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Abstract

Throughout the last century, earthquake activities can be monitored by a network of instrumentation, allowing reliable determination of the timing and magnitude of the events. Before this era of "instrumental" seismicity, information can be incomplete because earthquakes are not always acknowledged in ancient records, even though they affected human settlements and their surroundings. Archaeoseismology is an evolving study that aims to bridge that gap by defining significant, and preferably independent, criteria for recognizing past earthquakes in archaeological ruins. Next to the understanding of the ancient history, archaeological evidence may form the basis for long-term seismic-hazard assessment in earthquake-prone regions where there is a long and lasting cultural heritage. Moreover, the cultural heritage sites themselves are at stake here as well, since the seismic hazard assessment can also predict how ancient structures and monuments respond to faulting and ground shaking.

Many types of earthquake-related damage ('archaeoseismic indicators') have been proposed and debated, but rarely have they been subjected to a critical and systematic analysis. This study is aimed at setting up and testing an interdisciplinary workflow that provides such a critical and systematic analysis and that eventually can serve to extend neotectonic studies over a larger time period. The Eşen Basin in SW Turkey was selected as study area because it is situated in a regionally active fault zone, the Fethiye-Burdur Fault Zone (FBFZ), which is regarded as a seismically active zone with strong and major earthquakes. An interdisciplinary study of the Pınara site in the Eşen Basin (SW Turkey) is presented, which is innovative as it builds on integration of several disciplines and techniques in both earth sciences and archaeology. Observations and analysis relate to geological, historic and recent times and include geological-, palaeoseismological-, and archaeological- data, geophysical data acquisition, a regional seismotectonic evaluation, and numerical engineering modelling.

A geological study of the Eşen basin, including tectonic stress inversion based on fault kinematic data, reveals that from Late Miocene until Pleistocene E-W extension with oblique components prevailed. However, the spatial and temporal relationships between the different tectonic processes that converge in this area and contribute to the local stress field are poorly understood. Next to this, a seismotectonic background study for the Eşen basin and surroundings is conducted, which compiles various tectonic and seismological data from published catalogues. For the study area, the instrumental seismic records show seismicity only with minor or light earthquakes. The assumed relative seismic quiescence is puzzling, especially since stress inversion calculations of 36 focal mechanism solutions of earthquakes in the region indicates that the E-W trending extensional tectonic regime is prevalent at present as well. For the intervening historic period, the geological context and the framework of recent seismicity in SW Turkey suggest intensity ranges and earthquake magnitudes that authorize archaeoseismic investigation.

Seismic activity in historical times is proven through archaeoseismological research at the ancient city of Pınara that is located along the western basin margin fault of the Eşen Basin. This line of research includes a logic-tree approach to assess the suitability of the Pinara site as archaeoseismic data recorder, spatial surveying of the deformation patterns in the site using ground-based light detection and ranging system (LIDAR), and engineering modelling of laser-scanned damaged structures to determine the origin of deformation. All techniques provide information that enables an assessment of the probability that the Pınara site recorded earthquakes in historic times.

The quantitative logic-tree methodology proves the high earthquake-recording potential of Pınara and thus its suitability for conducting archaeoseismological studies. The archaeoseismological evidence supports that the city has been affected by at least three earthquakes with intensity VIII – IX (MSK) since about the 5th century B.C. Furthermore, the numerical experiments indicate that the slight tilt of the Roman theatre in Pinara is caused by the fault activity; however the rotation of the Arttumpara's sarcophagus is most likely caused by an anthropogenic effect and not by earthquakes. This approach indicates the necessity of a quantitative evaluation of damaged structures both to investigate details and to avoid exaggeration of the effects of earthquakes. This study reveals the pitfalls and indicates that the most of the structures at Pınara show damages and deformations that can only be caused by one or several of the historic earthquakes.

The evidence of continuous strong tectonic activity from Late Miocene until historical time and the intense recent regional seismicity proves that major seismic events can take place in and around the Eşen basin. Despite a long period of seismic quiescence, the identification of an "active" fault zone with the potential to generate large earthquakes necessitates re-evaluation of the seismic hazard potential currently assigned to the area.