# THE ATHENS (GREECE) EARTHQUAKE OF 7 SEPTEMBER 1999: THE EVENT, ITS EFFECTS AND THE RESPONSE

BY

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## SUMMARY

By striking the capital of Greece, hosting nearly half of the country's over 10 million population, roughly two-thirds of the economic activity and the administrative function almost in its entirety, the Athens earthquake of 7 September 7 1999 ($M_w$ 5.9) put to a severe test the existing building stock (and hence the seismic codes) as well as the government's emergency management preparedness. The seismotectonic setting and earthquake data (location, mechanism and aftershocks) are presented. Significant accelerograms of the main shock – all recorded outside the meisoseismal area – as well as their response spectra, are analyzed. The effect of the earthquake on infrastructure and lifelines is described. Damage to buildings is discussed in relation to their use and the seismic codes applicable at the time of their construction. Information and experience gained from this and past earthquakes are used to determine the factors that affect the seismic capacity of structures. Estimates of the losses in economic terms both in public and private sectors are given. Pre-earthquake preparedness measures and emergency management procedures are discussed, as well as relief measures taken by the authorities after the event.

## INTRODUCTION

On 7 September 1999, at 14:56 local time (11:56 GMT), a strong earthquake with magnitude $M_w$ 5.9 occurred in the vicinity of the capital of Greece Athens. The current best estimate of the hypocentre location is 38.06$^o$N, 23.57$^o$E, with a focal depth of 15 km (Fig. 1). The fault-plane solution by Harvard University indicates a WNW-ESE trending, almost south-dipping normal fault.

The earthquake caused the collapse of 65 buildings, all but a few residential, killing 143 persons and injuring about 7,000. (The death toll would have been considerably higher had the earthquake occurred later in the evening or at night.) More than 70,000 families became homeless. The most extensive and severe damage occurred in the northwestern suburbs of Athens (~1,000,000 inhabitants), located near the epicentre, in the meizoseismal area, apparently in the direction of the fault rupture. The dominant construction systems in these areas are reinforced concrete frames and one or two-story buildings with masonry walls. Most of the structures were built according to the (now obsolete) 1959 Greek Seismic Code; also, a significant number of mainly residential buildings were built illegally, without seismic provisions at all.

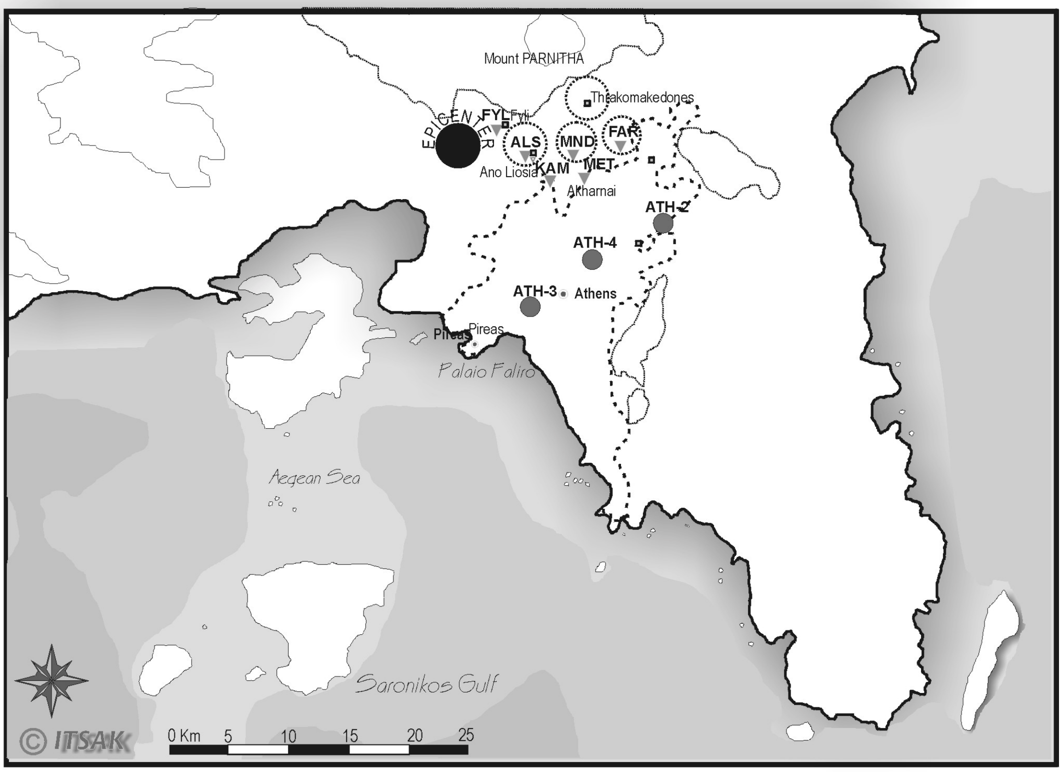


**Figure 1. Map of the broader area affected by the 7 September 1999 (Mw 5.9) earthquake.** Solid circles and triangles: permanent and temporary strong-motion stations operated by ITSAK. Dashed circles denote regions were Modified Mercalli (MM) intensity was from VIII to IX degrees.

## STRONG-MOTION DATA

The $M_w$ 5.9 earthquake inflicted severe damage upon several northwestern suburbs of Athens in the near-fault area, where estimates indicate a Modified- Mercalli (MM) intensity from VI to IX. All three analog SMA-1 accelerographs operated at the time by the Institute of Engineering Seismology and Earthquake Engineering (ITSAK) in the city of Athens recorded the mainshock (Fig. 2) as well as the aftershock activity. Within a few days after the main event, ITSAK deployed another six digital accelerographs in the meisoseismal area close to sites were major damage occurred, while its engineers carried out a preliminary damage survey. Furthermore, ITSAK used a mobile multi-channel recording system for the instrumentation and recording of the seismic response of two public buildings near the epicentral area.

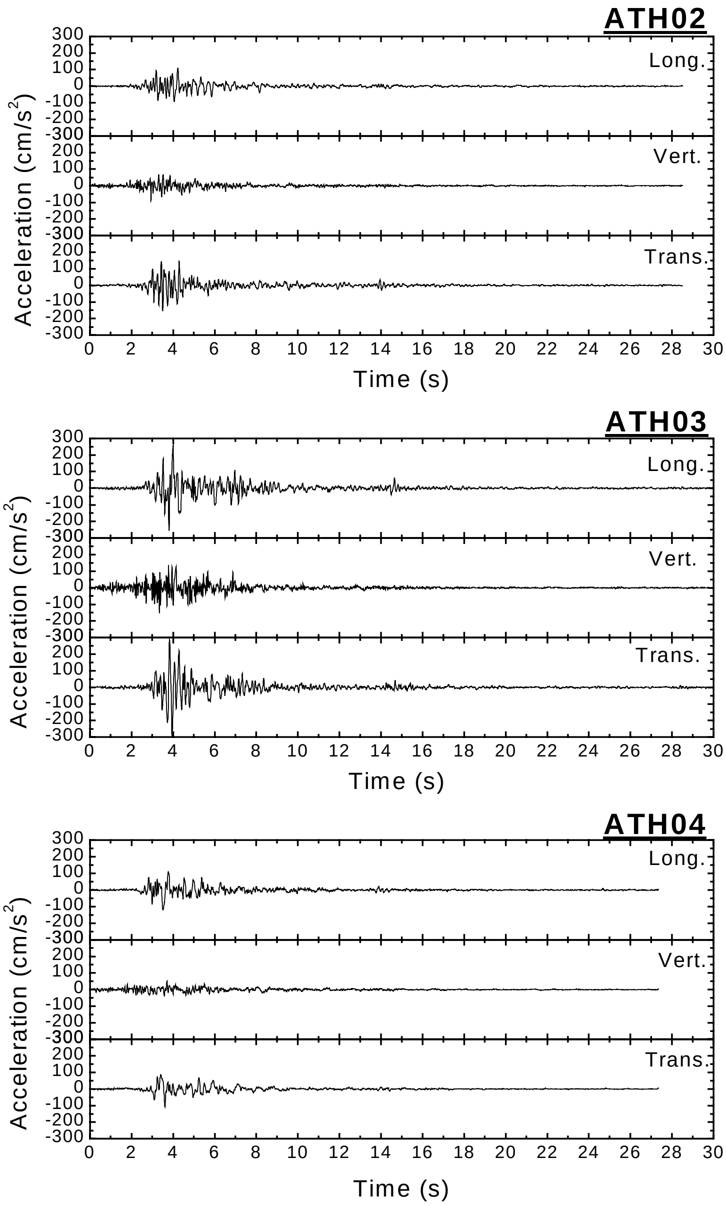


**Figure 2.** Corrected accelerograms of the 7 September 1999 (Mw 5.9) earthquake recorded by the permanent stations of ITSAK (see Fig. 1).

Upon a first comparison, the Athens earthquake appears to have been less severe than most of the events that recently hit major urban areas in Greece (Table 1). But one must keep in mind that the highest PGA unaffected by topography or other effects (0.35g) was recorded outside the meizoseismal area, at an epicentral distance of about 10 km. Within the meizoseismal area, closer to the fault, PGA may well have exceeded 0.5 g, especially considering near-fault and directivity effects, which apparently were significant. Moreover, there is macroseismic evidence that vertical accelerations may have locally exceeded 1g (e.g. the widespread unearthing of buried coffins at the cemetery of the municipality of Fili).

***Table 1.*** Comparison of recent, damaging normal-faulting earthquakes in Greece.

| Location | Date | $M_w$ | R km | PGA g | PGV cm/s | PGD cm | PGV/PGA cm/s/g | BD* s | EPA** g | SCZ*** Zone- g |
|---|---|---|---|---|---|---|---|---|---|---|
| **Thessaloniki** | 20/6/78 | 6.4 | 29 | 0.15 | 16.7 | 3.4 | 111 | 6 | 0.13 | II - 0.16 |
| **Corinthos** | 24/2/81 | 6.6 | 30 | 0.29 | 24.6 | 6.7 | 85 | 11 | 0.24 | III - 0.24 |
| **Kalamata** | 13/9/86 | 6.0 | 12 | 0.27 | 32.3 | 7.2 | 120 | 4 | 0.28 | III - 0.24 |
| **Kozani** | 13/5/95 | 6.6 | 19 | 0.21 | 8.8 | 1.5 | 42 | 7 | 0.14 | I - 0.12 |
| **Aigio** | 15/6/95 | 6.4 | 18 | 0.54 | 51.7 | 7.5 | 96 | 6 | 0.43 | III - 0.24 |
| **Athens-02** | 07/9/99 | 5.9 | 13 | 0.16 | 6.9 | 1.0 | 46 | 2 | 0.14 | II - 0.16 |
| **Athens-03** | | | 11 | 0.30 | 16.1 | 2.1 | 61 | 5.5 | 0.25 | II - 0.16 |
| **Athens-04** | | | 16 | 0.12 | 8.9 | 1.7 | 77 | 4 | 0.11 | II - 0.16 |

(*) Bracketed duration: time span between the first and last acceleration peak >= 0.05g.
(**) Effective peak acceleration after FEMA (1985)
(***) 1995 Seismic Code Zone – proposed effective acceleration

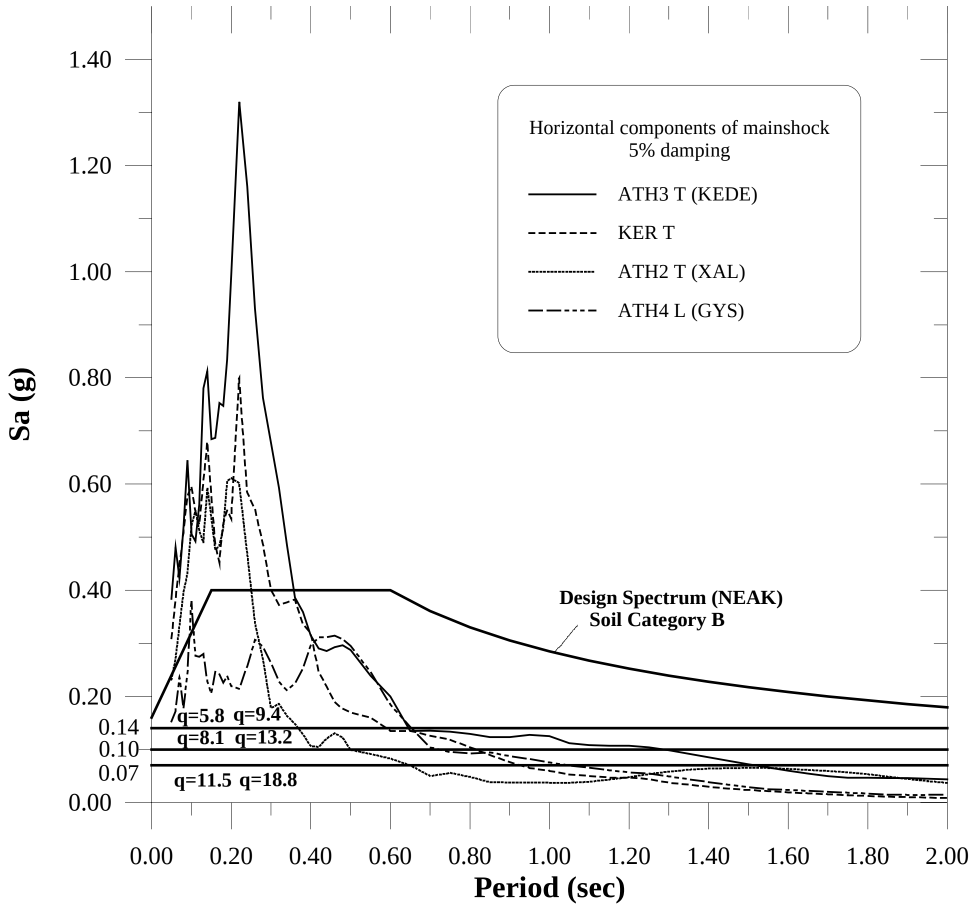


**Figure 3.** Acceleration response spectra (largest horizontal components) of the 7 September 1999 earthquake (Mw 5.9) and comparison with elastic design spectra of the New Greek Seismic Code - NEAK (enforced 1995) and the seismic coefficients of the 1959 and 1984 Seismic Codes.

## STRUCTURAL BEHAVIOUR

### Ductility demands and seismic code provisions

The great majority of buildings in Athens and suburbs were designed with a seismic coefficient of 0.04, 0.06 or 0.98 for firm, intermediate and soft soil conditions, respectively (1959 Seismic Code). The seismic force, assumed constant, was applied uniformly to all buildings irrespective of their individual dynamic characteristics (eigenperiods).

To assess the ductility demands imposed by the earthquake on the buildings of Athens, the normalized peak values of its elastic response spectra are compared with the corresponding design base-shear coefficients, modified to account for ultimate-strength design requirements (Fig. 3). Comparison of the ductility demands, which depend on the ratio between the two above quantities, with what is estimated to be the available ductility reserves of the buildings provided by the code in force shows that the former exceed the latter in the critical period range. The earthquake, as revealed by the response spectra of the recorded motion (Fig. 3), had the strongest effect on low to mid-rise buildings (two to four stories). In this period range (0.2 – 0.4 s), the shaking intensity considerably surpassed the provisions of even the more conservative 1995 New Greek Seismic Code, based on ultimate-strength design. At periods corresponding to buildings with more stories (T > 0.4 s), spectral accelerations decrease rapidly.

### Damage to buildings and lifelines

Part of the material presented in this section is drawn from References [1] and [2].

The typical building stock in the northern suburbs of Athens mainly consists of low and mid-rise (2 – 5 stories) RC buildings, the majority of which were built according to the 1959 Code (without ductility provisions), or, even worse, were illegally built and of poor construction, without conforming even to the minimum requirements of the 1959 Code. This, combined with the indisputable severity of shaking and certain design and construction deficiencies, explains the severity and extent of the damage, including the majority of the 65 collapses. In the municipalities of Ano Liosia, Aharnes, Philadelphia, Metamorfosi and Thrakomakedones there were several collapses of mid- and high-rise buildings built according to the revised 1984 Greek Seismic Code.

Since the earthquake struck during working hours, the greatest number of the deaths were caused due to the collapse of three industrial buildings (Ricomex SA, Fourlis SA and Faran SA) (Photo 1). These facilities were on, or in the vicinity of the banks of the Kifissos river (Chelidonou stream), which apparently greatly amplified shaking (site effects).

In the municipality of Menidi, around the town hall, one could observe typical damage patterns sustained by RC buildings, including several collapses and total failures of concrete frames. Buildings in the area of Thrakomakedones – a district with independent one- and two-story houses – performed comparatively better.


**Photo 1**. Partial collapse of an industrial complex (Faran SA).

Serious damage causing disruption of operation was inflicted on several hospitals, particularly those of Voula, Nikea and Sotiria; milder damage occurred in another 27 hospitals. About 150 school buildings in the broader metropolitan area suffered non-structural damage that, nonetheless, led to interruption of their operation. Some schools even suffered unrepairable damage. In addition, 80 day nurseries belonging to the Health and Welfare Ministry suffered extensive damage, with an additional 18 having to be demolished.

The earthquake also affected monuments. Seriously damaged were the Monastery at Dafni (11$^{th}$ century), the Fortress of Fili (5$^{th}$ century BC) and the wall of Elefsina (5$^{th}$ century BC). Also affected, though repairable, were also a large number of buildings hosting cultural activities or objects of cultural value, including the National Theatre, the National Opera and the Archaeological Museum.

The observed building failures in the meizoseismal area are very similar to those observed in previous earthquakes in Greece (Ref. [3]). Typical examples include: (1) shear failures of short columns (Photo 2); (2) damage due to lack of adequate shear walls, particularly around staircases; (3) damage in columns and failures at joints or even total collapse of buildings with soft ground stories (pilotis) (Photo 3); (4) damage due to insufficient horizontal reinforcement (stirrups) in columns. Moreover, concrete in Ano Liosia was apparently of poor quality. Furthermore, a number of buildings suffered damage due to pounding with adjacent ones (Photo 3). The overall performance of newer buildings (built according to the 1984 and 1995 Seismic Codes) was rather satisfactory.

**Photo 2.** Column failure due to the short-column effect (Fourlis SA industrial complex)

**Photo 3**. Soft ground story (pilotis) collapse of a mid-rise (4 story) building in the municipality of Menidi. Extensive damage on the right side possibly indicates pounding with the adjacent, lower-height building.

A summary of second-level inspection results for the broader metropolitan area of Athens is presented in Table 2, where the buildings are categorized according to their damage state as:

‘Green’: original seismic capacity unaltered, building immediately usable and entry unlimited.

‘Yellow’: decreased seismic capacity, repair work needed; continuous usage prohibited; limited entry at own risk.

‘Red’: unusable – dangerous, decision on demolition upon further thorough inspection; usage and entry prohibited.

***Table 2.*** Results of the second-level seismic inspection (broader Athens metropolitan area)

| | **Bldgs** | **Apart-ments** | **Commer-cial** | **Total Properties** | **Green** | **Yellow** | **Red** |
|---|---|---|---|---|---|---|---|
| **Industrial** | 1325 | 175 | 3542 | 3717 | 2324<br>62.5% | 1294<br>34.8% | 99<br>2.7% |
| **Other property** | 62650 | 186940 | 24698 | 211638 | 118391<br>*55.9%* | 87100<br>*41.2%* | 6147<br>*2.9%* |

Lifelines behaved in general well. No major damages were reported for water, sewage, telecommunication, gas and electricity networks. Bridges and highway overpasses were relatively unharmed, and vehicle circulation was in general problem-free. The most serious problem occurred on a highway overpass in Aspropyrgos (near the epicentral area), on the Athens-Korinthos highway. Damage of the brick cladding around the elastomeric bearings of the piers led local authorities to stop circulation, causing a severe traffic jam, aggravated by citizens trying to flee the city. After an in-situ investigation of the damage by experienced engineers, access to the overpass was allowed about five hours after the event. Noteworthy is the failure of telecommunication networks, stable and mobile alike, to manage the increased number of calls in the first hours following the earthquake.

Like previous earthquakes in Greece to hit urban areas, the Athens earthquake once again revealed the most common factors and design/construction malpractices affecting the seismic resistance of structures (Ref. [1]):

- Sites with poor soils (reclaimed land, river/stream beds, etc.) or irregular topography (hills or abrupt river banks)
- Unauthorized removal of infill walls (or even columns!) to increase usable area
- Soft ground stories (pilotis)
- Inadequate number of shear walls
- Short columns, especially on basement and ground levels
- Staircases without shear wall cores
- Adjacent buildings with unequal height (pounding effect)
- Foundations on different levels, nonuniform basements
- Nonuniform horizontal and/or vertical distribution of stiffness and mass
- Later modifications in load-bearing elements in order to house heating/cooling and drainage systems

**EMERGENCY RESPONSE AND MANAGEMENT**

A large part of the material in this section was presented in Reference [1].

Immediately following the event all human and material resources of the key disaster-response agencies and services were mobilized. The National Emergency Operations Centre at the General Secretariat for Civil Protection was activated, as well as the Operations Centres of critical services, such as the Fire Brigade, the National Centre for Emergency Health Care (EKAB), the Earthquake Planning and Protection Organisation (EPPO). The following emergency operations were conducted (in order of importance):

- Establishing critical communication links and informing the public
- Search and rescue of entrapped persons
- First aid and medical care
- Safety inspection of critical facilities (hospitals, police stations, fire departments, emergency-operations centres, bridges, etc.)
- Traffic control
- Inspection and (re-)operation of lifelines
- Safety inspection of public buildings
- Distribution of drinkable water, food and other items of immediate need
- Installation of sanitary facilities
- Housing provisions

Establishing communication links and informing the population was vital. Police and fire departments, through their radio-communication networks, primarily provided initial information on the situation, as all phone networks, including the cellular ones, were blocked. Disaster-assessment teams, equipped with hand radios, were dispatched all over the stricken area, and helicopters were used for aerial surveys. Volunteers helped to establish radio-communications between disaster-assessment teams and operations centres. The media, particularly TV networks, were very helpful in providing a continuous flow of firsthand information and putting pressure on decision-makers and disaster managers to find solutions to problems. Dissemination of instructions to the public, through the media, on how to behave began within the first hour after the earthquake.

Search and rescue operations were of first priority. Some 1,500 emergency personnel – the Greek Rescue Team, the Fire Brigade, EPPO engineers, EKAB medical personnel – participated in rescue operations of entrapped persons at 32 collapsed building sites. Rescue teams from Cyprus, France, Germany, Hungary, Israel, the Russian Federation, Switzerland and Turkey, as well as numerous volunteers, assisted in the rescue operations, which continued until all entrapped citizens were found.

First aid and medical care were provided in the earthquake-stricken area by medical personnel in mobile medical units and tents belonging to the Ministry of Health and Welfare and the Greek Red Cross. Hospitals and their facilities were also mobilized.

The next day following the earthquake, safety assessment of buildings began, starting with critical facilities (hospitals, bridges, fire stations, etc.) and extending to other public and private buildings. The standard “green - yellow- red” method of rapid inspection of buildings issued by the Earthquake Planning and Protection Organisation (EPPO) in 1998 was used. The operation was coordinated by the Ministry of Environment and Public Works and was carried out by teams of engineers, both public servants and individual volunteers (a total of about 1300 persons). More than 250,000 inspections were performed in the broader area of Athens, with approximately 50% of the buildings deemed unsafe (“yellow” or “red”).

A few weeks later, a second-degree (in some cases even a third degree) damage assessment was conducted for about 220,000 apartments and business premises in about 65,000 buildings. Some 93,000 were found damaged, out of which roughly 6% were characterized as “dangerous – beyond repair” (Table 2). The entire task of damage assessment (both stages) was completed in about two months – a rather satisfactory time span given the size of the building stock inspected.

As already mentioned, traffic was in general problem-free, except for a highway overpass in Aspropyrgos (near the epicentral area), on the Athens-Korinthos highway. Circulation resumed 5 hours after the earthquake, after engineers examined the overpass for safety.

Distribution of drinkable water, food and other necessary items, most of which were donated by food industries, large supermarket chains, etc., was organized and supervised by local authorities.

Accommodating those left without shelter was another priority. Tent camps – with some 8,000 tents – were quickly erected in the stricken areas, while an additional number of 12,000 tents were distributed to individuals. At campsites, free nourishment, communication, medical and sanitary facilities were immediately provided. Enhanced police measures were put in force for the protection of property. A large number of families were accommodated in hotels belonging to the National Tourism Organization (EOT) and the Union of Greek Hotel Owners. In about a month after the earthquake, 70 sites were selected in or near the damaged areas for the erection of about 7,500 semi-permanent houses (containers).

Given the severity and extent of the damage, the overall response of the authorities is deemed satisfactory. As the only major setback one might note the failure of authorities to provide adequate materials and personnel for the immediate propping of severely damaged – and in imminent danger of collapse owing to aftershocks – buildings. This may in part be attributed to a recent transition of the municipal jurisdiction from the central government to local authorities, which were still unprepared to handle such emergency situations.

## FINANCIAL AND OTHER RELIEF MEASURES

Most of the material in this section was adapted from Reference [1].

At the same time, certain financial relief measures were taken by the central government to support individuals and businesses that suffered from the earthquake. Thus a financial aid of GRD 200,000 (580 Euros) was given to over 120,000 families characterized as homeless by the first rapid safety inspection of buildings. Pensioners, workers and unemployed from the areas most stricken by the earthquake, received money cheques ranging from GRD 100,000 to 120,000 (290-348 Euros). The Ministry of Environment and Public Works issued a rent subsidy, from GRD 60,000 to 120,000 (173-345 Euros), for the homeless who lived in rented apartments or houses.

To facilitate repair of damaged property, the state granted owners financial housing assistance, covering 33% of the total repair cost, and provided interest-free loans for the remaining 67%. More specifically, for the reconstruction of houses that either collapsed or were deemed unrepairable (classified as "red"), the owners received a sum of GRD 130,000 (377 Euros) per sq. m. of property (eligible for up to 120 sq. m.). For the repair of houses that were deemed repairable, the relevant amount was GRD 65,000 (188 Euros) per sq. m. Similar measures were foreseen for business premises, churches, etc.

One should also mention the contribution of public utilities companies. The National Electric Power Corporation (DEI) provided free power to the organized tent camps and settlements of prefabricated houses. No electricity bills were issued after 7 September 1999 for buildings damaged by the earthquake. For those living in the earthquake-stricken areas, the Hellenic Telecommunications Organization (OTE) offered free local and long-distance telephone calls from card-phones for a month, suspended the collection of bills from its customers there and provided – free-of-charge – phone transfer and re-connection services.

The Ministry of the Interior approved a sum of GRD 800 million (2.3 million Euro) for supplying air conditioners to provisional houses. In addition, the same Ministry, in collaboration with local authorities, will send 1100 children aged between 6 and 14 from the worst hit areas to summer camps, free of charge.

In areas affected by the earthquake, land-use and industrial-regeneration programs are in progress, with the creation of special industrial zones to which industrial and manufacturing companies will be relocated. In addition, land-use studies are conducted for areas of estimated high seismic risk or where large numbers of illegally built buildings exist.

## CONCLUSIVE REMARKS

With the exception of some extreme cases, attributable to adverse site conditions, design deficiencies or poor construction, the majority of structures responded reasonably well to the admittedly very severe shaking, which exceeded the provisions of the seismic codes. The Athens earthquake thus reconfirmed the well known fact that the existing building stock possesses a substantial amount of strength reserves due to the redundancy and over-strength of individual structural elements, as well as additional energy-dissipation mechanisms usually not taken into account in the design stage. Experience gathered from this and previous events points out the key role of several vulnerability-reducing factors, such as the rational use of infill walls and the regular configuration of structural systems, along with good material and workmanship quality.

Given the extent and severity of the damage, the overall preparedness and response of the central government and local authorities can be rated as satisfactory.

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