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Impacts of the 2020 Samos earthquake on the modeling of ancient seismic events

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Abstract: The 2020 Samos, M7.0 earthquake was characterized by an unusual bi-modal-type distribution of damage: limited damage in the nearfield (especially northern Samos coast) and serious localized damage in multi-story buildings in the far field (İzmir area). This pattern is not consistent with the typical distribution of isoseismal lines, and it seems not to represent an isolated effect; the 2014 Samothraki- Gökçeada M6.9 earthquake, for example, may in fact represent a parallel, though at smaller scale. For this reason, the damage pattern of the Samos earthquake may characterize historical earthquakes in the wider region, and perhaps explain, among others, some apparently large meizoseismal areas of historical earthquakes. Furthermore, the fact that damage in a part of the İzmir area occurred under moderate background acceleration has important implications for various ancient, long-period structures, especially monumental Greek and Roman multi-block columns and temples. These structures are highly resistant to seismic loads and difficult to fail under common earthquakes. However, evidence from the İzmir area indicates that, under certain conditions, common background accelerations can be highly amplified and leave their traces in such structures, for example in the Heraion temple at Samos.

Key words: earthquake, historical seismology, ancient temple, earthquake resistant structure, seismic intensity, acceleration amplification

1. Introduction

Various studies indicate that the 2020 Samos, M7.0 earthquake was associated with a normal fault, with its upper tip very close to the northernmost cost of Samos Island (Aktuğ et al., in press; Altunel and Pinar, 2021; Bulut et al.; 2021; Chousianitis and Konca, 2021; Foumelis et al., 2021; Ganas et al., 2021; Karakostas et al., 2021; Mavroulis et al., 2021; Sakkas, 2021). This coast is characterized by a high gradient, both onshore and offshore, and bounds to the south the 1000 m deep Ikaria basin, one of the deepest basins of the Aegean, with its flanks in Samos and Ikaria marked by raised Holocene shorelines (Stiros et al 2000; 2011). This indicates that the 2020 fault was associated with one of the major fault-zones in the Aegean (Chatzipetros et al., 2013; Caputo and Pavlides, 2013), extending to the east to the Küçük Menderes graben (Altunel and Pinar, 2021).

Reactivation of a normal fault offshore, along the north coast of Samos typically predicts major destruction in the near field, i.e. along the north coast of the island, with damage attenuating away from the epicenter/fault. The term "near field" follows the terminology of Krinitzsky and Chang (1987), who suggest that for a M7.0 earthquake, "nearfield" corresponds to an area at a distance up to 40 km from the source, and, in this area, a maximum intensity X is expected.

In fact, the 2020 earthquake produced important horizontal acceleration in Samos, with a maximum recorded PGA 0.23 at Vathi (for location see Figure 1) and damaged about 8% of the ~24,000 buildings in the island (ITSAK, 2020; Cetin et al., 2020). Still, this statistic should be read in a different way. Most of the damaged buildings were made of masonry and lath-and-plaster, and in their majority were non-inhabited, in bad condition, and hence, they were highly vulnerable to shaking even by moderate seismic shocks. Consequently, the 2020 damage level in Samos was much lower than what is typically expected in the nearfield of a M7.0 earthquake.

Oddly enough, this earthquake was associated with a pocket of extraordinary damage in a part of İzmir (mostly in the Bayrakli area), about 70km away from the epicenter, in the far-field of this earthquake according to the terminology of Krinitzsky and Chang (1987). In the wider İzmir region, several accelerometers have recorded a maximum PGA of the order of 0.11g (ITSAK 2020; Cetin et al., 2020), which, for the standards of the wider region, indicates a low background PGA level. This essentially low background acceleration was characterized by a relatively long-period content, clearly expected for a shock of this magnitude and for the epicentral distance of the İzmir area (about 70km). For some reasons, which are not still

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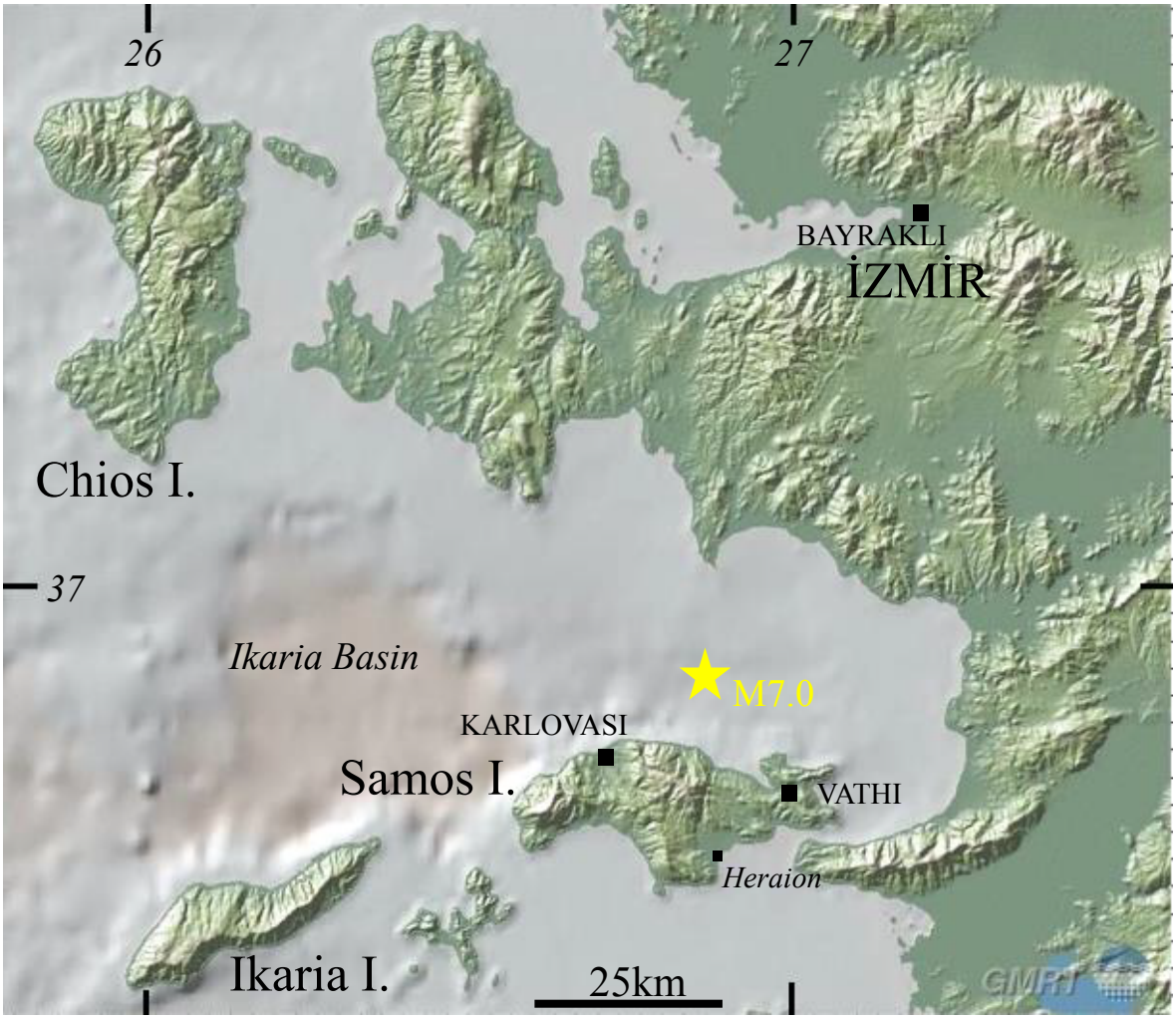


Figure 1. Major damage of the Samos 2020 earthquake was characterized by a bi-modal pattern and was limited to two main areas: in the nearfield, in the northern part of the Samos Island (especially in the two main towns, Vathi and Karlovasi), and in the far-field, in the Bayraklı District of the İzmir metropolitan area. A star indicates the location of the epicenter. The causative normal fault runs along the north coast of Samos Island, but its precise geometry is a matter of debate (see references in the Introduction Section). Figure is based on GMRT background.

very clear, this low background acceleration was locally amplified and led to the collapse of several multi-floor buildings and unfortunately to a death toll of about 150.

Localized damage in the İzmir area (in the far-field), in combination with mild damage in Samos (in the very near-field), testify to a kind of "bimodal" damage distribution. This pattern of damage is quite different from the common, ellipse-type pattern of the meizoseismal areas of most earthquakes. In typical cases, seismic intensities tend to attenuate away from the ellipse of highest intensities, while the center of this ellipse roughly corresponds to the epicenter of the earthquake (Papazachos et al., 1982).

The extraordinary pattern of seismic intensities of the Samos earthquake has very important implications in the understanding of historical earthquakes, which represent a major source of information for understanding seismicity in the Central and Eastern Mediterranean and the Middle East (Papazachos and Papazachou, 1997; Guidoboni et al., 1994; Boschi et al., 1999; 2009) but represent a matter of concern for cautious investigators (Rovida et al., 2020).

The aim of this article is to show first that other Aegean earthquakes may share common characteristics with the 2020 earthquake concerning the pattern of damage. On these grounds, a second aim is to investigate certain implications of the 2020 earthquake in the modeling of ancient earthquakes, derived from historical and archaeological data. A third aim is to investigate the possible impact of the recent earthquake on certain types of ancient monuments, mostly monumental classical to Roman temples. In fact, remains of this type

of structures are widespread in the wider region and are very important for various aspects of modern life in the Eastern Mediterranean and the Middle East. Just to notice that the 1970 Gediz earthquake and the 2017 Kos-Bodrum earthquakes caused the collapse of restored ancient columns, while the resistance to earthquakes of ancient monumental temples and, hence, the causes of their collapse and demise have recently proved a matter of debate (for a summary of ideas, see Stiros, 2020). For these reasons, the implications of the impacts of the 2020 earthquake represent a topic of broader impact for various fields of modern life especially in the Central and Eastern Mediterranean. The overall approach corresponds to a reverse approach since so far information for ancient earthquakes was used to model modern seismic risk.

2. The Samos earthquake, an extraordinary event?

Large earthquakes along the Aegean Arc are known to have produced damage in distant areas, for example in Egypt (Ambraseys et al., 1994). The 1928 Ms7.4 Rhodes earthquake, the only major earthquake along the Aegean Arc for which some at least primitive instrumental recordings are available, was associated with increased intensities in the central part of Crete (Ambraseys and Adams, 1998). Hence, such earthquakes may be described as multi-modal events concerning the distribution of seismic intensities. However, for earthquakes in the back-arc basin, no such effects have been discussed.

Still, the 2014 Samothraki- Gökçeada M6.9 earthquake, an essentially strike slip earthquake (Saltogianni et al 2015), seems to share some characteristics with the 2020 Samos earthquake. In fact, seismic intensities of the 2014 earthquake were much higher in the Turkish territory (in the farfield), than in the Greek territory (in the nearfield; Sboras et al 2017 and references therein). This is also derived from instrumental evidence. In the near field (in Samothraki island, about 12km from the epicenter, and in Lemnos Island, about 28 km from the epicenter), this earthquake produced no damage, and local coseismic GNSS (GPS)-derived dynamic displacements were rapidly attenuated (Figure 2b). However, at Çanakkale, at an epicentral distance of about 47 km (which can be categorized as far-field sensu Krinitzsky and Chang, 1987), moderate damage was produced. This area is beyond the area in which significant permanent coseismic displacements ("fling steps") occurred in 2014, but the GNSS (GPS) station CANA at Çanakkale recorded particular co-seismic displacements. CANA is at much longer epicentral distances than stations in Samothraki (station 018) and Lemnos (station 089), but its maximum co-seismic displacement was of the same order of amplitude with these two stations, and oddly enough, seismic dynamic displacement (oscillations) at CANA continued for an interval twice as that in all other stations (Figure 2b). Such a long oscillation interval (tens of seconds) may have led to fatigue and damage of

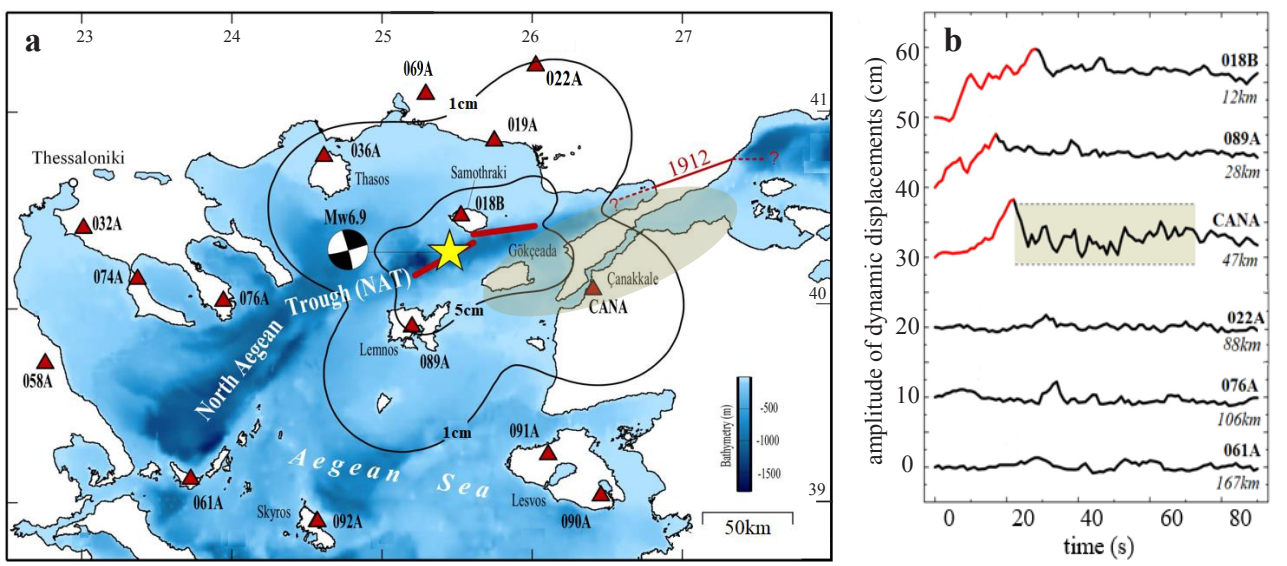


Figure 2. Dynamic displacements of the 2014 Samothraki-Gökçeada earthquake. **a**: Location map showing GNSS stations (red triangles), epicenter (star), faults (solid red lines), and contours of static displacements ("fling steps") of 1 and 5 cm (black lines). Shading indicates areas of increased intensities, mostly in the far-field. **b**: Time series of the amplitude of GNSS-derived horizontal dynamic displacements for selected stations; epicentral distance is marked below station code. Station CANA at Çanakkale shows dynamic displacements with maximum amplitude essentially similar to that in stations in the nearfield and with nearly double duration (shaded); this is evidence of amplification of seismic movement. Records of each station are displaced by 10 cm for clarity.

vulnerable structures, should any have existed in that area, and should the amplitude of oscillations have been higher. Hence, the pattern of seismic intensities of the strike slip 2014 Samothraki- Gökçeada M6.9 earthquake shares some common characteristics with the 2020 normal faulting Samos earthquake, though at much smaller scale. This is an evidence that earthquakes with a similar pattern in the distribution of seismic intensities may have occurred also in the past.

3. Modeling ancient earthquakes from reports/ observations of damage

During the last century was developed the technique to model an ancient earthquake, or at least some of its parameters, using historical (and occasionally archaeological) data. The overall approach is based on non-instrumental observations of structural damage (earthquake intensities) and of various environmental effects of earthquakes. The basic idea is to plot sites of damage in a map, and then produce a diagram of the affected areas, or of the meizoseismal areas of the earthquakes (Figure 3). This approach, however, is qualitative, and does not provide estimates of main parameters of an earthquake such as epicenter or magnitude. If, however, observations of different levels of damage are available for different sites, they may be converted into intensities, and hence, isoseismal curves can be produced. Intensities are usually in the form of ellipses (Figure 4), and the center of the area of maximum intensity corresponds to the epicenter of the earthquake. It has been found that the epicenter derived from intensities (macroseismic epicenter) is within 30 km from the epicenter derived from analysis of seismograms (Ambraseys and Melville, 1982). Exploiting the geometry of the contours of intensities, certain quantitative parameters of earthquakes can be computed (cf. Ambraseys and Jackson, 1998), and parametric catalogues of earthquake can be compiled, though with the reservation that some of their data may be questionable (Rovida et al., 2020).

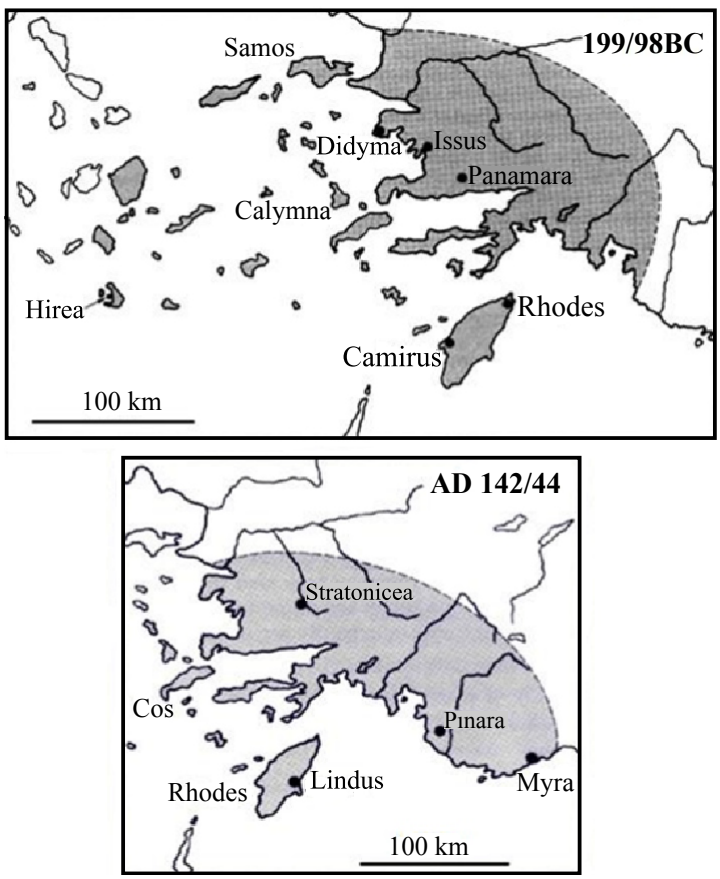


Figure 3. Meizoseismal areas (or affected areas) of the 199/198BC and AD142/144 earthquakes in the SE part of the Aegean. After Guidoboni et al. (1994) with additions. Note similarities in the order of magnitude of the meizoseismal (or affected) zones of the two events, which seem to be too large for modern experience.

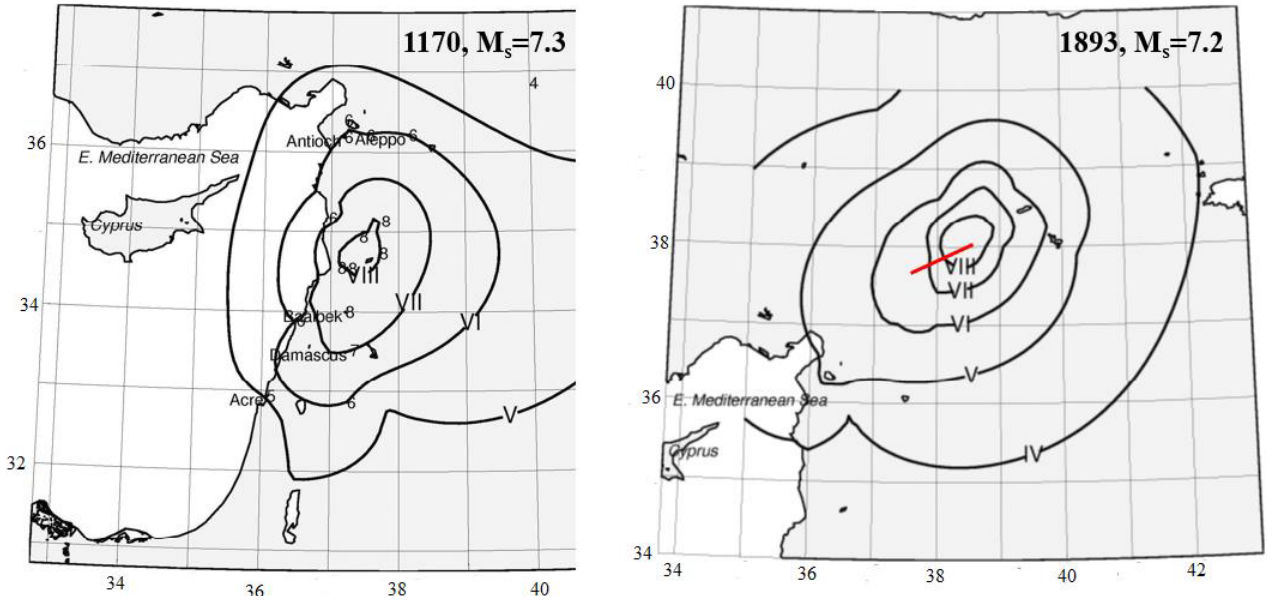


Figure 4. Isoseismal contours of the 1170, Ms 7.3 and 1893, Ms7.2 earthquakes. After Ambraseys (2009) with additions. Longitude degrees roughly correspond to 100km. A red line in the graph of the 1893 epicenter indicates the reactivated fault according to Duman and Emre (2013) and Taymaz et al. (2021), slightly offset relative to the area of maximum intensities.

The problem, indeed, with historical seismicity is that, especially in certain periods, information is scanty and vague (e.g., Kouskouna and Makropoulos, 2004), and the estimation of intensities may be quite noisy. This would affect any estimation of magnitude and of epicenters of historical earthquakes. For example, parameters of the 426BC earthquake in Central Greece can be found in most catalogues. This is a benchmark event because ancient texts indicate that this earthquake was associated with coastal changes and tsunami, and some of this information is derived from the first catalogue of earthquakes that was compiled in antiquity. However, a careful investigation of the ancient texts indicates not a single but probably two different earthquakes (Papaioannou et al., 2004). Apart from that, modern experience, especially after a series of strong earthquakes in the eastern part of the Aegean (2014 Samothraki - Gökçeada earthquake, 2017 Lesvos earthquake, 2017 Kos-Bodrum earthquake, 2020, Samos earthquake, all in the range of magnitude 6-7), indicates that the inferred meizoseismal (or affected) area of certain ancient events, such as those of Figure 3 seems too large. On the other hand, the area bounded by the contour of highest intensity in Figure 4 seems somewhat offset in comparison with the 1893 rupture along the 1893 East Anatolian Fault, derived from Duman and Emre (2013) and Taymaz et al. (2021). Can the evidence of the 2020 Samos earthquake provide some clues for problems such as those noticed above for ancient earthquakes?

If a Samos-type earthquake had occurred in the pre-instrumental seismology period, it would have affected two distinct areas. An area "S" with constructions similar to those in Samos (mostly short-period, low-rise structures) and at some distance, another area "B", with geotechnical characteristics and with relatively long-period constructions as in the wider Bayrakli area of İzmir (for example slender ancient Greek and Roman temples, colonnades, tall slender towers, minarets). If enough macroseismic information was available for this event, a modern investigator is likely to have identified not a single earthquake with bi-modal distribution of damage but two different earthquakes, which occurred within a short interval: a smaller local event responsible for damage in area "S", and a stronger earthquake (with energy in relatively long periods) responsible for damage in area "B". If, however, the information was scanty, an earthquake with a broad meizoseismal area is likely to have been assumed.

These simple arguments can be used to question whether for example, large meizoseismal areas such as those of Figure 3 may indeed reflect unusually large events, exaggeration by ancient sources, wrong interpretations of the ancient sources, possible multiple events regarded as one, or even Samos-type events.

The above rationale is not in variance with conclusions for the sources of earthquakes which affected Smyrna, ancient İzmir between AD47 and 1688. In a recent study, Tepe et al (in press) found that seismic damage in İzmir during this period can be assigned to nearby faults (local sources). This is reasonable because inferred damage was identified with relatively low-rise, high-frequency

buildings, which are vulnerable (resonant) to high-frequency waves only. High-frequency waves are rapidly attenuating with distance, and, for this reason, distant earthquakes can be excluded as sources of this damage. After 1688, however, a new building style was adopted in Smyrna, and houses were made with an essentially wooden skeleton and lightweight walls made of lath-and-plaster. As noticed by ancient writers, these new structures proved resistant to earthquakes which hit the İzmir area in the following 30 years (Stiros, 1995). However, in view of the recent Samos earthquake, it may be assumed that some of these post-1688, non-damaging earthquakes may have originated from rather distant faults and earthquakes, which produced long-period shaking and much panic, but no resonance and structural damage.

4. Impacts of earthquakes in ancient monumental structures

Ancient and modern earthquakes are known to have produced major damage in ancient structures (e.g., Guidoboni et al., 1994; Ambraseys et al., 1994; Ambraseys 2009). However, based on numerical modeling and of experiments, it has recently been argued that typical classical Greek and Roman temples and columns are practically non-vulnerable to earthquakes, the reason for their demise should be searched in human actions, and that survival of ancient temples indicates absence of strong accelerations, especially characterized by long-period pulses conspicuously produced by strong earthquakes (for the case of the Athens area, see Psycharis 2007; for a review of ideas see Stiros 2020).

The basic idea, first documented by Sinopoli (1989), is that classical and Roman columns (and whole temples including columns) are made of well-hewn blocks (drums), standing on top of each other thanks to gravity and dry friction (articulated structures). When excited by an earthquake, these structures have a behaviour very different from modern, rigid structures (made of concrete), as is explained schematically in Figure 5a. During an earthquake, certain structural components (drums) tend to move quasi-independently from the adjacent (overlying/underlaying) blocks ("mechanism") in the way explained in Figure 5b. For example, a part of a column is tilted along an edge of a drum, and then moves back to rotate along an opposite edge. This motion produces a collision of the bottom of oscillating part of the column with the underlying non-oscillating part, and horizontal slip of the drum, resulting to offsets like those seen in the drums of Figure 6. Collision and slip absorb energy and dissipate the oscillation. This effect can occur between different drums (Figure 6) and it tends to have a rather random character, so that offsets between various drums and at different directions is observed. In addition, some earthquakes tend to counteract offsets of previous events.

Recently, it was found that in addition to these effects, seismic tilting of a part of a column generates a torque counteracting tilting, a natural oscillation damping mechanism. This torque (schematically shown as a curved arrow in Figures 5a, b) is equal to the weight of the tilting part times distance of the center of mass from the edge of rotation of the upper part of the column, and is higher in tall and slender columns, and in rotating parts with a heavy load on top (a beam, architrave; Figure 5c; Makris, 2014; Makris and Vassiliou, 2014). Furthermore, modeling and experiments, mostly of isolated columns, tend to support this idea and tend to indicate that the seismic collapse of columns is possible only under extreme seismic accelerations. Hence, it has been concluded that survival of standing ancient columns could be regarded as evidence of absence of very strong seismic accelerations, mainly characterized by long-period pulses (cf. Psycharis 2007; for a review see Stiros 2020).

However, historical data provide evidence of failure of ancient classical temples, and this may be due to weaknesses in structures; for example, mechanical failure at the rotating edge of a drum, marked by a black arrow in the middle row of Figure 6) may lead to removal of a wedge (black part) and to lead to seismic collapse of a column, even of part of an ancient temple. These are realistic scenarios supported by historical evidence; for example, one of the columns of Roman, Olympieion temple in Athens collapsed during an extraordinary storm in 1853 (Stiros, 2020).

Evidence from the Bayrakli area of İzmir may shed more light to the conditions of collapse of ancient multi-drum columns. What we know is that the maximum background acceleration in this area during the 2020 earthquake was of the order of 0.11g and for certain reasons which are not quite clear, this acceleration was apparently highly amplified so that several multi-story buildings collapsed (Erdik et al, 2020; Cetin et al., 2020). Damage and collapse of these buildings clearly requires an acceleration several times higher than the corresponding background value. Hence the lesson from this earthquake is that under certain conditions, seismic waves may be locally highly amplified, and no extreme background accelerations may be required to explain damage in certain types of structures. Consequently, survival of ancient structures is not evidence of earthquakes not exceeding a certain level of accelerations, but alternatively, absence of amplification effects in the specific sites since the construction of the ancient buildings.

This result may be used to explain the offsets of the column of the Heraion Temple (Figure 6) at Samos (for location see Figure 1). Stiros et al. (2000) and Stiros (2020) have assigned the offset drums to earthquakes, which

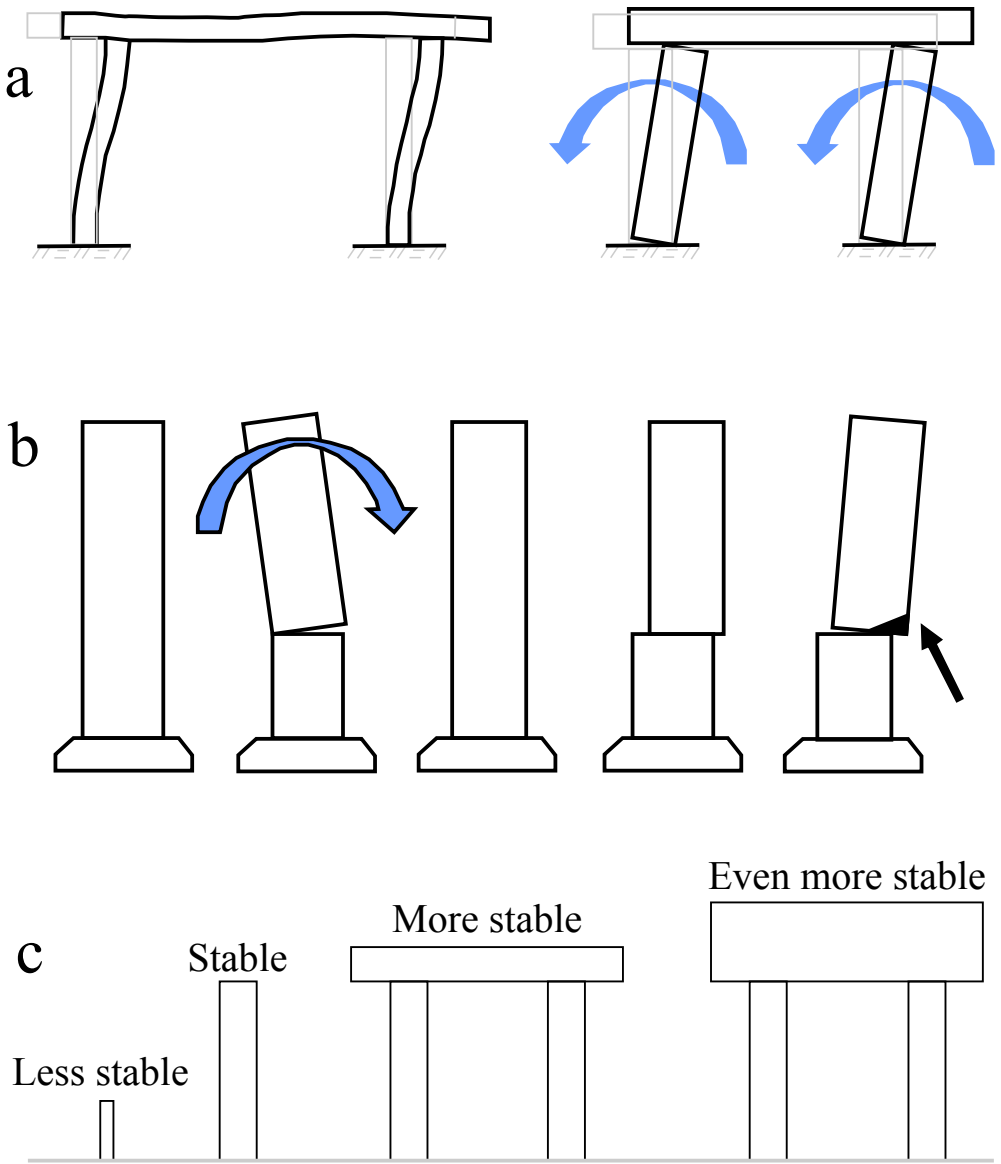


Figure 5. Pattern of instantaneous deformation of ancient monumental ancient Greek and Roman temples during earthquakes. a: Differences in the response of a typical rigid structure (made with concrete) from that of a multiblock temple (mechanism). b: Response to an earthquake of a multidrum column by rocking. Failure (or missing wedge, marked black) modifies the pattern of oscillation and may lead to failure. Blue arrows indicate a torque opposing to the seismic tilting and tending to stabilize the column. c: An apparent paradox in the seismic performance of ancient Greek and Roman columns and temples: stability increases with the column height and the load of horizontal beams (architraves). (a), (c) after Makris (2014) and Makris and Vassiliou (2014); (b) modified after Sinopoli (1989).

produced significant coastal uplift at the western part of the island. Evidence presented here indicates that this is not the only possibility, and other strong earthquakes, of the order of magnitude M7, at larger epicentral distances, for example with epicenters in the Anatolian mainalnd, may have been responsible for the deformation of the Heraion column. In fact, this temple is built on a layer of weak soil overlaying Neogene sediments, hence, a situation to some degree reminiscent of the Bayrakli area in İzmir (cf. Erdik et al., 2020).

A somewhat similar scenario may indeed be proposed for the collapse of the magnificent Adrian Temple, in Cyzicus, at a narrow strip of land connecting a peninsula in the Sea of Marmara with Anatolia mainland (Balikesir



Figure 6. Offsets between drums are clear in the only surviving column of the Heraion Temple in Samos (for location see Figure 1) and originate from oscillations (rocking) during strong earthquakes, as explained in Figure 5.

province of Turkey; location indicated by arrow and C in Figure 2a). This is indeed the only case of a major Roman temple for which there is a clear historical report that it was partly destroyed by a 2nd century AD earthquake (*Dio Cassius, Epit 70.4*), while its remains were partially obliterated in later periods and were found only recently (see Stiros 2020). The history of earthquakes of this period is unclear (Guidoboni et al., 1994), and hence different scenarios can be proposed. Reactivation of a strand of the North Anatolian Fault crossing the Sea of Marmara about 40km north of Cyzicus, or reactivation of a smaller fault passing close to Cyzicus (Figure 1 in Meghraoui et al., 2012) are the most likely possibilities. However, although this temple is apparently not founded on weak soil, its partial collapse due to amplification of background accelerations produced by an earthquake from a distant source, i.e. any of the faults that are within a radius of 70-80km (see Emre et al, 2013), may not be readily discarded.

5. Summary and conclusion

In this article, it is discussed that the 2020 Samos earthquake was characterized by an unusual, bi-modal distribution of areas of damage, and if detailed seismograms were not available, it would be unlikely to assign its damage pattern to a single event. Hence, this bi-modal pattern of damage (Figure 1) may be back-projected to the past, in order to refine the understanding of various ancient earthquakes. This is a very important task because ancient earthquakes represent a major source of information for seismology in the wider region, and because they are covered by scanty information, and hence, modeling of some of their parameters is in many cases uncertain.

Another implication of the Samos earthquake is that it revealed that, under certain conditions, moderate background seismic accelerations from a far-field strong earthquake can be highly amplified and produce damage and even cause collapse of multi-story (long-period) structures. Although the reasons of damage and of collapse of the buildings in İzmir are still somewhat unclear, their number and geography indicate a more generalized effect, which can be used to explain damage and demise of certain relatively long-period ancient structures. This is especially the case with articulated (multi-block) monumental ancient Greek and Roman temples, which seem to be highly resistant to common earthquakes. In fact, the evidence from İzmir has indicated that, under certain conditions, moderate background seismic accelerations from rather remote sources can be locally highly amplified and cause failure in such structures, and this is important both for the understanding the history of ancient monuments but also for their restoration and preservation.

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References

Aktuğ B, Tiryakioğlu I, Sözbilir H, Özener H, Özkaymak Ç et al. GPS Derived Finite Source Mechanism of the 30 October 2020 Samos Earthquake, Mw = 6.9 in Aegean extensional region. Turkish Journal of Earth 30: 718-737.

Altunel E, Pinar A (2021). Tectonic implications of the Mw 6.8, 30 October 2020 Kuşadası Gulf earthquake in the frame of active faults of Western Turkey. Turkish Journal of Earth Sciences 30: 436-448.

Ambraseys N (2009). Earthquakes in the Mediterranean and the Middle East, Cambridge University Press, Cambridge.

Ambraseys N, Adams R (1998). The Rhodes earthquake of 26 June 1926. Journal of Seismology 2: 267–292.

Ambraseys N, Jackson J (1998). Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region, Geophysical Journal International 133: 390–406.

Ambraseys N, Melville CP (1982). A History of Persian Earthquakes, Cambridge University Press.

Ambraseys N, Melville C, Adams R (1994). The seismicity of Egypt, Arabia and the Red Sea. Cambridge University Press.

Boschi E, Gasperini P, Valensise G, Camassi R, Castelli V et al. (1999). Catalogo parametrico dei terremoti italiani. Istituto Nazionale di Geofisica, Bologna.

Bulut F, Doğru A, Yaltirak C, Yalvaç S, Elge M (2021). Anatomy of October 30, 2020, Samos (Sisam) - Kuşadası Earthquake (MW 6.92) and its influence on Aegean Earthquake Hazard. Turkish Journal of Earth Sciences 30: 425-435.

Caputo R, Pavlides S (2013). The Greek Database of Seismogenic Sources (GreDaSS), version 2.0.0: A compilation of potential seismogenic sources (Mw>5.5) in the Aegean Region. doi: 10.15160/UNIFE/GREDASS/0200

Cetin KO, Mylonakis G, Sextos A, Stewart J (Report coordinators) (2020). Seismological and Engineering Effects of the M 7.0 Samos Island (Aegean Sea) Earthquake. Geotechnical Extreme Events Reconnaissance Association: Report GEER-069. doi: 10.18118/G6H088

Chatzipetros A, Kiratzi A, Sboras S, Zouros N, Pavlides S (2013). Active faulting in the north-eastern Aegean Sea Islands. Tectonophysics 597–598: 106–122.

Chousianitis K, Konca AO (2021). Rupture process of the 2020 Mw7.0 Samos earthquake and its effect on surrounding active faults. Geophysical Research Letters 48: e2021GL094162.

Duman T, Emre Ö (2013). The East Anatolian Fault: geometry segmentation and jog characteristics. Geological Society of London Special Publication 372: 495-529.

Emre Ö, Duman TY, Özalp S, Elmacı H, Olgun S et al. (2013) Active fault map of Turkey Mineral Research and Exploration General Directorate, Special Issue Series-30, Ankara-Turkey.

Erdik M, Demircioğlu MB, Cüneyt T (2020). Forensic analysis reveals the causes of building damage in İzmir in the Oct. 30 Aegean Sea earthquake, Temblor. doi: 10.32858/temblor.139

Foumelis M, Papazachos C, Papadimitriou E, Karakostas V, Ampatzidis D et al. (2021). On rapid multidisciplinary response aspects for Samos 2020 M7.0 earthquake. Acta Geophysica 69: 1025-1048.

Ganas A, Elias P, Briole P, Valkaniotis S, Escartin J et al. (2021). Co-seismic and post-seismic deformation, field observations and fault model of the 30 October 2020 Mw = 7.0 Samos earthquake, Aegean Sea. Acta Geophysica 69: 999-1024.

Guidoboni E, Comastri A, Traina G (1994). Catalogue of ancient earthquakes in the Mediterranean area up to the 10th century. Istituto Nazionale di Geofisica, Rome, p 504.

ITSAK (2020). The Earthquake of Oct. 30, 2020, Mw7.0 (11:51GMT) North of Samos Island (Greece): Observed strong ground motion on Samos island (in Greek). Preliminary Report ITSAK v3.0, Thessaloniki pp. 9.

Karakostas V, Tan O, Kostoglou A, Papadimitriou E, Bonatis P (2021). Seismotectonic implications of the 2020 Samos, Greece, Mw7.0 mainshock based on high-resolution aftershock relocation and source slip model. Acta Geophysica 69: 979-996.

Kouskouna V, Makropoulos K (2004). Historical earthquake investigations in Greece. Annals of Geophysics 47: 723-731.

Krinitzky EL, Chang FK (1987). State of the art for assessing earthquake hazards in the United States: parameters for specifying intensity related earthquake ground motions. US Army Corps of Engineering Waterways Experiment Station, Report 25.

Makris N (2014). A half-century of rocking isolation. Earthquakes and Structures 7: 1187–1221.

Makris N, Vassiliou MF (2014). Are some top-heavy structures more stable? Journal of Structural Engineering ASCE 140 (5): 06014001.

Mavroulis S, Triantafyllou I, Karavias A, Gogou M, Katsetsiadou KN et al. (2021). Primary and secondary environmental effects triggered by the 30 October 2020, Mw = 7.0, Samos (Eastern Aegean Sea, Greece) Earthquake based on Post-Event field surveys and InSAR Analysis. Applied Sciences 11: 3281.

Meghraoui M, Aksoy ME, Akyüz HS, Ferry M, Dikbaş A et al. (2012). Paleoseismology of the North Anatolian Fault at Güzelköy (Ganos segment, Turkey): Size and recurrence time of earthquake ruptures west of the Sea of Marmara, Geochemistry, Geophysics, Geosystems 13: Q04005.

Papaioannou I, Papadopoulos GA, Pavlides S (2004). The earthquake of 426BC in N. Evoikos Gulf revisited: Amalgamation of two different strong earthquake events? Bulletin of the Geological Society of Greece, XXXVI: 1477-1481.

Papazachos B, Papazachou C (1997). The earthquakes of Greece. Zitis, Thessaloniki.

Papazachos B, Comninakis P, Hatzidimitriou P, Kiratzi S, Papaioannou C et al. (1982). Atlas of isoseismal maps of earthquakes in Greece 1902 - 1981, Publication of the University of Thessaloniki, Geophysical Laboratory 4.

Psycharis I (2007). A probe into the seismic history of Athens, Greece from the current state of a classical monument. Earthquake Spectra 23: 393–415.

Rovida A, Albini P, Locati M, Antonucci A (2020). Insights into preinstrumental Earthquake Data and Catalogs in Europe. Seismological Research Letters 91: 2546–2553.

Sakkas V (2021). Ground deformation modelling of the 2020 Mw6.9 Samos earthquake (Greece) based on INSAR and GNSS data. Remote Sensing 13 (9): 1665.

Saltogianni V, Gianniou M, Taymaz T, Yolsal-Çevikbilen S, Stiros S (2015). Fault-Slip Source models for the 2014 Mw 6.9 Samothraki-Gökçeada Earthquake (North Aegean Trough) Combining Geodetic and Seismological Observations, Journal of Geophysical Research. (Solid Earth) 120 (12): 8610– 8622.

Saltogianni V, Gianniou M, Moschas F, Stiros S (2016). Pattern of dynamic displacements in a strike slip earthquake. Geophysical Research Letters 43. doi: 10.1002/2016GL069507

Sboras S, Chatzipetros A, Pavlides S (2017). North Aegean Active Fault Pattern and the 24 May 2014, Mw 6.9 Earthquake. In: Çemen I, Yılmaz, Y. (editors) Active Global Seismology: Neotectonics and Earthquake Potential of the Eastern Mediterranean Region 239-272.

Sinopoli A (1989). Kinematic approach in the impact problem of rigid bodies. Applied Mechanics Reviews 44 (11), Part 2: S233–S244.

Stiros S (1995). Archaeological evidence of antiseismic constructions in antiquity. Annali di Geofisica 38: 725-736.

Stiros S (2020). Monumental articulated ancient Greek and Roman columns and temples and earthquakes: archaeological, historical, and engineering approaches, Journal of Seismology 24 (4): 853-881.

Stiros S, Laborel J, Laborel-Deguen F, Papageorgiou S, Evin J et al. (2000). Seismic coastal uplift in a region of subsidence: Holocene raised shorelines of Samos Island, Aegean Sea, Greece. Marine Geology 170: 41-58

Stiros S, Laborel J, Laborel-Deguen F, Morhange C (2011). Quaternary and Holocene coastal uplift in Ikaria Island, Aegean Sea, Geodinamica Acta 24 (3-4): 123-131.

Tepe Ç, Sözbilir H, Eski S, Sümer Ö, Özkaymak Ç. Updated historical earthquake catalog of İzmir region (Western Anatolia) and its importance for the determination of seismogenic source. Turkish Journal of Earth Sciences 30: 779-805.

Taymaz T, Ganas A, Yolsal-Çevikbilen S, Vera F, Eken T et al. (2021). Source Mechanism and Rupture Process of the 24 January 2020 Mw 6.7 Doğanyol–Sivrice Earthquake obtained from Seismological Waveform Analysis and Space Geodetic Observations on the East Anatolian Fault Zone (Turkey). Tectonophysics 804: 228745.