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Observations and lessons learned from recent earthquakes in Greece

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ABSTRACT: Three recent earthquakes in Greece of moderate surface wave magnitude (M_s-6.0), namely, Kalamata 1986, Kyllini 1988 and Griva 1990, hit and caused damage to both masonry houses and modern reinforced concrete buildings. Macroseismic observations obtained have been correlated with recorded strong motion and geotechnical data at the damaged areas. Detailed analysis of this data can lead to certain conclusions that can be significant to earthquake resistant design. Comparisons of the response spectra of the various events with code provisions have been carried out, as well as correlations of observed damage with strong motion data. The results of this paper are corrected data, response spectra, and statistical values of damage for the three aforementioned meisoseismal areas. From damage surveys useful conclusions are derived, which are important for statistical studies of the behaviour of residential buildings under seismic excitation in Greece.

1 INTRODUCTION

Three recent earthquakes in Greece of moderate surface wave magnitude (Ms≈ 6.0) namely Kalamata 1986, Kyllini 1988 and Griva 1990 hit and caused damage to both mansory houses and modern reinforced concrete buildings. On September 13, 1986 an earthquake with magnitude Ms=6.2 occurred near the Greek city of Kalamata in the southwestern part of Peloponnesos with MSK epicentral intensity VIII$^+$. On October 16, 1988 another earthquake with magnitude Ms=5.9 occurred between Kyllini and Zakynthos island (district of Elias) in the western part of Peloponnesos with MSK epicentral intensity VIII. On December 21,1990 an earthquake with magnitude Ms=5.9 occurred at the northern part of Greece near the village Griva (between Edessa and Kilkis districts) with MSK epicentral intensity VII. Although these earthquakes had the same magnitude, different patterns of damage were caused in the cities near the earthquakes. Concentrations of damage in certain areas were well correlated with local site conditions and indicated their importance. Comparison between these earthquakes led to conclusions useful for the new Greek aseismic code.

2 STRONG MOTION DATA

Earthquake parameters and strong motion parameters concerning the three recent earthquakes in Greece are given in table 1. In Kalamata the meisoseismal area was clearly delineated on land and included the city where the accelerograph was installed (fig.1a). In Kyllini the epicenter was in the sea and the nearest accelerographs were outside the meisoseismal area on the Kyllini peninsula (fig.1b). In Griva the accelerograph was at Edessa and the associated damage statistics were obtained at a distance of 31 km far from the seismological epicenter (fig. 1c).

In figure (2) acceleration response spectra of the largest horizontal components are presented. The three earthquakes although of the same magnitude, have been recorded at different epicentral distances. Kalamata (KAL86) recording falls almost into the epicentral area (Anagnostopoulos et al. 1987) while Kyllini (ZAK88) (Theodulidis et al. 1992) and Griva (EDE90) (Pitilakis et al. 1992) recordings have been obtained out of the epicentral area, that is apparent from the spectral acceleration amplitudes of figure (2). EDE90 acceleration response spectrum is obviously shifted to larger periods

Table 1. Earthquake and strong motion parameters for the Kalamata 1986, Kyllini 1988 and Griva 1990 seismic events.

	KALAMATA 1986			KYLLINI 1988			GRIVA 1990		
Origin time*	13/9/86			16/10/88			21/12/90		
Magnitude (M_s)*	6.2			5.9			5.9		
Epicentral Distance (km)	9			17			31		
	Components			Components			Components		
	L	T	V	L	T	V	L	T	V
a_g (cm/sec^2)	235	268	178	125	167	69	100	96	40
v_g (cm/sec)	32.3	23.7	9.0	8.3	11.3	3.0	10.9	9.6	3.7
d_g (cm)	7.2	5.3	1.4	1.1	1.8	0.8	1.2	1.1	0.7
Bracketed dur.(sec)									
(a_g > 0.05g)	5.7	8.0	4.7	9.8	11.3	0.1	5.7	5.5	-
(a_g > 0.10g)	2.6	2.5	3.7	2.4	2.5	-	-	-	-

* : Data from Geophysical laboratory of A.U.T.

(0.5 to 0.6 sec) which has been mainly attributed to the local site conditions (Pitilakis et al. 1992).

In figure (3) the Husid plot (Husid 1969) of the relevant recordings are given. Considering the definition of significant duration, that is the time needed to build up between 5 and 95 per cent of total Arias intensity of the record (Trifunac and Brady 1975), the value of 6.2 sec for KAL86, 10.2 for ZAK88 and 6.2 for EDE90 are derived.

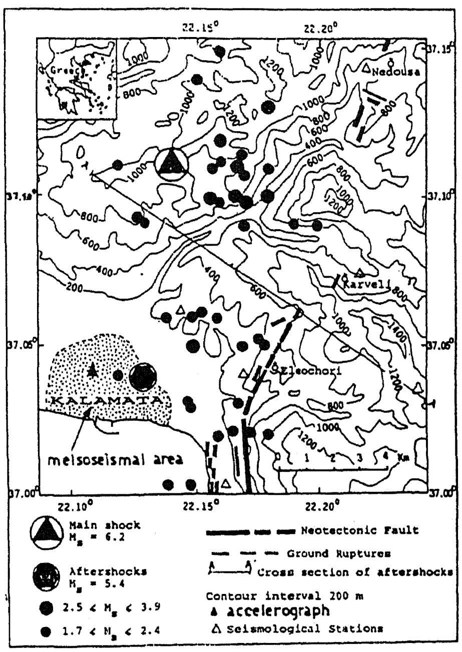

Figure 1a. Distribution of the epicenters of the shocks in Kalamata, meisoseismal area and location of the accelerograph (Papazachos et. all 1988).

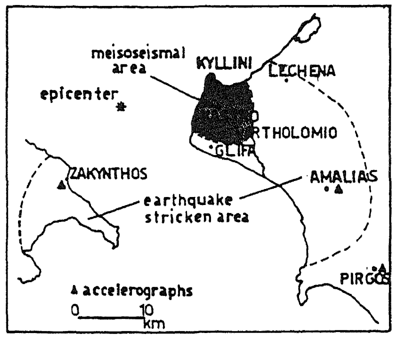

Figure 1b. Meisoseismal area of the Kyllini earthquake and locations of the accelerographs.

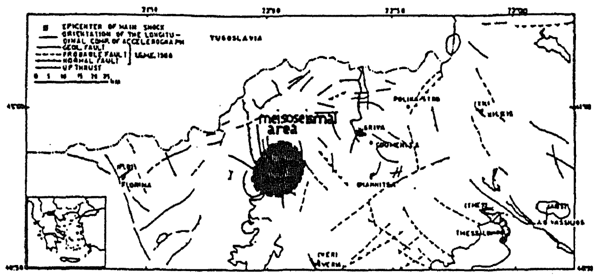

Figure 1c. Normal faults, meisoseismal area and locations of the accelerograph in Griva earthquake.

3 CODE PROVISIONS AND DUCTILITY DEMANDS

The buildings in Kalamata may be grouped in two broad categories. Buildings in category A are generally one or two-storey old houses, many of them over fifty years old, with load bearing masonry walls made of stone or brick, with mortar and typically without any seismic provisions such as horizontal concrete or wood tie belts. Buildings in category B are made of reinforced concrete and constitute the majority of modern residential and office buildings in Kalamata. Their number of storeys varies from two to seven depending upon the height limitations applicable at the time of their construction. Their load carrying system both for vertical and horizontal loads, is a skeleton of columns and beams, on which the floor slabs are monolithically supported.

For the area of Kalamata and Kyllini, Amaliada, Pirgos the base shear

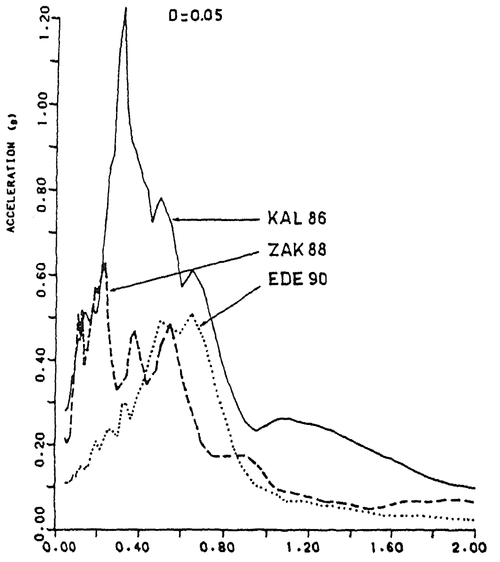

Figure 2. Comparison of acceleration response spectra of the largest horizontal components of the three seismic events.

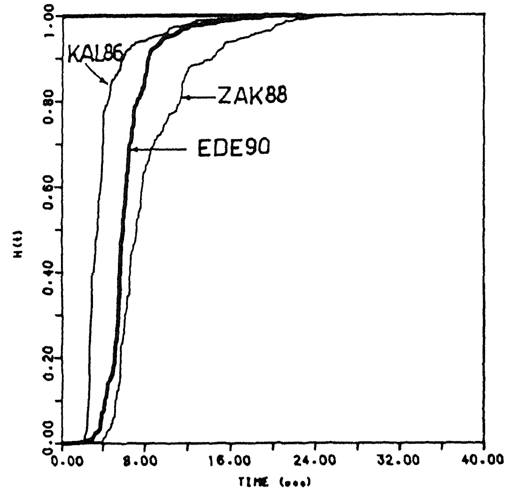

Figure 3. Husid plots of the three relevant recordings (Kalamata, Zakynthos, Edessa).

coefficient according to the Greek seismic code of 1959 (this code has been upgraded in 1984) is ε=0.06, 0.08 and 0.12 for good, medium and bad soils, respectively. This coefficient is constant, independent of a building's period and without considering importance or any other factor. For the area of Edessa the base shear coefficient according to this code is ε=0.04, 0.06 and 0.08 for good, medium and bad soils.

In order to have an idea of the ductility demands imposed on the buildings of Kalamata, Kyllini and Edessa by the three recent earthquakes, the spectral accelerations Sa of the highest horizontal components are compared with the three base shear coefficients applicable in the three aforementioned areas in figures (4,5,6), respectively. Instead of using the recorded response spectrum at the city of Zakynthos a reduced one to the village of Kyllini and the broader meisoseismal area was used. Reduction was based on empirical attenuation relations of pseudo-velocity in Greece (Theodulidis and Papazachos 1990). These coefficients have been modified to account for a factor of safety 1.75 and a 20% increase in allowable stresses for seismic design (Anagnostopoulos et al. 1987). The shaded areas are compared in figures (4,5,6) to the base shear coefficients applicable in the three areas, that is to 0.08 for Kalamata and Kyllini and to 0.06 for Edessa area. These values typically used by the local engineers. Fundamental periods of all the buildings in Greece, with two to six storeys are fluctuated between 0.2 to 0.65 sec. The ductility demands imposed by earthquakes to buildings were quite high, well above what is estimated to be available ductility of the buildings, according to the provisions in force of seismic Greek code. The structural damage of many modern reinforced concrete buildings and many collapses must be attributed primarily to poor seismic design, lack of ductility behaviour and construction practices.

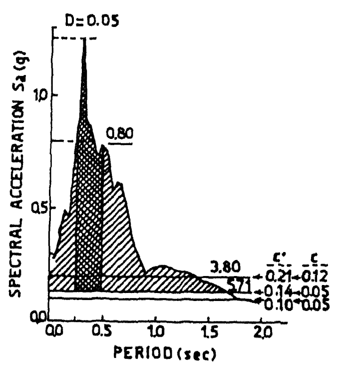

Figure 4. Comparison of response spectrum of the Kalamata Earthquake with code provisions.

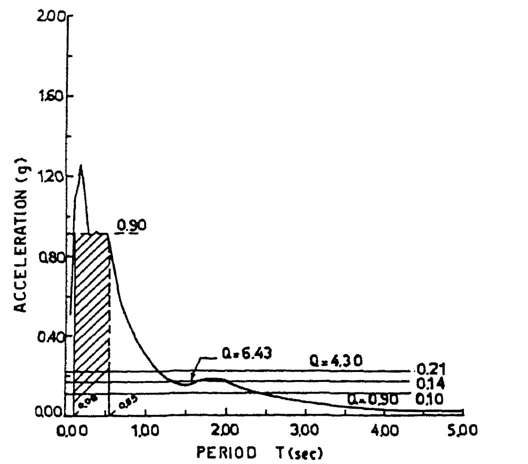

Figure 5. Comparison of reduced response spectrum of the Kyllini Earthquake with code provisions.

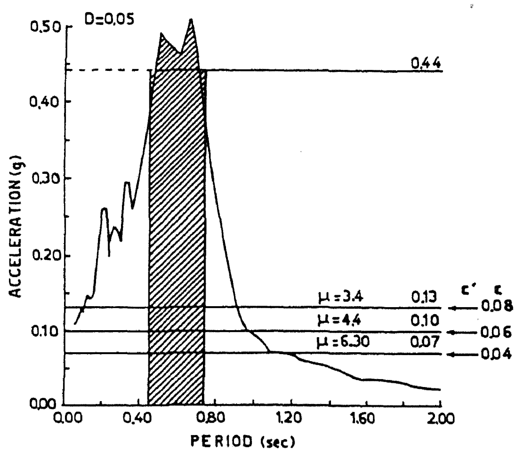

Figure 6. Comparison of response spectrum of the Griva Earthquake with code provisions.

4 DAMAGE SURVEYS AND STATISTICAL EVALUATION

It is widespread known that the effects of local soil conditions on the ground shaking characteristics is very important. The influence of the nonlinear effects associated with the seismic response of many soft soil types is widely accepted for the accurate analysis of the ground motions.

Especially for the cities of Kalamata and Edessa must be pointed out that although they does not extend over a large area - the distance between any two points in them is estimated at, less than 3 km - the distribution of damage (for the same type of construction) was quite non-uniform. This suggests significant variations in the ground motion, which is attributed to possible differences in local soil conditions, as well as to source mechanism characteristics that can play a dominant role when the affected area is near the epicentral area. This is a characteristic of the Kalamata earthquake in which the large variety in severity of damage was described by damage contours (Leventakis et al. 1992). As it is always the case, the buildings in category A paid the heaviest toll to the earthquake. Such buildings have low seismic resistance and practically no ductility. Due to their large stiffness, their accelerations were nearly equal to the accelerations of the ground and thus they were subjected to high horizontal forces that in many cases exceeded their capacity.

A number of churches in category A suffered also extensive damage. If we try to correlate response spectra with distribution of damage into the meisoseismal areas we will verify the macroseismic intensity for the previous areas. For this purpose we have to define structural damage criteria for buildings in category A. Despite of a lot of references, the structural damage estimation criterion has not been confirmed (Pomonis et al. 1991, Spence et al. 1991). For example the MSK (Medvedev 1965) gives the definition of damage degree of single storey buildings. We use in this paper the building structural damage estimation criteria as follows: Damage level D0(undamaged) with damage index=0, Damage level D1 (slight damage) with damage index= 0.20, Damage level D2 (moderate damage) with damage index=0.40, Damage level D3 (heavy damage) with damage index= 0.65, Damage level D4 (destruction) with damage index= 0.80, and damage level D5 (total collapse) with damage index= 1.0.

The classification of buildings in Kalamata was thorough, therefore damage statistics are reliable (fig.7). On the Kyllini peninsula damage statistics do not appear coherent.

This may reflect a) the broader area considered b) the inadequacies of the statistical sample (fig.8,9). Still, comparison with the Kalamata histograms shows that damage was heavier in Kalamata. For the traditional structures considered, this results

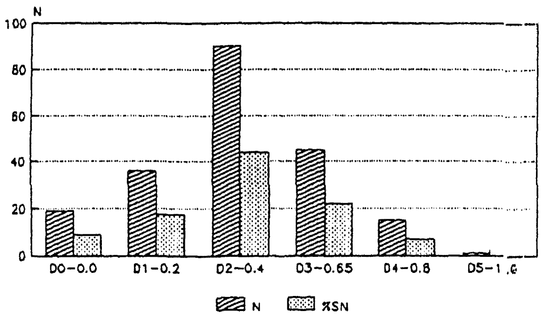

Figure 7. Damage statistics for traditional structures in Kalamata.

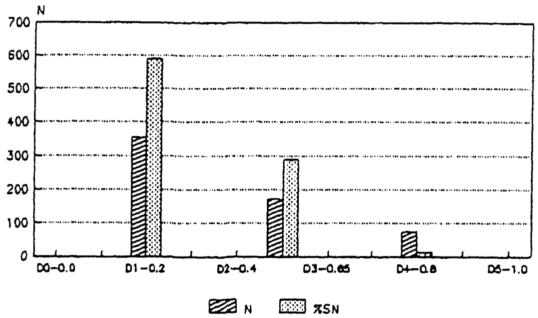

Figure 8. Damage statistics for masonry buildings in the village of Kyllini.

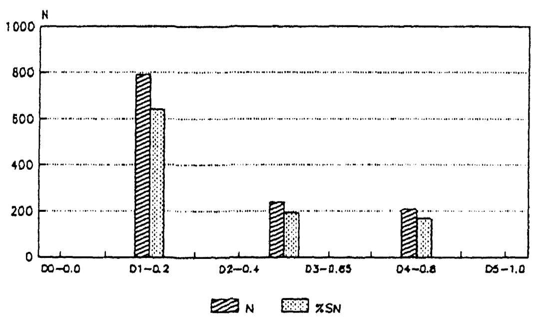

Figure 9. Damage statistics for masonry building in Vartholomio, after Kyllini earthquake, 1988.

may have been influenced by the fact that Kalamata has been exposed in the past less frequently in earthquakes. The response spectra, although open to the many uncertainities involved in extrapolating to the meisoseismal area at the Kyllini earthquake, look quite similar (fig.4,5). A major difference between the two earthquakes is apparent on the Husid plots (fig. 3) and is most probably related to the source mechanism (Theodulidis et al. 1992). The time characteristics

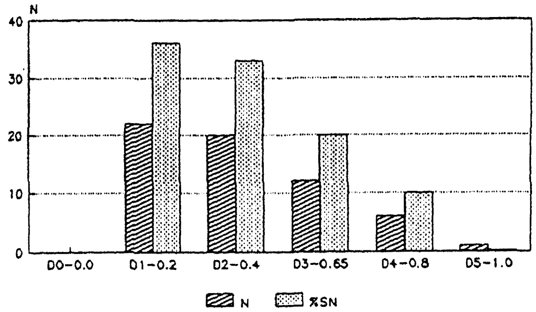

Figure 10. Degrees of damage for masonry buildings in Edessa.

of seismic energy release may play an important role in the earthquake damage.

At Edessa damage statistics were not as thorough as in Kalamata (fig. 10). They clearly show less but also more spread damage. In this case the response spectrum clearly suggests that the effect of local soil conditions could be also responsible for the spread of damage.

CONCLUSIONS

1. The correlation of damage with accelerograms requires a major effort. In the case of accelerograms the effort intesified before the earthquake, in installing and maintaining the accelerographs. In the case of damage the effort is concentrated soon after the earthquake on a systematic registration of initial conditions and of earthquake damage inflicted to structures. In field work it is important to form good statistical samples properly reflecting all degrees of damage.
2. Damage may be strongly affected by the time characteristics of seismic energy release. These characteristics are not apparent on response spectra.
3. Damage statistics are influenced by local subsurface conditions. Related studies should be combined with microzoning subsurface investigations.
4. Instrumentation on stuctures by special arrays will contribute to the effort for better evaluation of ductility demands on structures.

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