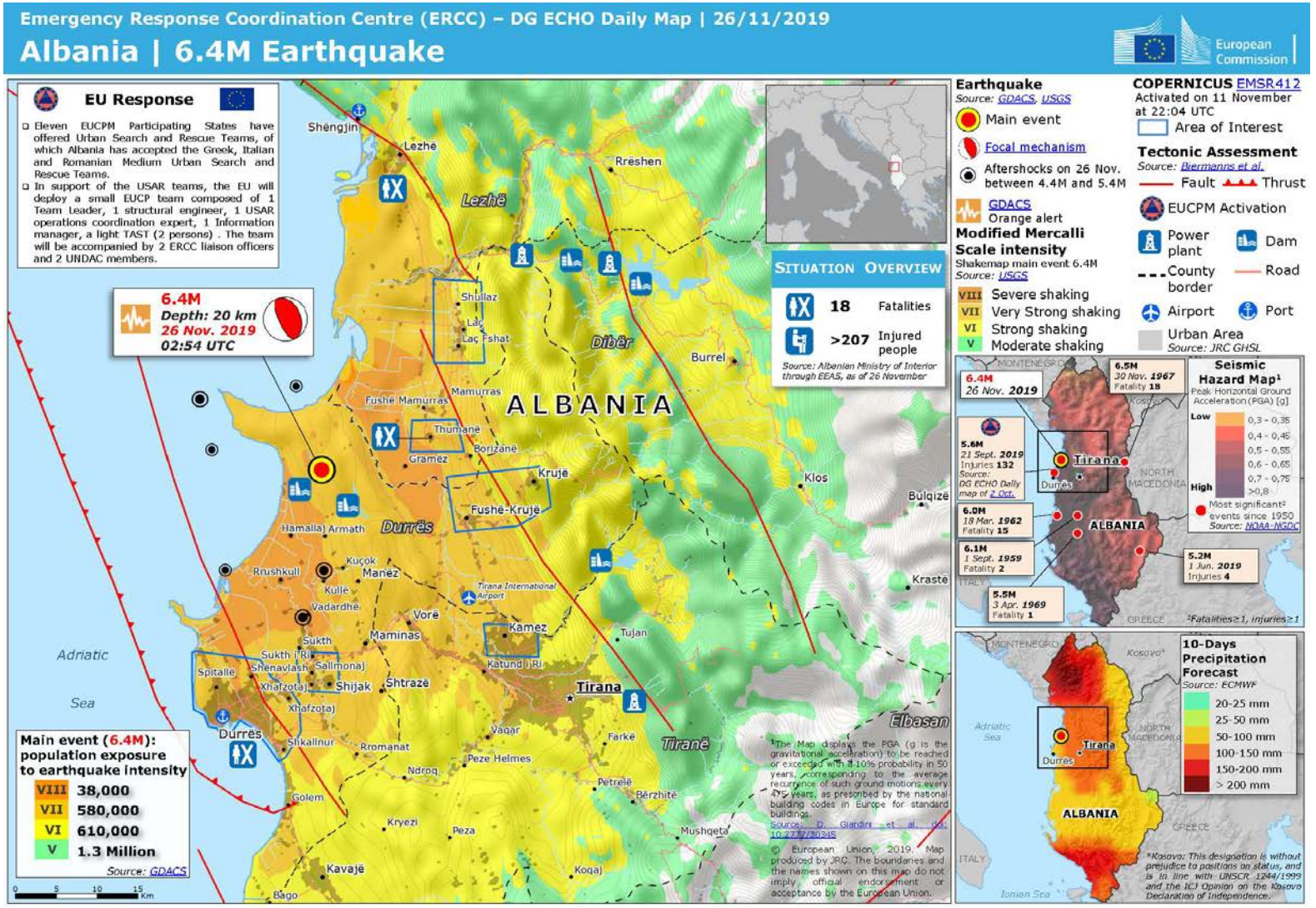
EMERGENCY RESPONSE COORDINATION CENTER - DG ECHO DAILY MAP

NOVEMBER 26, 2019



https://erccportal.jrc.ec.europa.eu/getdailymap/docId/3142

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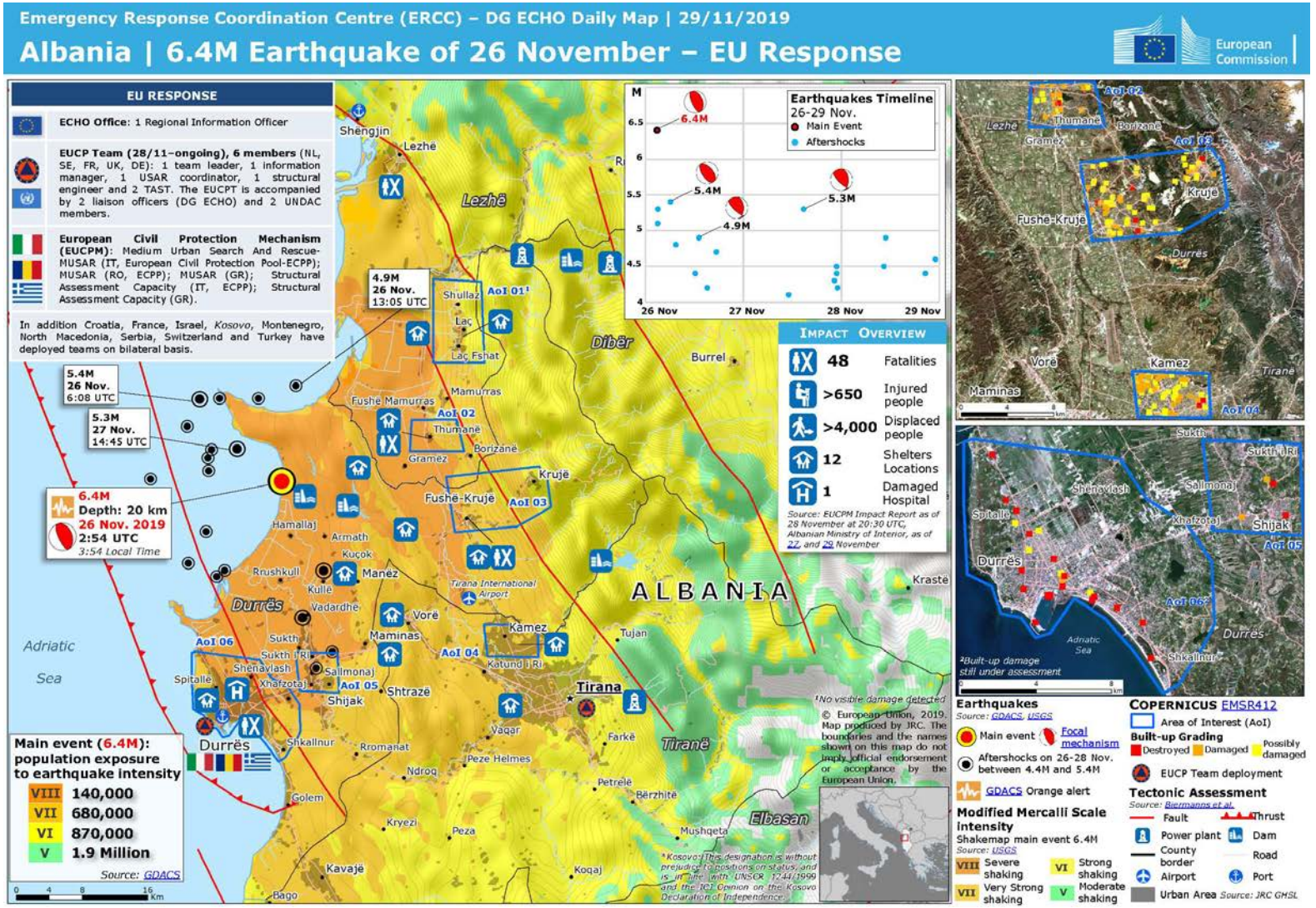
EMERGENCY RESPONSE COORDINATION CENTER - DG ECHO DAILY MAP

NOVEMBER 29, 2019



https://erccportal.jrc.ec.europa.eu/getdailymap/docId/3146

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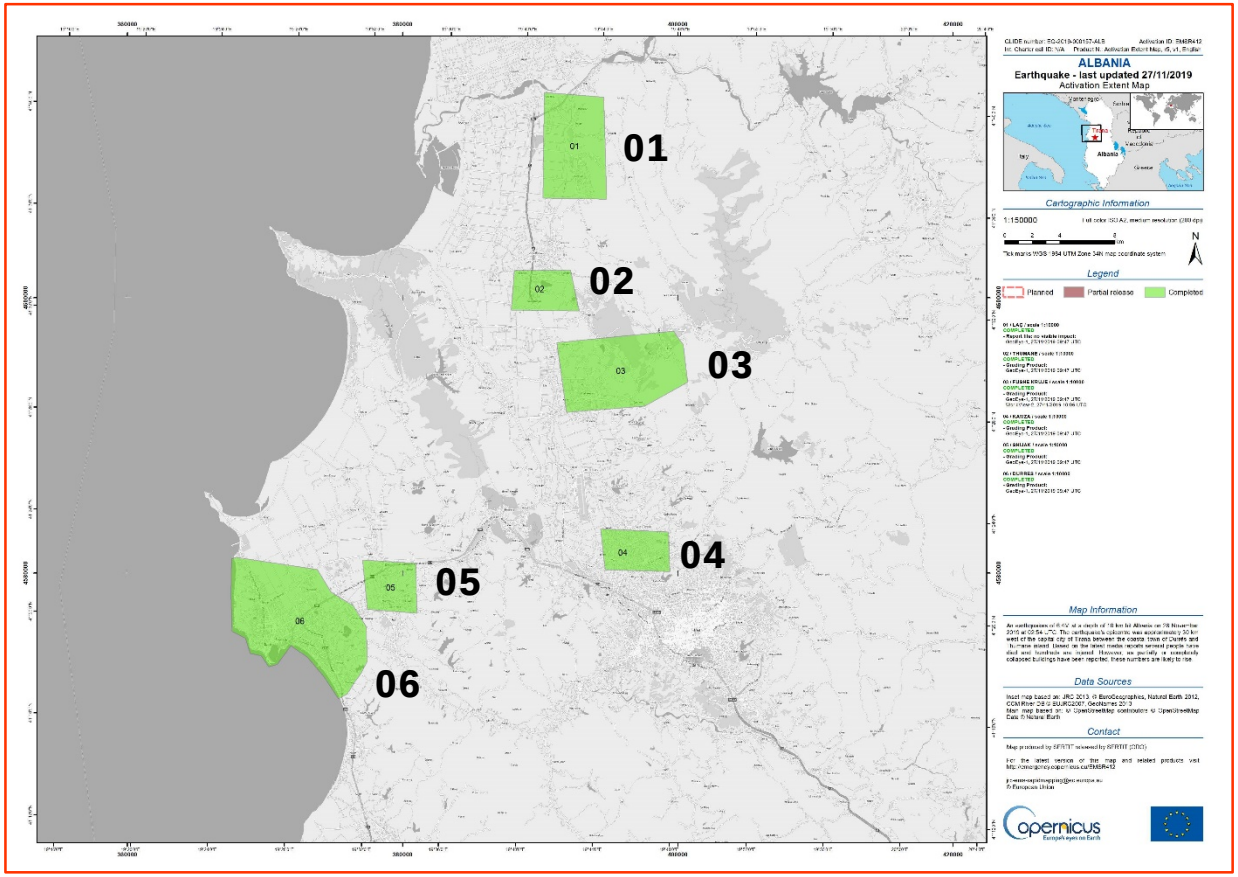
COPERNICUS
EMERGENCY MANAGEMENT SERVICE - MAPPING



Data and maps of the Copernicus Emergency Management Service/Mapping are freely available to all agencies and everyone competent to search and rescue operations and to the disaster management during the first crucial hours of the disaster response phase.

Maps were produced for six earthquake affected areas of the Durrës County of western Albanis:

01: Laç town
02: Thumanë town
03: Fushë-Krujë town
04: Kamëz
05: Shijak town
06: Durrës city

From
https://emergency.copernicus.eu/mapping/sites/default/files/thumbnails/EMSR412-AEM-1574925211-r05-v1.jpg

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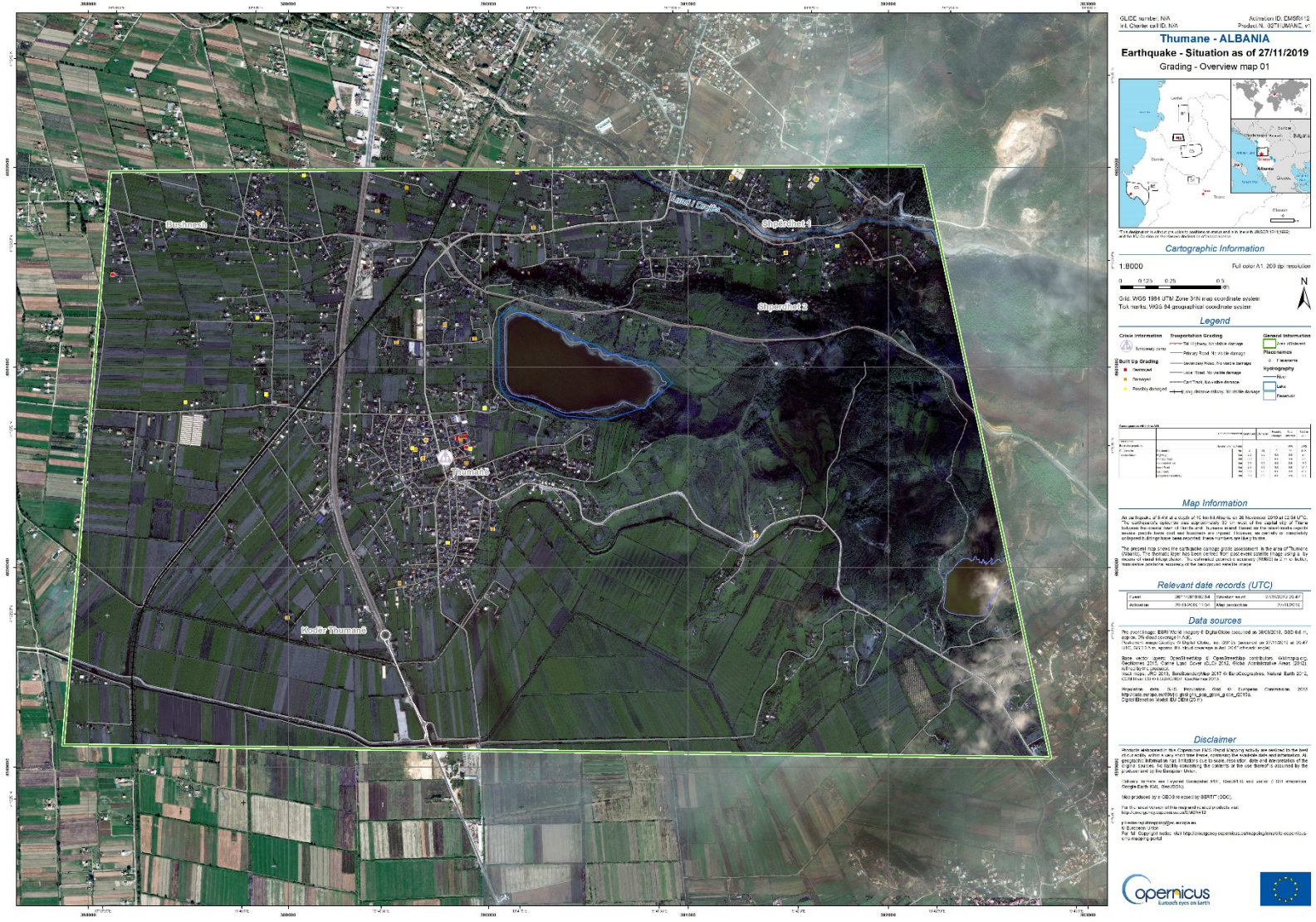
COPERNICUS MAP FOR THUMANË TOWN



https://emergency.copernicus.eu/mapping/system/files/components/EMSR412_AOI02_GRA_PRODUCT_r1_RTP01_v1.jpg

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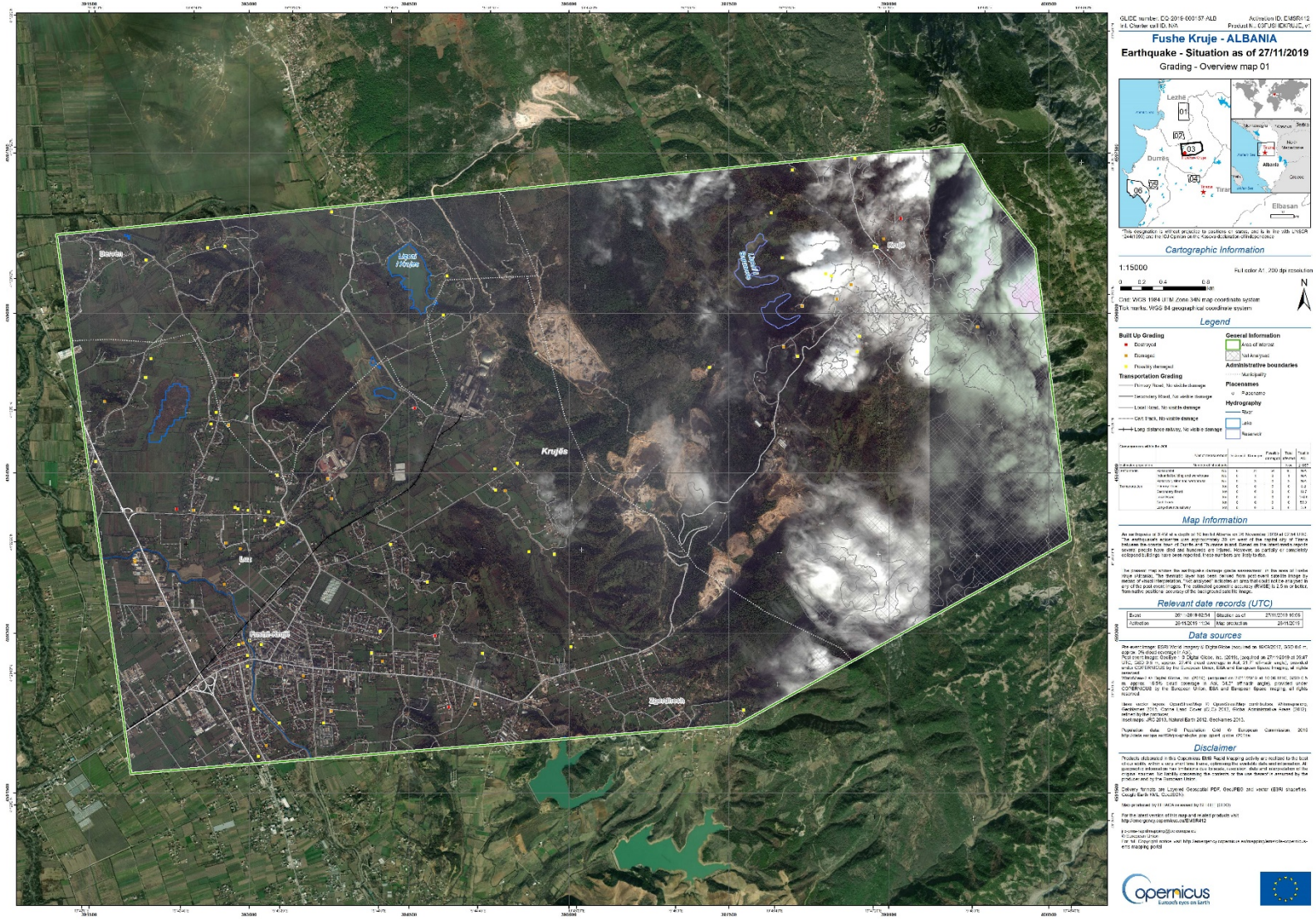
COPERNICUS MAP FOR FUSHË-KRUJË TOWN



https://emergency.copernicus.eu/mapping/system/files/components/EMSR412_AOI03_GRA_PRODUCT_r1_RTP01_v1.jpg

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COPERNICUS MAP FOR KAMËZ

https://emergency.copernicus.eu/mapping/system/files/components/EMSR412_AOI04_GRA_PRODUCT_r1_RTP01_v2.jpg

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COPERNICUS MAP FOR SHIJAK TOWN

https://emergency.copernicus.eu/mapping/system/files/components/EMSR412_AOI05_GRA_PRODUCT_r1_RTP01_v1.jpg

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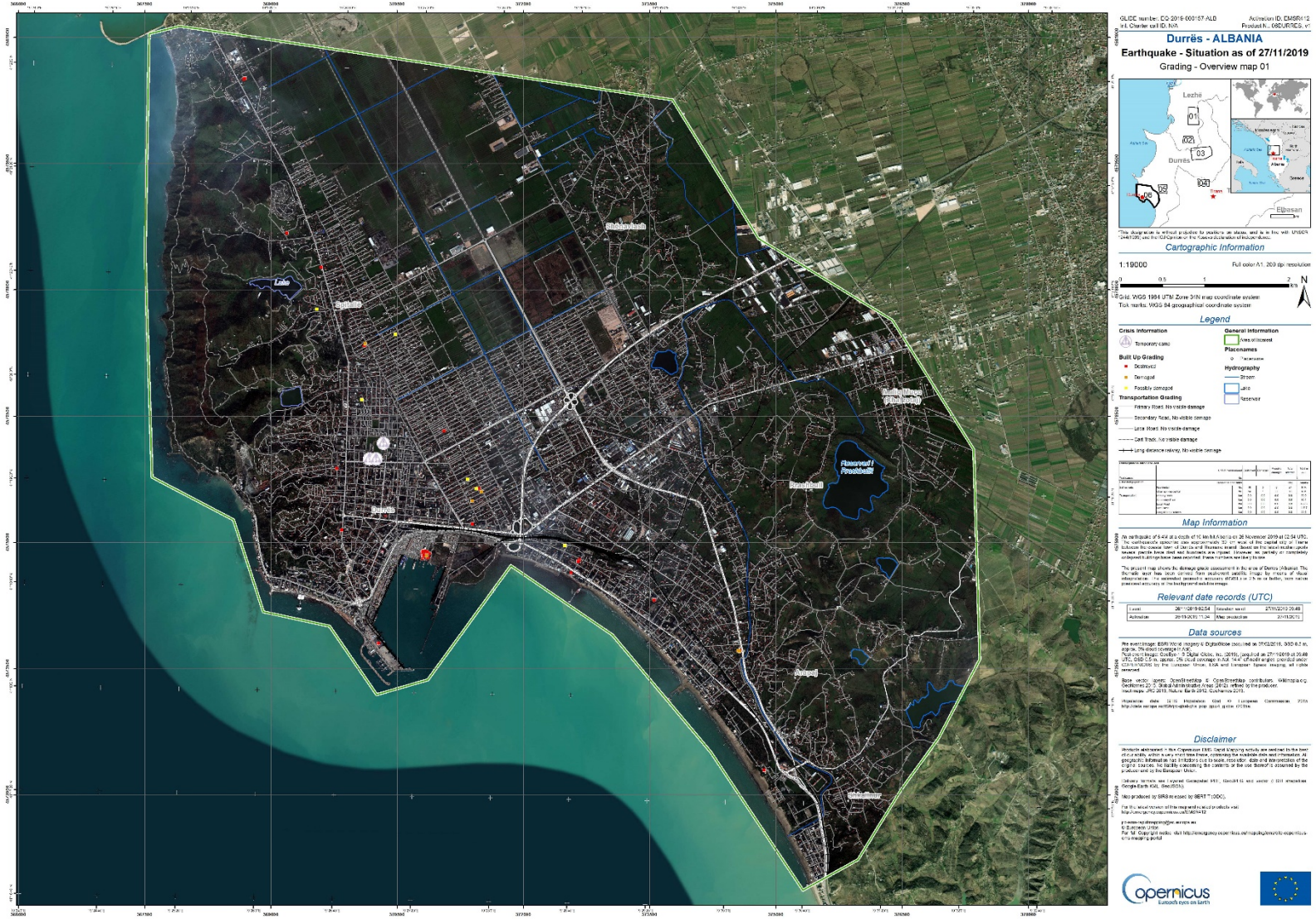
COPERNICUS MAP FOR DURRËS CITY



https://emergency.copernicus.eu/mapping/system/files/components/EMSR412_AOI06_GRA_PRODUCT_r1_RTP01_v1.jpg

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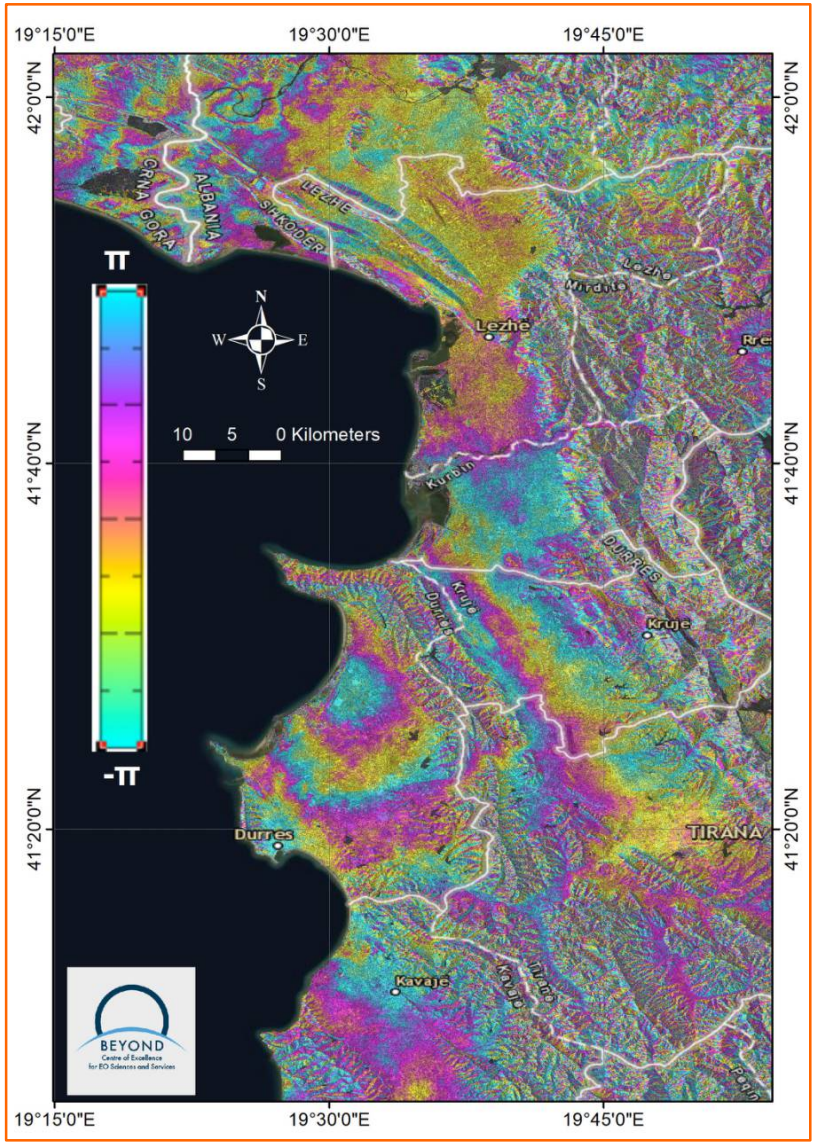
SURFACE DISPLACEMENT
INDUCED BY THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



Interferogram for the November 26, 2019 Durrës earthquake. Each color fringe represents 2.8 cm of surface displacement in the satellite line-of-sight.

Pre-seismic and co-seismic interferograms for this earthquake are available in https://bit.ly/2Legbsb. Fully automatic solution from BEYOND geObservatory.

http://beyond-eocenter.eu/index.php/news-events/222-pre-seismic-and-co-seismic-interferograms-for-the-latest-mw6-5-durres-earthquake-in-albania

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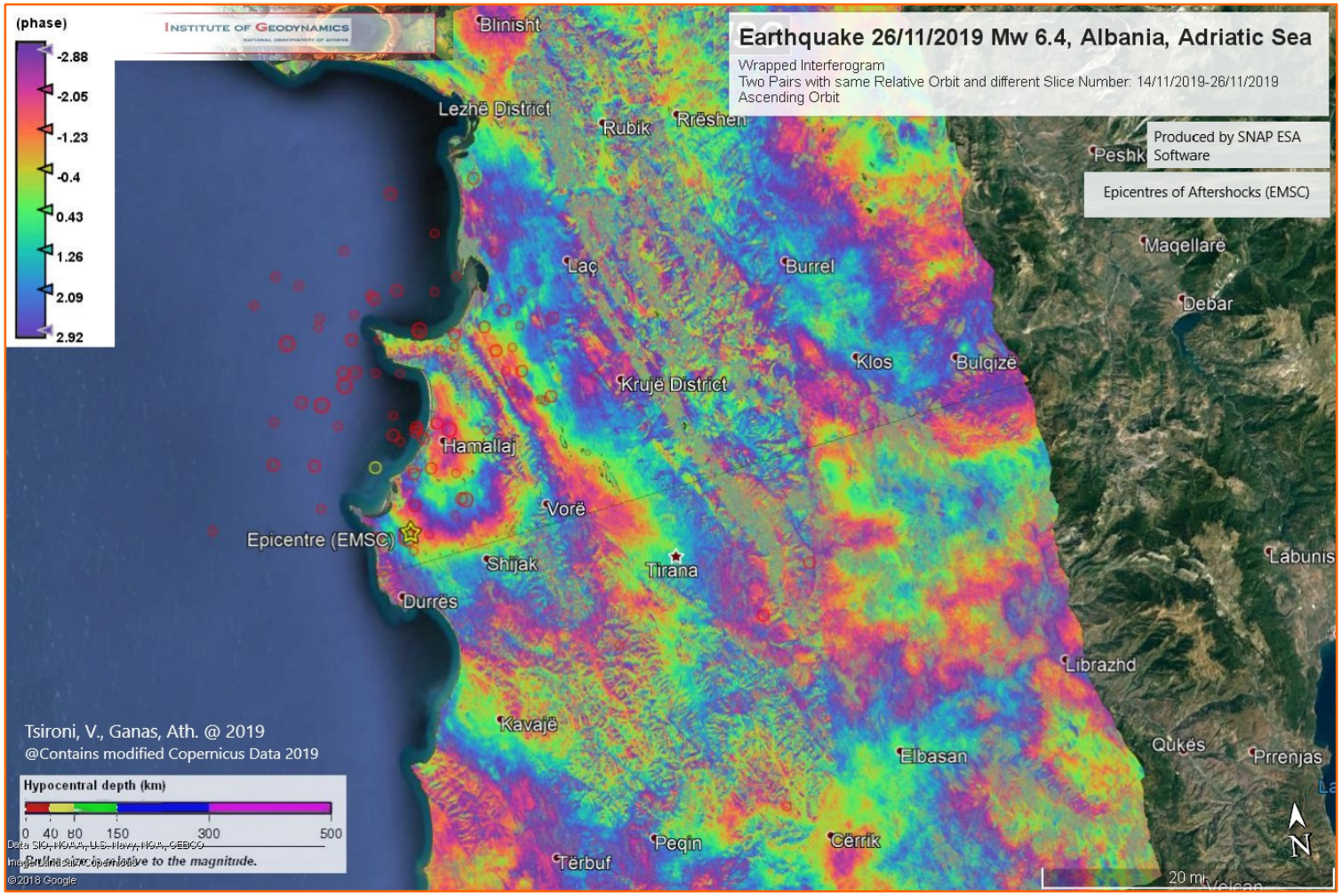
SURFACE DISPLACEMENT
INDUCED BY THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



The first differential interferogram of the November 26, 2019, Mw 6.4 Durrës earthquake using data from the Sentinel-1 satellite (ascending orbit). There are 3 fringes with a NNW-SSE direction as well as the seismic fault. Uplift of tectonic origin is observed up to 8.4 cm at Hamallaj (15 km NE of Durrës) (*Tsironi and Ganas, 2019*)

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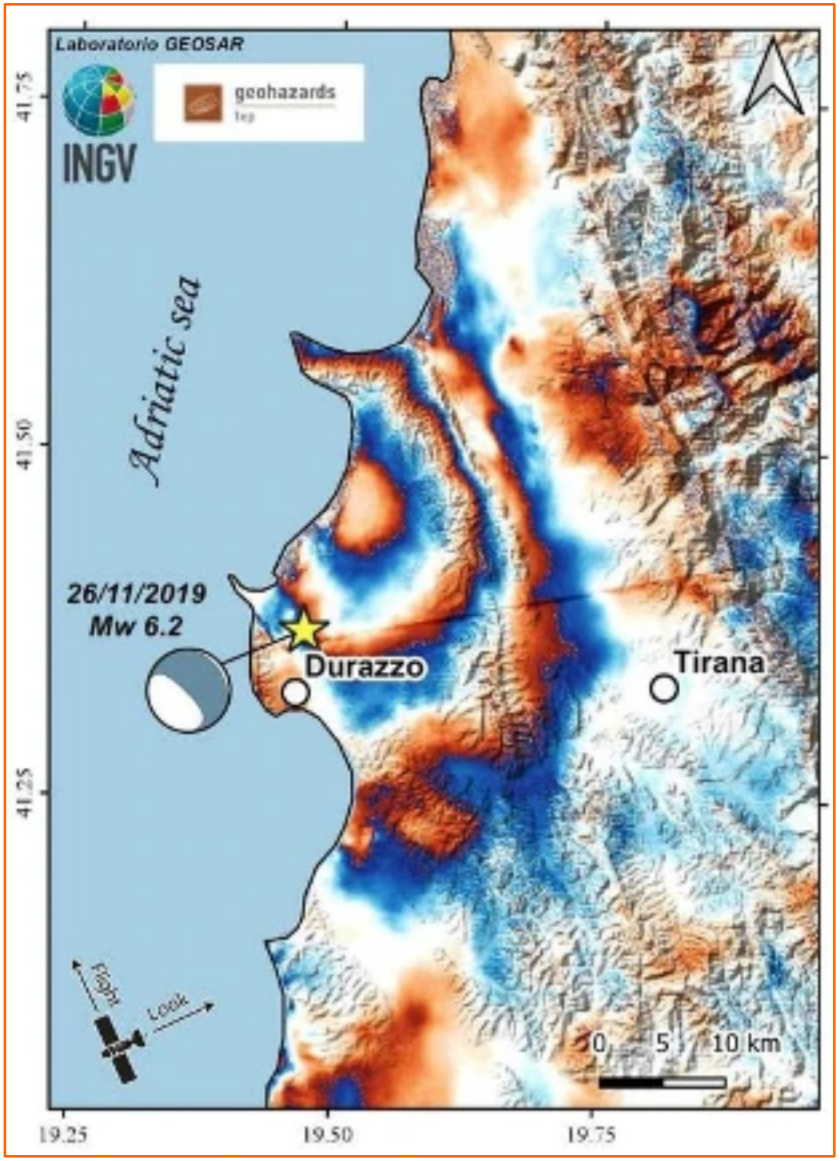
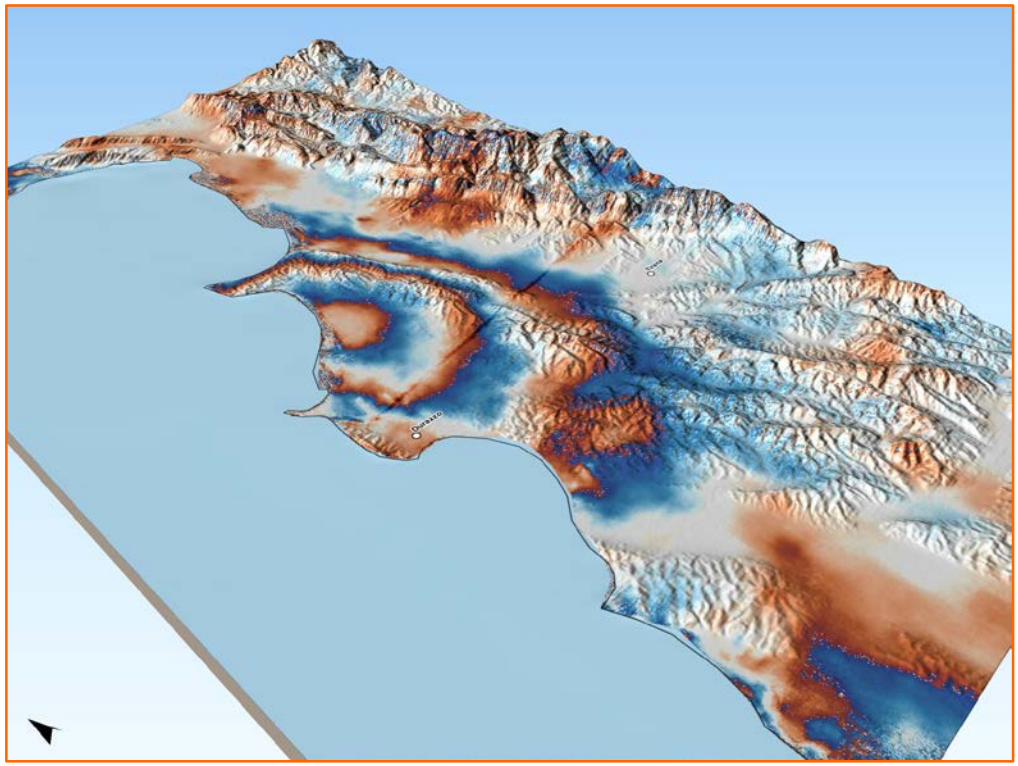
SURFACE DISPLACEMENT
INDUCED BY THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE



The earthquake raised the ground by about 10 cm near the city of Durrës. This is concluded by the radar images taken by the Sentinel-1 satellites of the European Copernicus program of the European Space Agency (ESA) and the European Commission, analyzed by the seismologists of the National Institute of Geophysics and Volcanology (INGV).



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BUILDING TYPES FOR ALBANIA

	1 - Detached house	2 - Semi-detached house	3 - Row/ terraced house	4 - Multifamily apartment
A - 1960				
B 1961-1980				
C 1981-1990				
D 1991-2000				
E 2001-2011				

The buildings in Albania are classified into 4 types:

- detached houses
- semi-detached houses
- row houses
- apartment buildings

They constructed in six construction periods:

- before 1960
- between 1961-1980
- between 1981-1990
- between 1991-2000
- between 2001-2011

These building types dominate the earthquake-affected area. It is interesting to investigate why other buildings were damaged and others not, although they are same structures in similar soil conditions. A plausible explanation for this phenomenon is the prevalence of the vertical component of the earthquake ground motion.

From *Novikova et al. (2015, 2018)*

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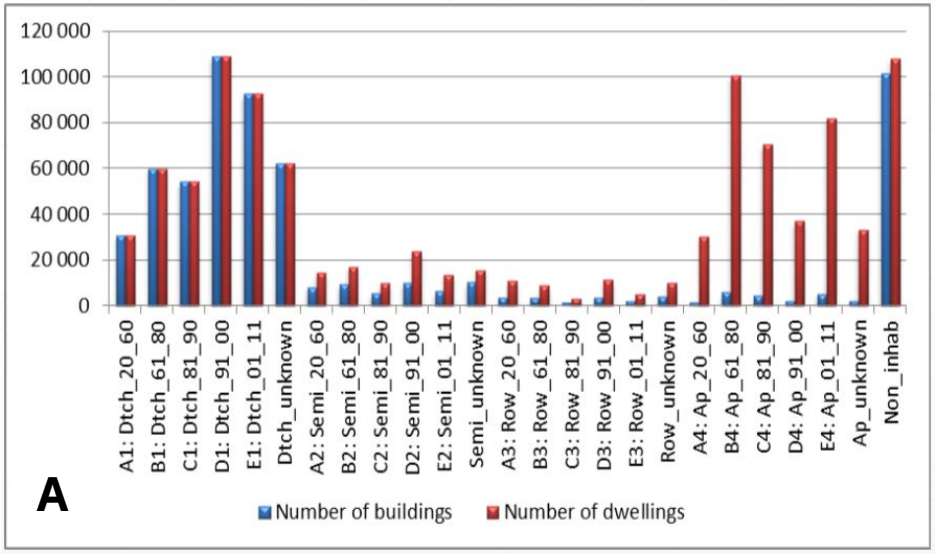
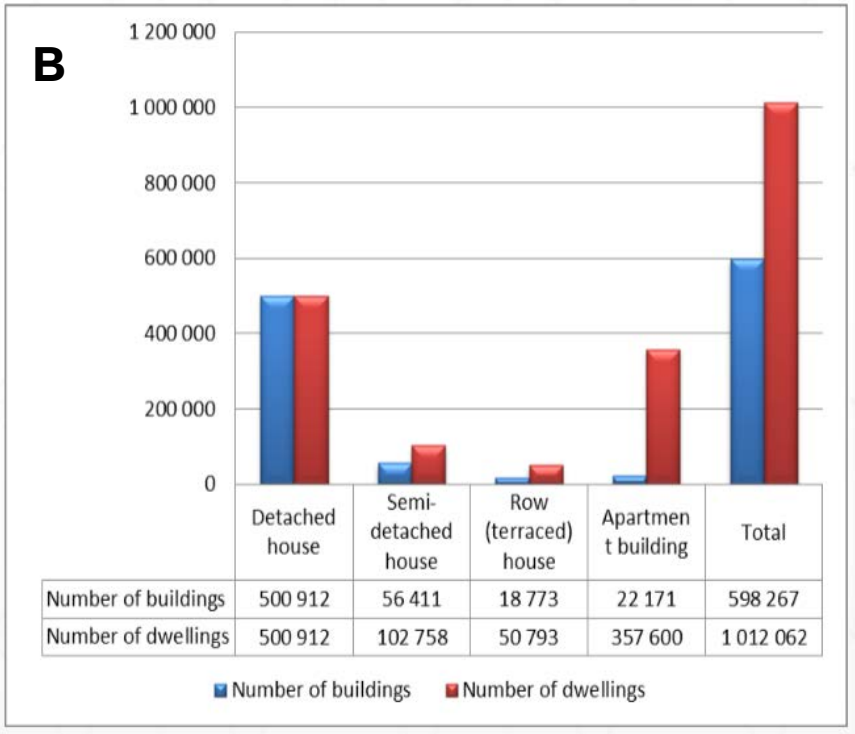
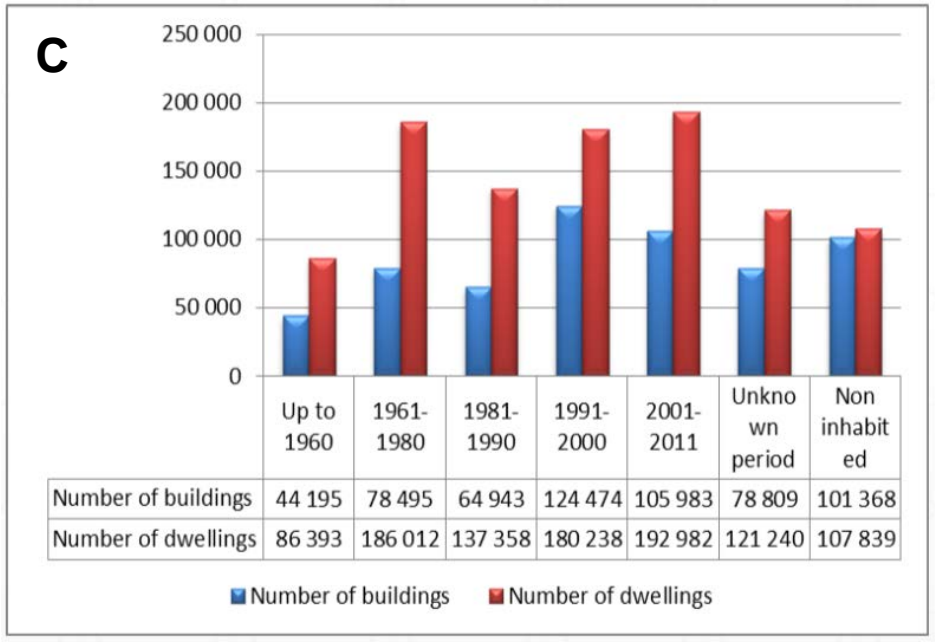
RESIDENTIAL BUILDINGS AND DWELLINGS FOR ALBANIA





	Detached house	Semi-detached house	Row (terraced) house	Apartment building	Total
Number of buildings	500 912	56 411	18 773	22 171	598 267
Number of dwellings	500 912	102 758	50 793	357 600	1 012 062



	Up to 1960	1961-1980	1981-1990	1991-2000	2001-2011	Unknown period	Non inhabited
Number of buildings	44 195	78 495	64 943	124 474	105 983	78 809	101 368
Number of dwellings	86 393	186 012	137 358	180 238	192 982	121 240	107 839

(**A**) Number of residential buildings and dwellings per building type
(**B**) Number of residential buildings and dwellings by building type
(**C**) Number of residential buildings by construction period
based on the 2011 census data on Albania building stock

From *Novikova et al. (2015, 2018)*

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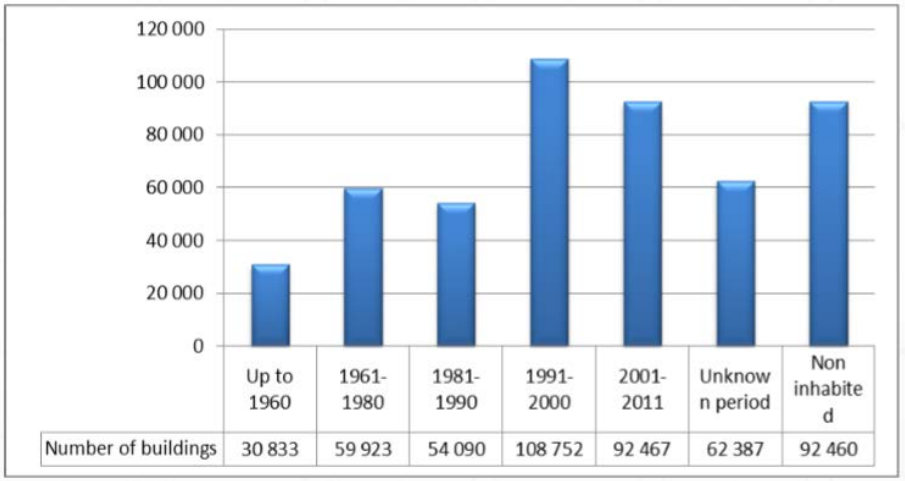
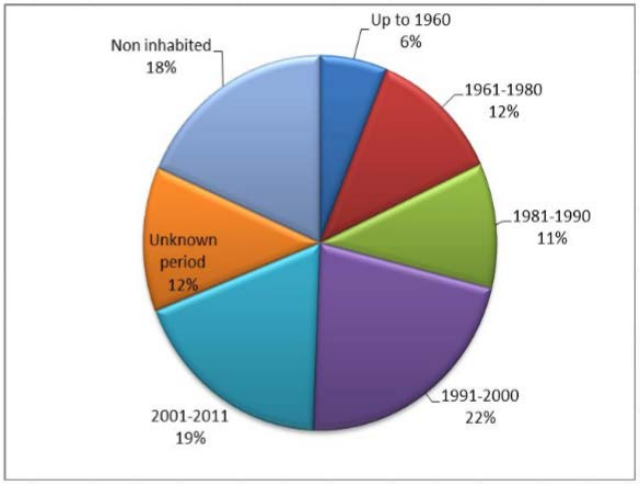
BUILDINGS AND CONSTRUCTION PERIODS IN ALBANIA

Detached houses by construction period

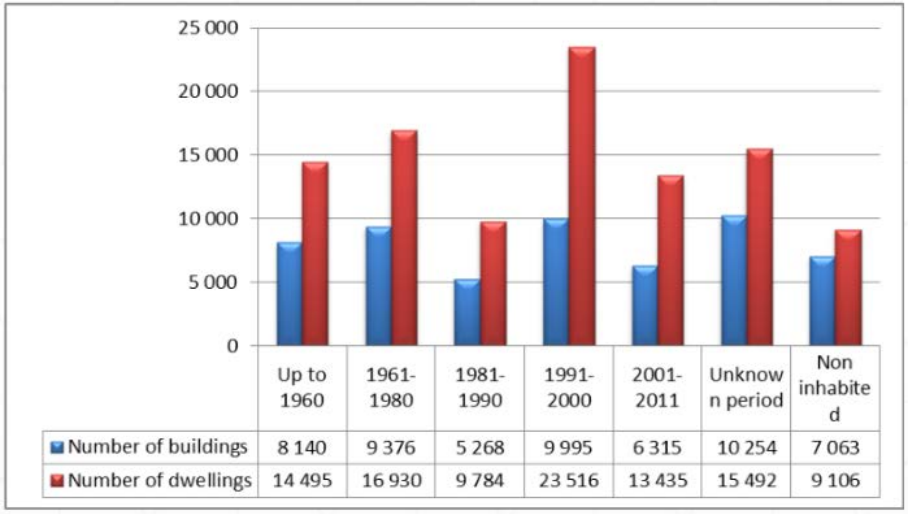


	Up to 1960	1961-1980	1981-1990	1991-2000	2001-2011	Unknown period	Non inhabited
Number of buildings	30 833	59 923	54 090	108 752	92 467	62 387	92 460

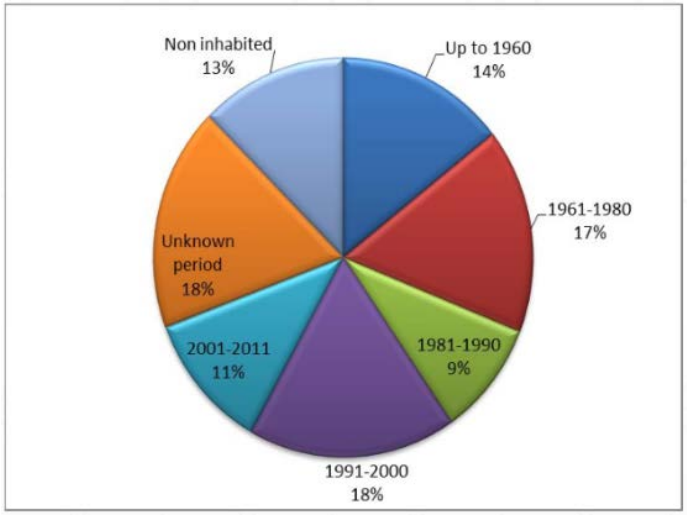


Semi – detached houses by construction period

From *Novikova et al. (2015)*



	Up to 1960	1961-1980	1981-1990	1991-2000	2001-2011	Unknown period	Non inhabited
Number of buildings	8 140	9 376	5 268	9 995	6 315	10 254	7 063
Number of dwellings	14 495	16 930	9 784	23 516	13 435	15 492	9 106



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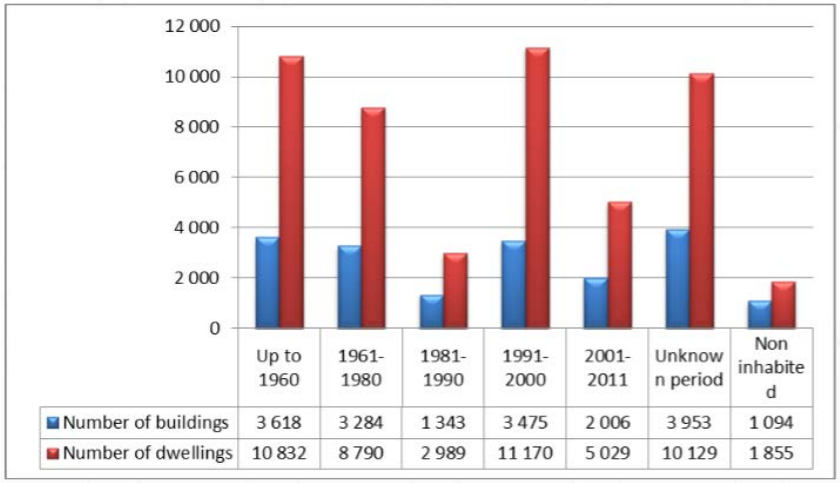
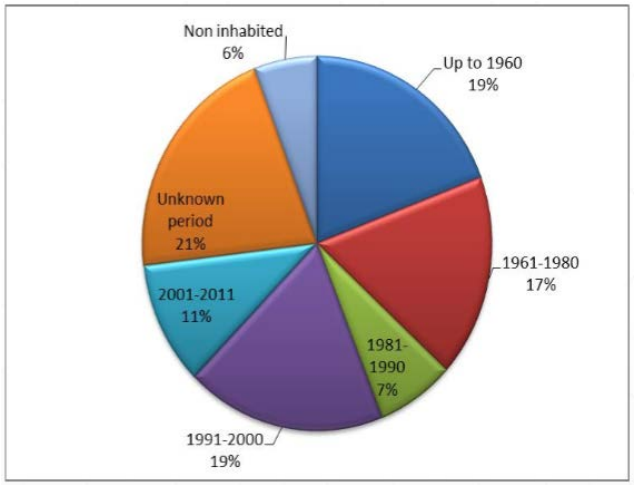
BUILDINGS AND CONSTRUCTION PERIODS IN ALBANIA

Row (or terraced) houses by construction period

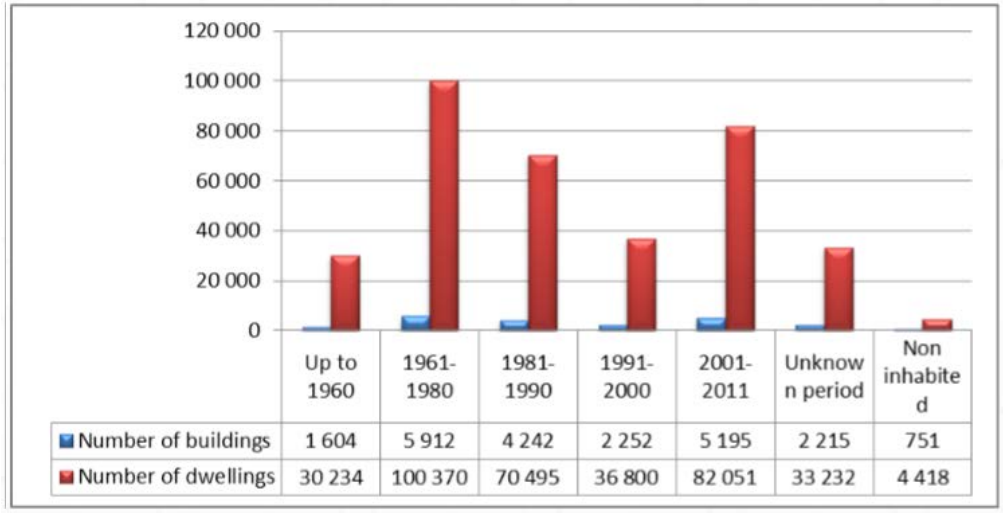


	Up to 1960	1961-1980	1981-1990	1991-2000	2001-2011	Unknown period	Non inhabited
Number of buildings	3 618	3 284	1 343	3 475	2 006	3 953	1 094
Number of dwellings	10 832	8 790	2 989	11 170	5 029	10 129	1 855

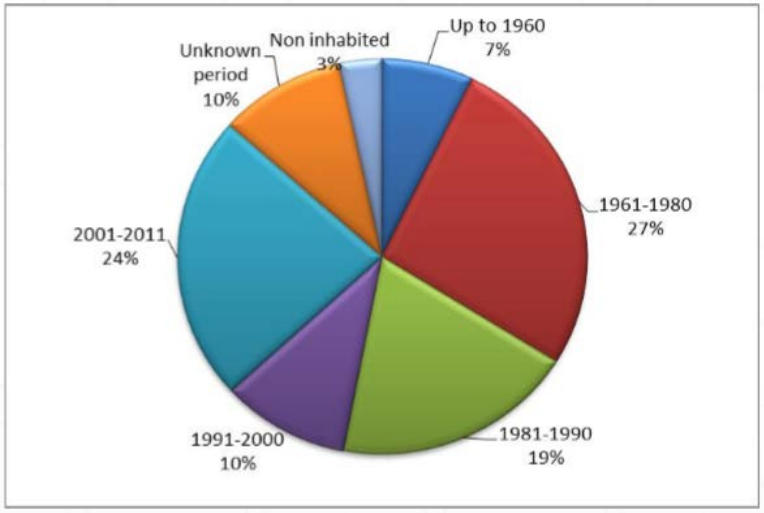


Apartment buildings by construction period

From *Novikova et al. (2015)*



	Up to 1960	1961-1980	1981-1990	1991-2000	2001-2011	Unknown period	Non inhabited
Number of buildings	1 604	5 912	4 242	2 252	5 195	2 215	751
Number of dwellings	30 234	100 370	70 495	36 800	82 051	33 232	4 418



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DOMINANT TYPES OF BUILDINGS

Buildings with load bearing brick walls and concrete floor slabs

in Durrës

in Thumanë

These buildings essentially consist of thick heavy unreinforced masonry (URM) of solid clay bricks, which supports the entire structure, including the horizontal floor slabs, which could be made of reinforced concrete members. A significant characteristic of this type of structure, not only in Albania but also around the world, is the lack of concrete columns and beams. The solid brick walls are the only and the main load bearing elements of the structure. This masonry type is unreinforced and thus it presents brittle - non-ductile behavior. Due to the construction material (solid clay bricks), they also present small stiffness resulting in good performance and flexibility during an earthquake up to a certain limit. Once this limit is exceeded, the damage is instantaneous.

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DOMINANT TYPES OF BUILDINGS

Buildings with load bearing solid brick walls and concrete floor slabs

In this case, the earthquake shaking and displacement did not exceed this limit and these structures remained intact by the earthquake. A very positive characteristic in this type of buildings is that the best possible continuity between the soil and the construction is achieved, in terms of material and stiffness. These elements appear to have a positive effect on the antiseismic performance, particularly with respect to the vertical component of the earthquake ground motion. Taking into account these elements, this building type excel in antiseismic performance.

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DOMINANT TYPES OF BUILDINGS

Buildings with load bearing brick walls and concrete floor slabs

Unreinforced masonry (URM) construction should not be used today. They do not present good performance during earthquakes. It is significant to mention that the majority of fatalities induced by earthquakes around the world have attributed to collapse of unreinforced masonry buildings. They are heavy brittle structures, which usually suffer heavy structural damage.

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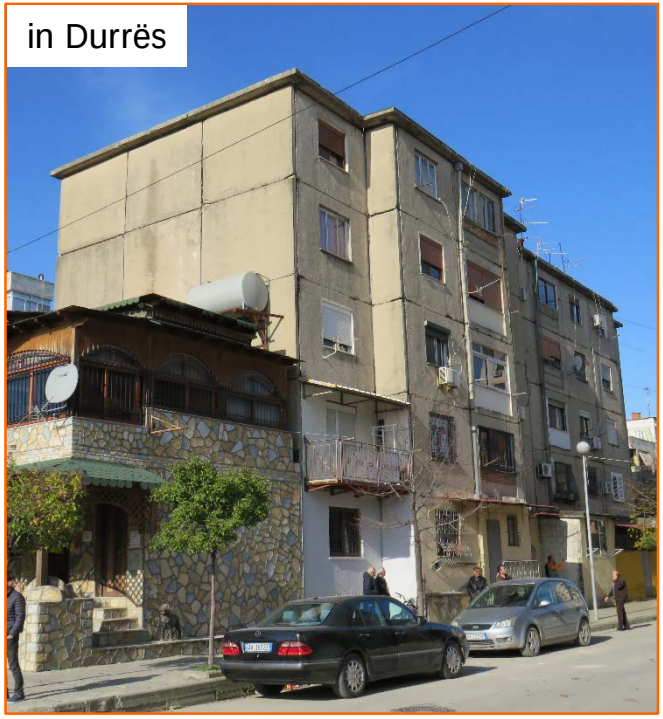
DOMINANT TYPES OF BUILDINGS
Prefabricated concrete panel buildings

in Durrës



Heavy and light prefabricated construction methods were also applied in Albania as a mean to further lower building costs and provide rapid urbanization to meet demand. As a result of this trend, up to 60% of these prefabricated concrete wall buildings were built after the 1960s not only in the port city of Durrës, but also in Tirana and in other large cities and towns of Albania. Based on the 2001 census data, the majority of the building stock comprised brick or stone (88%) and 5% prefabricated panel construction. Even though the number of prefabricated concrete buildings is lower than in situ masonry buildings, they are usually multi-storey structures, which include residential buildings. Most of the apartment buildings constructed after 1960 were built with this methodology.

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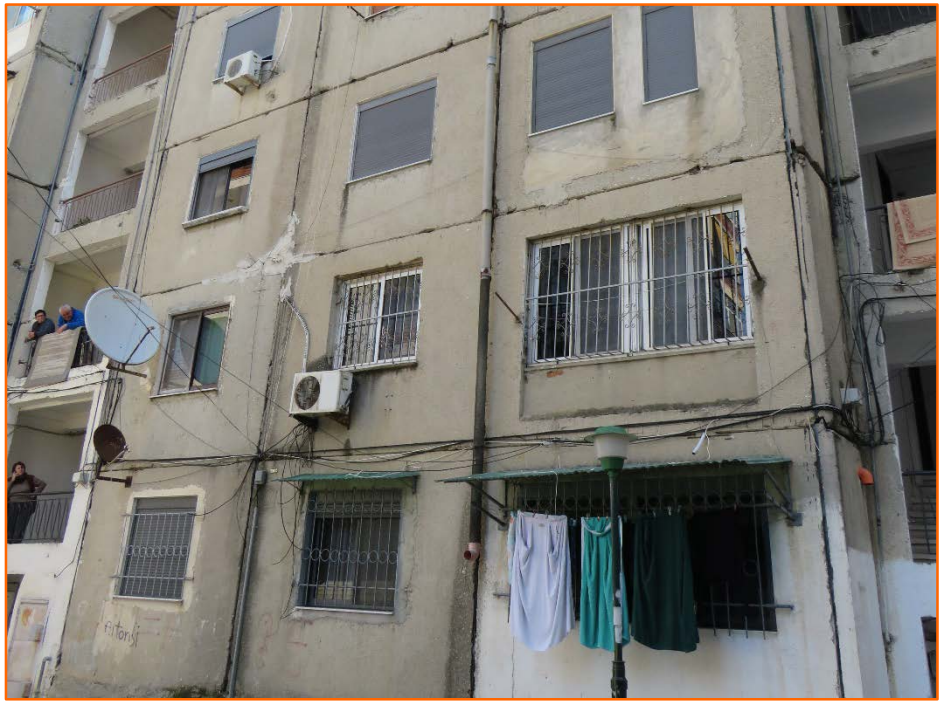
DOMINANT TYPES OF BUILDINGS
Prefabricated concrete panel buildings



In the majority of these structures, the prefabricated concrete walls are not covered with plasters and the welding joints between the prefabricated concrete walls have not been sealed. Thus, these buildings are not protected from the aggravating environmental conditions including humidity, rainfall, temperature variations, snowfall resulting in quick and easy ageing of materials.

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DOMINANT TYPES OF BUILDINGS

Buildings with reinforced concrete frame and infill walls

Buildings with a kind of light reinforced concrete frame and infill brick walls are also observed in the affected area. The performance of this type of buildings is strongly related to the presence or lack of strong columns and beams and the construction method of the slab. They are often multi-storey residential buildings, hotels and offices.

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STRUCTURAL DAMAGE TO BUILDINGS WITH LOAD BEARING BRICK WALLS IN THUMANË TOWN

Heavy structural damage to buildings with load bearing solid brick walls and concrete floor slab in Thumanë town are presented. Damage comprised detachment of large pieces of plaster from the brick walls, cracks in brick walls and partial collapse of the building. The floor slabs were composed of simply supported prefabricated reinforced concrete hollow core strap slabs. The concrete strap slabs are not transversally connected to each other neither to the load bearing system. In this way, the diaphragmatic function of the floors, which is beneficial for the earthquake safety of the structure, is totally missing.

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PERFORMANCE OF PREFABRICATED FLOOR SLABS DURING THE NOVEMBER 26, 2019 DURRËS EARTHQUAKE

Based on the field macroseismic reconnaiscance survey conducted after the September and November Durrës earthquakes, it is concluded that many buildings of all observed construction types used precast floor slabs. These slabs are prefabricated and then lifted with cranes or elevators. The slabs that were usually observed in collapsed or heavily damaged buildings mainly in Thumanë and secondarily in Durrës were simply supported prefabricated reinforced concrete hollow core strap slabs, not transversally connected to each other neither to the load bearing system. In this way, the diaphragmatic function of the floors, which is beneficial for the earthquake safety of the structure, is totally missing. These elements were subjected to the earthquake motion resulting in destruction.

The simple support of these precast elements is not allowed by modern earthquake codes due to the fact that in most cases the existing joints are not adequate and/or strong enough to undertake the vertical and horizontal seismic actions. The joints at the supports must be constructed in order to rigidly withstand the up-down jumping movement of the slabs and the differential horizontal displacements, i.e diaphragmatic function. The lack of these provisions in the joints may be the basic reason for numerous heavy structural damage and collapses of the buildings with precast floor slabs. Recent examples of this performance were also observed in buildings affected by the 2009 L' Aquila and 2012 Emilia - Romagna earthquakes in Italy (*Carydis et al., 2009, 2012*).

A collapsed building in Thumanë with load bearing brick walls and simply supported reinforced concrete hollow core slabs.

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STRUCTURAL DAMAGE TO BUILDINGS WITH LOAD BEARING BRICK WALLS IN DURRËS CITY






Collapse of the two lower floors of the building. The deformation of the steel bars of the columns is attributed to the movement of the building under the effect of the dominant vertical component of the earthquake ground motion. This building is located in the area of the macroseismic epicenter, where the vertical component prevails over the horizontal one.

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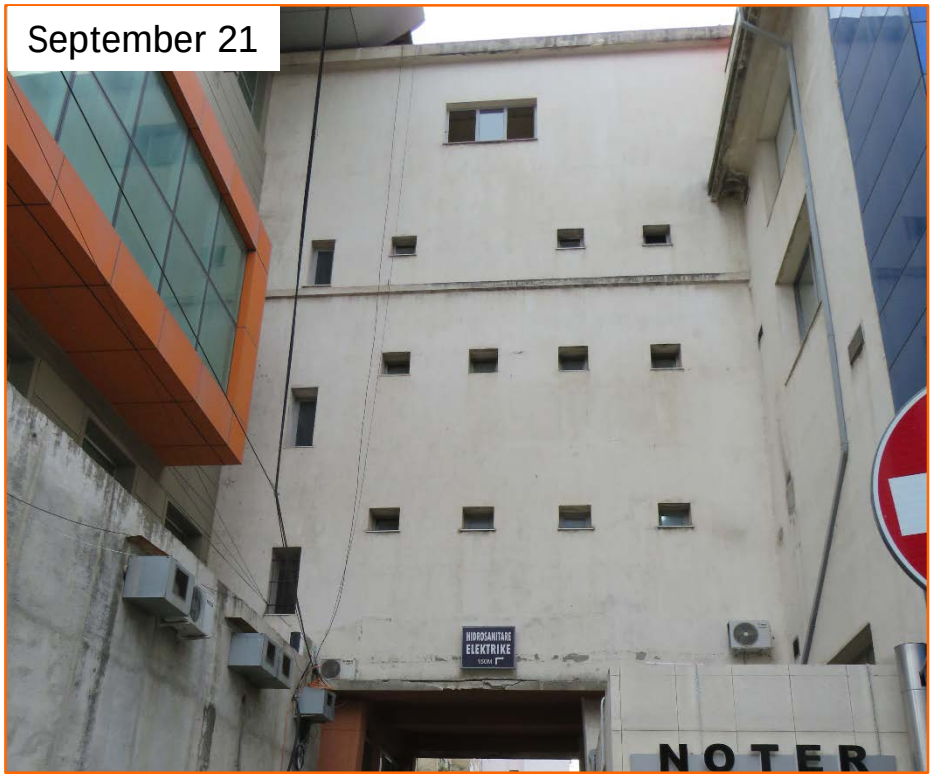
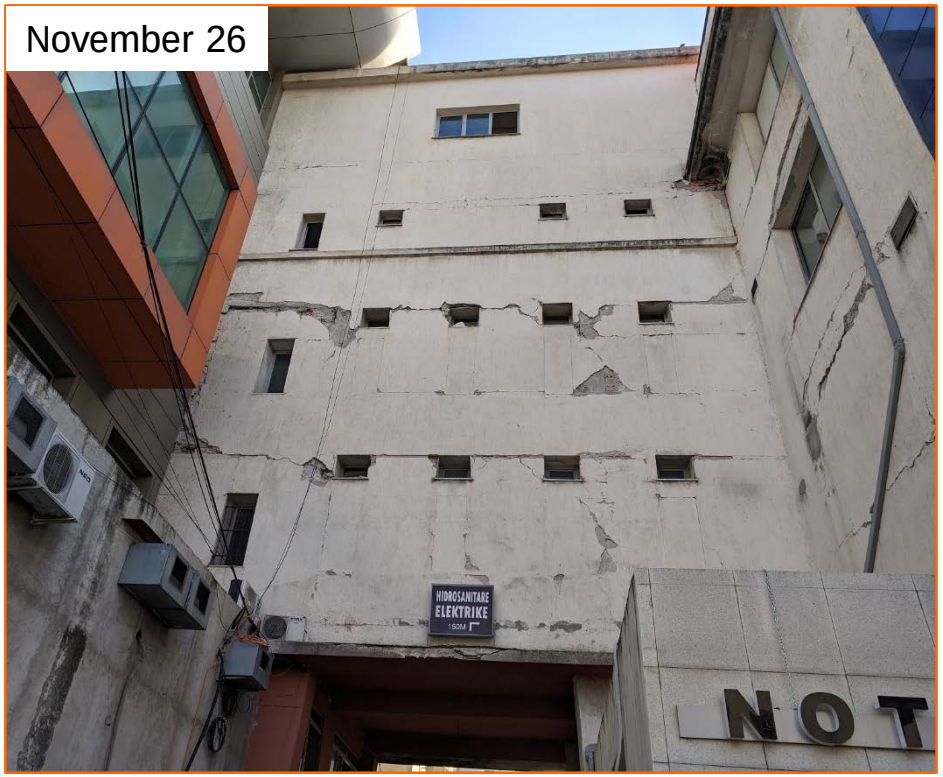
EARTHQUAKE DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE SEPTEMBER 21 AND NOVEMBER 26, 2019 EARTHQUAKES



The building in Durrës remained almost intact from the September earthquake.



The building suffered non-structural damage from the November earthquake including cracks in the brick wall, detachment of pieces of plaster from the wall and detachment of the brick wall from the surrounding slabs. No damage was observed in the upper level of the building. This type of damage (horizontal and no X-formed cracks) indicates the prevalence of the vertical component of the earthquake ground motion.

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EARTHQUAKE DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE SEPTEMBER 21 AND NOVEMBER 26, 2019 EARTHQUAKES

Separation of brick walls from the members of the RC framing system, which is a common phenomenon due to the deformational incompatibility between the two structural elements.

Total collapse of infill and partition brick walls from the members of the RC framing system. Damage are limited to the three lower storeys of the building.

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EARTHQUAKE DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE SEPTEMBER 21 AND NOVEMBER 26, 2019 EARTHQUAKES

September 21

Effect of the vertical component of the earthquake ground motion in combination with the horizontal one on brick walls on an RC cantilever.

November 26

Partial collapse of the brick wall of the ground floor and light cracks.

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EARTHQUAKE DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE SEPTEMBER 21 AND NOVEMBER 26, 2019 EARTHQUAKES

▲ No damage was induced to this building during the September earthquake.

▶ The lower floors suffered heavy damage by the November 26 earthquake including partial collapse of the brick walls at the lower floors.

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EARTHQUAKE DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE SEPTEMBER 21 AND NOVEMBER 26, 2019 EARTHQUAKES

Hotel Vila Verde was founded on the coastal zone of Durrës, few meters from the sea. No damage was induced to the hotel during the September earthquake. The two lower floors totally collapsed during the November earthquake, while the structure above remained almost intact.

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VERY HEAVY STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE NOVEMBER 26, 2019 EARTHQUAKE

Mira Mare hotel was founded on the coastal zone of Durrës, few meters from the sea. No damage was induced to the hotel by the September earthquake. During the November 26 earthquake, it totally collapsed.

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LIQUEFACTION PHENOMENA
CLOSE TO A COLLAPSE SITE

Few meters from the collapsed hotel Mira Mare, liquefaction phenomena were generated. Sand boils erupted during the earthquake from ground cracks resulting in the formation of small sand volcanoes and silt-covered pavements. The liquefaction phenomena observed in this site may contribute to the initial sinking and tilting of the building that led to its final collapse.

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VERY HEAVY STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE NOVEMBER 26, 2019 EARTHQUAKE



It is significant to note that the hotel Lubjana, located few meters from Mira Mare, presented tilting that might be attributed partially to the failure of the columns of the ground floor and partially to liquefaction phenomena, but it did not collapse.

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LIQUEFACTION PHENOMENA
CLOSE TO A COLLAPSE SITE



Ejection of liquefied material through cracks resulting in small sand volcanoes and covered pavements. These liquefaction phenomena took place few meters away from the collapsed Mira Mare Hotel and other tilted buildings in the coastal Durrës. Small scale liquefaction phenomena were also generated in the coastal area of Durrës by the September 21, 2019 Mw 5.6 earthquake (*Lekkas et al., 2019*, Newsletter of Environmental, Disaster, and Crises Management Strategies, Vol. 13)

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LIQUEFACTION PHENOMENA AND VERY HEAVY STRUCTURAL DAMAGE

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SPATIAL DISTRIBUTION AND TYPE OF THE EARTHQUAKE-INDUCED DAMAGE

As regards the distribution of earthquake-induced damage in the coastal area of Durrës, most damage were distributed in the areas north, west, east and southeast of Durrës port. These areas are composed of Pliocene clays, Holocene marshy and alluvial deposits and mixed phases of Quaternary deposits including Pleistocene formations and Holocene alluvial and marshy deposits.

The area, where three hotels suffered very heavy structural damage, is one of the most affected areas by the November 26, 2019 Mw 6.4 earthquake. Mira Mare Hotel totally collapsed, Vila Verde Hotel partially collapsed and Lubjana Hotel tilted after column collapse and probably liquefaction.

Close to the Mira Mare Hotel liquefaction phenomena were generated comprising ejection of sand through cracks, formation of small sand volcanoes and silt-covered pavements. The site with the three heavily damaged buildings is close to the sea and is composed of unconsolidated recent deposits that constitute the soft ground of the area.

The soft ground usually suffers differential displacements including subsidence among others. The multistorey buildings are trying to adapt to these displacements and restabilize. This adaptation and restabilization of the building is putting more strain on its structural and non-structural elements resulting in either slight deformation or failure of these elements. When a strong earthquake occurs in a distance from the soft ground and the multistorey buildings, then the synergy of the earthquake loading along with the local soil conditions, the shallow water table, the construction defects and the pre-existing stress of the building may result destruction. Moreover, damage from differential soil settlements are homologous to damage induced by an earthquake.

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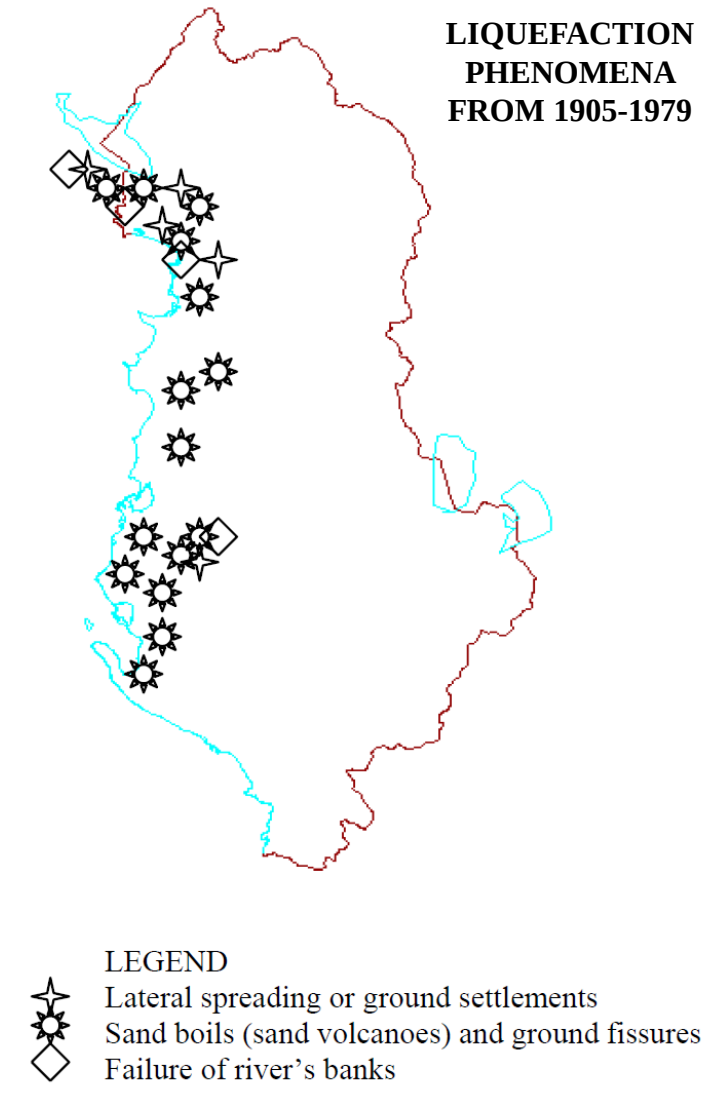
LIQUEFACTION HISTORY OF PREADRIATIC AREA IN WESTERN ALBANIA



During strong earthquakes of the 20th century many liquefaction phenomena were observed in the Preadriatic area in Western Albania. The main types of observed liquefaction phenomena from 1905 to 1979 are:

- Lateral spreading and ground settlements
- Sand boils (sand volcanoes) and ground fissures
- Failure of riverbanks

From *Kociu et al. (2004)*

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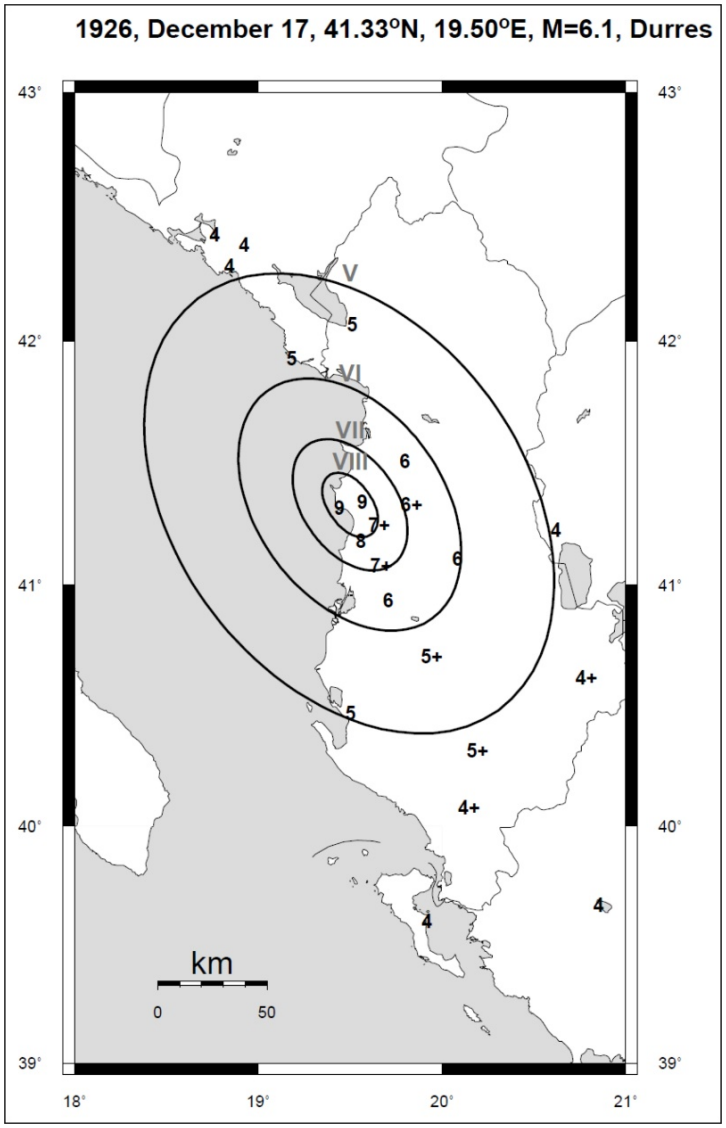
HISTORICAL AND RECENT EARTHQUAKES INDUCED LIQUEFACTION IN DURRËS



Based on various sources, the old town of Durrës has been affected several times from strong earthquakes resulting in severe human and economic losses. It is concluded that Durrës has been almost totally destroyed by earthquakes generated on 177 BC, 334 or 345 AC, 506, 1273, 1279, 1869 and 1870.

Data and information for the March 1273 earthquake indicate that the town with a population of 25000 people has been totally destroyed. Many fatalities were reported and the affected survivors left the town seeking for other places to live. After this earthquake the importance of Durrës as a city port in Adriatic Sea has been diminished.

On December 27, 1926 an earthquake struck the coastal area of Durrës and caused significant liquefaction phenomena. Fountains with hot water and sand, sand and mud volcanoes were generated.

From *Aliaj et al. (2010)*

Isoseismal map from *Papazachos et al. (2001)*

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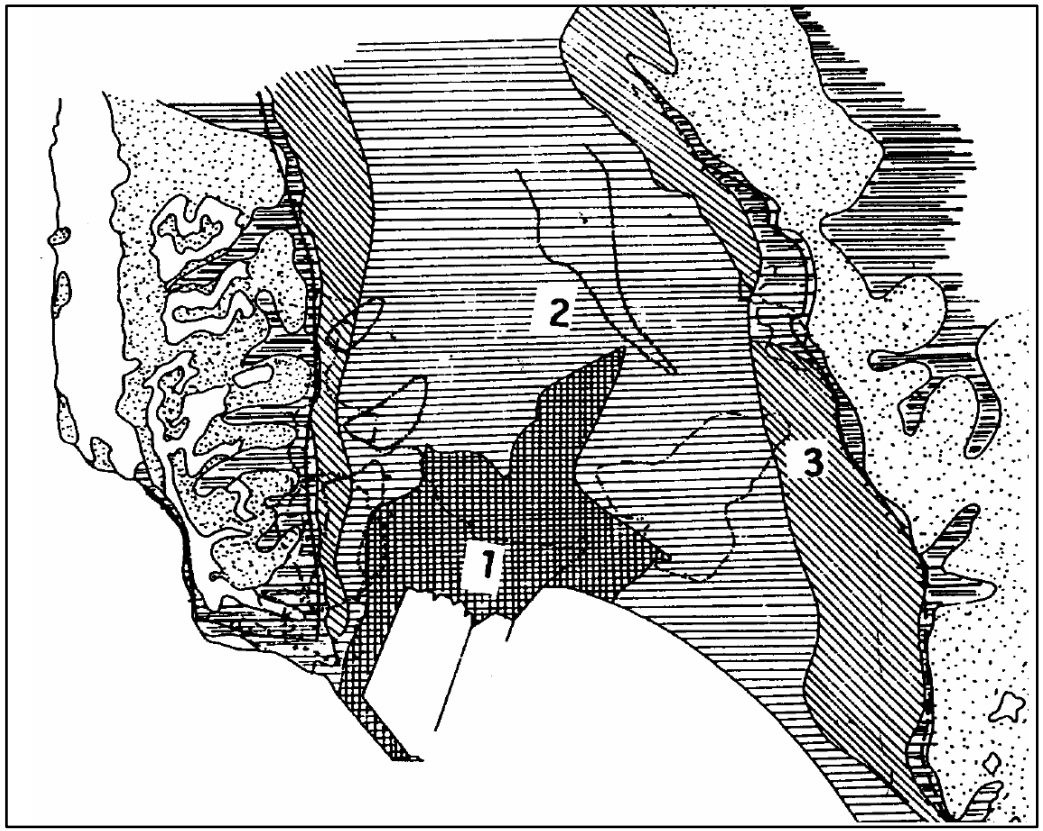
LIQUEFACTION POTENTIAL IN DURRËS AREA



From *Kociu (2004)*

From engineering geology point of view, the plain of the Durrës city is composed by very thick poor Quaternary sediments, which thickness reaches 130 m, with organic and historic layers of the former Durrës swamp in the upper part.

Based on analytical approaches applied by *Kociu (2004)* for the assessment of liquefaction potential in Durrës city, three areas with different potential for liquefaction are observed in the city:

1: Areas highly susceptible to liquefaction
2: Areas moderately susceptible to liquefaction
3: Areas with low susceptibility to liquefaction

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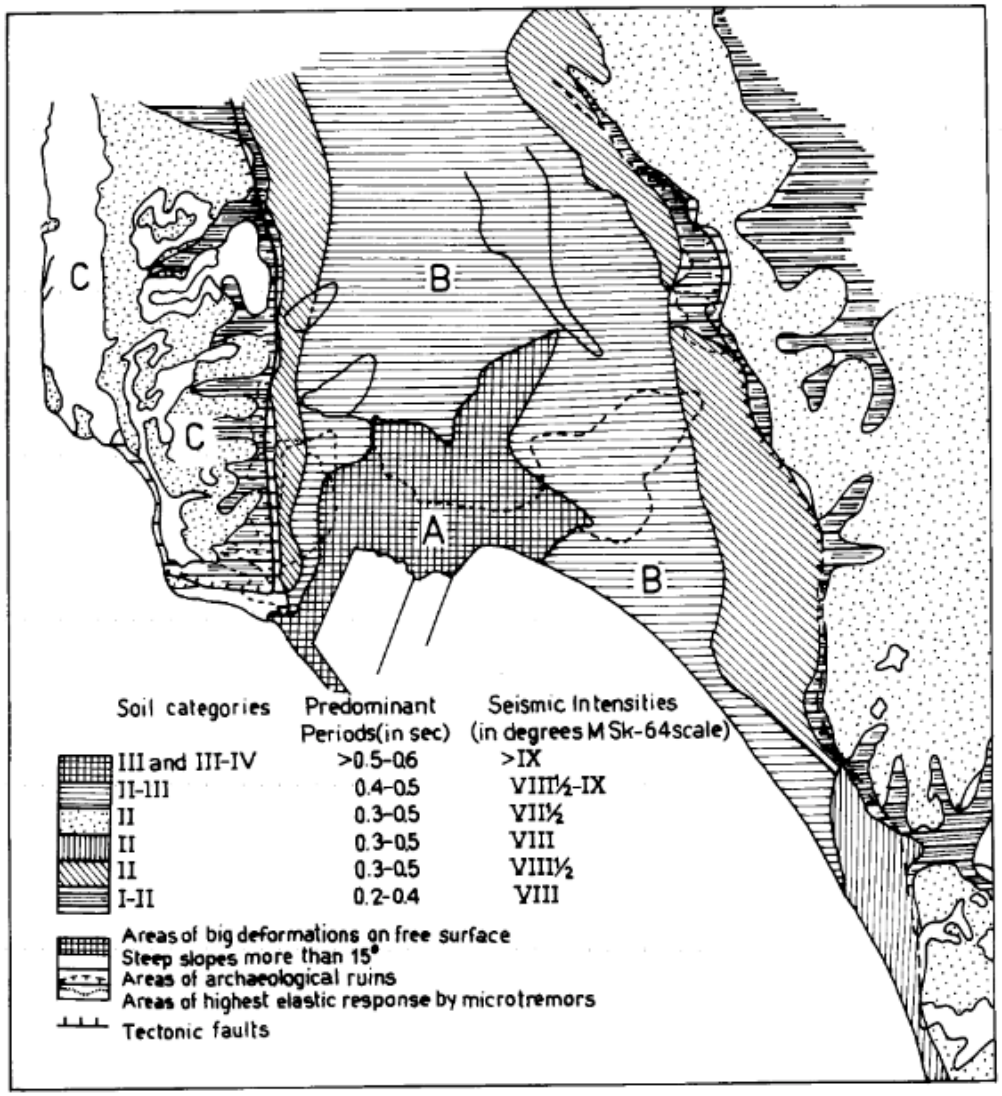
DEFORMATION EXPECTED IN DURRËS AFFECTED AREA AND ITS LIQUEFACTION POTENTIAL



Based on the microzonation map of Durrës city expressed through seismic intensity in degrees of the MSK-64 scale (*Aliaj et al., 2010*), it is concluded that the damage area in Durrës city is an area where big deformations on the free surface are expected in the event of an earthquake including liquefaction phenomena among others.

A: Areas of big deformation on free surface, with predominant periods larger than 0.5-0.6 sec and seismic intensities large than IX_{MSK64}

B: Areas with predominant periods equal to 0.4-0.5 sec and seismic intensities ranging from $VIII1/2_{MSK64}$ to IX_{MSK64}

C: Steep slopes more than 15°

From *Aliaj et al. (2010)*

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VERY HEAVY STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS
INDUCED BY THE NOVEMBER 26, 2019 EARTHQUAKE

A total collapse of a 5-storey building in Durrës. The short extensions of rebars in the columns of the first floor were only 30-40 cm long and adversely affected the performance of the building during the earthquake resulting in its collapse. The upper floors of the structure were overturned and crushed.

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NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS

A multistorey building in Durrës with damage observed only in the three lower storeys, while the upper storeys remained intact by the earthquake. Cracking of plaster, detachment of plaster from the brick walls, cracking and partial collapse of brick walls were mainly observed. The adverse characteristics of this building comprise cylindrical and thin columns and almost triangular shape of the building in top view. Moreover, beams are totally missing, especially in the interior of the structure. This lack constitutes a rule in the affected area. The slabs are prefabricated reinforced concrete hollow core slabs with no connections between them.

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NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS

A multistorey building in Durrës with damage observed only in the four lower floors, while the upper floors remained intact by the earthquake. Cracking of plaster, detachment of plaster from the brick walls, cracking and total collapse of brick walls between slabs were mainly observed. Moreover, the equipment of the apartments including furniture and electric devices among others overturned and slid. The equipment of the apartments was overturned and slid. This fact is attributed to high internal accelerations of the floors (floor accelerations). This is a rare phenomenon around the world and it is in accordance with all the seismic regulations of several countries. It is attributed to the action of a strong vertical component of the earthquake ground motion, which prevails in epicentral areas. However, this phenomenon is not rare in Greece and Italy due to the fact that most of the earthquakes that have stuck these countries during the last decades have been shallow, moderate to strong seismic events with their epicenters located close to large urban areas.

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NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS

A multistorey building in Durrës with damage observed only in the four lower floors, while the upper floors remained intact by the earthquake. Cracking of plaster, detachment of plaster from the brick walls, cracking and total collapse of brick walls between slabs were mainly observed. Moreover, the high plaster thickness generated sandwich walls and attracted seismic load that they could not resist.

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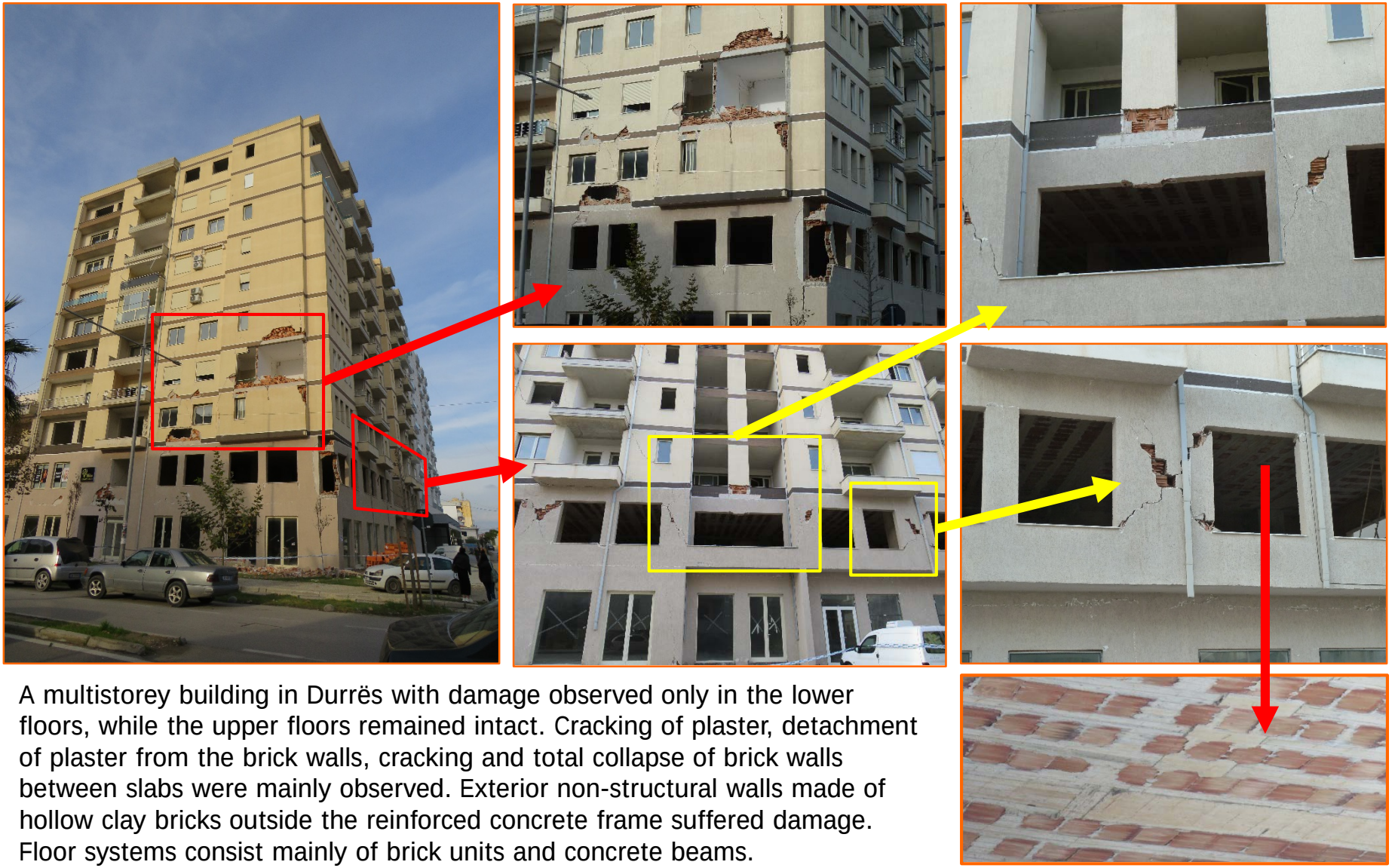
NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS



A multistorey building in Durrës with damage observed only in the lower floors, while the upper floors remained intact. Cracking of plaster, detachment of plaster from the brick walls, cracking and total collapse of brick walls between slabs were mainly observed. Exterior non-structural walls made of hollow clay bricks outside the reinforced concrete frame suffered damage. Floor systems consist mainly of brick units and concrete beams.

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NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS

Exterior non-structural walls made of hollow clay bricks outside the reinforced concrete frame suffered damage

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NON-STRUCTURAL AND STRUCTURAL DAMAGE TO BUILDINGS IN DURRËS

ONLY LOWER FLOORS AFFECTED IN MULTISTOREY BUILDINGS

It is significant to note that the high-rise buildings were damaged on their lower floors. Moreover, the same floors have been destroyed, indicating high floor accelerations, which is a rare phenomenon in relation to the intact upper floors. This is probably due to the action and prevalence of a strong vertical component of the earthquake ground motion in the affected areas. In this case, due to the shallow water table, the S waves are not easily propagated, while the P waves in the water are easily propagated with very small attenuation. In addition, such buildings have large fundamental period with a high base height ratio.

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COLLAPSED BUILDINGS IN DURRËS


Residential building


Hotel

The presented residential building (upper photos) and the hotel (lower photos) were among the totally collapsed buildings in Durrës. The destruction was almost complete with collapsed slabs leaving no gaps and empty spaces between them. The tangled mass of earthquake building debris reflects not only the strong seismic motion but also the poor construction of buildings and the inadequate quality of construction materials.

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CONCLUSIONS

Based on the geological reconnaissance and the field macroseismic survey conducted by the authors shortly after the Mw 6.4 Durrës earthquake, the following conclusions can be drawn:

- Building damage was distributed along two ellipses, whose major axis is oriented generally NW-SE. This direction coincides with the strike of the seismogenic fault as it is derived from the fault plane solutions provided by several seismological institutes and observatories. These ellipses could be characterized as macroseismic epicenters as the result of the interaction between the seismotectonic setting and the soil conditions and as the outcome of various reflections, refractions, conventions, directivity phenomena of seismic waves and resonance resulting in destruction in the earthquake-affected area.

- Major damage was observed along the NW-SE trending eastern boundary of a sedimentary basin, which is Tirana depression. The alpine basement is composed of flysch and limestone, while the sediments comprise Miocene, Pliocene, Pleistocene and Holocene deposits. Major damage was also observed in coastal area of Durrës port city, which is mainly consist of weak and unconsolidated marshy, alluvial and coastal deposits.

- The Durrës and Thumanë areas are composed of recent unconsolidated deposits comprising Holocene alluvial, marshy and coastal deposits. The effects of the earthquake on their building stock was probably amplified by the presence of this soft soil. The amplitude of the seismic waves can increase even 4 or 5 times compared to the amplitudes that would be in the same area but with hard and consolidated soil. Moreover, due to the shallow water table in the coastal area of Durrës, the S waves are not easily propagated, while the P waves in the water are easily propagated with very small attenuation. Thus, the prevailing movement is the vertical one, while the entire soil mass is oscillating in a wider basin as a flexible geological material.

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CONCLUSIONS

- The buildings in Durrës are mainly founded in recent alluvial and marshy deposits in an area where, based on the microzonation map, big deformation on free surface are expected, with predominant periods larger than 0.5-0.6 sec and seismic intensities large than $IX_{MSK64.}$

- The damage induced by the differential displacements and the deformation of these geological formations are similar to damage generated by earthquakes. Thus, the November earthquake hit overstrained structures not only from these differential movements but also from the September earthquake. The synergy of the soft soil along with the construction defects of the high rise building in the area and the pre-existing stress of the buildings due to their foundation in deposits suffering differential displacements resulted in destruction in the coastal area of Durrës. These structures suffer also from materials ageing processes more than those founded on hard and consolidated soil.

- Liquefaction phenomena were generated along the coastal part of Durrës city. The liquefaction included ejection of sand from ground cracks resulting in the formation of small sand volcanoes and silt-covered pavements. These phenomena were observed in an area where buildings suffered very heavy structural damage including collapse and tilting due to columns failure, while the adjacent buildings suffered non-structural damage.

- It is not the first time that the coastal part of Durrës city has suffered liquefaction. On December 27, 1926 fountains with hot water and sand, sand and mud volcanoes were generated. This area was known to be highly susceptible to liquefaction.

- The dominant buildings in the affected area are (a) buildings with load bearing solid brick walls and concrete floor slabs, (b) precast concrete panel buildings and (c) buildings with reinforced concrete frame and infill and partition walls. The main characteristic in the majority of these structures is the presence of prefabricated concrete floor slabs with width of 0.7-1.0 m and no connections between them.

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CONCLUSIONS

- The buildings with load bearing brick walls and concrete floor slabs did not present serious non-structural and structural damage in Durrës city. However, buildings of this type in Thumanë suffered very heavy structural damage including partial collapse resulting in many fatalities.

- The precast concrete panel buildings did not suffer significant non-structural or structural damage by the November 26, 2019 earthquake.

- The majority of the observed reinforced concrete multistorey buildings in Durrës suffered damage to the lower three to four storeys, while the above storeys remained intact. The equipment of the apartments comprising electric devices and furniture were overturned and slid. This is attributed to the prevalence of the vertical component of the earthquake ground motion, the flexibility of the structures, the thin flat slabs, the lack of beams, the high base height ratio (h/b) and the local soft soil conditions.

- The most observed damage to reinforced concrete buildings comprised hollow clay bricks failures, detachment of plaster from the brick walls, detachment and collapse of the brick walls as well as failures of walls on cantilevers.

- The epicenter of the earthquake was located in a large distance from the affected areas. Thus, it was a slow earthquake, with long duration and large period. Its uniform character resulted in matching of the large period of the soft soil with the large period of high buildings and consequently generated large oscillations and heavy damage possible in the lower storeys of the structures.

- The totally collapsed residential buildings and hotels in Durrës city present complete destruction. The slabs collapsed forming a pancake with no gaps and empty spaces between them due to the total lack of beams. Moreover, the tangled mass of earthquake building debris reflects not only the strong seismic motion but also the poor construction of buildings, the poor workmanship and the inadequate quality of construction materials.

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CONCLUSIONS

- The main factors that have affected the type and the spatial distribution of damage are the following:
  - the soft soils in the most earthquake-affected areas, which are characterized by resonance phenomena due to long duration, very low energy loss due to relative small amplitudes of the bed rock motion,
  - the undesired resonance phenomena in high buildings, which have large fundamental periods,
  - the large duration of the earthquake shaking due to the large distance of the affected area from the epicenter, the high buildings and the soft soils,
  - the shallow water table, which affect the propagation of the P and S seismic waves,
  - the pre-existing stress of the buildings founded on soft soils that characterized by differential settlements and possible liquefaction phenomena,
  - the poor construction quality of the affected buildings,
  - their poor workmanship,
  - the interventions made,
  - the ageing of materials due to differential displacements of the foundation soil,
  - the applicable antiseismic regulations of the time, if ever were applied,
  - the lack of maintenance and inadequate repair after previous destructive earthquakes and
  - the impact of the September 21, 2019 Mw 5.6 earthquake on the buildings of the affected area.

- The damage are considered typical of an earthquake of this magnitude. The effect of the previous September 21, 2019 Mw 5.6 earthquake in the same area should be also taken into account.

- Based on the seismic zonation map of Albania from the Earthquake Resistant Design Regulations, issued by the Seismic Center, Academy of Science of Albania, Department of Design, Ministry of Construction (1989), it is concluded that the resulted intensities from the earthquake under consideration, are within the limits specified in the Seismic Zonation Map.

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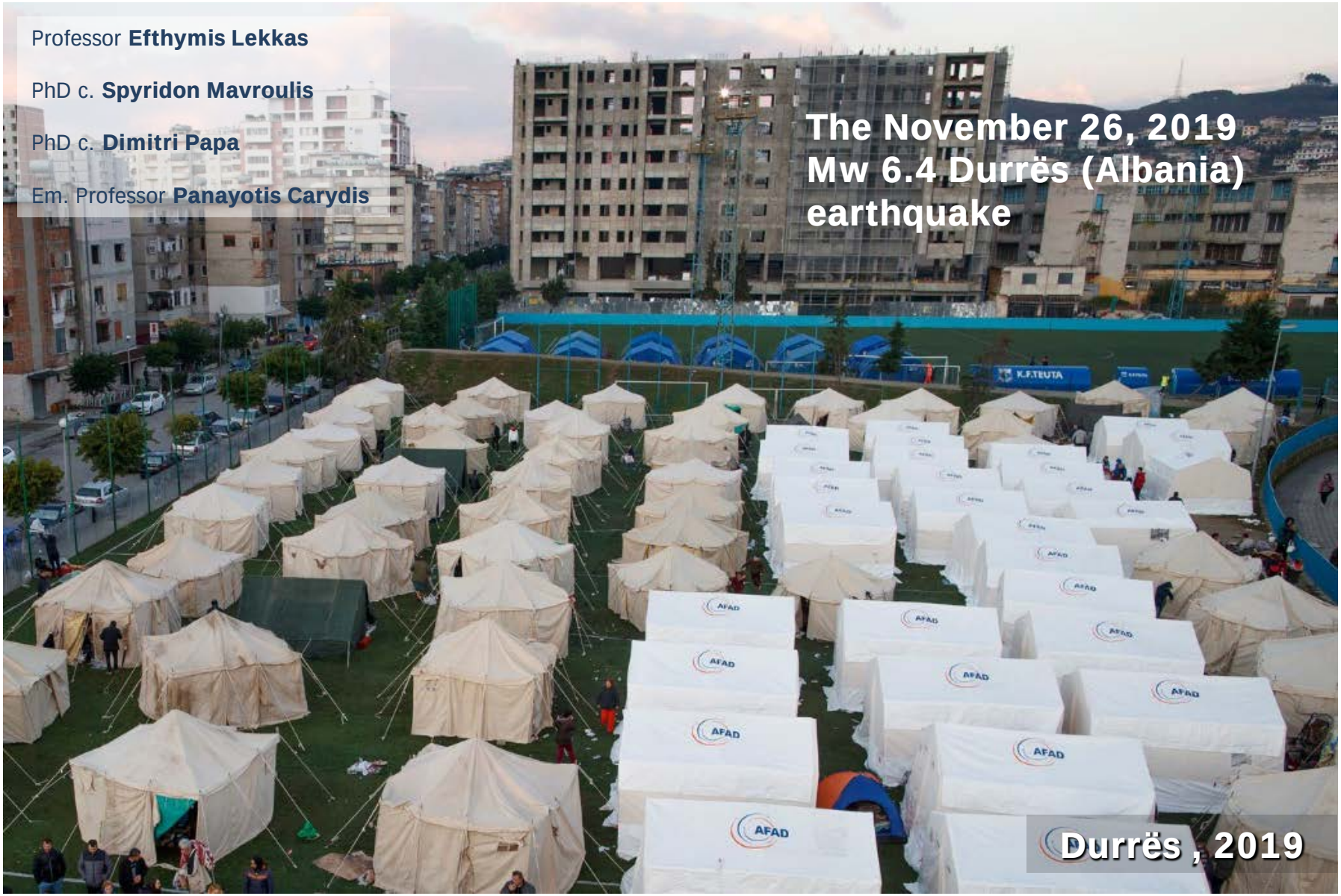
The November 26, 2019 Mw 6.4 Durrës (Albania) earthquake



Durrës , 2019