A few days after the strong, \(M_{6.9}\) Kythira earthquake of January 8, 2006 a team from the research staff of ITSAK visited the island of Kythira, where the effects of the mainshock were more strongly felt, in order to assess geotechnical and structural damage caused by the earthquake. The present report is based on material collected by the research team, as well as by various other sources, and was compiled by the following ITSAK researchers: Ch. Karakostas, T. Makarios, V. Lekidis, T. Salonikios, and S. Sous, structural engineers; K. Makra, A. Anastasiadis, and N. Klimis, geotechnical engineers; P. Dimitriou, B. Margaris, Ch. Papaioannou and N. Theodulidis, engineering seismologists; A. Savvaidis, geophysist.

INTRODUCTION

On January 8, 2006 at 13:34 local time (11:34 GMT) a strong earthquake of magnitude \(M_{6.9}\), occurred in Southern Aegean Sea close to the island of Kythira in Greece. The epicenter coordinates were 36.16\(^\circ\) N and 23.36\(^\circ\) E and the focal depth 66 km. The earthquake was strongly felt in an extensive part of Greece as well as in Southern Italy, Egypt, Cyprus, Turkey, Israel, Lebanon, Syria and Jordan. Several instruments (accelerometers) of the Greek National Network and Special Accelerometer Arrays operated by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) recorded the ground motions due to the Kythira event. Recordings at stations in the broader epicentral areas were collected through the telecommunication facilities of the Network, and data processing of the strong motion (peak ground accelerations, strong motion duration, response spectra) was carried out a few hours after the event by the Engineering Seismology Division ITSAK. A research team of engineers visited the island of Kythira a few days later in order to assess geotechnical and structural damage due to the mainshock. Since the main event was an intermediate depth earthquake, the post-event seismic sequence was minor, and the installation of a temporary accelerometer array in the area was not deemed necessary.

Due to the intermediate depth of the main event, the PGA recorded at the accelerometer installed at the village of Potamos in Kythira, was rather small \((a_g = 0.12g)\), despite the considerable magnitude of the earthquake. Damage of geotechnical nature was not extensive, and mostly occurred in the village of Mitata, where a road was out of use due to landslides. Damage to structures was limited almost exclusively to stone masonry buildings and churches, while R/C buildings did not suffer any significant structural damage, due to the
rather small PGA of the earthquake. The Greek Seismic Code (EAK2003) prescribes for new buildings in the island of Kythira a design acceleration of $a_g=0.24g$. As in the case of geotechnical failures, damage to buildings was particularly high in the village of Mitata, with local soil conditions seemingly having played an important role. A preliminary damage reconnaissance report regarding the island of Kythira, was also compiled for use by the Hellenic Ministry of Environment, Physical Planning and Public Works (ITSAK 2006).

1. SEISMOLOGICAL, MACROSEISMIC-INTENSITY AND STRONG MOTION DATA

1.1 Seismological Data.

The broadband recordings of the earthquake that occurred on January 8, 2006 at 11:34 GMT near island of Kythira reveal that a smaller rupture preceded the main rupture by 3 sec, and that the earthquake had a focal depth of 66 km (USGS, http://earthquake.usgs.gov/eqinthenews/2006/ushrak). Harvard University (HRV) and USGS assigned to this event a moment magnitude $M_W$ varying from 6.7 to 6.8.

The earthquake source volume belongs to the Hellenic Arc’s western section, which is one of the most active regions of the Eurasia-Africa collision belt. This part of the Eastern-Mediterranean lithosphere accounts for over 60% of the seismic-energy release in Europe, reflecting its high deformation rate. This deformation can lead to earthquakes as large as $M_W8.3$ (Papazachos, 1990, 1996) and is the result of the subduction of the Eastern Mediterranean lithosphere under the Aegean along the Hellenic Arc (Papazachos and Delibasis, 1969; Papazachos and Comninakis, 1971) as well as of the west-bound movement of the Anatolian plate along the North Anatolian fault (McKenzie, 1972).

On the map of Figure 1.1 the Kythira earthquake epicenter, as determined by the Geodynamic Institute of the National Observatory of Athens (NOA) and the Geophysical Laboratory of the Aristotle University of Thessaloniki (AUTH), and the seismic activity of the period 08.01.2006-12.01.2006, as provided by AUTH (www.gein.noa.gr), are presented. In the same figure the focal mechanism (an average of the solutions proposed by HRV, USGS, KOERI, AUTH, NOA, INGV and ETH) and the Kythira seismic fault, as given by Papazachos and Papazachou (2003) are shown. It is seen that the recent seismic activity can be associated with the Kythira fault, which during the 20th century generated five strong earthquakes (1903: $M_7.5$, 1910: $M_7.0$, 1926: $M_7.2$, 1937: $M_6.0$ and 1932: $M_6.3$).
Macroseismic-Intensity Data. The earthquake of January 8, 2006 affected more severely the island of Kythira and the Chania (Crete) prefecture. We combined intensity data provided by USGS with data obtained by processing a significant amount of information – including media reports – regarding damage caused by the Kythira earthquake to compile the (preliminary) macroseismic-intensity map shown in Figure 1.2. This map shows that locations in southern Italy, Sicily and Malta appear to have experienced shaking intensities comparable to those observed much closer to the epicenter. The earthquake was felt as far as inland northern Africa and Amman (Jordan). The geographic distribution of macroseismic intensities presented in Figure 1.2 is typical for intermediate-depth earthquakes in the southern Aegean (Papazachos and Comninakis, 1971; Papazachos et al., 1982; Tassos, 1984). Moreover, the distribution of earthquake-induced effects on the built environment and – to a lesser degree – to the natural environment bears significant similarities with that due to the M7.5 earthquake that occurred in the same area in 1903 (ESTIA newspaper; Papazachos and Papazachou, 2003).
Figure 1.2. Preliminary geographic distribution of macroseismic intensities of the 2006 Kythira earthquake (see text for details).

Strong-Motion Data. Instruments of the National and Special Accelerometer Networks operated by ITSAK recorded ground motions due to the Kythira event (Figure 1.3). In Table 1.1 we present relevant information regarding those instruments that recorded the earthquake (denoted by red symbols in Figure 1.3).

Figure 1.3. Geographic distribution of instruments of the National and Special Networks operated by ITSAK. Red symbols denote those sites that recorded the Kythira earthquake of 8 January 2006 (epicenter denoted by green star).
Table 1.1. Information regarding instruments, sites and recordings of the Kythira earthquake of January 8, 2006.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SITE CODE</th>
<th>INSTRUMENT TYPE / RESOLUTION</th>
<th>INSTALLATION SITE</th>
<th>OWNER</th>
<th>PGA (mg)</th>
<th>EPICENTRAL DISTANCE (KM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag. Nikolaos</td>
<td>ANS1</td>
<td>QDR ~11bits</td>
<td>Elementary school Ground level</td>
<td>ITSAK</td>
<td>130</td>
<td>42</td>
</tr>
<tr>
<td>Potamos (Kythira)</td>
<td>KYT1</td>
<td>ETNA 18bits</td>
<td>OTE Ground level</td>
<td>ITSAK</td>
<td>120</td>
<td>33</td>
</tr>
<tr>
<td>Heraklion (Crete)</td>
<td>HER1</td>
<td>QDR ~11bits</td>
<td>TEI Heraklion Ground level</td>
<td>ITSAK</td>
<td>50</td>
<td>183</td>
</tr>
<tr>
<td>Chania (Crete)</td>
<td>CHN1</td>
<td>QDR ~11bits</td>
<td>Public Building Underground level</td>
<td>ITΣAK</td>
<td>41</td>
<td>93</td>
</tr>
<tr>
<td>Koroni</td>
<td>KRN1</td>
<td>QDR ~11bits</td>
<td>Municipal Library Ground level</td>
<td>ITSAK</td>
<td>24</td>
<td>144</td>
</tr>
<tr>
<td>Chalkis</td>
<td>HAL1</td>
<td>K2 19bits</td>
<td>Free-field</td>
<td>ITSAK</td>
<td>7</td>
<td>255</td>
</tr>
<tr>
<td>Naxos</td>
<td>NAX1</td>
<td>GURALP 24bits</td>
<td>City Hall</td>
<td>ITSAK</td>
<td>3</td>
<td>208</td>
</tr>
<tr>
<td>Kos</td>
<td>KOS1</td>
<td>ETNA 18bits</td>
<td>OTE Ground level</td>
<td>ITΣAK</td>
<td>2</td>
<td>363</td>
</tr>
<tr>
<td>Polimilos</td>
<td>P9A</td>
<td>GEOSIG 22bits</td>
<td>Free-field</td>
<td>EOAE/ ITSAK</td>
<td>1</td>
<td>482</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>THE1</td>
<td>GURALP 24bits</td>
<td>Seismological Station Underground level</td>
<td>ITSAK</td>
<td>0.2</td>
<td>497</td>
</tr>
<tr>
<td>EUROSEISTEST</td>
<td>TST</td>
<td>M.WITNEY 18bits</td>
<td>Free-field Soft soil</td>
<td>ITSAK/ AUTH</td>
<td>1</td>
<td>501</td>
</tr>
<tr>
<td>EUROSEISTEST</td>
<td>STE</td>
<td>ETNA 18bits</td>
<td>Free-field Generic rock</td>
<td>ITSAK/ AUTH</td>
<td>0.5</td>
<td>499</td>
</tr>
</tbody>
</table>

In Figure 1.4 the corrected acceleration traces of the Kythira event of January 8, 2006 with PGA 20mg and higher are shown. Note the long duration of strong motion in the recordings, characteristic of deep- and intermediate-focus events.
**Figure 1.4.** Horizontal components of accelerograms with PGA≥0.02g due to the M 6.9 Kythira earthquake of 8/1/2006.

Figure 1.5 shows a plot of the recorded PGA as a function of the hypocentral distance (squares). The black thick line represents the mean attenuation of PGA for the intermediate depth earthquakes in Greece (Theodulidis and Papazachos, 1990) while the thick red and blue lines stand for the mean attenuation of the intraslab and interface subduction earthquakes proposed by Youngs et al. (1997). The dashed grey lines represent the +/- 1 sigma for the relation of Theodulidis and Papazachos (1990). The data used for this relation was up to 230 km. The sites at distances greater than 200 km are located at the inner part of the Hellenic arc, where the attenuation rate is higher compared to sites located along the arc (Papazachos and Comninakis, 1971; Papazachos and Nolet, 1997).
Figure 1.5. Recorded PGA as a function of hypocentral distance [open diamonds: along-arc site, crossed diamonds: inner-arc site]. Mean ± 1 standard deviation [black solid line, dashed grey lines, respectively] attenuation relation proposed by Theodulidis and Papzachos (1990). Mean attenuation relations proposed by Youngs et al. (1997) [red line: intraslab subduction, blue line: interface subduction].

In Figure 1.6 the pseudoacceleration response spectra (5% damping) of the 2006 Kythira event (M6.9) with those of the 1983 Cefalonia (M7.0) and 1995 Kozani (M6.6) earthquakes are compared. In spite of the fact that the three earthquakes had comparative magnitudes and that the traces were recorded at similar epicentral distances, the Cefalonia and Kozani response spectra significantly differ from the Kythira ones. Thus the higher spectral-value region of the Kythira spectra, occurring in the 0.4 – 0.8 sec period range, is shifted toward larger natural periods in comparison with the Cefalonia and Kozani spectra (0.1 – 0.5 sec period range). The crucial difference of the latter two events from the Kythira records is their shallow focal depth: < 20 km compared with 66 km. It is known that, along with focal mechanism, focal depth is the critical parameter affecting the spectral content of ground motion.
Figure 1.6. Comparison of pseudoacceleration response spectra (5% damping) of the 8/1/2006 Kythira (M 6.9) event (Kythira and Ag. Nikolaos sites) with those of the 23/1/1983 Cefalonia (M 7.0) and 6/5/1995 Kozani (M 6.6) shallow events (Argostoli and Kozani sites, respectively). The continuous and dashed lines correspond to the longitudinal and transverse components, respectively.

The Kythira earthquake of 8/1/2006 is one of the very few strong intermediate-depth earthquakes in Greece that provided strong-motion recordings. Due to their specific characteristics, time histories and response spectra from intermediate- and deep-focus earthquakes in Greece are of particular interest to the engineering community and should be taken into account in future seismic code revisions.
2. GEOTECHNICAL IMPACTS

2.1 GEOLOGICAL – GEOTECHNICAL INFORMATION FOR KYTHIRA ISLAND

The pre-neogene geological formations within the Kythira strait belong to several major units of the external Hellenides zones (Lyberis et al., 1982). The metamorphic formations, exposed in the northern portion of the island consist of gneiss, schists, and phyllites, which belong either to the Ionian zone or more likely to the Phyllite series. In the central and southern part of the island the wide pre-neogene outcrops belong to the Gavrovo-Tripolitsa and Pindos nappes (Theodoropoulos, 1973).

Using existing geological (mainly) information, the site at Potamos (Kythira) where the strong motion station is installed could be categorized as soil class A according to the Greek Seismic Code (EAK, 2000). Soil class A refers to: a) rock or weathered rock formations extended in area and in depth, provided that they are not highly weathered b) layers of dense granular materials with small percentage of silty-clayey mixtures, of thickness less than 70m and c) layers of very hard, overconsolidated clay, of thickness less than 70m.

According to a sampling borehole drilled in the past, on the local roadway Mitata-Viaradika, at the foot of B1 landslide (figure 2.1), the following soil layers are met (from top to bottom): a) surficial soil layer of 1m thickness consisting of artificial fills, b) a soft layer of brown to brown-yellow sandy clay with gravels of 5m thickness ($N_{SPT} = 6$), c) 11m of brown, very stiff to hard sandy clay ($N_{SPT} = 60$), with an intermediate layer of 0.8m consisting of slightly weathered sandstone, d) 4m of dark brown, hard clay ($N_{SPT} = 50/9$). The deepest layer that is met till the end of the borehole (22m) is grey - green sandy clay with gravels. The underground water table has been measured at a depth of 4.5 – 5.0m.

It can, thus, be concluded that at the broader area of Mitata village, the subsoil profile could be classified as a soil class A and / or B, according to the soil categorization of the Greek Seismic Code. Class B refers to: a) very weathered rocks or soils that from mechanical point of view can be characterized as granural materials, b) layers of medium density granular materials of thickness greater than 5m or high density granular materials of thickness exceeding 70m and c) layers of hard overconsolidated clay of thickness exceeding 70m.
Figure 2.1. Map of the Kythira Island with damage related to soil or rock behavior for the earthquake of 08/01/2006. Blue circle (A1) denotes damage to port or marine structures, red circles (B1-B8) stand for sites where landslides / rockfalls and damages along the road network were observed, whereas green circle (C1 denotes site where problems related to lifelines systems were reported.
2.2 DAMAGE AND IMPACTS OF GEOTECHNICAL CHARACTER

The 08/01/2006 earthquake caused local damages mainly to natural or cut slopes and embankments as a result of a combination of ground motion characteristics with the soil stratigraphy and topographic relief of the area. Damages or failures of geotechnical interest are shown in Figure 2.1.

A. Damage to port facilities

Damages related to port facilities are concentrated at Diakofti village (figure 2.1 - A1), which is the main port of the island. Enlargement of an already existing crack at the dock (approximately 7cm of width after the earthquake) and new cracks were observed as a result of differential movements or settlements at the base of the dock.

B. Landslides and rockfalls

Landslides, rockfalls and rock slidings were detected on natural slopes at sites B1-B8 (Figure 2.1), which resulted in cutting off parts of the road network and caused significant damage (fractures) of the road surface, and in some cases, local failure of road embankments. The largest landslides and rockfalls took place at Mitata village (B1) and its surroundings (B2). Site B1 is located at the main square of Mitata village. Plan and side view of this natural slope landslide is shown in Photo 2.1. Rockfalls at site B2 are shown in Photo 2.2a and nearby failure of the road embankment (B3 - photo 2.2b). Both of them (B1 and B2) resulted in cutting off the road connecting the villages of Mitata and Viaradika. Cracks and fractures on the road surface (B4) were also observed on the same road at the Sklavianika neighborhood of the village of Mitata. At other places of Kythira island, rockfalls (B5) were observed on the road network between Livadi and the Agia Ellessa Monastery, which caused limited local failure of road surface. Failures of road embankments were also reported at other sites of the road network of the island (B6 to B8, Figure 2.1).

C. Damage to lifeline systems

Just after the earthquake of January 8, 2006, problems were reported at the water supply network of the Mitata village (C1 – Figure 2.1). These problems were of local character and had to do with discontinuations in the water supply. No waste water system is available in the island. No problems were reported either at the power supply network or at the telecommunication network.
Photo 2.1 (a) Plan and (b) side view of the natural slope landslide (B1) at the main square of Mitata village

Photo 2.2. (a) Rockfalls at site B2 (near Mitata village) and (b) nearby failure of the road embankment
3. SEISMIC RESPONSE OF STRUCTURES

3.1. BUILDING TYPES IN THE BROADER AREA OF KYPHIRA ISLAND

Buildings in Kythira island can be classified in four broad categories, according to their load bearing system:

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DESCRIPTION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>One- or two story stone masonry buildings</td>
<td>Buildings with load bearing system of stone masonry with mortar of weak lime (and rarely cement or clay). Many of them old and/or in a poor condition. Only a small number of them incorporate some empirical, but in general insufficient, lateral load bearing systems.</td>
</tr>
<tr>
<td>B</td>
<td>Reinforced concrete buildings</td>
<td>Houses, office and hotel buildings, up to three stories high. Load bearing system with cast-in-place reinforced concrete. Walls with hollow bricks used as infill. The majority built according to pre-1992, old Greek Seismic Codes.</td>
</tr>
<tr>
<td>C</td>
<td>Byzantine and later-era monuments</td>
<td>Buildings of architectural heritage, with no special seismic provisions. Mostly churches and some castles, built with no special seismic provisions.</td>
</tr>
<tr>
<td>D</td>
<td>Bridges</td>
<td>Reinforced concrete and stone masonry bridges</td>
</tr>
</tbody>
</table>

According to the 2001 National survey, 4518 buildings exist in the island of Kythira. Of them, 2852 (63.12%), all of stone masonry, were built before the issue of the first Greek Seismic Code in 1959, 962 (21.29%) were built according to the 1959 Code, 439 (9.72%) according to the 1984 Seismic Code revision and only the remaining 265 (5.87%) were built according to the modern (post-1992) Seismic Codes. A detailed description of the Greek Seismic Codes follows.

3.2 STRONG GROUND MOTION COMPARED TO SEISMIC CODE PROVISIONS

The first Greek Seismic Code was issued in 1959 (AK59), and was revised in 1984 (AK84). A major new revision took place in 1992 (EAK1992), and upgraded versions were published in 2000 and 2003. Until 1992, design was based on maximum allowable stresses, and thereafter on ultimate strength.

For Kythira, the base shear seismic design coefficient, according to the 1959 Greek Seismic Code was \( \varepsilon = 0.06, 0.08 \) and 0.12, for firm, medium and soft soils, respectively.
This coefficient was constant, independent of the building’s period and applied uniformly to all buildings. Since the 1959 Code was based on the allowable-stress design method, the coefficient is modified to correspond to ultimate strength design, leading to values of $\varepsilon' = 0.10, 0.14$ and $0.21$ (Anagnostopoulos et al., 1987).

Seismic codes from 1992 and onwards, prescribe for Kythira a ground acceleration coefficient of $a_g = 0.24$ and typical design spectra (with a spectral magnification factor $\beta_0 = 2.5$). In Figure 3.1, the response spectra of the Kythira mainshock are compared with the elastic design spectra of the new seismic code (EAK) provisions (for different soil types). In the same figure, the pre-1992 provisions (AK) are also plotted.

![Response Spectrum - kyt10602 - Kythira (ζ=5%)](image)

**Figure 3.1** Elastic response spectra of the Kythira mainshock ($\zeta = 5\%$), recorded in the island of Kythira in comparison with the elastic design spectra of the old (AK) and recent (EAK2000) Greek seismic codes, for different soil categories.

It is obvious that the seismic provisions of the post-1992 Codes prescribe seismic design actions greater than those imposed by the 8/1/06 mainshock, irrespective of period and soil type. Older buildings, constructed before 1959 with no code provisions, or according to the 1959 and 1984 Seismic Codes, are in general low-rise (up to 2 floors), and the majority are of stone masonry. These buildings generally present a low fundamental period ($T<0.15$ sec), and were not heavily stressed, due to the particular shape of the response spectrum of the mainshock. The ductility demands imposed by this particular earthquake on buildings in this
specific period range were not too high (in general less than 2.0), thus explaining the very limited damage observed in R/C buildings. The majority of damaged buildings were of stone masonry, and, as expected, damage was higher in older buildings, with poor quality of materials and many of them already in poor condition even before the earthquake. Damage was also observed in Byzantine and later-era churches and bell towers, which, due to their morphology, are expected to present a higher fundamental period (in the range of 0.20 to 0.50 sec), and were thus more affected by this particular event.

With the exception of cases in which local soil conditions seem to have played an important role (e.g. in the village of Mitata), the majority of the building stock of the island presented a rather satisfactory seismic response. This fact proves once more a conclusion also reached in previous earthquake events, i.e. that existing buildings possess a substantial amount of strength reserves (depending mainly on their redundancy and the overstrength of individual structural members) as well as possible additional energy dissipation mechanisms, which contribute to a significant increase of their behavior factor (Lekidis et al., 1999, Karakostas et al., 2005).

3.3 DAMAGE IN THE MEISOSEISMAL AREA

The majority of damage to buildings and churches due to the 8/1/2006 mainshock was observed in the island of Kythira. Lesser damage was reported in the nearby island of Antikythera, as well as in the prefectures of Lakonia in Peloponnese and Chania in the island of Crete. Even in the island of Kythira, damage to buildings was limited, due to the reasons discussed in the previous section. From inspections of buildings in Kythira, which were performed after petitions to the local authorities, 169 were characterized as “yellow” and 53 as “red” (respectively, 3.6% and 1.2% of the total building stock of the island). The rest of the inspected buildings were classified as “green”. In the island of Antikythera, only two buildings were classified as “yellow”. The color classification refers to the degree of damage and denotes:

“Green”: Original seismic capacity has not been decreased, the buildings are immediately usable and entry is unlimited.

“Yellow”: Buildings in this category have decreased seismic capacity and should be repaired. Usage is not permitted on a continuous base.
“Red”: Buildings in this category are unsafe and entry is prohibited. Decision for demolition or repair will be made on the basis of more thorough inspections.

3.4 Damage to Buildings According to Their Structural System

As already mentioned, despite the M6.9 magnitude of the mainshock, the recorded strong motion at Kythira was rather small (max horizontal PGA=0.12g), due to the 66 km focal depth. This fact, in combination with other factors discussed in § 3.2 led to limited damage to buildings in the island.

Traditional stone masonry buildings (category A) have usually up to two (and very seldom three) stories and constitute a large percentage of the building stock in Kythira island. Observed damage to such buildings (mainly cracks and partial collapse of stone walls) should be attributed to lack of sufficient seismic resistance, as well as to their already poor condition (old age, inadequate maintenance) before the main event. Damage to stone masonry buildings was especially high in the village of Mitata, and in particular in the neighborhood of Skavianika (Photo 3.1). The local soil conditions at the site, in combination with the age and poor condition of many buildings, must have played an important role for the damage observed.

![Photo 3.1 Village of Mitata: (a) Collapse and (b) extensive damage of masonry buildings](image)
Reinforced concrete buildings (category B) in Kythira have in general up to three stories and constitute a small percentage of the building stock. No damage to R/C load bearing systems has been reported, and only in few cases small cracking of the brick infill walls has been observed. As already discussed in § 3.2, the ductility demands of the mainshock for buildings of this type and height were low, thus explaining the lack of damage.

Of the Byzantine and later era monuments (category C) of the island, churches suffered the most serious damage. Many churches are built with stone masonry walls and cracks were observed in several them, as well as in masonry arches and domes that constitute parts of the structural system. Partial or more severe damage was also observed in several bell towers, which in many cases is due to height and stiffness difference with the main church building to which they were attached. The more serious damage to its structural system witnessed the church of Agia Triada in the village of Mitata, built around 1909 (Photo 3.2). The two western bell towers suffered very serious damage, and extensive cracking was observed in the external walls, as well as in almost every interior arch and dome that consist its structural system, rendering the possibility and feasibility of repair a questionable issue. Due to its dimensions, the fundamental period of the church is expected to be within the $T=0.20\div0.50$ sec range, for which the spectral accelerations of the mainshock reach their maximum values. In the 12th century Agios Andreas church in the village of Livadi (Photo 3.3), the earthquake aggravated several cracks that already existed due to settlement of its foundations, and a detailed evaluation of its structural stability is necessary. Less important damage was also observed in several other churches throughout the island, namely in : Agios Georgios in the village of Mitata (Photo 3.4), Panagia Mirtidiotissa in the village of Mirtidia, Agioi Anargyroi in the village of Potamos (Photo 3.5), Osios Theodoros near the village of Potamos and Timiou Prodromou near the village of Gerakari.

The Venetian castle in the town of Kythira, namesake capital of the island, suffered no damage to its exterior walls. No mentionable damage was also reported for the various churches and other masonry buildings in its enclosure.

No damage was reported for the various bridges in the island (category D), several of which have a structural system of stone masonry arches while the rest are made of reinforced concrete.
Photo 3.2 Village of Mitata: Extensive damage to structural system of the church of Agia Triada
(a) SW view and (b) cracking of domes and arches

Photo 3.3 Village of Livadi, church of Agos Andreas: (a) Southern view and (b) cracking of arches
Photo 3.4 Village of Mitata, church of Agios Georgios: (a) Cracking of exterior walls and (b) tensile failure of steel rod used for bracing.

Photo 3.5 Village of Potamos, church of Agioi Anargyroi: (a) Cracking of eastern niche and (b) damage to bell tower.
4. CONCLUSIONS

The Kythira earthquake of 8/1/2006 is the first intermediate depth event in Greece, which was recorded by accelerometers. The enriched response spectrum of the earthquake in the intermediate period range \( T = 0.4 \pm 0.8 \) sec differs from that of the majority of Greek earthquakes, which typically present spectral peaks in lower (i.e. around \( T \approx 0.2 \) sec) periods. Additional future recordings of intermediate depth strong motions are expected to yield valuable information on how events of such type affect the build environment and accordingly to be taken into account in future seismic code revisions.

Geotechnical damage in the island of Kythira was rather limited, with the most serious case being the landslide of a natural slope in the village of Mitata, which resulted in the destruction of a road beneath.

Damage to structures was not extensive, and limited mainly to stone masonry buildings and churches, despite the magnitude of the main event and the age of the building stock in the island. The lack of extensive damage to structures can be attributed to the following reasons:

1. Due to the 66 km focal depth and the respective hypocentral distance, the PGA in the island of Kythira was rather low, despite the earthquake’s magnitude (max horizontal PGA \( 0.12 \)g).
2. Buildings in Kythira have in their majority a low fundamental period (\( T < 0.15 \)sec), away from the period range where the response spectrum presents its peak values, resulting in rather reduced seismic forces.
3. Damage observed in stone masonry buildings can in many cases be attributed to age, material quality and already poor condition of such buildings.
4. Local soil conditions and soil relief must have played an important role for the rather extensive damage observed in the village of Mitata. In other habitation areas of the island, with buildings of statistically similar quality, damage was noticeably less severe.
5. Existing buildings possess a substantial amount of strength reserves (depending mainly on their redundancy and the overstrength of individual structural members) as well as possible additional energy dissipation mechanisms, which contribute to a significant increase of their behavior factor.

ACKNOWLEDGMENTS

The contribution of the technical staff of ITSAK to the network readiness should be acknowledged. Special thanks are also due to the local authorities and the people of the island of Kythira for their support.

REFERENCES


