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Basin-effects observed during the 2012 Emilia earthquake sequence in Northern Italy

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ABSTRACT

During the 2012 Emilia earthquake sequence, prolonged shaking associated with long-period motions were observed in the Po Plain basin in Northern Italy. Such anomalous characteristics of ground-motion were unnoticed at the rocky sites outside the Po Plain basin. To explain these phenomena, a series of detailed analyses were carried out using the strong motion records from May 20 to May 29 main events. The observed *amplification*, calculated using the *spectral ratio* method indicates a fundamental *resonance period* at 5 s. Well-dispersed surface Rayleigh waves of periods between 3 and 10 s were noticed and the contribution of surface waves to the total motion was significant despite the source being located beneath the Plain. The late arriving long-period surface waves significantly increased the duration of ground shaking. The *envelope delay spectrum* shows that the duration lengthening of ground motion could be well correlated with the *dispersion* of surface waves. The greatest lengthening of the records was observed around the fundamental period of the basin. Large peak ground-motions were observed in the near-field region, especially in the vertical component which is attributed to source effects (predominantly vertical movement of the causative fault) while the prolonged duration of motions seems caused by surface waves.

1. Introduction

On May 20, 2012, Northern Italy was struck by a M_W 5.9 (M_L 5.9) earthquake which severely damaged the downtown area of Emilia region. The *mainshock* was followed by several aftershocks and among them, the M_W 5.65 (M_L 5.8) event which occurred on May 29, 2012 was relevant because of the large damage it caused[2] [24]. The Emilia earthquake sequence was monitored by the RAN (Rete Accelerometrica Nazionale, http://www.protezionecivile.gov.it/jcms/it/ran.wp) Italian strong motion network managed by the *Italian Department of Civil Protection* and RAIS (Rete Accelerometrica Italia Settentrionale, http://rais.mi.ingv.it/) seismic network managed by INGV (Istituto Nazionale di Geofisica e Vulcanologia), the Italian equivalent of USGS. A visual inspection of the records displayed well developed, long-period waveforms with prolonged durations which seem to suggest that the basin structure of the Po Plain has significantly influenced the ground shaking. This phenomenon is known in the literature as *basin-effects* which are due to an unfavorable combination of a particular geological configuration and the direction of wave propagation causing focalization of wave energy and generation of surface waves. It is a geometric process caused by interference of seismic waves due to geological irregularities and mechanical impedance contrasts. There are several well documented examples of *basin-effects* observed from past earthquakes from the September 19, 1985 Mexico City earthquake to the recent September 4, 2010 Darfield and February 22, 2011 Christchurch earthquakes in New Zealand [10,16,4]. Understanding how seismically-induced ground-motion is modified by complex basin geometry has been a fertile area of research for quite a long time. Basin related ground-motion can be studied from a seismological as well as engineering perspective. Seismologists are interested in *basin-effects* from the point of view of the conditions and physical mechanisms causing them, whereas earthquake engineers are more concerned with the characteristics of basin-related

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[2] The seismotectonic structure responsible for the May 29 event is different from the one that generated the May 20 earthquake. Thus it is still questioned whether the May 29 event may be technically considered an "aftershock" of the May 20 sequence [20].

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ground-motion that are detrimental to structures and engineering facilities. Both these perspectives have played a vital role in understanding the importance of *basin-effects*. The consequences of Emilia earthquake resulted in 27 fatalities, hundreds were injured and approximately 16,000 were left homeless from the two events of May 20 and May 29 [19].

This study concentrates on assessing *basin-effects* observed over the Po Plain during the May 20, 2012 *mainshock* as well as during the May 29 *aftershock*(1), and it covers the following aspects: (1) explaining the typical ground-motion features observed in the Po Plain, (2) evaluating the *amplification* observed in the Po Plain using the *spectral ratio* method, (3) identification of surface waves by analyzing the basin records, and (4) quantifying the duration lengthening due to surface waves, using the *envelope delay* spectrum method.

2. Seismicity of the region

According to the latest issue of the Italian seismic catalog [23], the area mostly affected by May–June 2012 Emilia sequence has centuries-old seismic history of comparatively low magnitude events. This region is on the outer front of the Northern *Apennines* which is characterized by low to medium seismic hazard. This can be understood from Fig. 1 which shows earthquakes with magnitude above 4.5 which occurred in the Emilia-Romagna region over the latest 200 years. The data were retrieved from the Italian earthquake catalog CPTI11 (http://emidius.mi.ingv.it/CPTI11/). Fig. 1 contains some important historical as well as instrumental earthquakes in the region. It is evident from the past seismicity that the eastern section of the *Southern Alps* is characterized by a relatively large frequency of earthquake occurrence as well as energy released per event. This defines a seismic belt at the foothills of the chain, where several active faults are located [2]. Most of the earthquakes in this region are concentrated South of the Po River along portions of the *pede-Apennines* thrust front and on some buried *Apennines* outer fronts [7]. Earthquakes are more infrequent north of the Po River and West of Milan [11]. The most destructive historical event in this area is the November 17, 1570 earthquake, which struck the town of Ferrara, and the March 17, 1574 event that yielded damage in Finale Emilia [23]. Both events have caused widespread phenomena of soil liquefaction [17]. The other important historical events within or close to the Emilia region occurred in 1624 and 1796. Other historical earthquakes with magnitudes up to 6 have occurred in the Southern part of the Emilia-Romagna Region, close to the *Apennine chain* (e.g. the September 10, 1781 earthquake). Furthermore, a M5.7 event occurred on May, 12, 1802, located West of Garda Lake in the central northern part of the Po Plain, which caused serious damage in Northern Italy, in the provinces of Brescia, Bergamo, Lodi, and Cremona [2]. The most recent large earthquakes of the region occurred in 1971 and 1983 near Parma. They were characterized by M_S 5.7 and M_S 5.0, respectively. On October 15, 1996 a M_S 5.1 earthquake occurred near the town of Reggio Emilia on the southern edge of the Po Plain which caused moderate damage in unreinforced masonry structures in Reggio Emilia and other small towns in the Po Plain [27]. The DISS (Database of Italian Seismogenic Sources) [5] lists many seismic sources within the Po Plain basin as well as in the foothills of the *SouthernAlps*.

3. Seismotectonic setting of Northern Italy

The Italian seismicity is mainly due to the movement of the *African plate* in the North direction, and the consequent (continent to continent) collision with the *Euro-Asiatic plate*. In the North-East, the *Adriatic* (micro) plate is a geologic structure playing a key role in the observed seismicity of that part of the Italian Peninsula. This is the remains of a large African promontory that in ancient times occupied most of the actual Central-Western Mediterranean basin [21]. In its Northern part, the *Adriatic plate* collides with the *Euro-Asiatic margin* along the *oriental Alps*, giving rise to systems of inverse faults leading to moderate to high seismicity. Some of the most significant earthquakes in this zone (e.g. Friuli earthquake, 1976–77) are due to the subduction of the *Adriatic plate* beneath the *oriental Alps*. The Central area of Northern Italy is characterized by the presence of the Po Plain which is a wide flexural basin covered by thick Quaternary sediments. It stretches East–West (EW) across Northern Italy for more than 40,000 km^2, the widest part being the alluvial basin of the peninsula. The Plain is locally up to 100 km wide, and is drained axially by the 652 km long Po River, the longest in Italy [11]. Fig. 2 shows a topographical map of

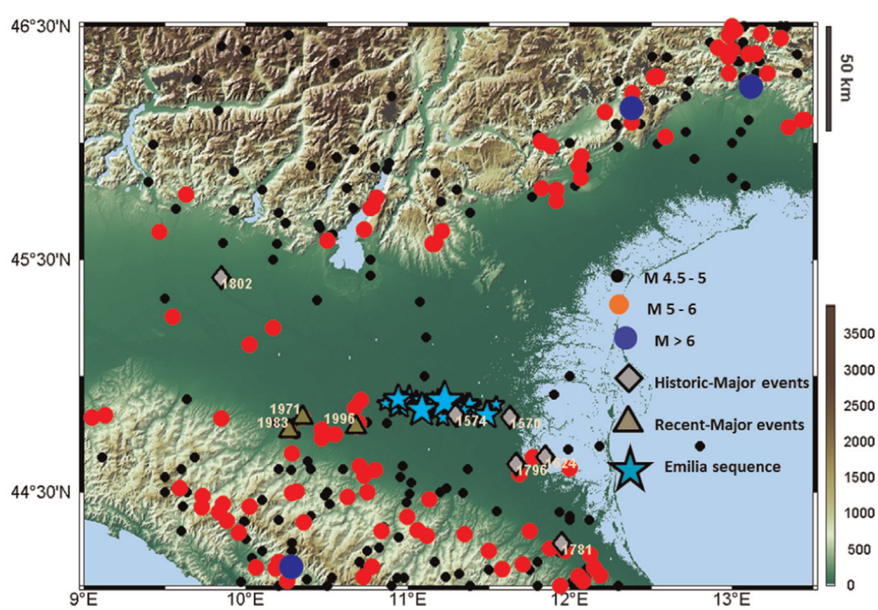

Fig. 1. Seismicity map of Northern Italy containing the following data: (1) distribution of epicenters with $M_W > 4.5$ over the last 200 years (http://emidius.mi.ingv.it/CPTI11/), (2) major historic events (diamonds), (3) recent major events (triangles), and (4) the 2012 Emilia sequence (stars).