4.5.6. EXPECTED PEAK GROUND ACCELERATIONS FOR SELECTED SITES OF THE TELECOMMUNICATION NETWORK IN CRETE (S. GREECE)

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4.5.6.1. Introduction

The recent Athens earthquake (M=5.9), caused loss of lives and heavy damage on structures, especially at the western suburbs of Athens. Among them damage on utility networks, as for instance mobile telecommunications were cut off for several hours after the earthquake, an effect that caused further confusion and panic among people. Despite the fact that the Athens earthquake was a moderate (M_W=6.0) magnitude seismic event, unexpectedly high seismic ground accelerations were recorded at many locations (Bouckovalas et al., 2002), much higher than the expected acceleration for the metropolitan area of Athens according to the Seismic Hazard Map of Greece (zones II and III with design values of ground acceleration 0.16 and 0.24g respectivelly).

The lack of telecommunication systems within a populated area was observed following the Thessaloniki earthquake and since that earthquake in many other cases, where also high accelerations were recorded (Kalamata 1986, Kozani, 1995 among others). Recently, the lack of telecommunication systems was also observed at the area of western Crete after the earthquake of January 8, 2006.

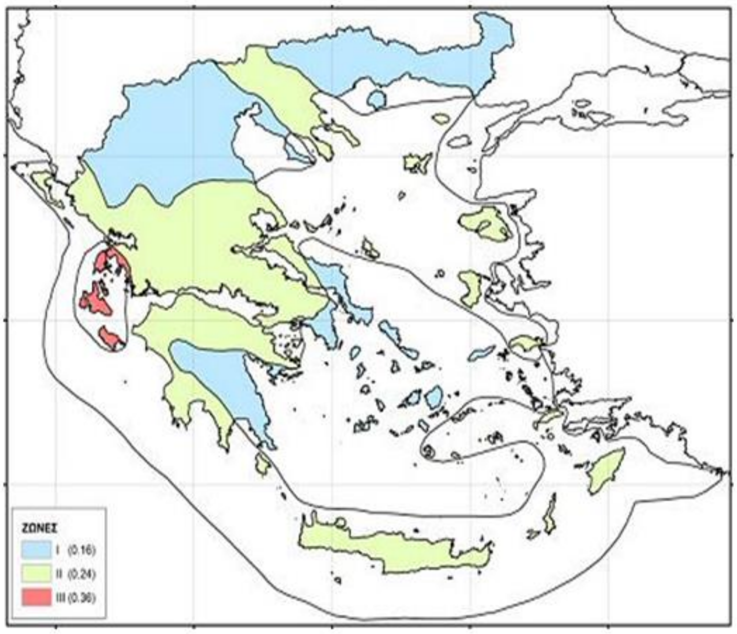

Fig. 4.5.6.1. Seismic Hazard Map of Greece (OASP, 2006). The country is divided to three zones with design acceleration values 0.16 g, 0.24 g and 0.36 g

However, it was only after the 1999 Athens earthquake that the Earthquake Zoning Map of Greece was revised in 2000/2002 and new estimates for the expected seismic ground accelerations, a crucial parameter for the design of earthquake resistant structures were adopted. According to the recently revised Map of Seismic Hazard of Greece (OASP), the country is divided at 3 zones with design values of the ground acceleration 0.16g, 0.24g and 0.36g respectively and the island of Crete is located within the zone 2 (Fig. 4.5.6.1).

Interruption of telecommunication, ranged from 3 hours to 3 days after the earthquake, was also observed after the Kocaeli, 1999 earthquake due to inadequate anchoring of electronic cabinets, collapse of hosting structures or rupture of underground transmission lines. Furthermore, improvement in the building codes in 1975 and 1998 did not necessarily lead in practice to improved structural design and details. It is not sufficient to improve the building codes in highest seismic zones to address deficiencies in existing constructions NEA/CSNI/R (2002).

The question about whether existing regulations are adequate and provide reasonable estimates of expected ground acceleration given the probability level still remains for important infrastructures. To give an answer to that question, expected values of peak ground acceleration are estimated taking into account recently published information on the active tectonics, seismicity and attenuation of strong ground motion parameters for selected sites of Crete, which is of high importance for the telecommunication network in the island. The area of the island of Crete is one of the most seismically active areas in Greece, at the border of the Hellenic Arc, very close to several kilometers deep marine troughs. This area has been affected by numerous strong earthquakes, with the most destructive of magnitude higher than 8.0 in 365 AD, producing more than 9 m ground uplift (Pirazzoli et al., 1982, Drakos, Stiros, 2001). Our estimates of ground acceleration are then compared to the expected acceleration values used in the revised Seismic Hazard Map of Greece.

4.5.6.2. Seismotectonic setting and seismic activity in the area of Crete

The area of Crete is part of the Hellenic Arc, which is one of the most active seismogenic regions along the Africa-Eurasia collision zone. In this area of the Eastern Mediterranean lithosphere the Aegean exhibits more than 60% of the European seismicity, which is the most prominent manifestation of the active deformation of the area. This deformation is expressed with earthquakes with magnitudes up to $M_W \approx 8.3$ (Papazachos, 1990). This deformation is the result of the subduction of the eastern Mediterranean lithosphere under the Aegean along the Hellenic Arc (Papazachos, Delibasis, 1969, Papazachos, Comninakis, 1971, Le Pichon, Angelier, 1979) and the westward motion of Anatolia along the North Anatolia Fault (McKenzie, 1970, 1972) and its continuation in the Aegean along the North Aegean Trough. The Aegean exhibits the typical characteristics of a marginal sea, with high heat flow, volcanic activity along its volcanic arc and high magnetic and positive gravity isostatic anomalies (Makris, 1976).

Shallow seismicity extends throughout the whole Aegean back-arc area, mainly with normal faults (McKenzie, 1978), except the North Aegean Trough and the Cephalonia Fault, which is the contact between the Eastern Mediterranean and Adriatic plates (Scordilis et al., 1985) where dextral strike-slip faults are observed. Along the Hellenic Arc, the subduction results in a high shallow seismicity with low-angle thrust faults (e.g. Papazachos, 1990). The subduction is clearly identified both by large scale (Spakman, 1988) and local (Papazachos, Nolet, 1997) tomographic studies, as well as by the high

intermediate-depth seismicity which is expressed along a well-defined Benioff zone (Papazachos, Comninakis, 1971). The Benioff zone in the Western Crete area is dipping at a shallow angle ($\sim 15^{o}$) up to the depth of ~80-90km and becomes steeper ($\sim 25^{o}$) at its deeper section (Papazachos et al., 2000).

Fig. 4.5.6.2 shows the geographical distribution of the complete earthquake data set used in the present study. The data source is the catalogue of Papazachos and Papazachou (2003) for the historical earthquakes and the catalogue of the Geophysical Laboratory of the Thessaloniki University (2006) for the data of the instrumental period.

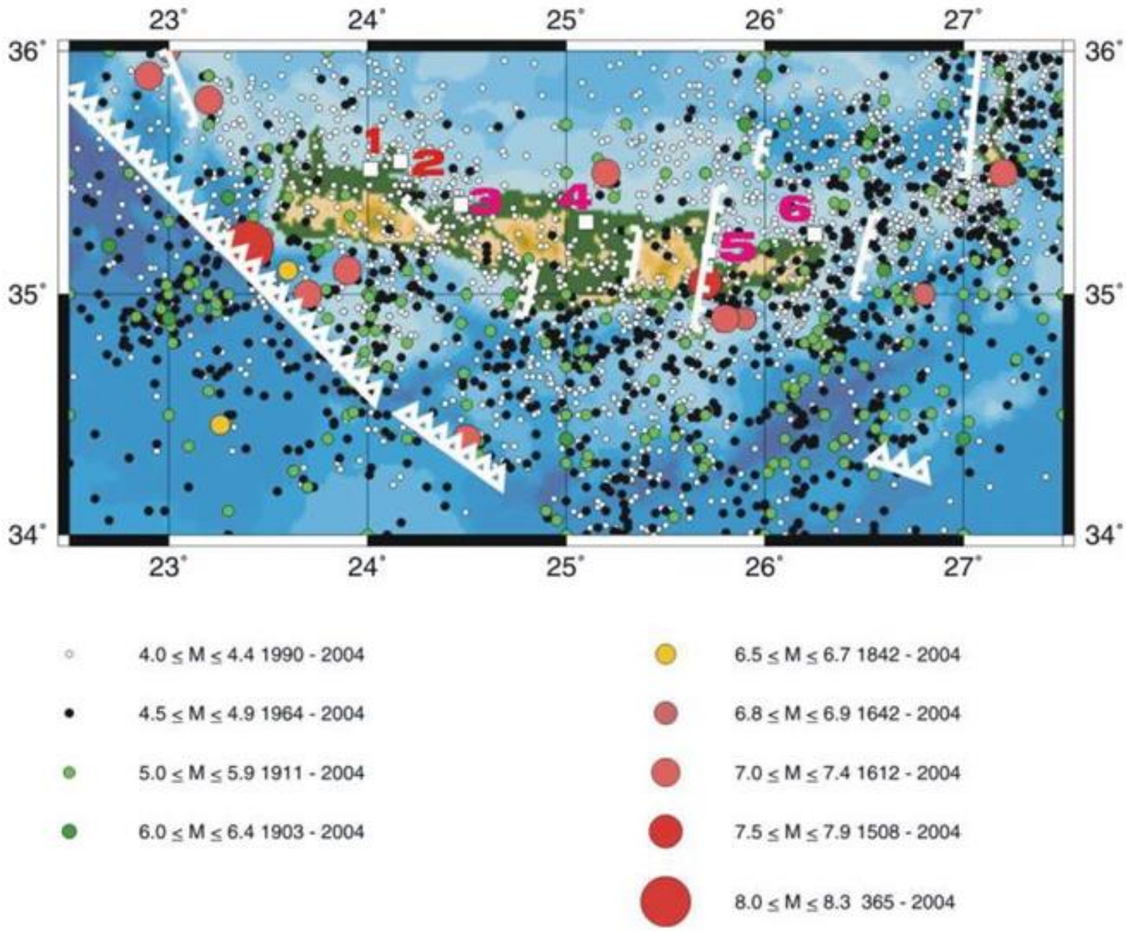

Fig. 4.5.6.2. Geographical distribution of the epicenters of the complete data set of shallow earthquakes with ($M \geq 4.0$) at the broader area of Crete. The faults associated with the strong earthquakes (Papazachos et al., 2001) are also shown. The examined sites are denoted by squares and the numbers correspond to Table 4.5.6.2.

It is clearly recognized that significant shallow seismicity is present in the outer part of the Hellenic Arc. In the vicinity of Crete most strong earthquakes occur approximately at the southwest corner and the southern part of the Crete mainland, which is in agreement with the historical information which suggests that shallow earthquakes with magnitudes up to over 8.0 occur in this part of the Hellenic Arc. On the other hand, limited shallow seismicity is identified on the Crete mainland during the instrumental period, in agreement with the historical information.

Fig. 4.5.6.3 depicts the geographical distribution of the complete earthquake data set for the intermediate depth earthquakes. The data sources are the same as for the shallow earthquakes. The seismic sources of the intermediate depth earthquakes (Papaioannou, Papazachos, 2000) and the faults of the strong earthquakes (Papazachos, Papazachou, 2003) are shown.

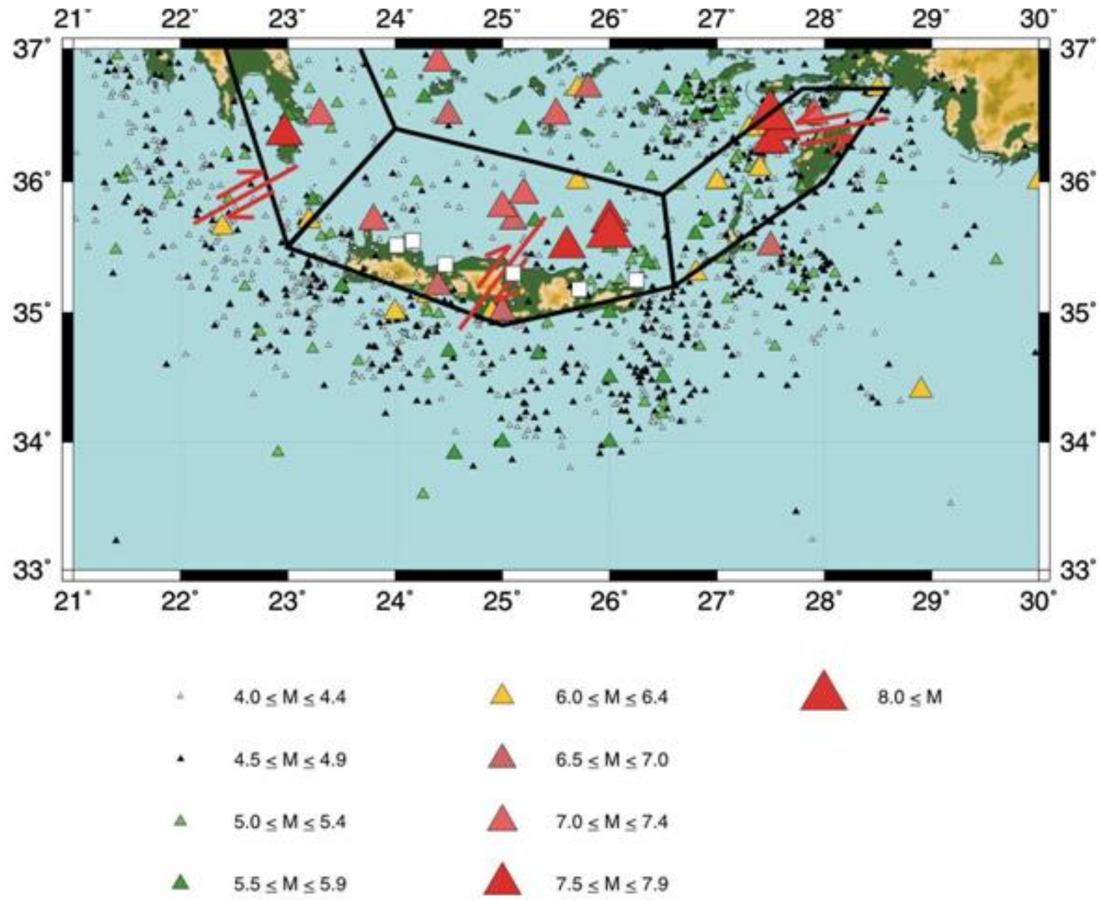

Fig. 4.5.6.3. Geographical distribution of the epicenters of the complete data set of intermediate depth earthquakes with (M≥4.0) at the broader area of Crete. The faults associated with the strong earthquakes (Papazachos, Papazachou, 2003) and the seismic sources (Papaioannou, Papazachos, 2000) are also shown. The examined sites are denoted by squares.

Most intermediate depth events are located in the central part of the Southern Aegean, north of the central part of Crete, further west in the Cythera area and extended to the east up to the Dodecanese Islands. Strong intermediate depth earthquakes located even at long distances cause extended damage over a large part of the Crete Island up to the northern coasts of Egypt (Papazachos, Papazachou, 2003).

4.5.6.3. Seismic Hazard Assessment

Table 4.5.6.1 gives information on the known macroseismic intensities with $I_{MM} \geq VIII$ for the selected sites (Papazachos et al., 1999, Papazachos, Papazachou, 2003).

Table 4.5.6.1. Information on the available Macroseismic Intensities for the examined sites

DATE			φ^{O}_{B}	λ^{O}_{A}	DEPTH	M	I_{MM}	SITE
1303	8	8	36.10	29.00	n	8.0	8.00	HERAKLEIO
1494	7	1	34.90	24.20	n	7.2	8.00	HERAKLEIO
1508	5	29	35.05	25.70	n	7.5	8.00	ITANOS (SITIA)
1508	5	29	35.05	25.70	n	7.5	8.00	HERAKLEIO
1595	11	26	34.90	25.30	n	6.8	8.00	HERAKLEIO
1612	11	8	35.50	25.20	n	7.0	8.00	HERAKLEIO
1665	1	0	35.90	25.00	i	7.0	8.00	HERAKLEIO
1681	1	10	35.40	25.20	n	6.3	8.00	HERAKLEIO
1805	7	3	35.10	23.90	n	7.2	8.00	CHANIA
1810	2	16	35.50	25.60	i	7.8	9.00	HERAKLEIO
1856	10	12	35.60	26.00	i	8.2	9.00	HERAKLEIO
1856	10	12	35.60	26.00	i	8.2	7.50	CHANIA
1926	6	26	36.50	27.50	100	8.0	7.50	CHANIA
1926	6	26	36.50	27.50	100	8.0	7.50	RETHIMNO
1926	6	26	36.50	27.50	100	8.0	7.50	AG. NIKOLAOS
1926	6	26	36.50	27.50	100	8.0	8.50	HERAKLEIO
1930	2	14	36.50	24.00	130	6.7	7.50	RETHIMNO
1930	2	14	36.50	24.00	130	6.7	7.50	HERAKLEIO

The seismic hazard assessment for the selected sites was accomplished using as parameter the peak horizontal ground acceleration for "rock" type of the foundation ground. The empirical predictive relations were the following:

(1) $$\ln PGA = 4.16 + 0.69M_W - 1.24\ln(R+6) + 0.12S \pm 0.70P$$

(2) $$\ln PGA = 3.47 + 0.75M_W - 0.85\ln R_{CER} + 0.27S \pm 0.66P$$

where PGA is measured in cm/sec^2, M_W is the moment magnitude, R the epicentral distance, R_{CER} the distance from the center of energy release, *S* is the variable accounting for the local site conditions and P is a variable with value 0 for the mean and 1 for the mean plus one standard deviation. Equation (1) is valid for the shallow earthquakes (Margaris et al., 2002) while equation (2) for the attenuation of the intermediate depth earthquakes (Theodulidis, Papazachos, 1990).

The calculations have been made with a modified version of the code FRISK88M (1995) in order to consider the attenuation of both the shallow and intermediate depth earthquakes. The seismotectonic model used is a hybrid model, which is constituted of area sources and faults (Papaioannou, 2002) and was used in the past for the compilation of the seismic hazard map of Greece and in other site-specific hazard studies.

Analyses were performed for three different mean return periods 476, 1000 and 2000 years for critical areas of the telecommunication system in Crete, namely Chania,

Sklopa, Rethimno, Herakleion, Ag. Nikolaos and Itanos, where major structures and utility networks are located. The seismic hazard curves for the examined sites are shown graphically in Fig. 4.5.6.4. Such information is more useful than ill-defined single numbers as the "probable maximum" or the "maximum credible" intensity. This is due to the fact that even well defined single numbers, as the "expected lifetime maximum" are insufficient to give the engineers an understanding of how quickly the hazard (annual probability of exceedence) decreases as the ground motion intensity increases (Cornell, 1968).

Papaioannou and Papazachos (2000) performed a seismic hazard analysis for selected sites of Greece using as parameter the macroseismic intensity, I_{MM}, and site specific attenuation relations for every site. They found that the results of the calculations can be fitted by relations of the form:

(3) $$I = c_1 \log T_m + c_2$$

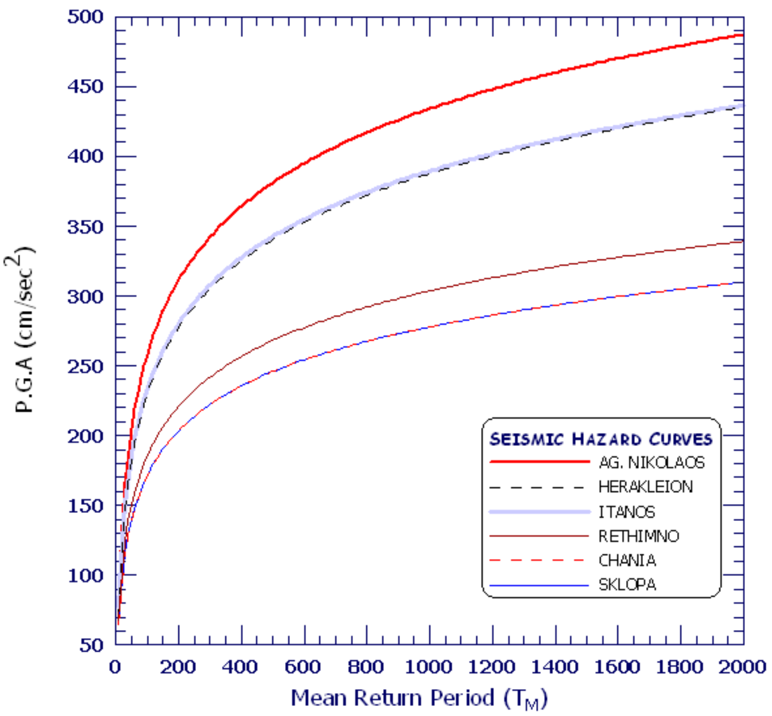

Fig. 4.5.6.4. Seismic hazard curves in terms of peak horizontal ground acceleration for the examined sites in Crete

for every site, where T_m is the mean return of the seismic motion with intensity I or larger and c_1, c_2 are constants. They adopted a constant slope for all sites with value c_1=1.096(± 0.008) because they found very small variations. The value of the parameter c_2 for the examined sites found equal to 4.425 (Chania), 4.280 (Rethimno), 4.280 (Herakleion), 3.865(Ag. Nikolaos) and 4.151 (Siteia). If we use these values for the examined mean return periods and considering the scaling relation:

(4) $$\ln PGA = 0.40 + 0.67 * I_{MM} + 0.618P$$

(Theodulidis, Papazachos, 1992) holding between peak horizontal ground acceleration, PGA, and the corresponding Macroseismic Intensity, I_{MM}, we can have an independent calculation of the expected accelerations.

Table 4.5.6.2 gives the expected values of the peak ground accelerations for the examined sites for the various mean return periods based on the hazard analysis using the code FRISK88M and the results based on the conversion of macroseismic intensities. The two independent methods for the calculation of the expected peak horizontal ground acceleration values gave higher values compared to the seismic code provisions. The differences in the results can be related to the seismotectonic model used in these studies and the high value of the standard deviation of equation (4).

Table 4.5.6.2. Information on the results of the hazard analysis for the peak horizontal ground acceleration (cm/sec^2) based on probabilistic method and the results of the conversion of the Macroseismic Intensities for the examined sites for three mean return periods. According to the seismic code of Greece the value of the design acceleration for all sites, corresponding to a mean return period of 476 years, is 0.24g.

		RESULTS BASED ON PROBABILISTIC HAZARD ANALYSIS			RESULTS BASED ON MACROSEISMIC INTENSITIES		
	Site Name	Mean Return Period			Mean Return Period		
		476	1000	2000	476	1000	2000
1	CHANIA	240	281	320	380	481	601
2	SKLOPA	240	281	320	-	-	-
3	RETHIMNO	261	307	351	344	437	545
4	HERAKLEIO	329	392	454	344	437	545
5	AG. NIKOLAOS	368	437	508	261	331	413
6	ITANOS	333	392.	454	316	401	500

4.5.6.4. Discussion and implications on T/C networks

Experience from recent earthquakes revealed that, except for typical engineering structures, telecommunication infrastructures are also vulnerable to seismic ground motions, even in cases of medium magnitude earthquakes, as was the case of the 1999, M=5.9 Athens earthquake.

Estimation of seismic ground acceleration at selected locations in Crete island, which are critical for the telecommunication system of the island, exhibited higher acceleration values compared to those adopted to the Seismic Hazard Map for typical structures and for mean return period of 476 years or equivalently 10% probability of exceedence in 50 years. Considering the importance of these systems to their key role during the post earthquake period of strong disastrous events, lower probability of exceedence must be considered resulting in higher mean return periods and more safe design values. This implies the demand for site-specific hazard analysis for the design of telecommunication infrastructures.

Besides the fact that parameters for design of critical earthquake-resistant infrastructures are obviously underestimated soil and topography effects may further amplify ground motion locally. High flexible structures for telecommunication and other utilities, usually located at the top of hills or ridges or at steep slopes, are at great risk because seismic motion is substantially amplified at such sites (Gazetas et al., 2002, Assimaki et al., 2005) and even permanent ground deformations, such as landsliding are expected.

4.5.6.5. Acknowledgments

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4.5.6.6. References

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