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A comprehensive analysis of the ground motions of the 2023 Kahramanmaraş, Türkiye earthquakes

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Abstract. With a focus on the dynamic characteristics of the ground motion recorded in Kahramanmaraş, Türkiye, this study provides an overview of the historical seismicity of the Eastern Anatolian Fault Zone (EAFZ) as well as the characteristics of the Pazarcik and Elbistan earthquakes (M_w=7.7 and M_w=7.6) that resulted in property loss and casualties on February 6, 2023. Analyzing the ground motion and local site effects for the earthquake region has been the subject of extensive research in the past. Ground Motion Prediction Equations (GMPEs) are one of the evaluation techniques utilised in the literature. Previous research employing this approach and other techniques suggested that the earthquake region's geotechnical and seismological conditions are complicated, particularly in Hatay City. In this study, to further investigate the ground motions, six GMPEs, which were previously proposed for the USA, Europe and the Middle East, are adopted. The findings of this study are integrated with those from previous research for comprehensive assessments. This study shows that the PGA of the Kahramanmaraş earthquakes cannot be fully predicted using GMPEs, which use epicentral distance (R_{epi}) in the equation. As a result, further research into rupture distance (R_{rup}) or Joyner-Boore distance (R_{jb})-based equations is necessary. Also, the complexity of the region (i.e., irregularities present in alluvial deposits) and the high PGA values could be responsible for such a result. This study emphasizes the region's need to have more sophisticated GMPEs in the future.

Keywords: 2023 Türkiye earthquakes; epicentral distance; ground motion prediction equations; the seismicity of EAFZ

1. Introduction

On February 6, 2023, the Kahramanmaraş province in southeastern Türkiye was struck by two successive earthquakes of magnitudes 7.7 and 7.6, which is one of the most devastating earthquakes have struck the earth in recent history. Both northern Syria and southeast Turkey were devastated by these earthquakes, which led to a large number of fatalities, mass evacuations, and serious damage to essential infrastructure (Balun 2023, Demir and Sezen 2024, Işık *et al.* 2023, Kiral and Ergün *et al.* 2024, Tonyalı *et al.* 2024). The event exposed vulnerabilities in structural resilience, urban planning, and disaster management strategies, particularly within a region characterized by complex tectonic activity at the convergence of the Anatolian, Arabian, and African plates (Atmaca *et al.* 2024, Kahya *et al.* 2024). This unprecedented disaster underscores the imperative for interdisciplinary research and policy interventions aimed at enhancing seismic resilience and preparedness.

The swift advancement of urbanization and population increase has resulted in the extensive construction of multi-story structures in urban areas, primarily to meet the rising housing market demands. This phenomenon has also contributed to unregulated construction practices and insufficient consideration of ground motion types and their soil-related impacts on structures (see ref. of Bhayusukma and Tsai (2014), Dogangun and Sezen (2012), Giarlelis *et al.* (2011), Günaydın and Tonyali (2018), Kappos *et al.* (2010), Kiral *et al.* (2024), Pitilakis *et al.* (2011), Tonyali and Kiral (2024), Tsonos (2019), Zhang *et al.* (2021)). Türkiye's earthquakes in 2023 are a clear example of the potential consequences of such a failure. Türkiye is bound by the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ), as shown in Fig. 1 (Cambaz *et al.* 2021). On 6 February 2023, a M_w7.7 earthquake at 01:17 UCT (4:17 am local time) occurred in Kahramanmaraş' Pazarcik district. The epicenter of the earthquake (lon. 37.043°, lat. 37.288°) was located approximately 33 km southeast of Kahramanmaraş, and approximately 40 km northwest of Gaziantep. The focus of the earthquake was at 8.6 km beneath its epicenter. A subsequent M_w7.6 earthquake occurred nine hours later in Kahramanmaraş' Elbistan district (lon. 37.239°, lat. 38.089°), at a depth of 7.0 km. Fig. 1 shows the epicenters of the two main shocks, as well as some of the aftershocks (Cetin *et al.* 2023). Türkiye's disaster management agency (AFAD 2023b) reported 18738 aftershocks following the two earthquakes. The two earthquakes and aftershocks led to over 50 k fatalities, 100 k injured and widespread devastation (Bas *et al.* 2024, Karalar 2023). The

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