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ANALYSIS OF THE KALAMATA, GREECE, STRONG MOTION RECORDS AND CORRELATION WITH THE OBSERVED DAMAGES

by

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1. INTRODUCTION

On September 13th, 1986, Kalamata and the surrounding area were struck by a very strong and destructive earthquake. According to the Seismological Institute of Athens the epicenter was located about 20 km north of the city and the local magnitude was calculated equal to 5.5 R. The earthquake was followed by a large number of aftershocks, the strongest of which occurred on September 15th, 1988. The epicenter was located about 15 km north of the city and the local magnitude was calculated equal to 4.8 R.

The city of Kalamata is located in SW Peloponese, Greece, and it is the administrative and commercial center of the area with a population of about 20000 people. The soil is alluvium and the city lays along the banks of the Nedon dry river. During the last two centuries the surrounding area has been struck by four earthquakes, shown in figure 1.

The earthquake of September the 13th caused the death of 21 people, the wounding of 300 people and the total destruction of the 44% of the Kalamata buildings.

In this study we present the results of the processing of some of the accelerograms that were obtained during the aftershock sequence. More specifically we have calculated the values of ground acceleration, velocity and displacement, and the response spectra of the recordings. Furthermore a correlation between the results and the observed damages caused by the main shock was performed.

2. DATA AND METHOD

The permanent strong ground motion network of the Seismological Institute of Athens at Kalamata and the surrounding area consists of four accelerographs, SMA 1 type, which are installed in Kalamata, Sparti, Kiparissia and Pilos (figure 1), the main shock of the seismic sequence triggered the Kalamata and Sparti accelographs. The Kalamata instrument was triggered in addition by fifteen aftershocks. The Seismological Institute of Athens installed two more instruments in the city of Kalamata at sites with different observed damages, but no reliable record was obtained because of the small magnitude of the recorded shocks. The seven well recorded earthquakes which have been used in the present study are shown in Table 1.
The strong ground motion instrument at Kalamata is installed at the basement of the 3 storey building of the Telecomm-

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nication Company. The building is a stiff structure with a reinforced concrete load - carrying system. The longitudinal component of the instrument has an E - W orientation.

The methodology that was followed for the processing of the records was the one that the Laboratory of Earthquake Engineering, National Technical University of Athens, uses and is based on the methodologies by Trifunac and Lee (1973), Petrovski and Naumovski (1979), Hudson (1979), Basili and Brady (1978) and Jennings and Nigam (1968). The main steps of the method are the following:

a) First the production of the contact copy of the record is made, which is magnified three or four times in order to be digitized.

b) The digitization process is performed manually, with the crosshair following the middle of the line of the copy. The digitization is made on unequal time intervals, picking prominent points on the records such as peak values and points of inflection.

c) A computer plot of the digitized data at the same scale as the original record is used to check the digitization accuracy. By superimposing the two accelerograms incorrect points are identified and corrected.

d) Computer processing of strong motion accelerograms. The steps involved are these:

i) Start with the uncorrected accelerogram digitized at unequal time intervals.

ii) Interpolate equally spaced time data to facilitate digital filtering.

iii) Extend accelerogram at beginning and end to permit ORMSBY low pass filtering in order to remove high frequency noise.

iv) Calculate derivatives of X.

v) Substitute in transducer equation to find true ground acceleration.

vi) Remove linear trends in acceleration and velocity by least squares fit.

vii) Extend record for digital filering.

viii) Filter through ORMSBY low pass filter by unequal weight running average.

ix) Interpolate points at same time ordinates as input accelerogram and subtract from input to produce high pass filtered accelerogram, thus performing baseline adjustment.

x) Eliminate linear trends again by least squares fit producing final form of the corrected accelerogram.

xi) Integrate accelerogram, eliminate linear trends, filter through low pass filter to produce final corrected ground velocity.

xii) Integrate again and filter through low pass filter to produce final corrected ground displacement.

e) For digital calculation of the response spectra we use the Nigam and Jennings method (1978).

In the present case, because of the bad developing of the film, it was impossible to obtain a contact copy. So, the digitization was made straight from the original many times and by many users. Then the best one was selected.

The cut off frequency of the low pass filter was determined by using the USGS and Basili and Brady (1978) procedures.

3.- RESULTS

After the digitization and the correction of the recordings done we obtained the maximum ground values (Table II). We finally obtained the responce spectra of the shocks. In fig. 2 and 3 the responce spectra of the main shock and the largest aftershock for 0%,2%,5%,10% and 20% damping and for the three components are shown. The 5% damping (the middle line) generally corresponds to buildings made of reinforced concrete.

For the main shock the value of the spectral acceleration for the longitudinal component varies between 0.4 and 0.6g for natural periods between 0.15 anp 0.7 sec. The peak value is about 0.6g for period about 0.3 sec. The vertical component shows a peak value of the order of 1.5g corresponding to a natural period of 0.18 sec. The acceleration for the transverse component varies between 0.6 and 1.0g for natural periods between 0.15 and 0.7 sec and reaches a peak value of 1.0g for a natural period of 0.28 sec. The peak spectral velocities are considerably high for the horizontal components (60 cm/sec for the longitudinal component and 85 cm/sec for the transverse), while for the vertical component the peak value is 40 cm/sec. As for the displacements, the two horizontal components show peak values of about 15 cm, while the vertical one is about 7.5 cm.

For the major aftershock and for the longitudinal component the higher spectral acceleration values vary between 0.6 and 1.0g for natural periods between 0.15 and 0.7 sec, with a peak value of about 1g at 0.32 sec. For the vertical component and for values of natural period between 0.1 and 0.7 sec the spectral acceleration varies between 0.15 and 0.5g and shows a peak value of 0.51g at 0.3 sec. The transverse component shows spectral accelerations between 0.2 and 0.35g for natural periods between 0.15 and 0.5 sec with a peak value of 0.33g at 0.25 sec. The peak spectral velocities for the longitudinal, vertical and transverse components are 67, 20 and 10 cm/sec respectively and the peak spectral displacements are 7, 2.8 and 2.5 cm respectively.

Table III shows the maximum spectral acceleration for 5% damping, for each of the shocks analyzed.

4. CORRELATION OF THE RESULTS AND THE OBSERVED DAMAGES

According to the relation connecting the natural period with the number of storeys of the building after Carydis and Mouzakis (1986), almost all buildings in Kalamata have natural periods between 0.1 and 0.7 sec. that is values that coincide with the area of the peak spectral accelerations caused by these earthquakes.

In order to calculate the seismic coefficient developed to the buildings of Kalamata during the earthquake, we use the following steps: We select a 7.5% damping (the mean value of 5% and 10%). For values of natural periods between 0.1 and 0.7 sec, the values of spectral accelerations observed, vary for the longitudinal component (east - west direction) between 0.4 and 0.5g, while for the transverse component (north - south direction) vary between 0.55 and 0.95g. The relation connecting the seismic coefficient with the spectral acceleration is:

$$\varepsilon = \frac{1.2\ SA\ /\ g}{1.75\ Q}$$

where: ε is the seismic coefficient
1.2/1.75 = 1.42 is the safety factor
SA is the spectral acceleration for 5% damping
Q is the quality factor of the structure and varies between 1 and 6.

In this particularity case we considered three of buildings, for which Q = 5 (good quality, ductile construction), Q = 3 (medium quality, reinforced concrete buildings) and Q = 1.5(common adobe structures or bad quality buildings from reinforced concrete). Table 2 shows the seismic coefficients developed for each of the two horizontal components and for the three quality coefficients confederated From the point of view of seismicity the area of Kalamata is placed to zone II and the seismic coefficient according to the soil category is 0.06 for soil α, 0.08 for soil β and 0.12 for soil γ.

We estimate that buildings with a load bearing system of reinforced concrete, constructed according the Earthquake Resistant Code of 1959, an corresponding to Q=3, suffered a seismic coefficient considerably higher than the one they had been studied for, for the north-south orientation (transverse component), while for the east-west orientation (longitudinal component) they suffered a seismic coefficient almost equal to the one they had been studied for. But because of the fact that the coefficient Q=3 assumes considerable inelastic deformation, the damages to the east-west direction were also extensive. The load bearing masonries, which are studied for the same seismic coefficient that is in use for other constructions, suffered during the main shock quite higher seismic coefficient than those used for their study. We also have to take in account the vertical component for which the spectral acceleration is quite high for the low periods, characterizing the various parts of the buildings (roofs, floors etc).

As far the above conclusions are concerned, we are reserved as to the fact that the results are extracted from the recordings of one single instrument, while for more accurate results more than one instruments are required.

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TABLE I : PARAMETERS OF THE EARTHQUAKES, THE ACCELEROGRAMS OF WHICH WERE USED IN THE PRESENT STUDY

CODE NUMBER	DATE	ORIGIN TIME	φ° N	λ° E	M_L (ATH)
S1	13 SEP	17:24	37.10	22.19	5.5
S2	13 SEP	18:30	37.11	22.14	3.3
S3	13 SEP	22:40	37.12	22.16	3.6
S4	14 SEP	22:48	37.15	22.04	3.4
S5	15 SEP	05:15	37.22	22.01	3.2
S6	15 SEP	11:41	37.08	22.07	4.8
S7	15 SEP	12:47	37.09	22.04	3.6

TABLE II. MAXIMUM SPECTRAL ACCELERATION FOR 5% DAMPING

CODE NUMBER	COMPONENT	ACCELERATION (g)
	L	0.635
S1	V	1.491
	T	1.007
	L	0.124
S2	V	0.102
	T	0.100
	L	0.117
S3	V	0.079
	T	0.092
	L	0.102
S4	V	0.071
	T	0.062
	L	0.108
S5	V	0.087
	T	0.072
	L	0.986
S6	V	0.513
	T	0.331
	L	0.133
S7	V	0.098
	T	0.113

TABLE III: MAXIMUM PEAK GROUND VALUES

CODE	COMP	ACC/TIME (g/sec)	VEL/TIME (cm·sec⁻¹/sec)	DISPL/TIME (cm/sec)
	L	0.22/4.2	34.35/3.53	8.94/4.03
S1	V	0.32/3.11	14.21/2.86	4.02/3.09
	T	0.29/3.67	33.00/3.47	7.18/3.66
	L	0.04/1.03	3.06/1.21	3.29/6.35
S2	V	0.03/1.02	1.59/8.69	1.30/9.60
	T	0.03/1.04	2.60/11.21	2.67/5.21
	L	0.05/0.98	1.99/4.53	1.92/5.78
S3	V	0.02/1.07	1.14/7.00	0.32/6.75
	T	0.04/1.02	2.20/11.85	1.71/4.19
	L	0.04/0.64	2.47/0.53	1.15/9.99
S4	V	0.02/0.71	1.56/7.87	5.35/6.00
	T	0.02/0.79	1.47/0.71	1.07/9.10
	L	0.05/0.68	3.41/0.63	0.81/1.31
S5	V	0.02/0.27	1.19/9.79	1.53/9.31
	T	0.03/0.68	2.60/8.88	0.79/8.53
	L	0.32/2.41	26.75/2.30	4.15/2.11
S6	V	0.16/1.88	7.91/2.12	1.05/2.12
	T	0.10/2.26	9.50/1.63	1.24/1.87
	L	0.05/1.22	1.71/1.33	0.41/6.39
S7	V	0.03/0.22	0.81/5.10	0.27/7.95
	T	0.03/1.19	2.72/11.41	3.33/9.11

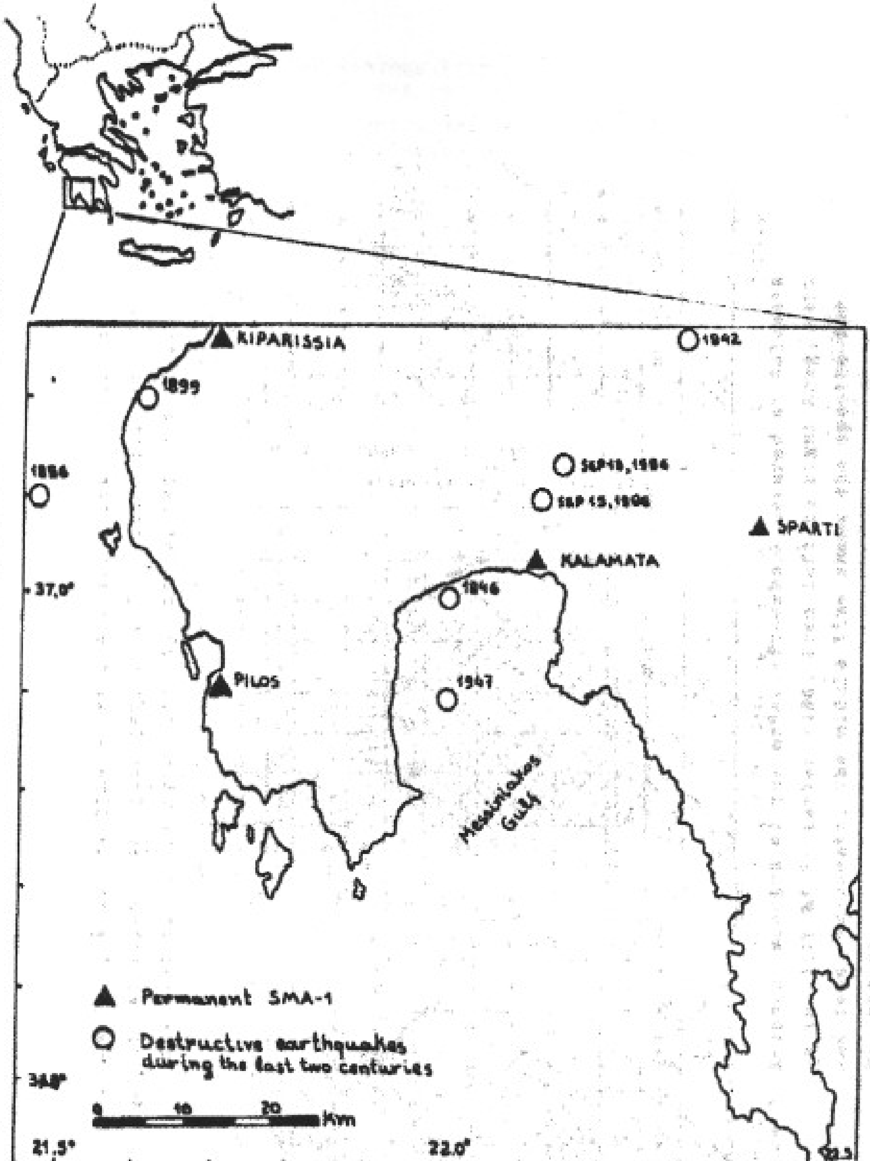

Figure 1. Map, that shows the destructive earthquakes around Kalamata, Greece, during the last two centuries and the permanent strong ground motion network of the National Observatory of Athens in the area.

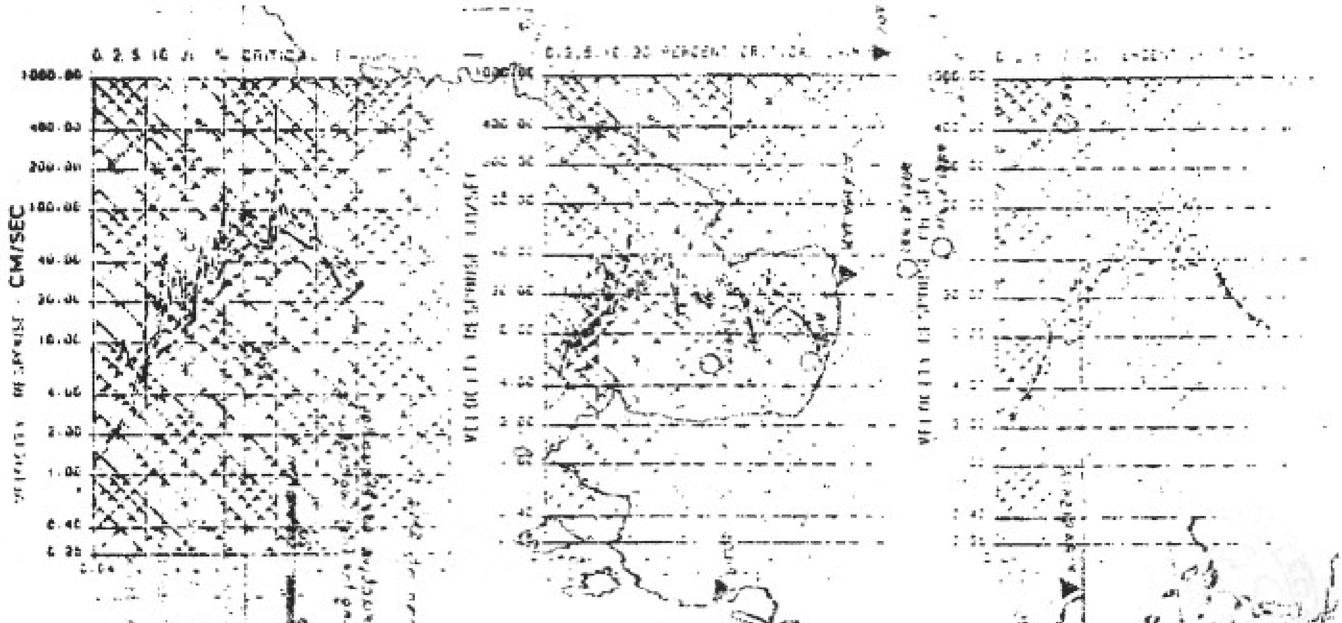

Figure 3. Response spectra of the main shock occured at Kalamata on the 13th of September 1986. From left to right Long, Vert and Tran components. The middle line shows the spectra for 5% damping.

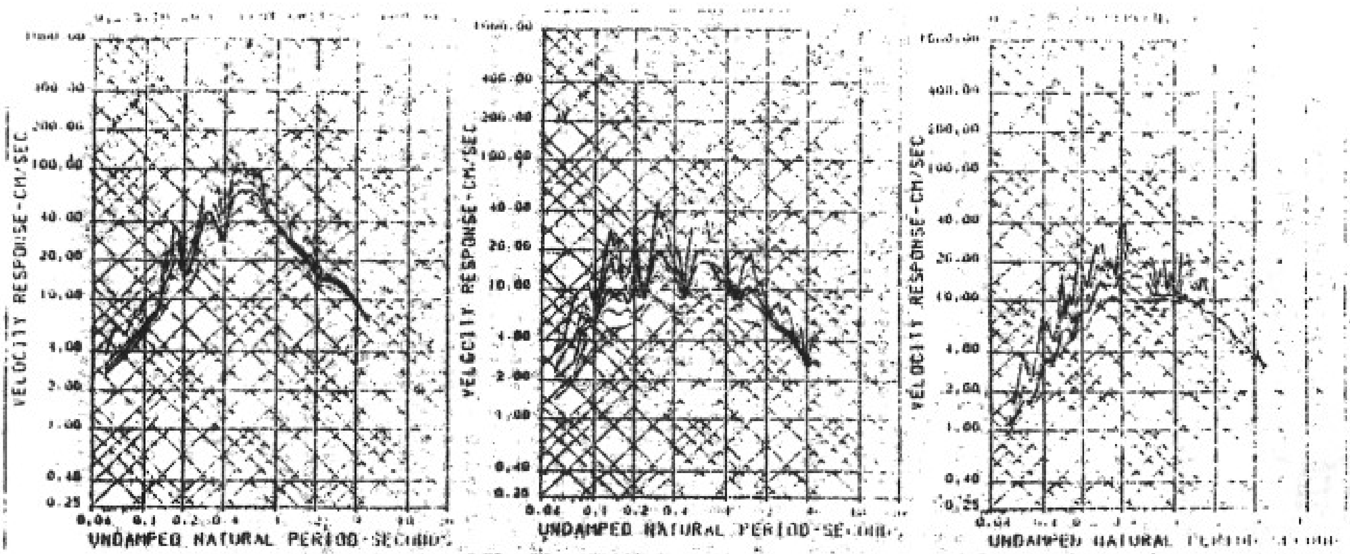

Figure 3. Responce spectra of the major aftershock occured at Kalamata on the 15th of September 1986. From left to right Long, Vert and Tran components. The middle line shows the spectra for 5% damping.