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Publication Date
2018-06-25

Peer reviewed

Eleventh U.S. National Conference on Earthquake Engineering
Integrating Science, Engineering & Policy
June 25-29, 2018
Los Angeles, California

GROUND MOTION CHARACTERISTICS OF THE 2016 CENTRAL ITALY EARTHQUAKE SEQUENCE

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ABSTRACT

The 2016 Central Italy earthquake sequence occurred between August and November 2016. During the sequence, three mainshock events were well recorded by networks operated by the Italian Institute of Geophysics and Volcanology (INGV) and the Italian Department of Civil protection (DPC): (1) 24 August 2016 (**M**6.1), (2) 26 October 2016 (**M**5.9), and (3) 30 October 2016 (**M**6.5). These events occurred on normal faults roughly trending southeast-northwest. Each mainshock event has been followed by many aftershocks. We have analyzed recorded ground motions and supporting metadata for the three mainshocks and three of the principal aftershock events. Processing is performed on a component-by-component basis and the usable frequency range is identified. We take the seismic moment, moment magnitude, and moment tensor from an INGV catalogue. Finite fault dimensions, strike, and dip are assigned to each mainshock event. We compare ground motion intensity measures to local and global ground motion models, which shows several interesting features, including (1) fast distance attenuation for high frequency intensity measures at distances > 100 km; (2) over-prediction of ground motion by global models at short periods; and (3) a general under-prediction of ground motions at close distances. Effects 1 and 2 were also observed from the 2009 L'Aquila earthquake data, and may represent regional features. We analyze the spatial distribution of ground motions for the three mainshock events by means of a Kriging analysis performed on within-event peak ground acceleration residuals.

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Zimmaro P., Scasserra G., Kishida T., Tropeano G., Stewart J.P., Ground motion characteristics of the 2016 Central Italy earthquake sequence. *Proceedings of the 11th National Conference in Earthquake Engineering*, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.

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Introduction

Based on the information presented by the Geotechnical Extreme Events Reconnaissance (GEER) association (GEER, [1, 2]) and Zimmaro et al. [3] the 2016 Central Italy earthquake sequence, we summarize: (1) a comprehensive ground motion database, (2) comparisons between ground motion models and recorded data, and (3) an analysis of ground motion spatial distribution in the epicentral area. We obtained digital unprocessed recordings from the European strong motion (ESM) database [4] for the following six earthquake events that occurred between August and October 2016: (1) **M**6.1 24 August, (2) **M**5.3 24 August, (3) **M**4.8 26 August, (4) **M**5.4 26 October, (5) **M**5.9 26 October, and (6) **M**6.5 30 October.

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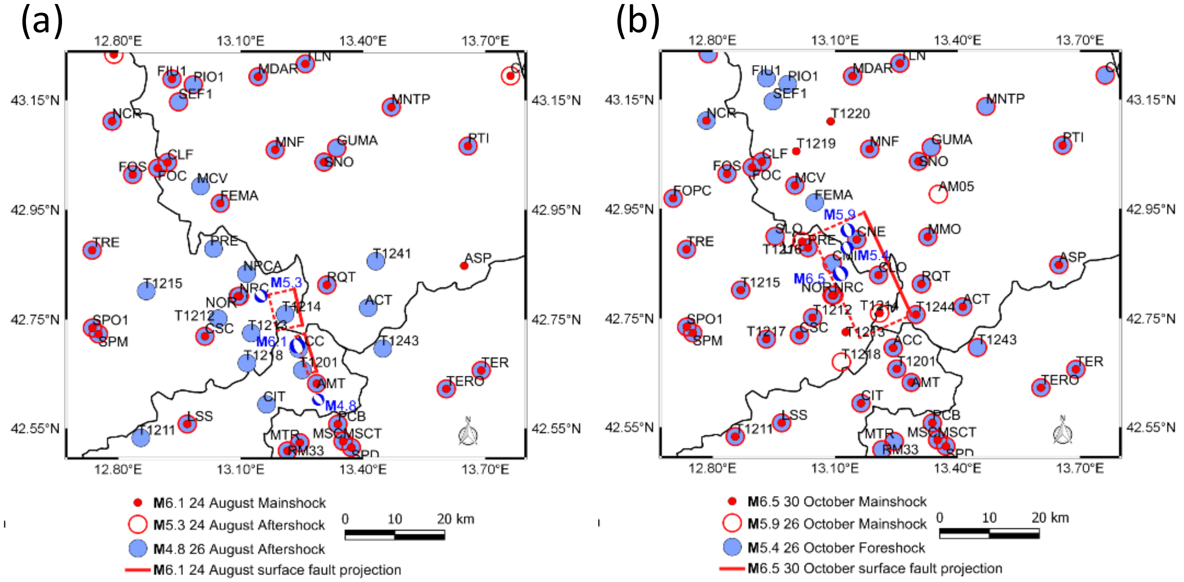

Figure 1. Locations of instruments in the epicentral area that recorded: (a) **M**6.1, **M**5.3, and **M**4.8 August 2016 events, and (b) **M**6.5, **M**5.9, and **M**5.4 October 2016 events.

The selected database contains recordings from 298 recording stations. Figure 1 shows the spatial distribution of all permanent recording stations relative to the August and October event sources, respectively. The fault planes shown in these figures are as described by Galadini et al. [5]. For the 24 August event, the finite fault model has two segments [5]. The ESM database has both unprocessed and processed accelerograms. The unprocessed records were corrected using Pacific Earthquake Engineering Research (PEER) center procedures [6]. This processing includes applying component-specific low-pass filters and identifying the lowest usable frequency.

Comparisons to Ground Motion Models

In this section, we compare GMM predictions to observed data. The objective of these comparisons is to facilitate visualization and identification of the main features of the recorded data. In recent years, several studies focused on the selection of suitable GMMs to use in seismic hazard analysis applications [7-9]. These selections are often performed by comparing GMM predictions over a parameter space of engineering interest. While local models can reflect local geologic and tectonic conditions, the limited database size used to develop local models may be inadequate to constrain GMMs for conditions often critical for application (large magnitudes and small distances). Global models are more effective for such conditions, because they are typically based on much larger databases, but may contain bias with respect to local effects. Regional adjustment factors can be used to reduce the bias of global models (e.g. 9-10). We compare recorded data to the following GMMs: (1) an Italy-specific model by Bindi et al. [11] (hereafter Bea11), (2) the average of three NGA-West2 GMMs, without regional adjustments [10, 12-13] hereafter NGA2), and (3) the average of those same three NGA-West2 models but now applying regional adjustments for Italy (NGA2-I).

Figure 2 show the distance-dependence of RotD50 peak ground acceleration (PGA) defined by [14] for six events of the sequence. Also shown in Figure 2 are median predictions from the Bea11 model, the average of the three NGA2, and NGA2-I models. All predictions have been calculated using $V_{S30} = 580$ m/s. The models fit the data reasonably well for $R_{JB} = 0\text{-}100$ km.

Beyond this distance, there is a relatively fast attenuation of ground motions in all six events. This feature, captured only by the NGA2-I models (with regional adjustment for Italy), is a characteristic of Italian data observed from pre-2006 data by Scasserra et al. [15] and from the L'Aquila event sequence by Stewart et al. [16]. It should be noted that the distance range of applicability of the Bea11 model is only 0-200 km (prediction beyond 200 km represent an extrapolation of the model), while the distance range of applicability for the NGA2 and NGA2-I models is 0-400 km.

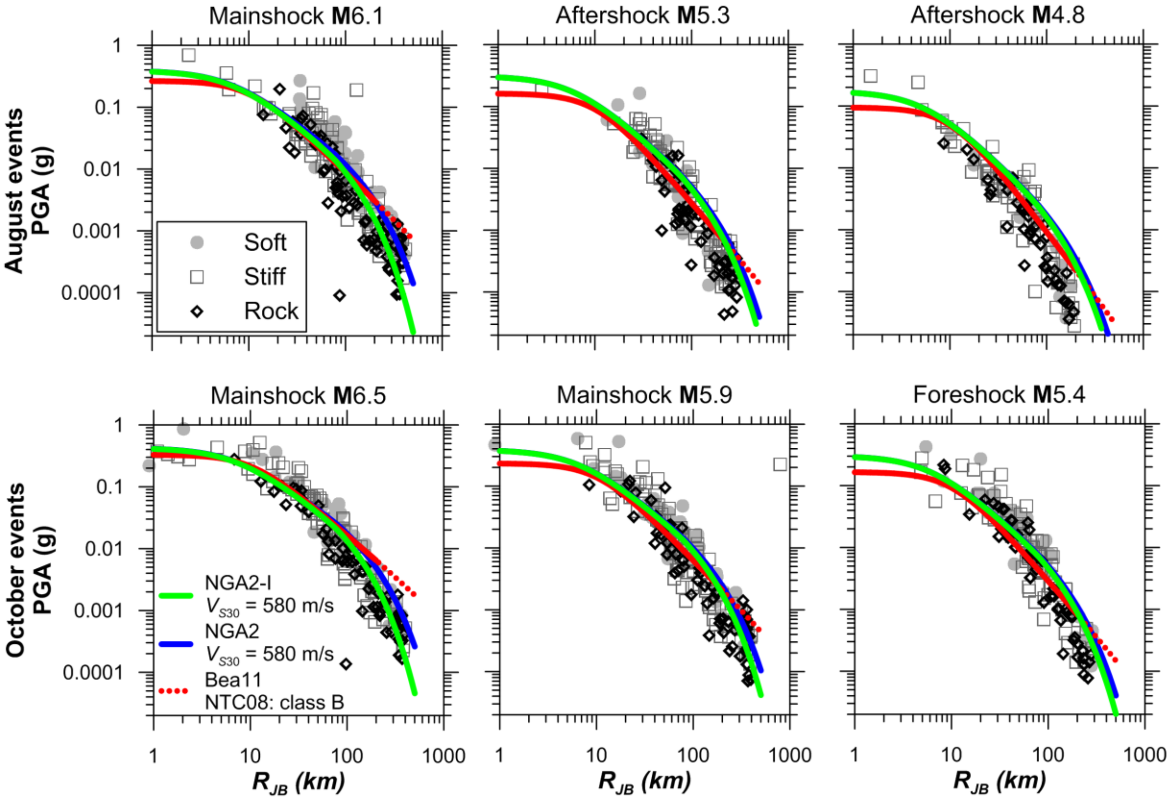

Figure 2. Variation of PGA with R_{JB} and comparisons with selected GMMs. Dotted lines used when the Bea11 estimations fall outside the published distance range for the model.

Spatial Distribution of Ground Motions

For well recorded earthquakes like those in the 2016 Central Italy sequence, ground motion distributions are invariably more complex than suggested by the smooth variation with distance provided by GMMs. Spatial distributions are best evaluated from Kriging applied to within-event residuals in lieu of Kriging of ground motions themselves.

We perform Kriging of within-event residuals for the three mainshock events using the NGA2-I GMMs. Kriging is performed using a global semi-variogram model to guide interpolation between observations [17]. Using results from this approach, we then estimate ground motion intensity measures throughout the whole studied area. Figure 3 shows maps for the two largest events of the sequence (**M**6.1 24 August and **M**6.5 30 October). These maps are calculated for a uniform site condition of $V_{S30} = 580$ m/s, and as such will be biased for particular sites having different stiffnesses. Moreover, the ground motions in these maps do not account for local site response effects (including topographic amplification). Figure 3 shows that the spatial distribution of peak accelerations for both earthquakes are most intense south-east of Mt. Vettore.

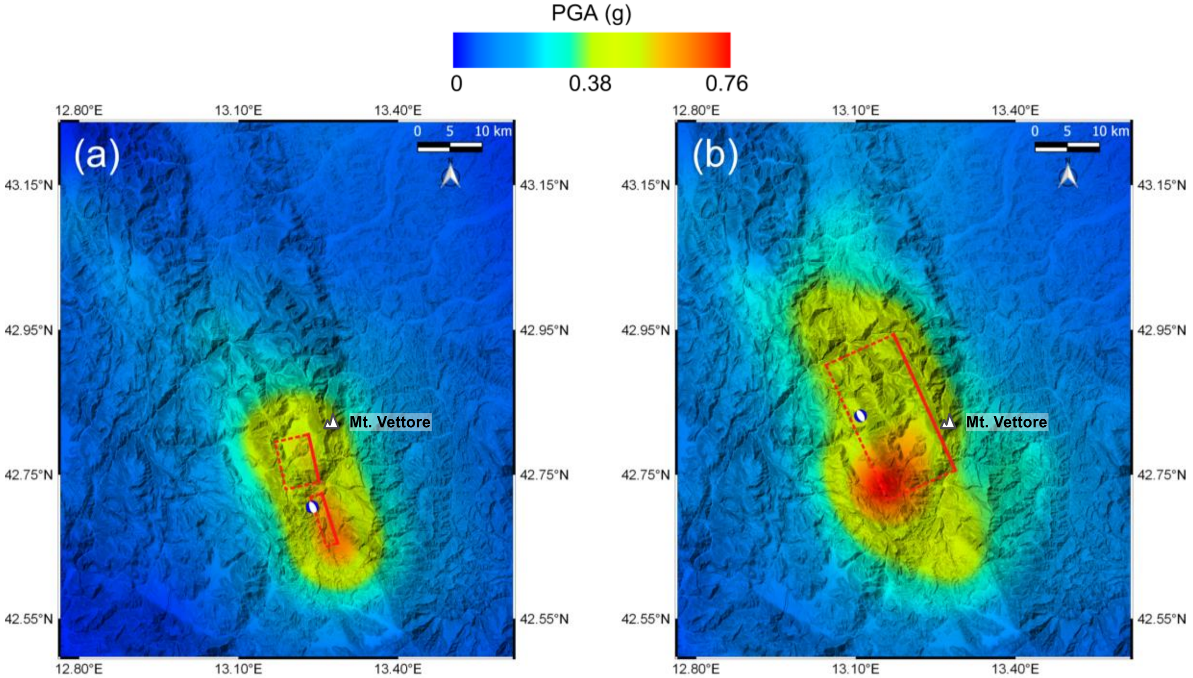

Figure 3. PGA maps for: (a) **M**6.1 24 August, and (b) **M**6.5 30 October 2016 events.

Conclusions

The ground motions recorded during the 2016 Central Italy sequence are an invaluable resource for improving current understanding of seismic hazard associated with normal fault earthquakes. Our goals in this paper and related work [1-3] were to provide a uniformly processed dataset, consisting of recordings and metadata for three notable mainshocks and three aftershocks.

Analysis of data relative to ground motion models shows trends of scaling with distance that are generally consistent with available models up to about 100 km, and relatively fast distance scaling beyond 100 km that is captured to a mixed degree by available models, but significantly is not captured by the Italy-specific model of Bindi et al. [11], whose range of validity is 0-200 km.

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