Journal of Nepal Geological Society, 2023, Vol. 66, pp. 131–136
https://doi.org/10.3126/jngs.v66i01.57958

Ground motion characteristics of the 2015 Central Nepal (Gorkha-Dolakha) Earthquake and 2023 SE Turkey Earthquake doublets

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ABSTRACT

The Alpine-Himalayan orogenic belt, the well-identified seismically active region in the world, has been evidenced by the occurrence of recent two devastating earthquake doublets in 2015 in central Nepal (M_W 7.8 and M_W 7.3) and in 2023 in southeastern Turkey(MW 7.8 and MW 7.5). In this study, seismic ground motion characteristics of two damaging earthquakes namely the 2015 central Nepal earthquake doublet that occurred in the central Himalaya and the 2023 southeastern Turkey earthquake doublet that occurred in the eastern Mediterranean has been investigated. The observed strong-motion recordings indicate that the peak ground acceleration (PGA) values are about 152.61–154.96 cm/s^2 of the 2015 central Nepal earthquake doublet at KATNP station and about 451.834–842.924 cm/s^2 of the 2023 southeastern Turkey earthquake doublet at station 3137. The seismic ground motion of both the 2015 central Nepal and the 2023 SE Turkey earthquakes doublet shows that the 2015 central Nepal doublet produced much lower peak ground acceleration than the 2023 southeastern Turkey earthquake doublet.

Keywords: Earthquake doublet, strong ground motion, central Nepal Earthquake, southeastern Turkey Earthquake

Received: 28 April 2023 **Accepted:** 10 July 2023

INTRODUCTION

The Alpine-Himalayan orogenic belt is one of the most identified seismically active regions in the world. This belt has been frequently affected by destructive earthquakes including the recent 2015 central Nepal earthquake doublet (M_W 7.8, M_W 7.3) that occurred in the central segment of the Himalaya and the 2023 southeastern Turkey earthquake doublet (M_W 7.8 and M_W 7.5) that occurred in the eastern Mediterranean region. Centra1 Nepal doublet earthquakes of 25 April 2015 with moment-magnitude (M_w) 7.8 occurred at 11: 56 Kathmandu Time (06:11 UTC) in Gorkha District (28.23° N, 84.73° E) and 12 May 2015 earthquake of M_w 7.3 occurred at 12: 50 Kathmandu Time (07:05:19 UTC) in Dolakha District (27.80° N, 86.06° E) altogether left about 10, 000 people death, injuring more than 22,000 people, damage exceeding 5 million houses and estimated economic losses about 7 billion US dollars in Nepal (Government of Nepal, 2015). Eastern central Turkey doublet earthquakes of 6 February with Mw 7.8 occurred at 01:17 UTC near the Nurdağı city (37.28° N, 37.04° E), and with Mw 7.5 earthquake occurred at 10:24 UTC near the city of Ekinözül (38.08° N, 37.23° E) altogether caused 50,000 fatalities, injuring more than 100,000 people and collapsing more than 40, 000 buildings. The origin time, epicenter locations, magnitudes and depths of these earthquake doublets compiled from the United States Geological Survey (USGS) are tabulated in Table 1.

An overview of the seismicity and seismic hazard of this region is given by several authors in global scale studies in general (e.g., Gutenberg and Richter, 1954; Giardini et al., 1999) and in national scales studies in particular to Nepal (e.g., Pandey et al., 1999; Thapa and Wang, 2013; Thapa et al., 2017; Thapa, 2018) and Turkey (e.g., Erdik et al., 1999; Akkar et al., 2018; Demircioglu et al., 2018; Şeşetyan et al., 2018). The 2015 central Nepal earthquake doublet (M_W 7.8, M_W 7.3) and the 2023 southeastern Turkey earthquake doublet (M_W 7.8, M_W 7.5) are the latest devastating earthquakes after 80 years in each country (Thapa et al., 2018; Dal Zilio and Ampuero, 2023) and have captured worldwide attention. These two doublet events are of similar size magnitudes with shallow focus events and reported heavy damage in each country. The damage surveys of both earthquakes (e.g., Çetin KÖ et al., 2023; Goda et al., 2015) indicated that the strong seismic ground motion is the primary driving force for inflicting unparallel damage to buildings and natural landscape, geotechnical effects such as soil liquefaction and landslides in the mountainous areas, and the resulting loss of human life. The different levels of damage and ground motions by these earthquakes were observed at different sites and the knowledge of seismic ground motions is a very significant parameter for better resilient seismic design and construction in the region. Moreover, the well-recorded accelerograms are the widely used seismic input motion parameters in both theory and engineering practice for structural non-linear dynamic analysis today because they provide basic and significant datasets to better understand the earthquake source processes (Boore, 1983). It is, therefore, necessary to investigate the available recorded ground motion time histories.

The aim of the present study is to investigate the ground motion characteristics of two earthquake doublets, the 2015 central Nepal earthquake doublet, and the 2023 southern eastern Turkey earthquake doublet. For this purpose, the strong ground motion database of these two earthquake doublets are analysed. The analysis of strong motion characteristics of these earthquakes provides an opportunity for a better understanding of the ground motion parameters of recent earthquake doublets recorded in seismic-prone regions and ultimately contributes to the prevention and mitigation of disaster from future seismic events.

STRONG MOTION DATABASE AND RESULTS

The strong ground motion database used for this study was taken from the center for engineering strong motion data (CESMD). The database of CESMD consists of several thousand worldwide earthquakes and strong motion records in tectonically active regions, including the database of 2015 and 2023 earthquakes. Until recently there is a limited number of strong motion stations in Nepal, whereas Turkey has a good network of strong motion instruments. Based on the correlation of shear-wave velocity in the upper 30 m depth (*V*S30) data with topographic slope (Wald and Allen, 2007) using the USGS global server, Goda et al. (2015) assigned the values of shear wave velocity (*V*S30) at KATNP accelerometric station ranges between 180–360 m/s (correspond to NEHRP site class D). In this study, ground motion data recorded at KATNP accelerometric station, located in the Kantipath in the Kathmandu basin, was used.

Since there are a large number of strong motion stations in Turkey, the successfully recorded seismic strong motion by the Turkish strong motion network provides valuable datasets for better understanding the characteristics of ground motion and its destructive effects on building structures. For this analysis, strong motion records at two stations 3126 and 3137 from the Turkish Civil Defense Network (AFAD, Republic of Türkiye, Ministry of Interior Disaster and Emergency Management Presidency) were selected. Station 3126 is located on a site with NEHRP site class D (*V*S30 equal to 350 m/s) in Antakya at 143.54 km from the epicenter of the 2023 Turkey earthquake, whereas station 3137 is located on a site with NEHRP site class C (*V*S30 equal to 688 m/s) in Hatay City at 82.48 km from the epicenter of the event.

It is important to note that the ground motion of the first main shocks of both doublet events is higher than the second events, therefore the ground motion records of the 2015 Nepal earthquake with Mw 7.8 and the 2023 Turkey earthquake with Mw 7.8 are presented herein in this analysis. Figure 1 shows strong motion records of the 2015 central Nepal earthquake doublet, whereas Figures 2 and 3 show strong motion records of the 2023 southern eastern Turkey earthquake doublet.

The 2015 central Nepal earthquake is the instrumentally well-recorded latest large earthquake that occurred northwest of Kathmandu city. The strong ground motion of this earthquake is well recorded by the KATNP station which is located over the thick soil sediments. Figure 1 displays the recorded

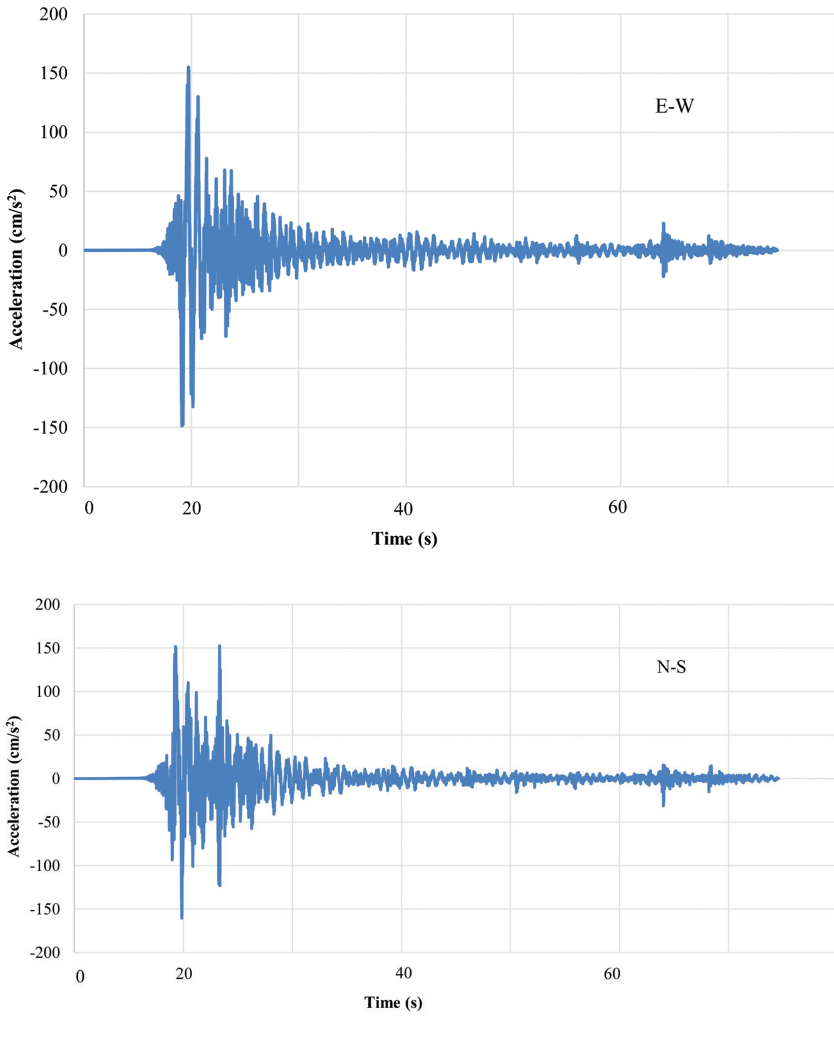

Fig. 1: Acceleration time-history of the 2015 central Nepal earthquake recorded at KATNP station.

Table 1: Epicentral parameters of the 2015 Nepal doublet and 2023 Turkey doublet earthquakes.

Date	Origin time (UTC)	Longitude (E)	Latitude (N)	Magnitude (M_w)	Depth (km)
25 April 2015	06:11:25	84.73	28.23	7.8	8.22
12 May 2015	07:05:19	86.06	27.80	7.3	15
6 February 2023	01:17	37.043	37.288	7.8	8.6
6 February 2023	10:24	37.239	38.089	7. 6	7.0

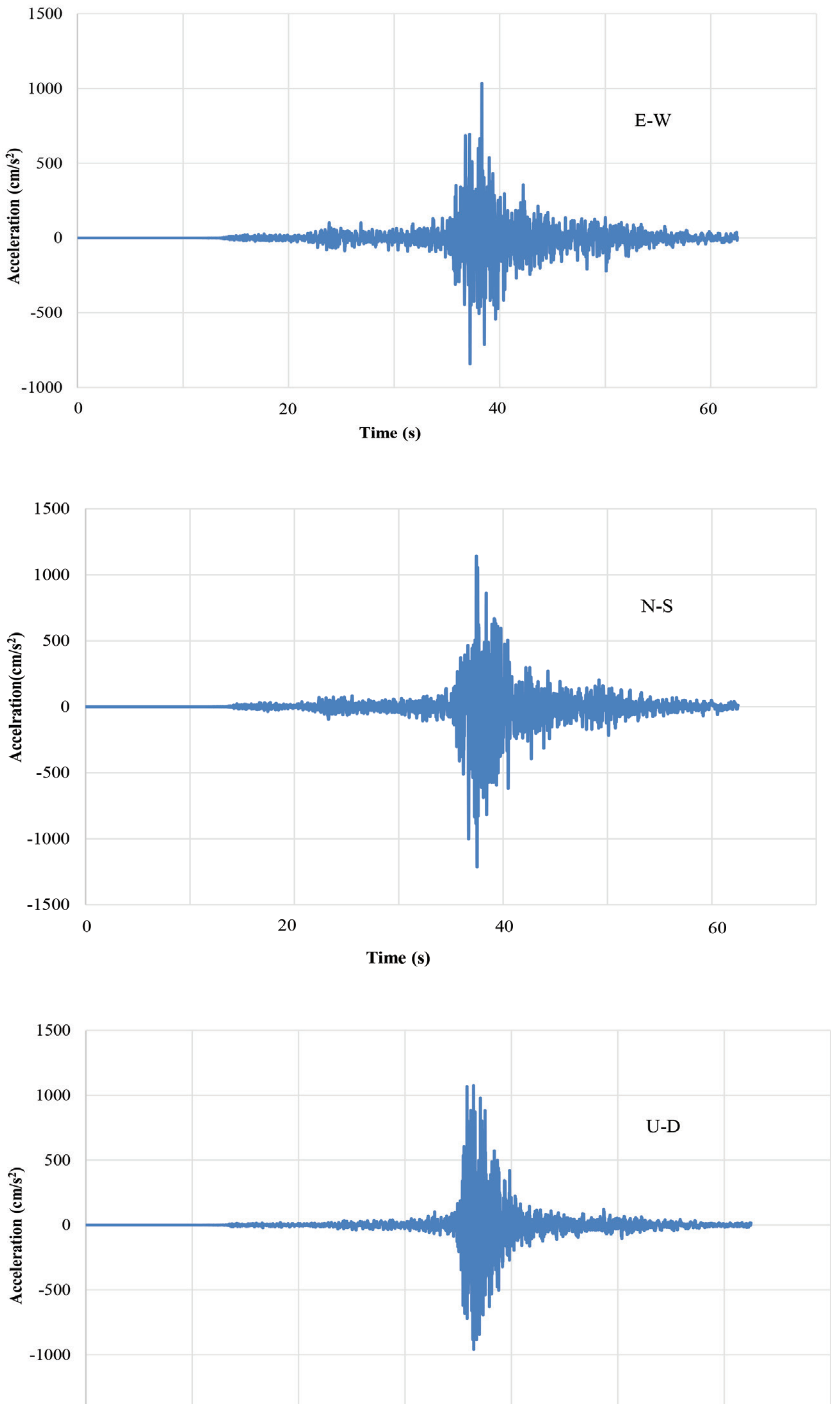

Fig. 2: Acceleration time-history of the 2023 Turkey earthquake recorded at 3126 station.

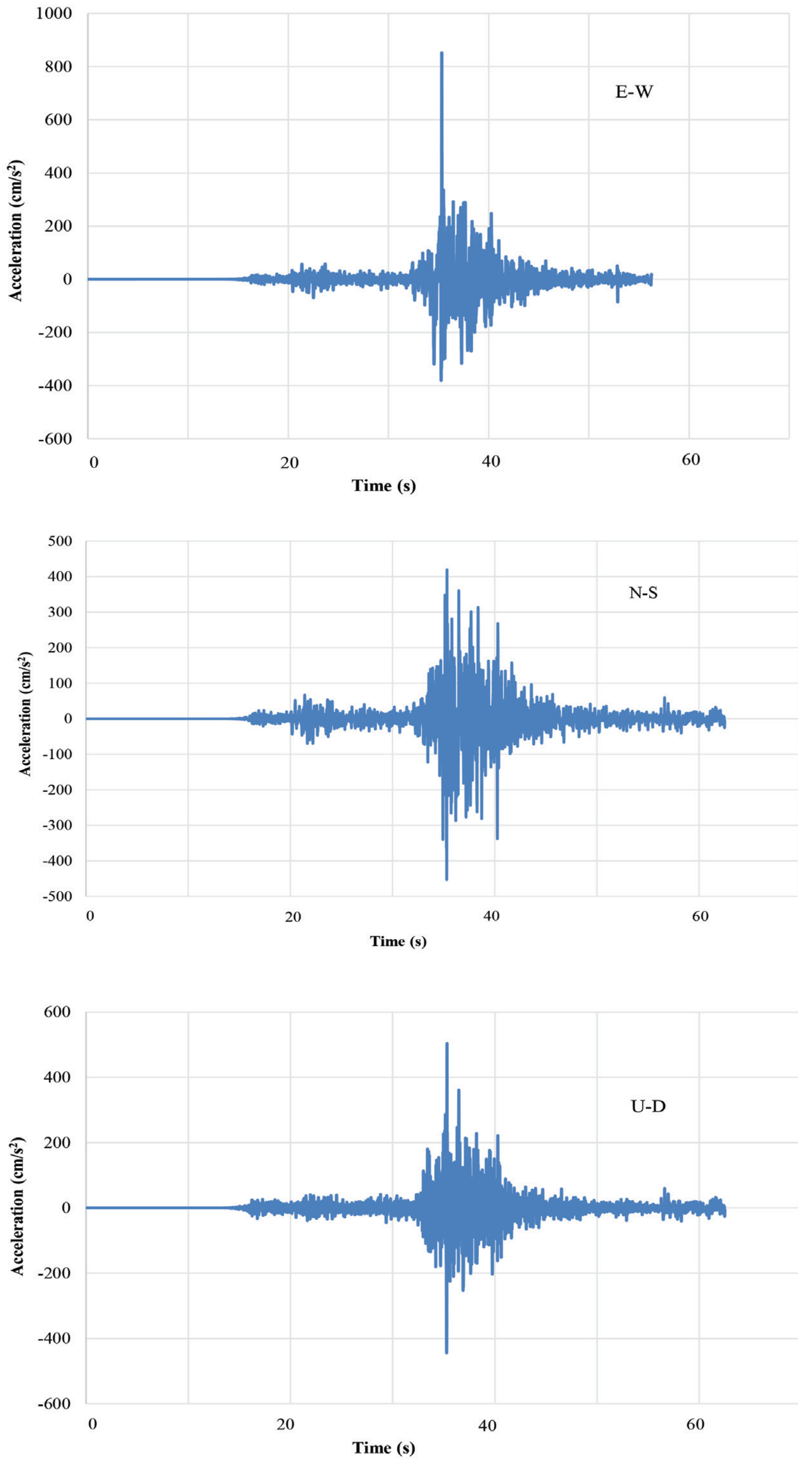

Fig. 3: Acceleration time-history of the 2023 Turkey earthquake recorded at 3137 station.

accelerograms of the 7.8 central Nepal earthquake. It can be observed from the time-history plot that the Peak Ground Acceleration (PGA) values of the recorded ground motions are about 154.96 cm/s^2 in the east-west component and 152.62 cm/s^2 in the north-south component.

As mentioned previously there exist several digital strong motion stations in Turkey before the 2023 earthquake. The mainshock was recorded by strong-motion accelerometers in different sites that are invaluable in the investigation of earthquake source, propagation path characteristic and site. The uneven distribution of strong motions was observed in different sites.

The recorded accelerograms (three components) of the 2023 Turkey earthquake at station 3126 is shown in Figure 2. It can be observed from the time-history plot that the PGA values of the recorded ground motions are about 1028.770 cm/s^2 in the east-west component, 1141.752 cm/s^2 in the north-south component, 1070.168 cm/s^2 in the up-down component.

The recorded accelerograms (three components) of the 2023 Turkey earthquake at station 3137 is shown in Figure 3. It can be observed from the time-history plot that the PGA values of the recorded ground motions are about 842.924 cm/s^2 in the east-west component, 451.834 cm/s^2 in the north-south component, 498.957 cm/s^2 in the up-down component.

The 2015 central Nepal earthquake has the same size magnitude and a similar shallow hypocentral depth as the 2023 Turkey earthquake. It is important to note that due to the lack of strong motion stations at 200–300 km from the epicenter of the 2015 central Nepal earthquake in Nepal, it is not possible to compare with the strong motion recorded at the similar epicenter distance of the 2023 Turkey earthquake. However, the well-recorded ground motions at the epicenter distance of 70–90 km of these same-size earthquakes with similar depths are compared.

The comparison of the recorded PGA for the 2015 central Nepal and 2023 Turkey earthquakes shows that the PGA values of the recorded PGA for 2023 Turkey earthquakes are about 2.9–5.5 times higher than the values of PGA for the 2015 central Nepal. These differences in the PGA values obtained from these two events suggest that earthquakes with equal magnitude and more or less similar hypocentral depth, different source mechanisms, and path characteristics yield greatly different level of ground motions for geotechnically quite dissimilar site-conditions. The focal mechanism of the 2015 central Nepal is thrust while the 2023 Turkey earthquake is strike-slip.

In a nutshell, the recorded accelerograms shows that the 2015 central Nepal doublet produced much lower peak ground acceleration than the 2023 southeastern Turkey earthquake doublet.

The analysis of strong motion characteristics of these earthquakes could be helpful to deepen our understanding of the earthquake doublet and ultimately contribute to the prevention and mitigation of future seismic events in these regions.

CONCLUSIONS

This study presented strong-motion recordings of the 2015 central Nepal earthquake doublet and 2023 southeastern Turkey earthquake doublet. The observed strong-motion recordings of the 2015 central Nepal earthquake doublet at KATNP station indicate that the values of PGA are 154.96 cm/s^2 in the east-west component and 152.62 cm/s^2 in the north-south component. Similarly, the observed strong-motion recordings of the 2023 southeastern Turkey earthquake doublet at station 3137 indicate that the values of PGA are 842.924 cm/s^2 in the east-west component, 451.834 cm/s^2 in the north-south component, 498.957 cm/s^2 in the up-down component. This strong-motion recording demonstrates that the PGA of the 2023 SE Turkey earthquakes doublet at station 3137 is about 2.9–5.5 times higher than the values observed PGA for the 2015 central Nepal earthquake at KATNP station. The observed recordings of earthquakes show that these two similar size earthquakes have yielded different levels of strong ground motions in different tectonic environments at the epicenter distance of 70–90 km.

In the context of Nepal, it is pointed out that there exist strong motion monitoring stations in and around the Kathmandu area, a dense network of stations covering the entire Nepal is needed for improving our understanding of the ground motion and development of the ground motion relationships for the region in the future. Moreover, this study is only focused on the recorded ground motion datasets, the simulation of the acceleration field of the 2015 central and 2023 Turkey earthquake doublets is necessary considering source, medium, and site characteristics in detail to compare with the recorded ones and better understanding the ground motion characteristics and seismic ground motion hazard in the region in the future.

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