SIMILAR ANOMALIES IN THE MACROSEISMIC FIELDS OF TWO RECENT SHOCKS IN GREECE AND CALIFORNIA

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ABSTRACT

On 16 October 1988 a shock of M=5.9 created extensive damage in a part of the Elia prefecture, west Greece. Field observations revealed a shift of 20-30 km of the meizoseismal area (I_{max} = VIII) in respect to the instrumental epecentre while anomalously distributed intensities were observed even within small residential zones. On the other hand, macroseismic observations made in California after the large (M=7.0) Loma Prieta earthquake of 17 October 1989 showed a similarly anomalous intensities distribution with high variation in small zones, the meizoseismal area (I_{max} = IX) being located at ~ 110 km from the epicentre. These anomalies are mainly attributed to ground effects favouring local absorbtion and amplification of the seismic waves. In both cases soil liquefaction has been observed at epicentral distances which appear to be very close or even outside the bounds of the limiting distances corresponding to the earthquake magnitudes.

INTRODUCTION

One of the most important problems in the seismic risk assessment is the determination of the expected earthquake intensity at particular sites. Many factors determine the intensity at a given area; the seismic source parameters, the frequency content of seismic waves, the local geological conditions, and the properties of the material extended between the area and the source.

After the great Michoacan, Mexico, earthquake of 19 September 1985, which reportedly created anomalously distributed intensities, special attention has been given to local ground effects as a factor governing unusually high intensities.

Observations made in the macroseismic fields of the 16 October 1988 strong (M=5.9) shock in Elia, western Greece, and the 17 October 1989 Loma Prieta large (M=7.0) shock in California, showed similarly anomalous intensity distribution. This double experience of the author, coming from two seismically very active but tectonically very different regions of the world, suggests that in both cases local ground effects seem to be responsible for the local seismic motion amplification leading to anomalously distributed intensities.

THE ELIA 1988 EARTHQUAKE

According to the Institute of Geodynamics, National Observatory of Athens (IG, NOA), the Elia earthquake hypocentre, at a depth of about 1 km, was located at 37.92°N, 20.99°E, that is between northwestern Peloponnesus and the islands of Cephallonia and Zakynthos (Fig. 1). However, considerable damage occurred only in Elia.

Field observations in the striken area were performed from 21st to 25th of October 1988. Descripitons of damage in the ground and structures as well as information on precursory and post-seismic phenomena have been made elsewhere (Papadopoulos and Profis, 1990).

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Γεράσιμος Α. Παπαδόπουλος. Όμοιες ανωμαλίες στα μακροσεισμικά πεδία δύο πρόσφατων σεισμών στην Ελλάδα και την Καλιφόρνια.

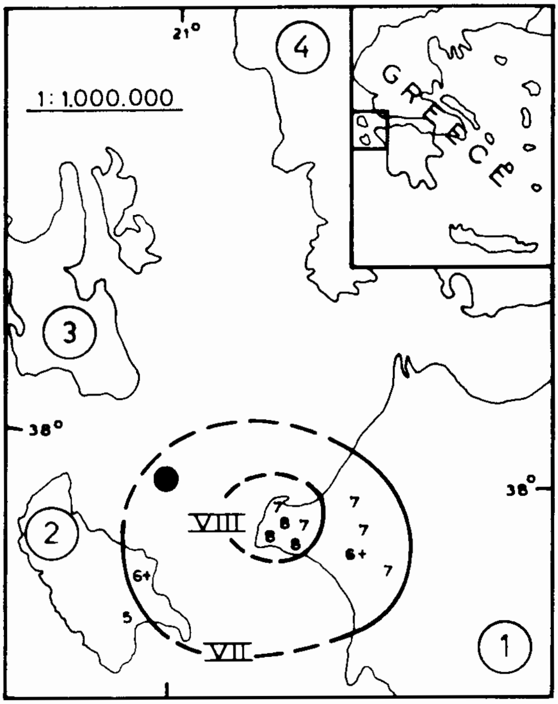

Fig. 1: The macroseismic field of the October 16, 1988 shock in Greece. The two higher intensity isoseismal lines are shown. Numbers indicate observed intensities. In the meizoseismal area of Elia an intensity of 8th degree has been assigned to Kastro (at SW), Neochori (middle), and Vartholomio (at SE). Solid circle shows the instrumental epicentre. Numbers in circles are: 1=Peloponnesus, 2=Zakynthos, 3=Cephallonia, 4=Greek mainland.

Figure 1 shows the two isoseismal lines of higher intensity degree in the modified Mercalli-Sieberg (MM) scale. Intensities up to $I_{max}=VIII$ are concentrated in the villages of Kastro and Neochori at epicentral distance of Δ ~ 20 km and Vartholomio at Δ ~ 27 km (Fig. 1). The overall picture suggests a significant directional aspect, the damage observed in Zakynthos, at Δ ~ 20-30 km, being minor in respect to that reported in the meizoseismal area. Moreover, a spatial intensity variation has been observed even within small residential zones. In Kastro, its north-northwest part, which is founded on Pleiocene and colluvial deposits, suffered heavy damage of reinforced concrete buildings (Fig. 2). On the contrary, at a distances of 200-300 m, in the east-northeast side which is founded on the Maestrichtian limestone basement, only few buildings were slightly affected by the earthquake. A strong horizontal component is evident in the damaged area of Kastro (Papadopoulos and Profis, 1990). At west of Kastro, in the coastal zone of dunes and alluvium, heavy damage has also been observed in the three-floor reinforced concrete buildings of the hotel unit "Robinson Club" constructed in 1970.

Ground factors seem to be of crucial importance in interpreting heavy damage in Vartholomio: (1) the alluvial soils covering the whole area, and (2) the proximity of the water table to the ground surface lying at a depth no more than 2 m in the centre of the village. The damage tends to decrease towards W and NW where the elevation increases and consequently the depth of the water table increases. In Neochori the damage appears uniformly distributed in the whole residential zone where the plain consists of alluvium deposits and a shallow water table also exists.

Interpreting the observed heavy damage I suggest an amplification of the larger period components of the seismic ground motion due to the soft, loosely compacted alluvium as well as the shallow water table in Vartholomio and Neochori; the incoherent Pleiocene and colluvial deposits in the damaged side of Kastro; and the soft, loosely compacted alluvium deposits and dunes in the coast at west of Kastro. This is consistent with evidence indicating high peak ground acceleration in the meizoseismal area. The strong shock was recorded by a SMA-1 accelerometer installed at Amaliada (Δ ~ 37 km) by the IG, NOA (1989). Records showed peak ground acceleration of a = 0.16g on the transverse component which is exactly equal with that expected (Ambraseys, 1978) from the felt intensity (I=VII) at Amaliada. For the meizoseismal area we expect a = 0.32g.

Elaboration of earthquake intensity data concerning past earthquakes which affected the Kastro-Vartholomio-Neochori area clearly indicates that intensities observed in this area are anomalously higher than those expected from attenuation models and than those observed in surrounding regions (Papadopoulos and Profis, 1990). This anomaly seems to be independent of epicentral distance, focal

Fig. 2: Typical damage in reinforced concrete house in Kastro.

depth, and azimuth, which means that it probably does not depend on the focal mechanism and the energy radiation pattern.

THE 1989 LOMA PRIETA EARTHQUAKE

The macroseismic field of the Loma Prieta earthquake showed similarly intensity anomalies. Macroseismic observations were made between 18 and 26 November 1989 while the author visited the striken area as member of a specialists committee of the Greek Ministry of Environment, Physical Planning and Public Works.

According to the Seismographic Station, University of California, Berkeley, the epicentre was lacated 10 miles NE of Santa Cruz on a section of the San Andreas fault (Fig. 3). An intensity rating of VIII characterized the epicentral area where single-storey unreinforced masonry lying mainly on the flatland of Santa Cruz were the hardest hitted. However, a IX rating has been assigned to the Marina area of San Francisco (Figs. 4 and 5) and west Oakland at $\Delta \sim 110$-115 km. In Marina the buildings are founded on thick alluvium deposits while liquefaction of sandy soils have been documented in some places. Moreover, according to information supplied by specialists of the Department of Public Works of San Francisco, the Marina area had been used as rubbish dump during the first decades of our centrury. That is, the high intensity observed in Marina is consistent with local ground factors favouring the absorbion and amplification of seismic waves. On the contrary, some hundreds of meters from Marina, in the hilly areas of San Francisco rested on marly limestone bedrock, the intensity reached up to only VI-VII. Similarly, in the San Francisco great shock of 1906, buildings set on water-soaked sand, gravel, or clay suffered up to ten times as much damage as similar structures built on solid rock nearby.

In west Oakland the most important damage observed is the collapse of the upper tier of the Nimitz Freeway (Figs. 6, 7 and 8). Although construction defects may contributed to the collapse, it seems that the role of ground has been critical. The collapsed section of the structure was built on fill over unlithified mud while the section built on alluvium did not collapse. Seismograms recroded (Hough et al., 1989) for a magnitude-4.1 aftershock on mud near the collapsed section, on Quaternary alluvium near the uncollapsed section, and on Franciscan rock in the Oakland Hills showed an amplification factor of 5-8 between 2 and 5 Hz of horizontal components of weak ground motion on the mud site relative to the alluvium site, while similar amplification is confirmed at the alluvium site

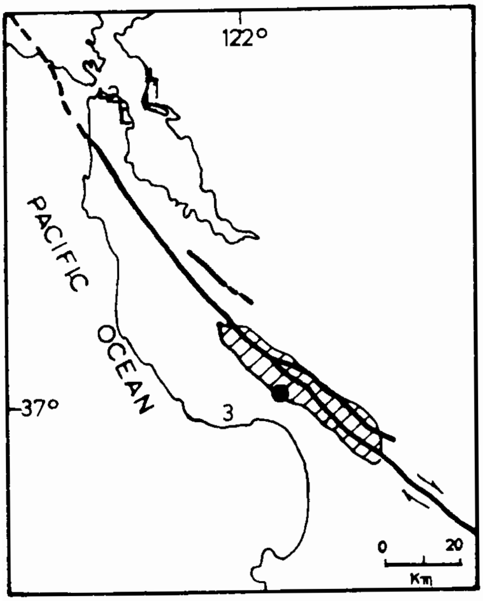

Fig. 3: The San Andreas fault trace (heavy line), the epicentre of the Loma Prieta earthquake (star) and its aftershock zone (hatchured area) (after USGS Staff, 1990). "L" marks the most distant sites where liquefaction-induced ground failure occurred. 1=position of the collapsed Nimitz Freeway at west Oakland, 2=Marina District, 3=Santa Cruz.

relative to the rock site. Analogous variation in the seismic waves amplification has been instrumentally documented (Manguήa et al., 1985) for some Michoacan 1985 aftershocks.

LIQUEFACTION IN SOIL

Existing observations justify the notion that intensity anomalies associated with the recent shocks in Greece and California were closely connected with site effects. Saturated sandy soils leading to liquefaction was one of them in Marina at $\Delta \sim 115$ km. Generally, liquefation associated with the Loma Prieta earthquake occurred in man-made fill around the margins of the San Francisco Bay and in flood plain deposits in the Salinas-Santa Cruz area (USGS Staff, 1990; Schwing et al., 1990). Maximum epicentral distance at which liquefaction occurred is $\Delta \sim 110$-120 km along the northern shores of the San Francisco Bay including Marina. Typical soil liquefaction has also been observed near Vartholomio at $\Delta \sim 30$ km from the 16 October 1988 instrumental epicentre (Fig. 9) (see also Papadopoulos and Profis, 1990).

One of the most important aspects in the research of soil liquefaction is the investigation of how the maximum distance at which liquefaction can occur increases with earthquake magnitude. In an exhaustive study, Ambraseys (1988), presented a relationship between maximum epicentral distance of liquefied sites R_e and moment magnitude M_w by utilizing world data of 137 earthquakes which are known to have caused ground failures due to liquefaction; R_e is defined as the maximum epicentral distance measured from the adopted epicentre to the most distant site where there was clear evidence of liquefaction-induced ground failures. He found that the data points M_w and R_e are bounded by the curve (a) in Fig. 10 or by the equation:

$$M_w = -0.31 + 2.65 \times 10^{-8} R_e + 0.99 \log(R_e) \quad (R_e \ \text{in cm}) \quad (1)$$

which represents an upper limit for R_e, as a function of M_w. Figure 10 also shows curve (b) which represents the equation:

$$\log(R_e) = 0.77(M) - 3.60 \quad (2)$$

derived from Japanese data by Kuribayashi and Tatsuoka (1975) and drawn assuming that $M = M_w$. According to Ambraseys (1988) the implication of equation (1) is that for $\Delta > R_e$, liquefaction is very unlikely for practically all sites - except, perhaps, where conditions are ultra soft, and that for $\Delta < R_e$, liquefaction is likely but that this will depend on other factors that determine in situ strength.

The writer's observations from Elia and California indicate that in both cases R_e is clearly outsite the bound of the Japanese limiting distances corresponding to the earthquake magnitudes. Regarding the curve (a) given by Ambraseys (1988), it seems that the California R_e-value (~ 110-120 km) is almost normal for $M = M_w = 7.0$, while the Elia R_e-value appears to be larger than normal assuming that $R_e = 30$ km. Taking into account that the error involved in the epicentral location is no more than 10 km, we get $M = 6.0$ for $R_e = 20$ km.

Fig. 4: A view of the damage created in Marina, San Francisco.

Fig. 5: A view of the damage created in Marina, San Fransisco.

Fig. 6: A view of the collapsed upper tier of the Nimitz Freeway.

Fig. 7: Ruins of the collapsed Nimitz Freeway.

Fig. 8: Detail of the damage produced in the Nimitz Freeway.

Fig. 9: Liquefaction in soil observed near the coastal position Bouka at ' 6.5 km southesterly from the village of Vartholomio, Elia.

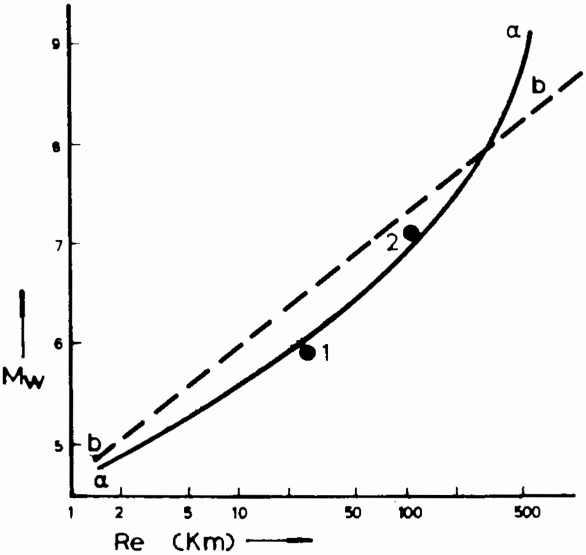

Fig. 10: Plot of the maximum epicentral distance of liquefied sites R_e and moment magnitude M_w for the Elia 1988 (1) and Loma Prieta (2) 1989 earthquakes. Curves (a) and (b) are the graphs of Ambraseys' and Kuribayashi and Tatsuoka's equations, respectively.

Previous observations imply that the problem of determining limiting distances at which liquefaction in soil can occur still remains open. In a recent project which is in progress we try to establish a Greek curve similar to those shown in Fig. 10 (Papadopoulos and Lefkopoulos, under preparation). Obtaining results of such a type is of great practical importance for the determination of liquefaction potential in earthquake-prone regions.

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