COMPARATIVE SEISMIC RISK ANALYSIS. EATHQUAKES M7.8 (1904- BULGARIA) AND (2023-TURKEY)

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Abstract: *The remarkable strong earthquakes occurred on 6th February 2023, attracted the whole world. Many victims and damages created worldwide wave of sympathy and help for the affected people and countries – Turkey and Syria. A lot of investigations have been done in all aspects of these tremendous events – seismological, geological, geodetic, geodynamic, social, economic, etc. The same magnitude seismic event struck a neighbor country – Bulgaria in 1904. Both events except of their magnitudes (M7.8) are also similar in the behavior of the strongest accompanying event – a foreshock (M7.2) in Bulgaria 20 minutes before the main event and the Turkish aftershock (M7.6), 9 hours after the main shock in Turkey thus giving the reason to consider these seismic events as "doublets" (by definition "doublets" are very strong seismic events in close time and space domain). The main focus of this research is to compare all possible similarities and differences of such doublets, thus giving the public a topic for discussion why, where and how we can learn our lessons and consider all details for the people protection and infrastructure safety.*

СРАВНИТЕЛЕН АНАЛИЗ НА СЕИЗМИЧНИЯ РИСК. ЗЕМЕТРЕСЕНИЯТА С М7.8 (1904 г.- БЪЛГАРИЯ) И (2023 г.-ТУРЦИЯ)

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Ключови думи: *Земетресения, Турция, България, сеизмичен риск*

Резюме: *Забележителните силни земетресения, настъпили на 6 февруари 2023 г., привлякоха вниманието на целия свят. Многото жертви и щети създадоха световна вълна от съпричастност и помощ към засегнатите хора и страни – Турция и Сирия. Извършени са много изследвания във всички аспекти на тези грандиозни събития – сеизмологични, геоложки, геодезически, геодинамични, социални, икономически и др. Сеизмично събитие със същия магнитуд става в България през 1904 г. И двете събития, имат сходни магнитуди (М7.8), но се отличават в поведението на най-силното съпътстващо събитие – форшок (М7.2) в България (20 минути преди основното събитие) и вторичен трус (афтершок) в Турция (М7.6), 9 часа след основния трус в Турция, което дава основание тези сеизмични събития да се разглеждат като „дублети" (по дефиниция „дублетите" са много силни сеизмични събития в близка времева и пространствена област). Основният фокус на това изследване е да се сравнят всички възможни прилики и разлики на такива дублети, като по този начин се даде на обществеността тема за дискусия защо, къде и как можем да научим нашите уроци и да разгледаме всички подробности за защитата и безопасността на хората и инфраструктурата.*

Introduction

The terrible and devastating earthquakes (M7.8 and M7.5) on 6th February 2023 demonstrate the power of the nature and weakness and fragility of the human society to fight against powerful natural hazards. Affecting more than 20 million people in Turkey, the death poll reaches about 60 000 deaths and about three times more injured, 120 000 buildings destroyed and more than 60 billion economic losses in Turkey and Syria, this tremendous seismic event at the same time gave the possibility to study and extract the lessons learned and to prevent such heavy consequences when next similar event occurred. Following the context of the specific behavior of the seismic process this event can be attributed to the terminology using the word “doubles” of such a combination of two very strong earthquakes occurred in close space and time window – near Gaziantep and Kahramanmaraş. The two strong earthquakes of 6th February demonstrated all peculiarities of the seismic process and its geophysical, seismological and social consequences. The similar effects have been observed also in 1904 in Bulgaria. On 4th of April, 1904 two very strong earthquakes (M7.2 and M7.8) occurred in a very close time and space domain. These seismic events can also be classified as a “doublet”. So the comparative analysis of such very strong earthquakes can help to understand better the seismic process and the following risks for the population, infrastructure and the affected countries as a whole. This paper is targeted to the comparison of the case studies to the seismic doublets in Bulgaria and Turkey and their peculiarities with a focus on the seismic process, destructions, negative social consequences and the specifics if they exist and to extract knowledge which can be useful for the prevention of all possible negatives.

Geology conditions and tectonic setting

The investigated areas– Krasna-Kroupnik seismic source (Bulgaria-BG) and Gazientep-Kahramanmaraş (Turkey-TR) seismic zones are located in SW Bulgaria and SW Turkey respectively – as presented on Fig. 1. [1, 2]

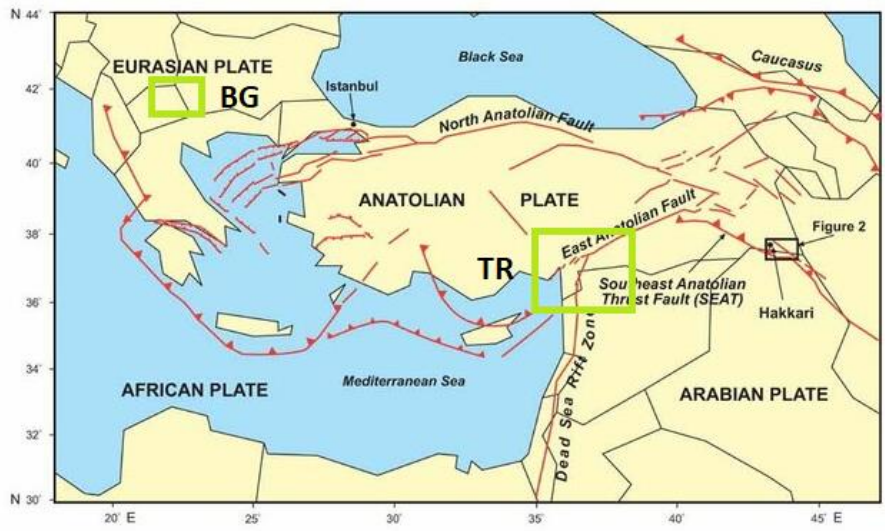


Fig. 1. Location of the investigated sites (green quadrangles) in Bulgaria (BG) and Turkey (TR)

Gazientep – Kahramanmaraş, Turkey earthquakes

The East Anatolian Fault (EAF) is positioned to the NE of Iskenderun bay of Aegean Sea and has more than 700 km long major strike-slip fault zone running from eastern to south-central Turkey. It forms the transform type tectonic boundary between the Anatolian Plate and the northward-moving Arabian Plate. The difference in the relative motions of the two plates is manifest in the left-lateral motion along the fault. The East and North Anatolian faults together accommodate the westward motion of the Anatolian Plate as it is squeezed out by the ongoing collision with the Eurasian Plate.

The East Anatolian Fault runs in a northeasterly direction, starting from the Maras Triple Junction at the northern end of the Dead Sea Transform, and ending at the Karlıova Triple Junction where it meets the North Anatolian Fault (NAF).

Triassic and cretaceous old metamorphic rocks, covered by Eocene limestones and younger sediments and an ophiolite belt of the ancient obduction of the continental crust over the oceanic of Thetis are the main geologic units developed in the area. The fault zone produced several large M~7 earthquakes during the last centuries. The average rate is about a large earthquake in every

20–25 years. This means very high seismic activity and the EAF is recognized as a primary unit dominating the seismic hazard in Turkey, together with the North Anatolian fault. Both fault zones are under compression and the dominant mechanisms of earthquakes are the strike-slip type. The Anatolian microplate surrounded by the both main fault zones is squeezed and moved in general to the west – Fig. 2.

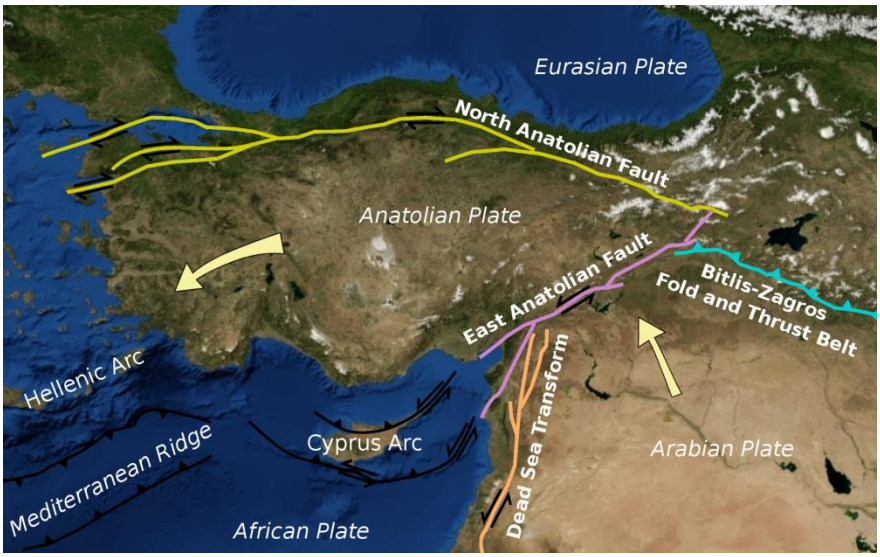


Fig. 2. Tectonic sketch (CSEM-EMSC) and main tectonic units dominating the geodynamic environment in Turkey

The active seismogenic faults are well studied in Turkey – Fig. 3 [3].

Aftershock activity is another parameter outlining the source zones of both events. Just for the statistics is important to mention that the aftershock process is not yet finished and will continue at least several years. This is a process of relaxation of the earth's crust substance generated the strong events.

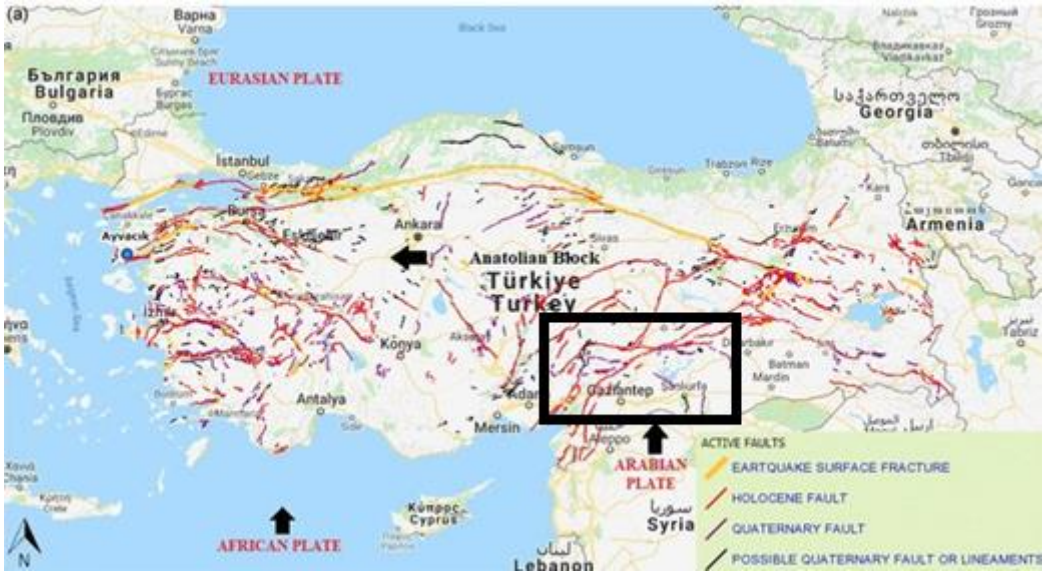


Fig. 3. Active faults map of Turkey and area of 6th Feb. 2023 earthquakes (black polygon)

Kresna-Kroupnik Bulgaria earthquakes

The geology of the Kresna-Kroupnik seismic zone (the most recently active area in Bulgaria) is dominated by Late Cretaceous intrusive rocks and Neogene sediments [3]. The tectonics is formed by the recent extension geodynamic regime due to the protrusion of the north branches of NAF. The area of the Kresna-Kroupnic earthquakes (M7.1 and M7.8) is located at the triple junction of the main three tectonic units – Rila-Rhodopean and Pirin, Ograzden and Struma – Fig. 4. They outlined typical block structures limited by grabens and faults sometimes seismically active [4]. As the main

geodynamic regime is extension the most mechanisms of the stronger events are normal type. Due to the complicated structure and the earth's crust fragmentation in the area frequently the low magnitude seismic events demonstrate variety of mechanisms and combinations of strike-slip, normal and trust type. The general neotectonic setting in the area is the block structure. This means that the Earth's crust is consistent with different sizes of blocks separated by vertical (large) and listric (mostly smaller) faults inclining to horizontal lineaments. The active faults have sparse distribution and demonstrate seismic activity, creep and sliding effects. – Fig. 5.

Fig. 4. Tectonic sketch (according [4]) and main tectonic units in Bulgaria.
Red polygon indicated the area of 4th April, 1904 earthquakes

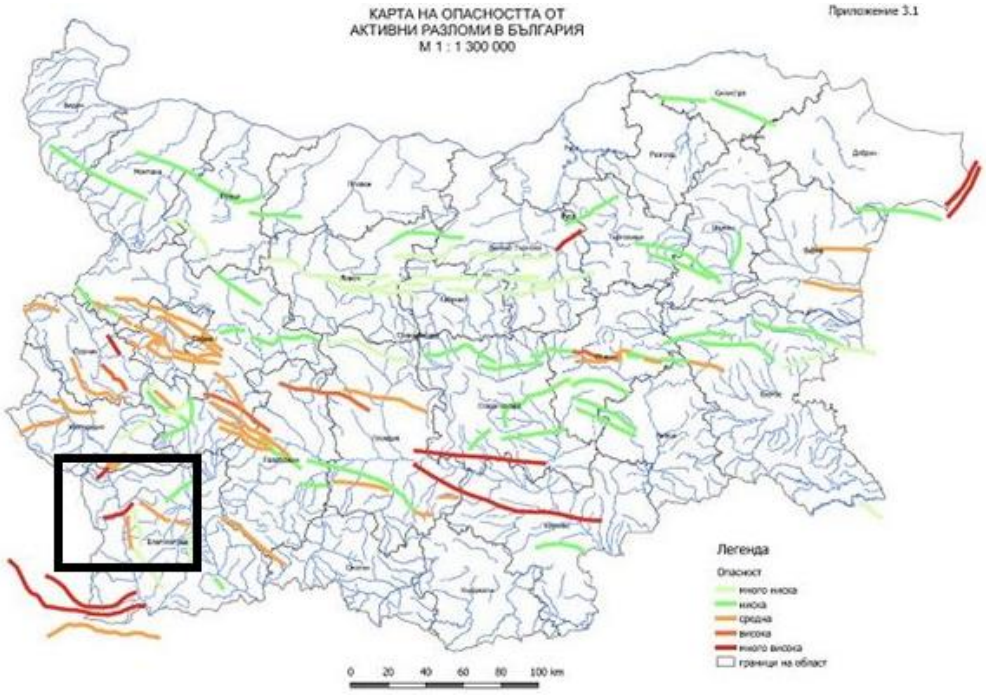


Fig. 5. Active faults map of Bulgaria and area of 4th April 1904 earthquakes (black polygon)

Data and comparison

Gazientep and Kahramanmaraş (Turkey) earthquakes

The strongest earthquakes (M7.8 and M7.5) shaken Turkey and Syria on 6th February 2023 are rather well studied and documented with all recent possibilities of the different sciences – seismology, geodynamics, geodesy, social sciences, remote sensing and space technologies, etc. Data about the earthquakes, mechanisms and geodynamics of the shocks, co-seismic displacements,

surface deformations, aftershock distributions, landslides and rock falls, tsunami and other primary and secondary effects are collected and published widely [5]. The intensive collapses and destructions of buildings, roads, dams, infrastructure, deaths, injured and homeless people, all these data are much more exact and correct in comparison with previous earthquakes, affected this area. The EAF produced many very strong seismic events in the past times. They were historically described and documented in the catalogues of the local and regional seismicity [5]. Recent technologies permit us to use remote sensing, satellite interferometry and other techniques which were not available in the previous times. This approach enrich our possibilities to study and investigate the processes and consequences of events with rather more efficiency.

Only for illustration two pictures are presented. Fig. 6a. shows the developments of the aftershock process after the first (M7.8) and prior the second (M7.5) earthquakes and Fig. 6b. presented approximately same time interval after the second seismic event. It is clearly visible that the aftershock sequence of the M7.8 event is strictly linked to the EAF, but the source of the M7.5 outlined by its aftershocks has mainly E-W direction [6].

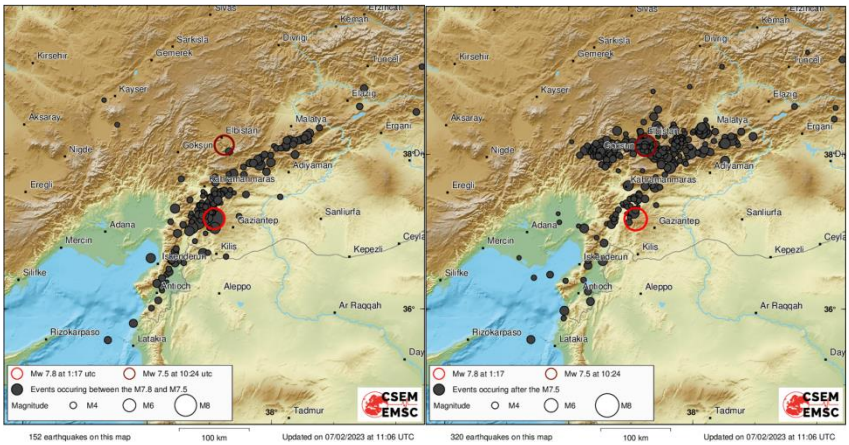
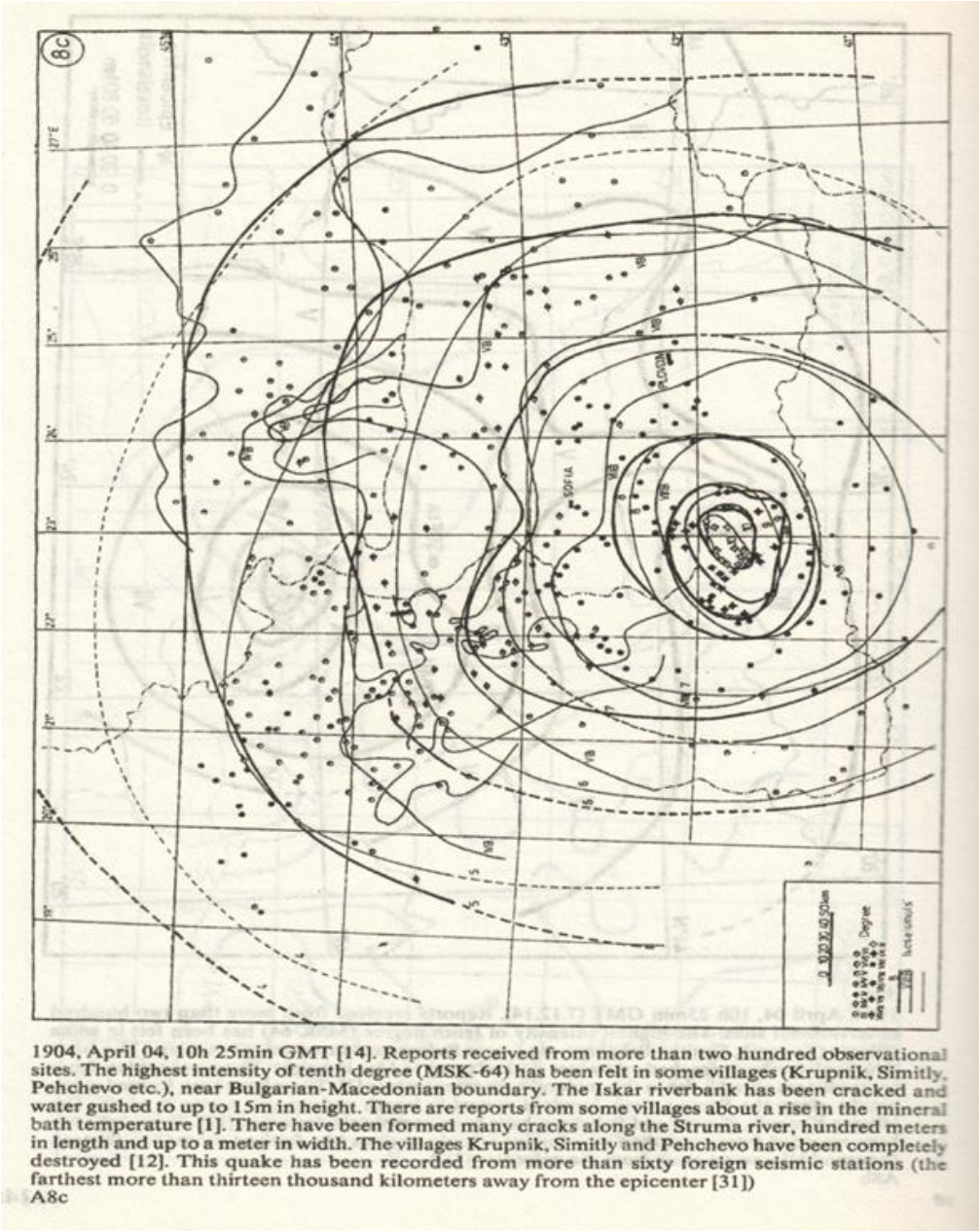


Fig. 6a (left) and 6b (right). Aftershocks after first (a) and second (b) shocks – 6th Feb.2023.

Kresna-Kroupnik (Bulgaria) earthquakes

The strongest earthquakes occurred on 4th April, 1904. M7.1 (considered foreshock) and M7.8 (main event) occurred in a time domain of about 20 minutes during the day time – around 10 o'clock AM. Most people were outdoor that's why the number of victims and injured were surprisingly low – several tens. The destructed buildings are estimated about several hundreds. It is important to mention that the epicenter was in a low populated mountain region. The felt aftershocks reported between the two strong shocks are about 20 (the strongest ones – 2 with magnitudes around 5.0) [7]. The immediate strongest aftershock of the sequence was reported about 8 hours later with magnitude 5.5 (intensity VII) and 1.5 year later the strongest aftershock of the whole sequence with magnitude 6.4. A set of more than 50 updated macroseismic maps related to these strong seismic events and their aftershocks have been prepared and published in 2001 [7]. A catalogue of historical earthquakes in the area (more than 100 events – years 890-1899) and more than 3 000 seismic events (1900-1975) has been created. All catalogue parameters of the investigated seismic events are extracted from the local reports and estimated magnitudes from the macroseismic information. A facsimile presents the macroseismic map of the M7.8 earthquake of 4th April, 1904 – Fig. 7. Twenty five macroseismic maps related to these strong events and their aftershocks have been created and published in 2001 [7]. For the transformation of the macroseismic map to Peak Ground Acceleration (PGA) specialized seismic hazard modelling was performed. The results might be useful for the comparative analysis. The obtained PGA values of the model are compatible with the macroseismic observations. The important issue is the partial location of the village Kroupnik on the trace of the observed fault dislocation due to the M7.8 earthquake – Fig. 8. The modelled values of the PGA reach 0.5–0.55 g.

To be able to study and compare both – Bulgaria and Turkey doublets several tables were created reflecting the main parameters (similarities and differences) of these earthquakes.



1904, April 04, 10h 25min GMT [14]. Reports received from more than two hundred observational sites. The highest intensity of tenth degree (MSK-64) has been felt in some villages (Krupnik, Simitly, Pehchevo etc.), near Bulgarian-Macedonian boundary. The Iskar riverbank has been cracked and water gushed to up to 15m in height. There are reports from some villages about a rise in the mineral bath temperature [1]. There have been formed many cracks along the Struma river, hundred meters in length and up to a meter in width. The villages Krupnik, Simitly and Pehchevo have been completely destroyed [12]. This quake has been recorded from more than sixty foreign seismic stations (the farthest more than thirteen thousand kilometers away from the epicenter [31])
A8c

Фиг. 7. A facsimile of the macroseismic map of the 1904 (M7.8) earthquake [8]

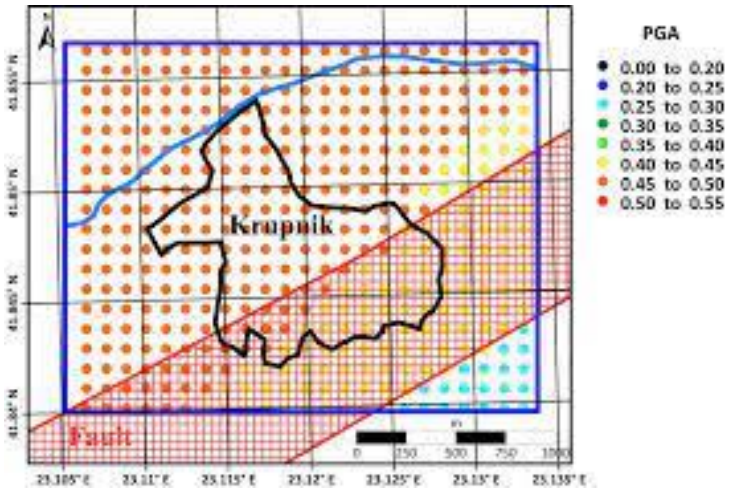


Fig. 8. Map of the PGA values modeling results [8]

Table 1. General parameters of the investigated main seismic events in Bulgaria (4th April, 1904) and Turkey (6th February, 2023)

Earthquake "doublet"	Time	Coordinates	Magnitude	Intensity (max)	Depth [km]	Time difference	Distance difference
Bulgaria (BG-Kresna-Kroupnik)	Day				In Earth's crust	~20 min	~20 km
First event- BG1- (foreshock)	10h 02 min	41.78N 22.98E	7.2	IX-X EMS	15		
Second event- BG2 (main)	10h 26 min	41.80N 23.10E	7.8	X EMS	18		
Turkey (TR-Gaziantep - Kahramanmaraş)	Night/ Day				In Earth's crust	~9 hours	~100 km
First event - TR1 (main)	01h 17 min	37.22N 37.02E	7.8	XI-XII EMS	10		
Second event- TR2- (aftershock)	10h 24min	38.02N 37.20E	7.5	X-XI EMS	15		

Table 2.Characteristic parameters and geodynamic environment

Events	BG1	TR1	BG2	TR2
Secondary effects:				
Faults	Normal	Strike-slip	Normal	Strike-slip
Geodynamic environment	Extension	Compression	Extension	Compression
Coseismic deformations	Vertical displacement up to 1-2m	Extremely large deformations up to 20m width and 10^2 – 10^3 m length. 7m horizontal displ.(-5 to +4 m) – vertical.	Large displacement (~5-10m), 40km (E-W) length	Large deformations up to 10m width and 10^2 – 10^3 m length. (~5m) horizontal displacement. (-4 to +4 m) – vertical.
Cracks	Many cracks – Up to 1m width.	400 km surface ruptures	Many cracks, 1perpendicular to the river bed. Length ~40 km.	60-80 km total surface ruptured cracks
Foreshocks	3 felt (M~3)	1 felt (M~5)	n/a	n/a
Aftershocks	10^2-10^3 (7 years)	10^3-10^4 (expected)	10^2-10^3 (7 years)	10^3-10^4 (expected)
Tsunamis	River flow	(1-2m Alexandreta)	River flow	n/a
Intensity areas	60 000 km^2 – felt 100 km^2–IX-EMC	200 000 km^2-felt 3 000 km^2 - XEMC	80 000 km^2-felt 300 km^2- X EMC	150 000 km^2 – felt 2 000 km^2- X EMC
Max felt distance	More than 200 km	More than 2000km	More than 300 km	More than 1000km
Max acceleration:	No records	Very rich collection of records ~150	No records	Very rich collection of records ~160
measured	No data	0.5-1.2(2.2)g	No data	0.6g
calculated	0.45-0.5g (model)	1-1.2g modelled	0.5g (model)	0.7-0.8g
"Unusual" observations	Rumbling, 5 m water rise	Strong sounds. Lack of destructions in Erzin (30-50 km from the fault – Intensity IX) Earthquake prediction by Frank Hoogerbeets -NL	Mineral water temperature rise, Dam formed like lake on Struma river bed (tsunami ?).	Strong sounds. Lack of destructions in Erzin (50-80 km from the fault – Intensity IX-VIII). Earthquake prediction by Frank Hoogerbeets - NL

Total losses and Social effects

Deaths – 60 000 (~50 000TUR) (10 000 SYR), Injured ~120 000, homeless, buildings collapsed – TR 67 209, buildings damaged-111 120, cities and villages affected, losses –primery-secondary about 100 bil (TUR) and about - 11 bil in Syria, infrastructure `fires and dam collapse (Syria), roads disruption, etc.[9]. Data extracted from [12].

The extensive study has been performed by different authors of the GPS, satellite and on-land measurements of the co-seismic deformations. Similar results have been obtained by the Bulgarian team [10].

Conclusions

A comparative study of the very strong earthquakes in Kresna-Kroupnik (Bulgaria, 1904 [11]) and Gazientep – Kahramanmaraş (Turkey, 2023) has been done considering the geophysical, seismological and social parameters and sequences in the context of the geological and tectonic environment of the shocks.

The comparison shows that these similar in power events have very significant differences in many aspects. Even their seismological parameters are close; the produced effects are completely incompatible [12].

The main conclusion about these differences are revealed and the dependencies discovered – larger area of destruction for the Turkish case, huge number of fatalities, incredible economic losses are due to the very much specifics outlined in the paper – low quality of buildings, extended infrastructure, high density of population, etc. are the main factors for such huge negative effects.

On the other side – Bulgaria case – low density of population, day time of occurrence, much smaller area of high intensities, stable wood flexible constructions of the buildings and lack of industries leads to extremely low number of victims, destructions and economic losses.

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