Dec. 2011, Volume 5, No. 12 (Serial No. 49), pp. 1065–1090
Journal of Civil Engineering and Architecture, ISSN 1934-7359, USA

Consequences on the Urban Environment in Greece Related to the Recent Intense Earthquake Activity

George C. Manos

Laboratory of Strength of Materials and Structures, Department of Civil Engineering, Aristotle University, Thessaloniki, Greece

Abstract: Past earthquake disasters in Greece, during the last thirty years, demonstrate that the severity of destruction is not only due to the intensity of the seismic event but also to the urbanization of the affected region and the vulnerability of certain types of buildings. Considerable damage was sustained by both old unreinforced masonry structures as well as by relatively new multistory reinforced concrete structures with “soft story” at their ground floor level. The most important observations made during six past earthquake disasters are presented in a summary form and discussed. The most remarkable case of extensive structural damage was caused from the resent Athens 1999 earthquake. The consequent discussion focuses on the following issues: (1) Classification of structural damage and their underlying causes. (2) Repair and strengthening of damaged structures. (3) Upgrade the seismic design. (4) Plans for earthquake preparedness. (5) Assessing the vulnerability of certain type of structures (schools, hospitals, public buildings etc). (6) Education specialized in earthquake engineering. (7) The enrichment of the strong motion data base.

Key words: Earthquake damage, R/C multistory buildings, cultural heritage, masonry infill, soft story.

1. Introduction

During the last thirty years various parts of Greece have been subjected to a number of damaging earthquakes ranging from Ms = 5.2 to Ms = 7.2 on the Richter scale (Table 1 and [1, 2, 17, 31, 37, 38, 41, 46, 49]). Some of these earthquakes, not necessarily the most intense, occurred near urban areas and thus subjected various types of structures to significant earthquake forces leading to damage. In this sense, the most destructive earthquakes are the Thessaloniki 1978, Kalamata 1986, Pyrgos 1993, Kozani and Egio 1995, and Athens 1999. For some of these earthquakes, ground motion acceleration recordings were obtained at distances relatively close to the area of intense shaking, thus providing valuable information for correlating the observed damage with this ground motion recording and its characteristics. Moreover, following the most damaging of these earthquakes, studies were initiated that led to the revision of the provisions of the Greek Seismic Code. The most important of these revisions took place in 1984 and 1992. The beneficial impact resulting from these seismic code revisions are validated by the observations during the Athens 1999 earthquake where all of the severely damaged and collapsed structures were built prior to 1981. On the contrary, structures that were designed and built according to the provisions of the 1992 New Greek Seismic Code, albeit less numerous, did not sustain any significant structural damage although they were also located at the epicentral area close to heavily damaged or collapsed structures.

The effect of the New Greek Seismic Code [40, 42] will become more pronounced in the future as structures designed and constructed according to this code will gradually become a relative large percentage of the total building stock on a national level. Consequently, the main problem at hand will be the earthquake performance of buildings designed prior to the date that the New Greek Seismic Code became effective.

Corresponding author: George C. Manos, professor, research fields: structural engineering, earthquake engineering. E-mail: gcmanos@civil.auth.gr.

Table 1 Significant earthquakes in Greece during the last three decades.

Earthquake	Location of Accelerograph	Distance (km) of Recording from epicenter	Recorded PGA cm/sec^2 corrected values	Time of EQ	Magn. (Ms)	Remarks
Volvi Thessaloniki 1978	Thessaloniki (City Hotel)	27.5	Long 139.6 Vert 133.1 Trans 151.5	20/6/78	6.4	48 Deaths 2% BuildingsDestroyed 26% Buildings Damaged
Magnesia 1980	**	**	**	9/7/80	6.5	13% Buildings Destroyed 26% Buildings Damaged
Alkyonides Athens 1981	Athens (Telecommunica-tion Building)	20	Long 284.5 Vert 98.1 Trans 235.4	24/2/81	6.7	20 Deaths 1% Buildings destroyed 9% Buildings Damaged
Lesbos 1981	**	**	**	19/12/81	7.2	10% Buildings Destroyed 65% Buildings Damaged in Ippio and Pamphyla villages
Cephalonia 1983	Cephalonia	20	Long 175.7 Vert 77.5 Trans 147.0	17/1/83	7.0	15% Buildings Destroyed and 50% Buildings Damaged in Sklavena village
Kalamata 1986	Kalamata (Prefecture Building)	7	Long 235.3 Vert 178.4 Trans 268.0	13/9/86	6.2	20 Deaths 20% Buildings Destroyed 52% Buildings Damaged
Killini 1988	Zakynthos (Telecommunica-tion Building)	16	Long 127.5 Vert 88.3 Trans 157.0	16/10/88	6.0	6% Buildings Destroyed 20% Buildings Damaged
Griva 1990	Edessa (Prefecture Building)	31	Long 98.1 Vert 39.2 Trans 98.1	21/12/90	5.9	1 Death 3% Buildings Destroyed 18% Buildings Damaged
Pyrgos 1993	Pyrgos (Agricultural Bank Building)	5	Long 143.8 Vert 122.2 Trans 437.0	26/3/93	5.2	1 Death 20% Buildings Destroyed 23% Buildings Damaged
Patras 1993	Patra (National Bank / Ag. Dimitrios)	5	Long 139. / 138. Vert 47. / 119. Trans 168./ 386.	14/7/93	5.4	4% buildings Destroyed 5% buildings Damaged
Kozani 1995	Kozani (Prefecture building)	20	Long 206.0 Vert 78.5 Trans 147.0	13/5/95	6.6	More than 50% of the houses destroyed or damaged in many villages. In Kozani 10% buildings damaged
Egio 1995	Egio (Telecommunica-tion Building)	14.5	Long 490.5 Vert 196.0 Trans 530.0	15/6/95	6.1	26 deaths 15% Buildings Destroyed 20% Buildings Damaged
Athens 1999	KEDE Pireos Str.	16.0	Long 258.6 Vert 153.7 Trans 297.2	07/09/99	5.9	140 deaths 10% of buildings destroyed in Adames, Aharnes, Ano Liosia 25% of buildings Damaged Epicentral Population 5% of Metropolitan Athens

2. Description of the Most Important Observations

2.1 The Thessaloniki Earthquake of 20th June 1978

The most important observations and lessons from this earthquake disaster (Fig. 1 and [7, 22, 35, 36, 43]) are listed below in a summary form.

- The epicentral region of numerous villages was devastated. The damage was amplified by the surface appearance of ground faulting combined with large deformations of the soil layers at the surface. Most of the structures in these villages were non-engineered low-resistance unreinforced masonry or old reinforced concrete (R/C) low-rise (two-story) buildings.
- The mainly affected urban center was the Thessaloniki Metropolitan area with one million

inhabitants (25 km from the epicenter). It included a large number of relatively newly constructed R/C multi-story apartment blocks up to 9 stories high, being designed according to the provisions of a seismic code dated from 1959. An 8-story R/C apartment building collapsed in the city center (Fig. 2a). The death toll in the city was mainly due to this collapse. Factors contributing to the collapse of this building as well as to the structural damage of similar buildings are the badly designed structural system for resisting earthquake forces together with the non-ductile nature of its R/C members and the considerable eccentricities between the center of mass and the center of stiffness. In addition, the observed serious structural damage can be attributed to the poor foundation of such structures built on the underground remains of the ancient city by means of spread footings. The pounding effects from attached buildings and the amplification of the strong motion that was caused by the soft soil conditions, as demonstrated by acceleration recordings during the aftershock activity, were also significant contributors. The detrimental influence of a "soft story" at the ground floor was not recognized at the time and it continued as an architectural feature, being used either as a shop or as a parking lot, for many buildings and for many years to come (Fig. 2b).

- The temporary shoring of damaged structures was applied successfully and proved effective as no other major collapse occurred, despite the fact that a strong aftershock subjected the already damaged structures to strong ground motions 15 days after the main shock.
- The repair and strengthening of damaged structural members, mostly in the "soft" ground floor, employing epoxy resins and R/C jacketing techniques were used extensively. Many engineers became familiar with those techniques, an experience that was to prove very beneficial in future earthquake disasters in Greece.
- Several hospitals and schools were in need of varying degrees of urgent repair. Thus, repair techniques, such as jacketing for the R/C elements, were urgently put into practice both for schools, hospitals and for many other state-owned buildings. Shot-crete jacketing was employed in some cases as a repair technique for the damaged structures. The construction of new structures for hospitals or schools took from three to six years. The nearby large industrial facilities, such as petrochemical plants, steel works, wheat and tobacco processing factories etc. did not exhibit any distinct major failure and they soon reported operational.
- The most demanding projects were those of the cultural heritage structures (Figs. 3a, 3b and 4a), mainly churches as well as relatively old state owned masonry buildings. For a small number of such structures, external or internal jacketing was permissible. Such a case was the 80-year-old cathedral church of Thessaloniki (St. Grigorios Palamas, Fig. 4b). For the much older Byzantine churches in Thessaloniki and the surrounding area such "drastic" intervention with irreversible repair and strengthening solutions was deemed unacceptable. The intervention-repair effort for most of these cases took a long time. These monumental structures, some of them more than 1500 years old, have interior features (e.g., mosaic) attached

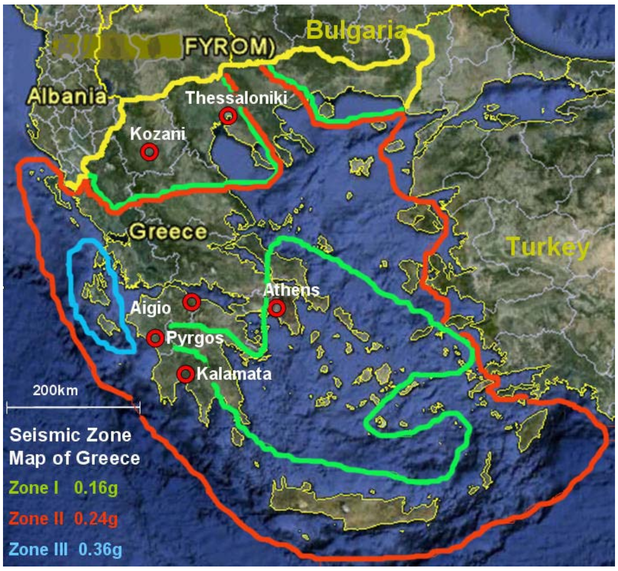
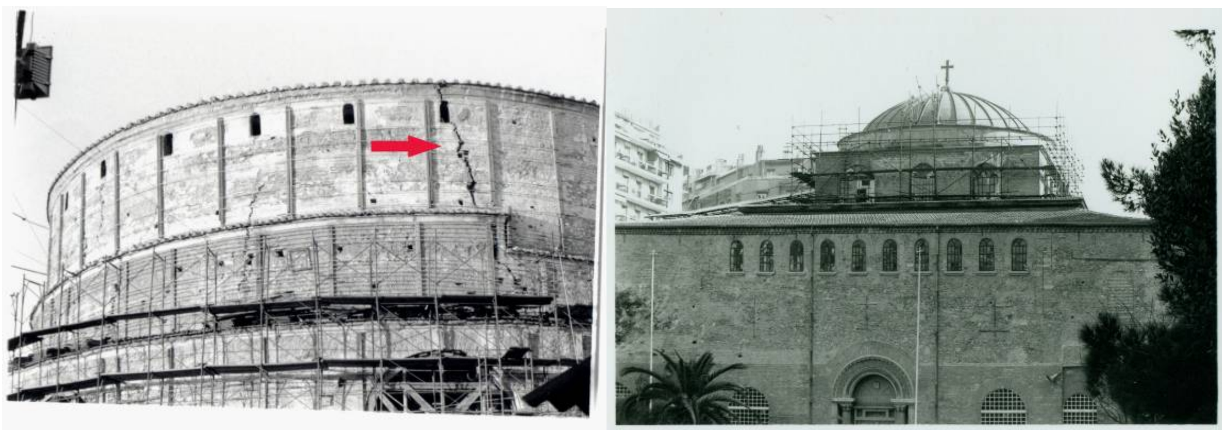


Fig. 1 The location of the six most damaged urban areas of Greece form the earthquake activity during the last thirty years together with the seismic zoning map (see also Tables 1 and 5).

(a) (b)

Fig. 2 (a) The remains of the collapsed building together with the damaged adjacent structure; (b) Damaged column at the ground "soft story" floor.



(a) (b)

Fig. 3 (a) The St. Sophia old Byzantine church at the city center; (b) The Rotunda's damaged cylindrical dome.

(a) (b)

Fig. 4 (a) The St. Panteleimon old Byzantine church at the city center with the scaffolding for temporary support during the repairs; (b) The damaged Cathedral (St. Gregorios Palamas).

to their structural components. In addition, these monumental structures had accumulated such long-term detrimental influences from other factors that the earthquake forces amplified and brought into the foreground (such as man-made damaging interventions or alterations of the past, damages from long term atmospheric influences, foundation settlements etc.) that the effort of intervention in most cases took the shape of an in-depth archaeological study. The great benefit from these projects, despite the long delays, was that a volume of extremely valuable information was gained for such monumental structures utilized in their repair and strengthening effort.

2.2. The Kalamata Earthquake of 13th September, 1986

This earthquake, of magnitude 6.2, occurred with an epicentral distance of 9km from the city of Kalamata, with 40,000 inhabitants (Fig. 1 and [3, 4, 10, 16, 19, 51, 53]). The main event was followed two days afterwards by a strong aftershock (Ms =5.4 on the Richter scale) that caused partial or total collapse to structures already damaged by the main shock. The following is a brief presentation of some important observations from this earthquake.

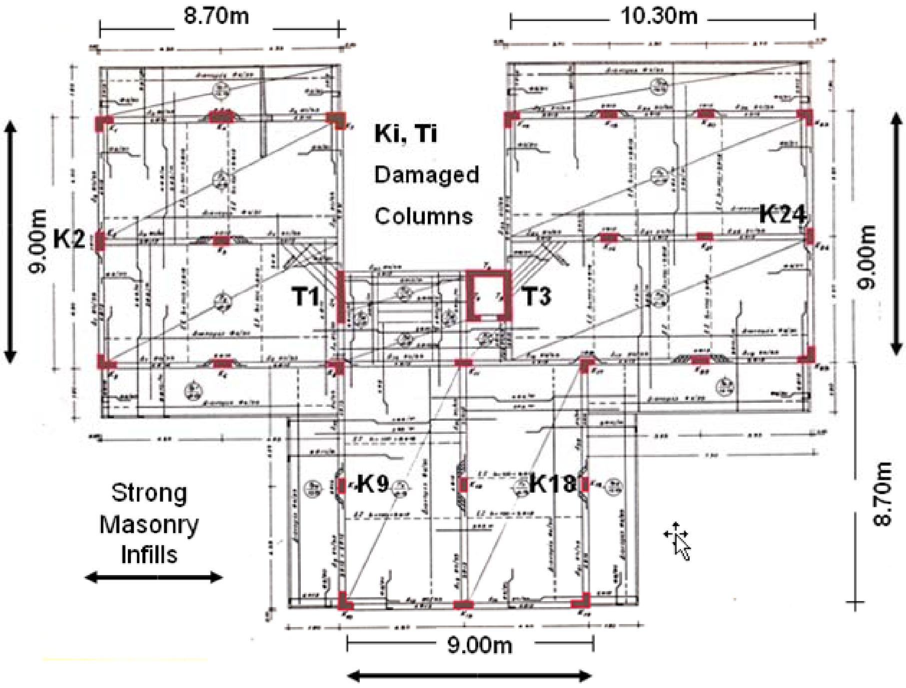
- Very high spectral accelerations were obtained from the processing of the recorded motion (see Tables 1 and 5) reaching a peak of over 1.2 g for 5% damping ratio in the period range of 0.25 to 0.40 seconds, which includes the fundamental frequencies of most of the 4 to 6 story R/C multistory buildings in the city. For such high values of spectral accelerations, exceeding by far any seismic-design provisions, what saved this city from a total catastrophe was the short duration of the strong phase of the ground motion (2.5 seconds).
- Many R/C buildings were seriously damaged and three multi-story apartment buildings collapsed. In almost all damaged multistory buildings the "soft" and usually weak ground floor was heavily damaged, the story immediately above had extensive damage on its masonry infills, while the upper stories were essentially intact.
- The absence of shear walls as well as the fact that in most of these buildings one could not identify a well-defined lateral load resisting system, are worth noting; in this sense the "non-structural" masonry infills served as a first line of defense providing the primary stiffness.
- The shear type of failure was the common pattern of damage in many ground floor columns, indicating shortcomings in the design provisions of the time that did not require checks to ensure flexural ductile behavior. Moreover, in many cases the ground floor became a "soft story" because of the presence of strong masonry infills in the upper floors. The four-story building in Figs. 5a, 5b and 5c is indicative of this type of "soft story" failure.
- Substantial evidence does exist indicating that both soil and source effects have contributed to the non-uniform spatial distribution of damage [19].
- The severely damaged columns (Ki, Ti, Fig. 5a) are shown together with the position of the strong masonry infills in the upper stories (see also Figs. 5b, 5c and 6). A numerical analysis performed by Mpoufides [32, 33], similar to the one presented in section 3, verified the cause of such damage. This structure was constructed as a typical building by the Department of Workers Housing.
- Lifelines, industrial facilities, bridges and other civil engineering works survived this earthquake virtually unaffected. A few examples of damage to a facility were recorded at the city harbor, where the dock wall separated from the infill and gaps up to 10 cm were formed (Fig. 7); in addition, a silo had its wheat unloading machinery dislodged from its supports.
- Experiences gained from previous earthquakes in Thessaloniki, 1978 (see section 2.1) and Athens-Loutraki, 1981 [12] on immediate post-earthquake relief and structure inspection, shoring, repair and strengthening was successfully applied here. Moreover, this earthquake gave a very significant

incentive for the revision of the seismic code as well as for research on earthquake engineering topics with practical consequences.

- New (Fig. 8a) as well as old (Fig. 8b) churches made of unreinforced masonry suffered very heavily.

2.3. The Pyrgos-Elia Earthquake of March 26th, 1993

On March 26th 1993 a Ms = 5.2 magnitude earthquake occurred in the prefecture of Elia in the Southwest of Greece (Fig. 1 and [8, 51]). The epicenter of this earthquake was quite close to the capital of the prefecture, the town of Pyrgos with about 30,000 inhabitants. The expected maximum peak ground acceleration, as specified in the seismic zoning map of Greece (Fig. 1), is 0.24 g (see also Tables 1 and 5). In addition, it must be pointed out that for the seismic source's area near the city of Pyrgos [1, 2], the maximum expected earthquake has a magnitude of Ms = 7.0 and the mean return period for an event with magnitude Ms = 5.2 is 2 years. This earthquake, instead of being looked at as a rare event, should be regarded as a sequence with a rather high probability of occurrence. The buildings in this region sustained considerable damage that is described in a summary form in Table 2.



(a)

(b)

(c)

Fig. 5 (a) Damaged "soft story" in workers building (Kalamata); (b) Damaged "soft story"; (c) Damaged "soft story".

(a) **(b)**

Fig. 6 (a) Damaged column T1, "soft story" workers housing building; (b) Damaged column K2.

Fig. 7 Damage of the dock abutment.

(a)

(b)

(c)

Fig. 8 (a) Collapsed church at the city center; (b) Collapsed old cathedral church at the city center; (c) Collapsed 2nd story of old masonry house.

Table 2 Summary of Damage for the city of Pyrgos and surrounding area (31st March 1993).

Damage category	City of Pyrgos damaged structures No: / %	Surrounding area damaged structures No: / %
I Light non-structural damage (Structure can be used).	3.748 /67.09%	3.288 /49.0%
II Moderate non-structural damage and light structural damage (Structure rendered temporarily out of use).	969 /17.34%	1.791 /26.7%
III Non-structural damage as well as structural damage rendering the structure either out-of use on a long-term basis or to be demolished.	870 /15.57%	1.630 /24.3%
Total	5.587 /100%	6.709 /100%

The following is a summary report of the observed performance of man - made structures.

- The overwhelming majority of the buildings classified in the third category were one or two-story houses over thirty years old, built of non-engineered masonry of various qualities including stone, adobe and brick masonry that may have been subjected to previous earthquakes. Generally, these buildings are built according to the traditional laws of construction practice [24]. In some of these old masonry buildings, one may observe steel ties either incorporated into these structures since their construction or installed afterwards for repair and strengthening purposes. These buildings with steel ties behaved quite well during the current earthquake activity. The degree of damage from previous earthquake activity is not known and any measures that may have been taken to repair previous earthquake damage are not documented.
- Low rise R/C structures, built after the introduction of the seismic provisions of the building code, sustained damage relatively less severe than the old masonry houses apart from certain cases with design and construction flaws. Such flaws were more obvious for the houses located in the villages of the area surrounding Pyrgos where the low rise houses, although built employing reinforced concrete (R/C) elements, were not designed by chartered Civil Engineers.
- The newly built structures in the city of Pyrgos are typical in type and construction of the ones built all over Greece during the past 30 years and include mainly multistory apartment structures using R/C slabs, beams, columns, and shear walls with masonry infills for the apartment partitions. Most of these structures in Pyrgos varied from 4 to 6 stories high. The majority of them were constructed in the city center which was founded on better soil, according to unconfirmed reports. These structures have strong masonry infills on all the stories as well as on the ground floor apart from the side of the building adjacent to the main street, which in the ground floor has metal and glass displays as the ground floor space is used for shops. No serious structural damage was observed for these buildings apart from separation of the masonry infills from the surrounding R/C frame or cracking of these infills and spalling of the layer of mortar covering their surface.
- Another class of structure that exhibited a particular type of damage was that of newly designed and constructed (5-6 stories high) R/C multistory buildings with masonry infills at all floors apart from the ground floor, that is left without any masonry infills so that it can be used as a car park (Figs. 9a, 9b and 9c). There were a considerable number of such structures with shear type failure damage at the R/C columns or shear walls at the ground floor. This type of weakness for a structure has been documented by observations and subsequent studies during the Thessaloniki, Alkyonides [12] and Kalamata earthquakes [10, 16, 19, 32, 33], as was presented in the previous sections. In the aftermath of this earthquake, the columns and shear walls, damaged mostly by shear-type failure, were very quickly contained by steel encasing, in order to prevent the shear failure from progressing to total collapse (Fig. 9c). These measures were taken by local designers and contractors under the guidance of engineers experienced

(a) (b) (c)

Fig. 9 (a) A 5-story structure damaged at the "soft story" ground floor as it stands today; (b) The damaged vertical elements of the "soft story" after being repaired; (c) A typical "soft story" shear wall damage being temporaririly strengthened.

from previous earthquakes, the author being among them. Epoxy resin injections were also used. The whole effort was very successful resulting in maintaining the structural integrity of all the heavily damaged structures, without the occurrence of any collapse, despite the sequence of aftershocks.

The observed damage of structures designed to resist earthquakes may be attributed to the following:

- Soft story mechanism at the ground floor due to the absence of the infills.
- Poor shear strength design of the vertical R/C elements especially of the shear walls.
- Torsional response from various types of eccentricities.
- Amplification of the ground motion due to the soil conditions in conjunction with the dynamic properties of these structures (Fundamental period 0.3 Hz–0.5 Hz). However, an obvious relation between damage and local soil conditions was not evident. It was observed that similar structures situated close to each other, did not suffer the same degree of damage. This was also observed in other strong local earthquakes in Greece. The distribution of damage in various parts of the town is at least partially attributable to local soil effects. The small epicentral distance of the earthquake, connected with the direction of the fault rupture, as well as the quality and techniques of construction, are additional factors that may have influenced the extent and distribution of damage [8].
- Special Structures: The damaged structures that were rendered unusable include the old hospital building, a number of schools, and a number of churches. The new hospital building was undamaged while the building housing the various offices of the Prefecture suffered minor damages, concentrated on the partitions made of brick masonry. This building became the headquarters of the post earthquake relief effort. The recently renovated municipality building, an old style structure with heavy thick masonry walls, escaped with only minor damage to the internal masonry partitions. The newly constructed low-rise building of the Courts of Law was undamaged. There were some small industrial facilities in the area that, while not exhibiting structural damage, were affected by the falling of free standing objects and disruption of the operation of their equipment. Considerable financial loss from damaged pottery was observed in an industrial establishment located in the epicentral area. The lifelines in the city of Pyrgos reported to be operational during the aftermath of the quake. The circuit breakers of a substation of the Electric Power Corporation of Greece sustained damage. The rich agricultural area surrounding the city of Pyrgos operates a water distribution system for irrigation with canals, water tanks, small reservoirs and pump houses that utilize the water supplied by the river that springs from the mountainous area of Central Peloponnesus. Structural damage was observed to two of the buildings

out of many that house the pumping stations for this water distribution system.

2.4. The Kozani Earthquake of 13th May, 1995

On May 13th, 1995, a Ms = 6.6 earthquake occurred in the prefecture of Kozani in the Northwest of Greece (Fig. 1 and [11, 20, 21, 39, 47]). The epicenter of this earthquake was quite close (20 km) to the city of Kozani, the capital of the prefecture with 50,000 inhabitants. This region belongs, according to the seismological studies before this earthquake, to the less seismically active area of Greece. Consequently, it was classified with the lowest probability of being subjected to strong ground motions (seismic zone I, see Tables 1 and 5 and Fig. 1). Despite the fact that this event was initially attributed to the construction of a dam and the filling of its lake, it was finally concluded that the Kozani–Grevena earthquake was an event in the framework of the regional seismicity rather than an event triggered by the impounding of the Polyphyto artificial Lake [14].

Despite the severity of the ground motion there was no human loss; this must be attributed to the fact that this earthquake occurred at noon on a Saturday with the schools and the churches closed and the people being out of their houses. A small fore-shock prior to the main event gave sufficient warning to the people so that the main shock found them outdoors.

The following are the main observations from this earthquake:

- A very heavy toll was again paid by the old unreinforced masonry structures that were located in numerous villages in the epicentral region, which were not built according to current code provision [18, 24]. These structures have been totally demolished and have already been replaced by contemporary low-rise reinforced concrete structures, designed according to the provisions of the current seismic code (Table 5 and Fig. 1). Although these villages were not so densely populated, they were numerous, thus the cost of reconstruction, partly shared by the central government budget, was quite considerable, especially bearing in mind that this was supposed to be the region of Greece with relatively low seismic activity.
- An interesting failure was sustained in the fill of the south abutment of the bridge crossing the Polyphyto artificial lake at its South-West corner. This was the location where the seismic-fault rupture was initiated and must have experienced very strong ground motions. This bridge includes a number of free supported spans on multiple column supports founded at the bottom of this lake by pile foundation. The performance of this part was satisfactory without any damage. However, the gravel fill of the south abutments exhibited a spectacular failure that disrupted the road connection for at least two weeks (Fig. 10 and [50]).

Fig. 10 Damaged abutment of the “Rymnio” bridge.

- The epicentral area is crossed by numerous steel towers transporting electricity from the nearby coal-mining region of Kozani-Ptolemaida, where the power generation stations are located. Moreover, there is a large dam and a hydro-electric power station at a distance of 25 km from the epicenter. All these lifelines performed satisfactorily without any disruption. An asbestos mining and processing plant, quite close to the epicentral region, including a large steel multi-story structure exhibited only slight signs of the initiation of buckling of the steel bracing system at the ground level. Moreover, there was indication of sliding of floor beams from their supports without initiating any subsequent failure, as this sliding displacement was contained by the existing margin. An old monastery at a very close distance from this processing plant, having unreinforced masonry structures was heavily damaged. Close to the same area are plants for mining and processing stone marble. These sustained considerable loss due to the overtopping and breakage of their final products at their storage facilities.
- The level of earthquake forces exceed by far the levels provided by the old seismic code that the majority of the multi-story buildings, located in the nearby cities of Kozani and Grevena, were designed for. These buildings sustained structural damage of only moderate severity without any collapse. This must be attributed to the geological formation of the region that may have attenuated the strong ground motion over the distance. The design and construction of building structures was similar to that in other regions of Greece; consequently, the damage that developed was similar, namely shear type of failure in shear-walls and columns, "soft" story damage, and heavy damage in short columns (Fig. 11 and [30]).
- Heavy damage was sustained by relatively newer churches, built with reinforced concrete elements, incorporating contemporary construction practices. One of the many churches in this category to sustain structural damage and one of the largest in the area is located in the city of Kozani, devoted to St. Konstantine [26]. The most spectacular damage in this category was observed in the village of St. Paraskevi and the village Kentro. Apart from these relatively newer churches, numerous other old Byzantine and Post-Byzantine churches, mostly built with stone masonry, were also heavily damaged. These churches span a period of over 800 years [28, 29]. The most spectacular damage to an old church is that of Taxiarchis in the outskirts of Eani (12th century AD). Despite its small size, the walls of this church were totally destroyed, indicating the severity of the ground motion. A short distance away, at the center of Eani, the church of The Virgin Mary (11th century) also sustained damage; however, this was less severe. Other examples of such damage are at the Monastery of St. Nikanoras (Zaborda, 15th century, Fig. 12), and at the church of The Virgin Mary (Tourniki, 12th century).

(a) (b)

Fig. 11 (a) Damaged "soft story"; (b) Damaged "short" columns.

(a) (b)

Fig. 12 (a) 3-D representation of the Katholikon of the Metamorfosi tou Sotiros with its narthex; (b) Damage of the cruciform vaults and the pendatives supporting the central dome.

2.5 The Egion Earthquake of 15th June, 1995

This earthquake of magnitude Ms = 6.1 on the Richter scale occurred just a month after the Kozani earthquake (Fig. 1 and [6, 9, 34, 44]). Unfortunately this time there was a death toll of 26 caused by the collapse of two multi-story buildings. The time of the earthquake (after midnight) was very unfavourable as most people were sleeping indoors. The strong motion of this earthquake was recorded by an instrument located on the ground floor of the telecommunications building, a two story building with a basement. It is very significant to note that the recorded horizontal peak acceleration is quite high: equal to 0.49 g; similarly, the peak spectral acceleration is equal to 1.436 g at 0.425 seconds, the highest spectral value of all the destructive earthquakes listed in Tables 1 and 5. This is also true when the comparison is made in terms of effective peak acceleration (EPA).

The following are the most important observations:

- The destruction in the city was almost equally spread between low-rise old-type construction and new multi-story buildings. The old buildings were of unreinforced masonry that included certain earthquake resistant construction details as a result of past earthquakes. Most of the new buildings, made of reinforced concrete, were unfortunately from an era characterized by the weaknesses already mentioned for this type of construction. That is, short columns (Fig. 13a), "soft story" (Fig. 13b) at the ground floor, unsuitable structural system for resisting lateral loads, structural elements of low ductility prone to shear failure, foundation of spread footings connected with beams, irregular shape in plan and in elevation, absence of adequate number of shear walls etc.
- Many reinforced concrete structures, typical of the design and construction according to the old seismic code, reached their limit of strength with no potential for post-elastic ductile deformations, thus leading to their collapse. Similar observations were made from the devastating earthquakes of Thessaloniki, Alkyonides and Kalamata and Pyrgos. The design and construction practices started to change gradually after 1983, when an interim revision of the seismic code came out in draft form. However, these changes, although moving in the right direction, were not as drastic as the ones introduced by the new seismic code (1992); its provisions, as already stated, deal with all these weaknesses [42].

2.6 The Athens Earthquake of September 9th, 1999

On September 9th, 1999, a Ms = 5.9 earthquake occurred in the Metropolitan area of Athens (Fig. 16 and [5, 12, 15]). This earthquake subjected the North-West part of the Metropolitan area of Athens to considerable ground motions, since its epicentral distance was approximately 16 Km from the center of Athens and less than 10 Km from the North-West part of the city (Fig. 14). Despite the fact that this earthquake was not one of the most severe seismic events occurring in Greece during the last thirty years (see Table 1), its consequences were the most serious, causing 143 deaths and widespread structural damage or collapse of numerous contemporary R/C multi-story buildings, located near the epicentral area. This was mainly due to the proximity of this earthquake to a densely populated metropolitan area like Athens, with approximately four million inhabitants, as was also the case 32 years ago for the Thessaloniki earthquake of 1978.

This author's view coincides with that of other researchers [15] that also concluded that in comparison with other Greek seismic excitations, the seismic parameters provided by the Athens earthquake were of medium severity. The destructive consequences may be attributed firstly to the proximity of the epicenter to the urban area and secondly to the relatively high vulnerability of the structures. The following are the main observations for this earthquake and the conclusive remarks from the impact of the recent earthquake activity in Greece on the building environment and its infrastructures.

(a) (b)

Fig. 13 (a) Short column failure; (b) Total collapse of ground floor (failure of all ground floor "soft story" columns).

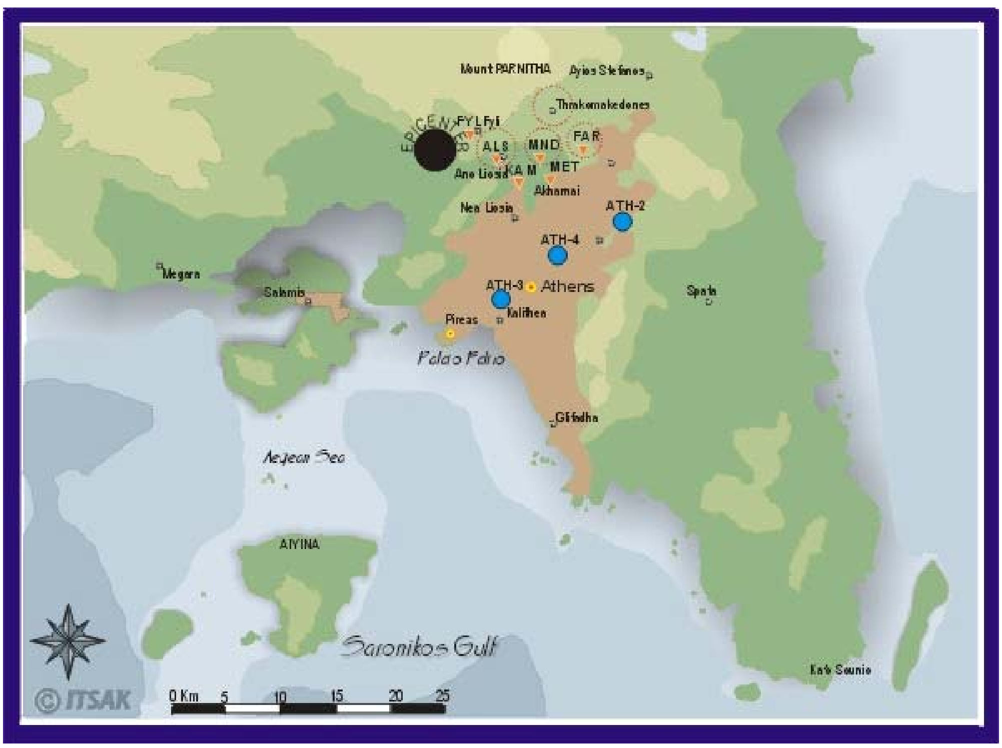


Fig. 14 Athens Metropolitan Area.

- One of the main conclusions from the damage observations for this earthquake that is also valid from the observations of the rest of the strong earthquake sequences presented in this paper, is the fact that all the severely damaged or collapsed structures, were designed and built prior to 1984, when the first revision of the provisions of the Greek Seismic Code, first published in 1959, took place (Figs. 15 and 20). Moreover, structures that were designed and built according to the provisions of the second drastic revision of the seismic code (1992, the New Greek Seismic Code, [42]) did not sustain any significant structural damage (Fig. 19) although these structures were also located at the epicentral area close to heavily damaged or collapsed buildings. The effect of the New Greek Seismic Code [42] will become more pronounced in the future as structures designed and constructed by this code gradually become a relative large percentage of the total building stock in nationwide. In this sense the main problem at hand will be the earthquake performance of buildings designed prior to the date that the New Greek Seismic Code became effective.
- There is a special category of building structures where the cause of damage lies in the fact that they have been extended or altered without any seismic design provisions being followed (Figs. 15 and 20). This is particularly valid for facilities housing small industries. The damage in these cases is very heavy. Faults in detailing and the severity of shaking caused spectacular damage in the epicentral area (Fig. 16)
- Main causes of damage for multi-story R/C structures in all presented cases arises from "soft-story" mechanisms (Figs. 17 and 18) and short columns. The most common case of "soft-story" is at the ground floor to be used as parking lot.
- Despite the experience gained during the last 30 years by post-earthquake immediate measures in temporary shoring of damaged structures in order to avoid partial or total collapse during subsequent strong aftershocks this was applied with considerable delay in the case of the Athens1999 earthquake (Fig. 18 and [13, 27, 48]).

Fig. 15 The collapse of the "Ricomex" building (epicentral region).

Fig. 16 Failure of all the central columns (epicentral region).

Fig. 17 Column shear failure – "Soft story" Metamorfosi building.

Fig. 18 Temporary strengthening of the damaged "Soft story" of the Metamorfosi building.

Fig. 19 Excellent performance of "Gnomon" building designed by the New Greek Seismic Code (epicentral region).

Fig. 20 Total collapse of ground floor with short columns—"Prokos" building (epicentral region).

3. Case Study "The Hardas-Pyrgos Building"

This building (Figs. 23-26) was designed and constructed in 1990 according to the provisions of the Old Greek Seismic Code [23, 40, 42]. It included at its ground floor a "soft-story" which was seriously damaged during the 1993 Pyrgos strong earthquake sequence (see section 2.3). As a case study, for the effect of the provisions of the New Greek Seismic Code, the earthquake (EQ) performance of this 5-story R/C appartment building has been numerically investigated extensively by performing a series of elastic analyses, utilising all the geometrical and structural information available for this building. In what follows the most important findings will be presented including the study of the follwing influences:

(1) Displacement and stress numerical predictions of the EQ response according to the provisions of the Old Greek Seismic Code (Equivalent Static Analysis).

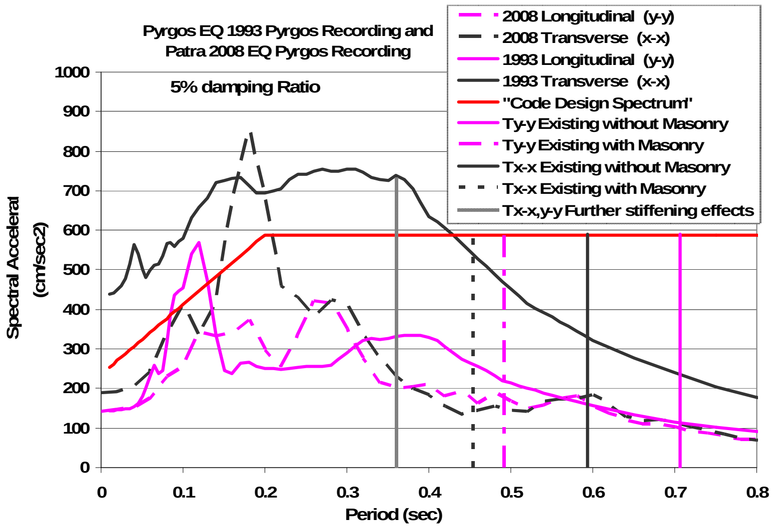


Fig. 21 The spectral characteristics of the ground acceleration recorded at the city of Pyrgos during the 1993 and the 2008 events.

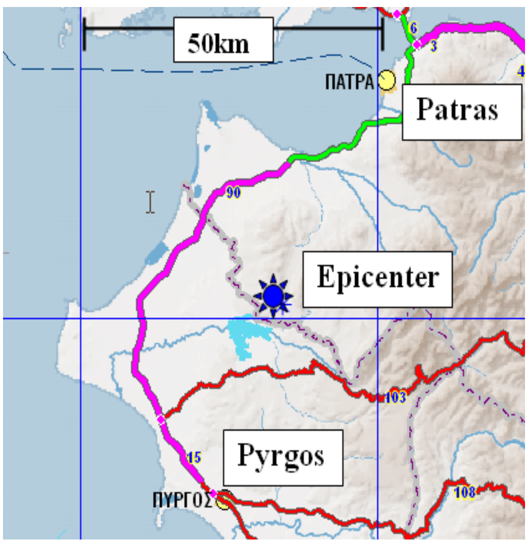


Fig. 22 The location of the epicenter for the 6th June 2008 event.

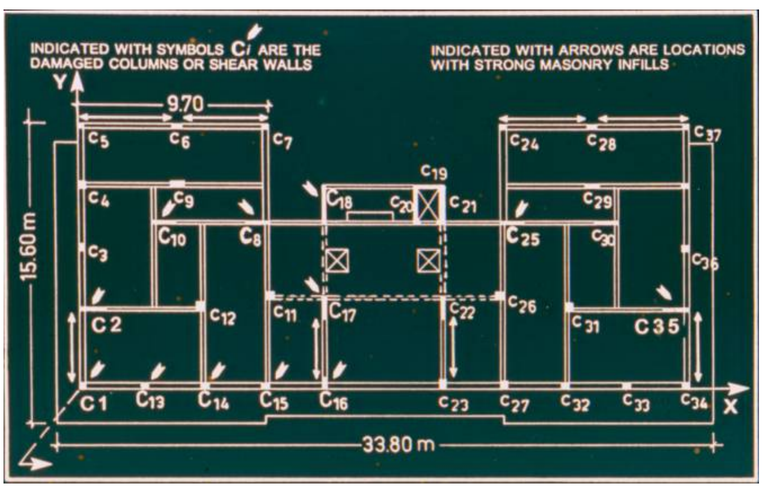


Fig. 23 Plan of the "soft story" of the "Pyrgos Hardas" building.

Fig. 24 Temporary strengthening of the damaged "soft story" of the "Pyrgos Hardas" building.

Fig. 25 Pyrgos Hardas building with columns at the ground floor "soft story" strengthened by R/C jacketing. The performance of this repaired building during the 2008 earthquake sequence was satisfactory without signs of any distress.

Fig. 26 Damaged column C35 of the Pyrgos Hardas Building.

(2) Displacement and stress numerical predictions of the EQ response according to the provisions of the New Greek Seismic Code (Equivalent Static Analysis and Dynamic Spectral Analysis with the design spectrum included in the New Greek Seismic Code).

(3) Displacement and stress numerical predictions of the EQ response utilising the ground motion information provided by the actual ground motion record obtained by an instrument located at a distance of approximately 1-2 km from the location of this building. This time the EQ response numerical predictions were obtained through dynamic spectral and time history analyses based on this main event ground motion recording.

(4) The influence on the EQ response if this building by the presense of strong masonry infills built in the bays of this R/C frame structural system is also studied. As disccussed in the previous sections the presence of such strong masonry infills results in the ground froor of this structure performing as a "soft story", a common cause of damage.

In Fig. 21 the spectral acceleration curves are plotted corresponding to the two horizontal components (longitudinal and transverse) of the ground motion recorded at the city of Pyrgos during the March 1993 main event as well as another event with a magnitude on the Richter scale Ms = 6.5 that occurred in June

2008 with an epicenter approximately 30 km North-East from the city of Pyrgos (Fig. 22). Together with these spectral curves the design spectrum, as defined by the New Greek Seismic Code for the city of Pyrgos, is also plotted for soft soil conditions and for response modification factor equal to 1. The fundamental x-x (Transverse) and y-y (Longitudinal) period values, as obtained by the numerical simulation of the structural system with or without masonry infills of the studied building are also plotted in Fig. 21. The stiffening effect of the masonry infills is evident from this plot resulting in eigen-period values that correspond to larger spectral acceleration amplitudes having as an end result larger displacement and stress response for the structural elements of the ground floor "soft-story" where most of the damage was concentrated.

Table 3 lists the displacement response at the South-West corner of the building as obtained from the time history dynamic analysis employing the horizontal components pf the Pyrgos-1993 ground motion record.

As can be seen from the values listed in Table 3 the displacement response at both the 5th and the 1st story are much larger when the masonry infills are in place. This is true particularly for the direction y-y as well as for the torsional response. The corresponding stress demand on the columns of the soft story in terms of bending moment (M), axial force (N) and shear force (Q) is listed in Table 4.

The values in row 1 termed OGSC are obtained when the provisions of the Old Greek Seismic Code are applied. In row 2 the stress response values are listed (NGSC1) when the provisions of the New Greek Seismic Code are applied together with the corresponding acceleration design spectrum included in the code and the equivalent static analysis as provided by this code, whereas in row 3 (NGSC2) the

Table 3 Time-history dynamic analysis displacement response of the Hardas-Pyrgos building.

	5th story (top of the building)			1st story (top of the soft-story ground floor)		
	u_x (m)	u_y (m)	φ (rad)	u_x (m)	u_y (m)	φ (rad)
Without Masonry Infills	0.03625	0.02851	0.00136	0.006125	0.005176	0.0002357
With Masonry Infill	0.02975	0.05049	0.00229	0.00726	0.01070	0.0005346

Table 4 Stress resultants for the soft story vertical structural elements of the Hardas building.

	Column C1			Shear Wall C2			Column C3		
	M (KNm)	N (KN)	Q (KN)	M (KNm)	N (KN)	Q (KN)	M (KNm)	N (KN)	Q (KN)
1. OGSC	164.86 -127.66	85.46 -528.69	71.29 -47.22	779.95 -767.12	-336.73 -871.92	271.77 -261.05	829.91 -816.71	136.64 -1103.04	278.42 -270.93
2. NGSC1	263.19 -245.60	267.76 -328.90	118.79 87.83	1145.19 -1058.31	-368.53 -879.29	400.87 -359.84	1476.81 1625.89	708.37 547.17	496.04 553.82
3. NGSC2	-185.18 -207.79	-880.42 -844.84	84.34 -78.41	739.95 -648.85	-368.53 -983.45	261.44 -220.42	1331.31 1352.33	396.96 389.24	460.91 477.19
4. SPX-M	-359.85 398.45	-1385.44 552.90	-162.97 145.25	1577.01 1583.11	-1222.16 13.50	-544.05 554.78	-2630.72 2643.93	-2287.79 1321.39	-936.13 943.62
5. SPX+M	-462.82 499.58	-1688.21 847.65	-231.87 214.39	-2027.51 2033.84	-1475.25 278.26	-788.70 799.37	-3146.08 3159.08	-1999.26 1038.23	-1250.80 1258.24
6. SPY-M	39.70 -154.67	-163.79 -668.75	15.59 -57.00	-1852.46 191.35	-822.97 -385.68	-58.61 69.34	-991.49 1004.69	-1290.87 324.48	-328.25 335.74
7. SPY+M	21.46 224.68	355.53 -1196.09	8.69 94.70	-120.15 126.48	-981.73 -215.25	-56.18 66.85	-1398.66 1411.67	-1260.12 299.09	-526.53 533.97
8. DTH-M	411.22 -321.90	877.31 -514.62	-24.57 -125.36	2016.64 2000.16	96.76 105.10	691.57 686.26	-2067.95 1705.10	-1668.23 810.92	-741.03 597.41
9. DTH+M	545.51 -712.89	202.62 -2227.73	272.98 -308.80	2482.73 -219.31	105.13 574.60	970.97 -156.13	-4433.82 -4430.53	-2823.32 -2836.63	-1731.78 -1735.35

same provisions and design response spectrum are applied but the dynamic spectral analysis is followed. Next, in rows 4 to 9 the provisions of the New Greek Seismic Code are again applied but this time, instead of the design spectrum, the information provided by the earthquake ground acceleration recorded at Pyrgos is utilized. In row 4 the spectral dynamic analysis is applied for a structural system without masonry infills with the strong motion spectral amplitudes in the x-x (Transverse) direction (SPX-M) whereas in row 6 the same is obtained for the y-y (Longitudinal) direction SPY-M. Next, in rows 5 and 7 the same is done with the simulation of the masonry infills included, again following the dynamic spectral analysis in the x-x (SPX+M) and y-y (SPY+M) directions, respectively. Finally, in rows 8 and 9 the corresponding stress response values are listed, obtained from the numerical simulation of the Hardas-Pyrgos building utilizing the two horizontal components of the acceleration record in the Dynamic Time History Analysis; this is done for the structure without masonry infills (DTH-M) and then when masonry infills are included (DTH+M).

The following observations can be made based on the summary results included in the table above:

- The M, N, Q stress resultant predictions for the soft story vertical structural elements, obtained by applying the provisions of the Old Greek Seismic Code (1.OGSC), have values that are in all cases lower than the corresponding values obtained by applying the provisions of the New Greek Seismic Code (2.NGSC1/3.NGSC2). This observation is in agreement with the relevant comments already made relating to the application of the New Greek Seismic Code with an expected better earthquake performance of the new building stock than the old buildings designed and constructed before this code became effective.
- The M, N, Q stress resultant predictions for the soft story vertical structural elements, obtained by applying the provisions of the New Greek Seismic Code (2.NGSC1/3.NGSC2), have values that are in all cases lower than the corresponding values obtained by applying these provisions but, instead of the design spectrum included in this code, the ground acceleration characteristics included in the strong motion recorded during the 1993 Pyrgos earthquake sequence, were utilized (4. SPX-M, 5. SPX+M, 6. SPY-M, 7. SPY+M, 8. DTH-M, 9. DTH+M). This must be attributed to the characteristics of the particular earthquake plus those of the structural system being examined.
- The M, N, Q stress resultant predictions for the soft story vertical structural elements (obtained by applying the provisions of the New Greek Seismic Code together with the characteristics of the strong motion recorded during the 1993 Pyrgos earthquake sequence and including in the simulation the influence of the masonry infills, e.g., 5. SPX+M, 7. SPY+M, 9. DTH+M) have larger values than the corresponding values when the presence of the masonry infills is ignored (e.g., 4. SPX-M, 6. SPY-M, 8. DTH-M). This observation is more pronounced when the comparison is made on the basis of the results obtained by applying the dynamic history analyses that yield the largest stress resultant demands on the structural elements. According to the New Greek Seismic Code provisions a dynamic time history analysis is not obligatory except in the case of special structures. Moreover, the new code does not require the inclusion of the masonry infills in the analysis although it *penalizes* structures that include a “soft-story”. In any case, it must be borne in mind that, through certain additional provisions of the new code, the ductility requirements and the satisfactory performance of the various structural elements against shear failure are enforced through additional checks that were not included in the provisions of the old code. For this particular Hardas-Pyrgos building, the shear strength, provided for in the various vertical structural elements by their detailing, was found to be much lower than the shear force demand (Q) listed in the above table, a fact that explains the observed extensive shear-type damage in these elements. As already discussed, this has been a

typical form of serious structural damage observed in numerous similar buildings in all the earthquake sequences reported here, which is hoped to be avoided in the future through the provisions of the New Greek Seismic Code.

In Fig. 23, the particulars of the 2008 earthquake sequence (M = 6.5) that occurred in June 2008 with an epicenter approximately 30km North-East from the city of Pyrgos is shown. The damaged vertical structural elements of the Hardas-Pyrgos building were repaired after the 1993 event by jacketing (Fig. 25), which has been a common repair technique that has been applied in numerous similar cases over the past 30 years. The fundamental period of the repaired building, as shown by the numerical investigation results and indicated in figure 23 with the term Tx-x,y-y further stiffening effects (T = 0.36 sec), is lower than the period values of the unrepaired building. At this period range the spectral acceleration amplitudes of the 2008 recording are considerable, although lower than the New Greek Seismic Code design spectral values and the 1993 spectral values. The damaged and repaired vertical structural elements for the Hardas-Pyrgos building exhibited satisfactory performance during the 2008 event without signs of any distress. The same observations could be made for the performance of the vertical structural elements of similar buildings in the city of Pyrgos that were damaged during the 1993 EQ and were subsequently repaired.

4. Plans for Earthquake Preparedness

During the last thirty years the continuous earthquake activity in Greece and the corresponding damage in the urban environment resulted in an effort to upgrade earthquake preparedness [13, 48, 27]. This can be seen as a preparedness that results in pre-event actions or in preparedness that aims at post-event actions.

In Greece there is a preparedness plan that spans from the central government and branches to the various levels of prefecture or municipal authorities.

The following can be listed as the main weaknesses of this plan [27]:

(1) It is designed for all types of natural disasters (e.g., fires, floods, snowfalls as well as earthquakes).

(2) It lacks funds and technically competent personnel.

(3) The plan is very rarely put to a trial test for its effectiveness prior to an actual event.

(4) The plan must be upgraded to make use of all new technological achievements and recent international experience.

A momentum has been initiated to check the vulnerability of various structures to earthquake loads. In order for such an effort to be effective, it means that, apart from identifying structures with a relatively high earthquake vulnerability level, repair and strengthening interventions should be then introduced that will lower as a result this earthquake vulnerability to acceptable levels. The main difficulties to materialize the necessary interventions stem from the following:

- The legal process in the cases of multi-ownership buildings. In Greece, this comprises the majority of contemporary housing construction in the main cities, where approximately 80% of the total population presently reside.
- The lack of funds. In order to counteract this difficulty there is a necessity for the earthquake research community to find and validate effective repair and strengthening engineering solutions which will improve the cost-effect ratio of the currently available repair and strengthening techniques.

In order to address the above difficulties a priority list has been gaining social acceptance. This means that structures of social importance such as schools, hospitals etc. should be given priority in this upgrading effort. However, the recent economic crisis has deemed funds even for structures in the priority list very difficult to obtain. In an effort to prepare for future earthquake disasters a special code has been in preparation addressing the repair and strengthening of structures damaged by earthquakes under the auspices of the Greek Organization for Earthquake Planning and Protection.

In all the past earthquake disasters during the last thirty years in Greece, the observed damage and the death toll was due to the partial or total collapse of structures that were constructed either with no seismic code provisions (old masonry structures) or of R/C multi-story buildings that were designed with seismic code provisions but included certain important weaknesses, such as low-ductility vertical structural elements in soft-stories and detailing that entailed low shear strength. Fortunately, neither main industrial facilities with hazardous contents nor other infrastructures (like bridges, dams etc.) were affected by these earthquake disasters. However, as shown by the international experience of developed countries the long-term preparedness effort should also include a thorough check and possible upgrading of such critical facilities and infrastructure as the impact to the urban regions as well as the environment can in this case be devastating.

In the long term, earthquake preparedness should involve specialized education and training of earthquake engineers. During the last decade almost all Greek Technical Universities have introduced special postgraduate courses in Earthquake Engineering Design. At the same time new laboratory facilities have been installed dedicated to earthquake engineering education and research. Furthermore, training courses for practicing engineers have been running on a regular basis aiming to teach current technological and design development in the field of earthquake engineering. The Department of Civil Engineering of Aristotle University of Thessaloniki has been running such a post-graduate Earthquake Engineering Design course for the last ten years with almost 200 graduates.

5. The Enrichment of the Strong Motion Data Base

Table 5 lists the peak values of the recorded strong ground motions of the aforementioned earthquake events. Most of this ground motion information was obtained from the strong motion network of accelerographs, which is deployed all over Greece and is operated by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) based in Thessaloniki [17, 41]. This network is continuously upgraded and expanded and includes instruments designed to record the strong earthquake ground motion as well as instruments to record the response of special structures, such as important bridges [45] and other infrastructures during strong seismic activity. In columns 2 to 4 of Table 3, the peak values of the recorded horizontal and vertical acceleration is listed and in columns 6 and 7 the corresponding peak spectral values for the horizontal acceleration plus the relevant dominant period value. In column 5 an assignment is made to the local soil conditions according to the current Greek seismic Code that provides for three categories; A-rocky or hard soil layers, B-stiff soil formations and C-soft alluvia deposits. The effective peak acceleration value for the longitudinal and transverse component for each recorded motion is given in column 8; this was obtained by averaging the corresponding spectral values in the period range 0.1 to 0.5 seconds and taking the ratio with an assumed amplification factor equal to 2.5. In column 9 values of the parameters (Magnitude Ms and Source Distance r), used in deriving peak acceleration and spectral prediction according to the approach proposed by Abrazeys et al. [1, 2] are listed, together with the resulting horizontal peak acceleration value. Finally, in column 10 the design peak ground acceleration assigned to the location where the strong motion was recorded, is listed together with the corresponding seismic zone assigned by the same code. There are four seismic zones with I being the least severe and IV the most severe.

The following observations can be made by comparing the values of the various parameters listed in Table 5.

Table 5 Peak values of the recorded strong ground motions and their spectral values.

Earthquake	Peak Long. (g)	Ground Trans. (g)	Acceler. Vertical (g)	Soil Conditions	Spectral Longitud. Peak (g) at T (sec)	Spectral Transv. Peak (g) at T (sec)	E.P.A. * Lon/Tran (g)	Ambrazeys Rock PGA (g)	Greek Code¹ PGA (g)	Greek Code² PGA (g)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Thessalo-niki 1978	0.143	0.154	0.136	Soft (B or C)	0.486 at 0.3	0.557 at 0.44	0.126 / 0.149	(Ms = 6.4) (r =27.5 km) 0.096	Zone II 0.16	Zone I 0.16
Kalamata 1986	0.240	0.273	0.182	Soft (B or C)	0.771 at 0.33	1.245 at 0.32	0.248 / 0.303	(Ms = 6.2) (r = 7 km) 0.272	Zone III 0.24	Zone II 0.24
Edessa (Griva) 1990	0.100	0.100	0.040	Soft (B or C)	0.508 at 0.65	0.366 at 0.52	0.106 / 0.085	(Ms = 5.9) (r = 15 km) 0.121	Zone I 0.12	Zone I 0.16
Pyrgos 1993	0.147	0.445	0.125	Soft (B or C)	0.579 at 0.12	0.770 at 0.30	0.123 / 0.273	(Ms = 5.2) (r = 5 km) 0.186	Zone III 0.24	Zone II 0.24
Patra 1993 (Ekklisia)	0.141	0.393	0.121	Stiff (B)	0.455 at 0.12	1.162 at 0.12	0.122 / 0.197	(Ms = 5.4) (r = 5 km) 0.210	Zone III 0.24	Zone II 0.24
Patra 1993 Trapeza	0.142	0.171	0.048	Soft (C)	0.371 at 0.14	0.525 at 0.18	0.122 / 0.129	(Ms = 5.4) (r = 5 km) 0.210	Zone III 0.24	Zone II 0.24
Kozani 1995	0.210	0.150	0.080	Stiff (B)	0.741 at 0.19	0.511 at 0.21	0.152 / 0.131	(Ms = 6.6) (r = 20 km) 0.146	Zone I 0.12	Zone I 0.16
Aigio 1995	0.493	0.500	0.200	Stiff (B or C)	1.207 at 0.42	1.436 at 0.425	0.364 / 0.425	(Ms = 6.1) (r = 5 km) 0.322	Zone III 0.24	Zone II 0.24
Athens 1999 (KEDE)	0.290	0.350	0.190	Soft (C)	0.800 at 0.10 sec.	1.310 at 0.22 sec.	0.450 / 0.600	(Ms = 5.9) (r = 10 km) 0.171	Zone II 0.16	Zone I 0.16

¹ Greek Seismic Code 2000. ² Greek Seismic Code Revision 2003.

(1) In all cases of the recorded peak ground motion the vertical acceleration component, as expected, has a smaller peak value than the horizontal components.

(2) By comparing the peak ground acceleration values, as provided in each case by the current Greek seismic code[1] or code[2], with the corresponding values of the recorded peak horizontal acceleration it can be seen that for Thessaloniki, Kalamata, Edessa, and Patra (Trapeza) the code value is approximately of the same amplitude as the recorded value. However, the code value is exceeded by far in the case of Pyrgos, Patra (Ekklisia), Kozani, Egio and Athens-99.

(3) A more meaningful comparison, that can also be correlated to the observed damage, is when the code[1] or code[2] provided value is compared with the effective peak acceleration value, because, in this case, the influence of sharp spikes in the recorded acceleration is smoothed out. In this case, the code[2] value is approximately of the same amplitude as the recorded value for the majority of the cases, e.g., Thessaloniki, Edessa, Pyrgos, Patra (Trapeza and Ekklisia), and Kozani. This time, the code value is exceeded in the case of Kalamata and Egio. Thus it correlates well with the observed destruction and collapses observed in these two earthquakes. In the case of Athens-99 the ground motion recordings were at some distance from the area with the heavily damaged structures [5, 15]. Thus, direct correlation of the ground motion with the damage cannot be accurately performed at this stage. It must be borne in mind here when making these comparisons that the listed code[2] values are the current seismic code (2003) values and are higher than the old code seismic force levels.

(4) By comparing, for the various earthquakes listed in Table 5, the peak spectral values of the recorded ground motions and the corresponding dominant period values, the influence of the local soil condition can be observed. Thus the hard and stiff soil recordings (Patra-Ekklisia and Kozani) have peak spectral values, as expected, for shorter period ranges than the rest of the recordings that are in relatively soft soil conditions. Moreover, in the case of Edessa and Egio the amplification from the local soil conditions and the site effects is also noticeable.

(5) The validity of specially derived spectral amplification or spectral acceleration values in this long period range that is of interest for base isolated structures, is debatable and should be considered with great caution especially when the structure in question will have its fundamental vibratory response within this long period range. Such cases may be long span bridges, tall flexible buildings or large storage tanks [25, 45].

6. Conclusions

Experiences from earthquake disasters in Greece, during the last thirty years, links the severity of destruction not with the intensity of the seismic event but rather with the urbanization of the affected region and with the vulnerability of the building stock. Considerable damage was caused both to old masonry structures as well as to relatively weak multistory reinforced concrete structures. The most remarkable case of extensive damage was for the Athens 1999 earthquake. A brief list of the most important seismological parameters are given together with the recorded ground motion data and a summary of the induced damage. Through these observations the focus is on the following issues and corrective measures:

(1) Classification of structural damage and their underlying causes: *Improve effective measures to contain damage.*

(2) Repair and strengthening of damaged structures: Improve the means of such interventions by establishing relevant code provisions as well as by introducing effective methods and techniques.

(3) Upgrade the seismic design: Revise the Seismic Code provisions.

(4) Plans for earthquake preparedness: Assimilate past experience and provide for effective future plans and actions.

(5) Assessing the vulnerability of certain type of structures (schools, hospitals, public buildings etc): Introduce measures for upgrading their seismic resistance.

(6) Education specialized in earthquake engineering: Introduce specialized studies in Universities. Establish special courses for the retraining of Engineers.

(7)The enrichment of the strong motion data base: Expand the national network. Introduce specialized networks with modern instruments.

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