THE 1894 APRIL 20 AND 27 ATALANTI EARTHQUAKES: 100 YEARS AFTER - LESSONS LEARNT

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Abstract

A hundred years ago (April 20 & 27, 1894) two consequent destructive earthquakes occurred in Atalanti (Lokris, central Greece), at distances of approximately 90 and 75 km from Athens, with magnitudes 6.7 and 7.0 (epicentral intensity X) and evidence of surface faulting 55 km in length (Galanopoulos, 1960). The isoseismal lines of these two events had a direction NW-SE, reaching intensity VI in Athens. Had these earthquakes occurred today, their consequences on the capital of Greece are examined in the present study.

The sources referring to the two earthquakes are collected and re-evaluated and the distribution of damage is reconstructed through the recently introduced European Macroseismic Scale (EMS), in an effort to re-evaluate the intensities of these historical earthquakes. The contribution of these events to the seismic hazard of Athens is finally determined, taking into consideration the present building situation in the area, i.e. the high degree of vulnerability of modern structures and the large expansion of the metropolis in unfavorable soil conditions, as well as the instrumentally recorded major earthquakes of the area in the 20th century.

Introduction

The area of Atalanti had been a seismically quiescent area for several centuries until 1894. Although it is surrounded by areas well known for their high or moderate seismicity, such as Thivai, Volos, Maliakos gulf, etc., it was not known to have produced any significant earthquakes since 551 or 552 AD. Even after 1894, when the two destructive earthquakes studied here occurred, the seismicity of this area remained at a relatively low level.

On April 20 and 27 1894 two destructive earthquakes, separated by a time interval of one week only, struck the area of Atalanti causing considerable death toll (253 people dead), extended damage in almost all the villages and towns in and around the Lokris area and economic problems for the country. Had the area been more densely populated, these effects would have increased at a serious degree for the whole country.

At that time Greece was already equipped by seismoscopes and macroseismic observations were in some cases quite well organized. Apart from local reports concerning these earthquakes, and due to the existence of long surface ruptures and earthquake related geological effects mainly after the second earthquake, detailed field observations were carried out by the seismologists and geologists shortly after the events.

From the damage reports and the extent of the felt area, as well as from reports from the European seismological stations, it was assumed that the first event was a foreshock and the latter was the mainshock (M=6.7 and 7.0, after Papazachos and Papazachou, 1989), both followed by numerous aftershocks that continued for several days and months. Due to the vicinity in time between the two events, the macroseismic intensities assessed from them in many cases are considered to be cumulative. It is also noteworthy that no foreshock activity was observed.

In the present study an attempt is made for the assessment of the macroseismic intensities of these two earthquakes, using the EMS92 scale, from localities in which detailed and specific

information is given for each event. In addition, and since a repetition of such magnitudes would be a potential threat for Athens in the future, their seismic hazard with respect to the capital is estimated, taking into consideration its expansion in area and height due to the increase of its population within the 100 years that have passed since.

Seismicity and seismic background of the area

The area of Atalanti is not known to have suffered from strong historical earthquakes. One earthquake in 426 BC., with epicentre further to the north, in Maliakos gulf, mentioned by Thucydides and Strabo, destroyed villages and killed thousands. Another strong event in 551/2 AD. in Boeotia, which also destroyed several towns and killed many, can be considered to have affected the studied area. In any case none of these earthquakes are associated to the Atalanti epicentral area.

Mitsopoulos (1895) notes that the Lokris area must have been a seismic quiescent area for a long time, since the Ayios Yeoryios monastery in Malesina which was built in 1512 and was destroyed during the 1894 earthquakes, had not suffered any damage from earthquakes in its history.

After the 1894 earthquakes the seismicity of the area followed the pattern of long quiescence as far as strong earthquakes are concerned. Figure 1 shows the distribution of seismic epicentres with magnitudes greater than 4.0 for the period 1900-1994 in the broader area of Atalanti (Makropoulos et al.; 1989). Although some small events are observed near the Atalanti fault, very few are located along and around it.

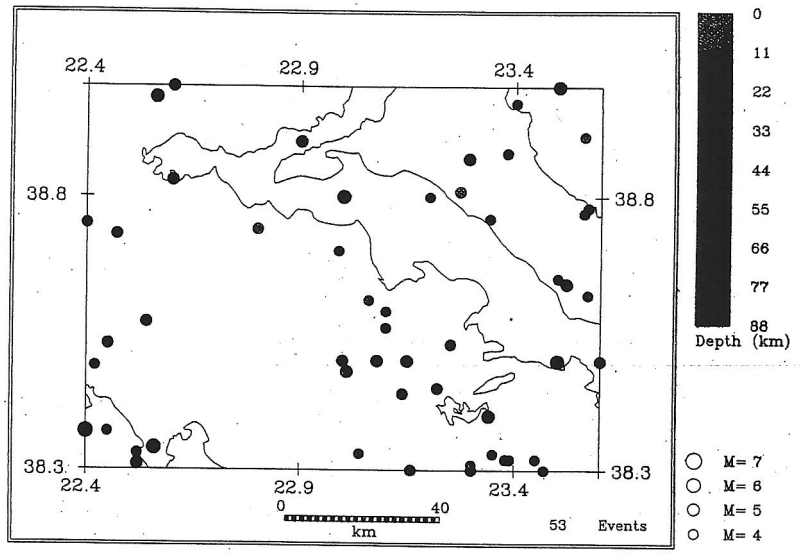

Figure 1: Earthquakes since 1900 in the area of Atalanti

Similar results were obtained during a two-month microseismicity survey carried out in the area in 1981, together with a microgravity survey (Lagios et al.; 1987). Again the number and magnitudes of the events detected by a local 5 station network installed along and around the fault were found to be at significantly low levels.

The local digital seismic network VOLNET, operating in the area of eastern central Greece (Volos-Almiros-Atalanti) since 1983, records the seismicity of the studied area, which has been found to be the lowest within the network, although the lowest magnitude detected is M=0.9.

Tectonic, geological and other related effects of the 1894 earthquakes

Liquefaction of the coastal plain and slumping of shore into the sea in some places along the Atalanti gulf were observed after the foreshock. Ground cracks in the valley, landslides and rockfalls between Proskina and Atalanti are also associated with this earthquake.

The mainshock caused surface faulting from Martino to Atalanti, i.e. a distance of about 25 km (Ambraseys and Jackson, 1990). Field reports indicate normal faulting, landslides, and a series of short scarps suggesting an extension of the rupture zone for another 15 km. Liquefaction was observed up to 40 km from the epicentral area, and a seismic sea-wave flooded the coast of the gulf of Atalanti. Another effect was the significant increase of the level of the hot springs in Loutra Aidhipsou.

Macroseismic intensity assessment and distribution of the 1984 earthquakes

The earthquakes of 1894 are characterized as major events and they are listed in european and international earthquake catalogues (e.g. Montandon; 1953, Richter; 1958, etc.), as well as in all historical earthquake catalogues and relevant studies of Greece (e.g. Galanopoulos; 1960, Papazachos and Papazachou; 1989, Ambraseys & Jackson; 1990, etc.). Ample information was derived from reports compiled by field investigators shortly after the earthquakes, who described them in detail and surveyed the area affected (e.g. Mitsopoulos; 1895, Skouphos; 1894, Papavassiliou; 1894a,b, etc.). The neotectonic features and changes that arose after the earthquakes have also been studied in detail (Lemeille, 1977).

In this study the assessment of macroseismic intensity was attempted using the more detailed of all the available reports on the earthquakes (AONA; 1899, Mitsopoulos; 1895 and Papavassiliou; 1894a). In the Annales de l' Observatoire d' Athenes, localities and damage reports are given in great detail in some cases, as well as the time of occurrence of the earthquake in each locality, with the unavoidable uncertainty in time due to the subjective judging of time by the local observers. Tectonic and geological features are also briefly described. The report of Mitsopoulos, compiled during field observations, contains more detailed damage reports from the affected area near the epicentre. In both cases the foreshock of April 20 is better described than the earthquake of April 27, since any damage reported relating to the mainshock could be considered to be cumulative, especially at and near the epicentral area. Finally, the study of Papavassiliou (1894a) was used only for information on damage at the village Ayia Anna concerning the foreshock.

In the above sources the dates of the events may appear as 8/20 and 15/27. This was due to the change of calendars from Julian (8 and 15 April) to the Gregorian (20 and 27 April), according to which 12 days should be added to the dates in the 19th century. Also the time reported is the local time, which is here corrected to GMT by subtracting two hours.

Tables I and II contain the summary of information on the two earthquakes, as derived from all studies, as well as the time of occurrence in each locality. For the foreshock, which was not preceded by any increase of background seismicity of the area, uncertainties on whether this earthquake was felt in some localities away from the epicentre are very low. In the case of the mainshock, and because in the area affected by the foreshock tremors were felt during the whole time span between the two strong shocks, it was more difficult to distinguish whether the mainshock was felt in one locality or whether this was one of the aftershocks of the strong foreshock, overestimated by the local observers who had already been surprised by the foreshock. This problem is also increased by the fact that the time of the earthquake reported from each locality was rather subjective.

LOCALITY	TIME	EFFECTS	IEMS92
Athens	16:52:30	Two strong shocks, one of 3-4 sec duration the other of 5-6 or 6-7 sec duration Some houses were cracked A stone was dislodged from Adrian's Arch, the capital of an old column in the Agora was thrown down Felt by few outdoors, by many indoors Many people run out of the houses	5-6
Larisa	16:55	Weak shock, 3 oscillations	3
Patras	16:55	Two successive shocks of 10 sec duration in a W-E direction, vibration	4?
Thivai	16:55	Some workers were injured, one woman was killed Very strong shock Some houses collapsed, serious damage	7
Syros	16:58	Shock	2
Xerokhori	17:00	Very strong shock In Berdini, large stone blocks fell down	4
Delfi	17:00	Strong shock of 9 sec duration	4?
Amphissa	17:00	Very strong shock of 7 sec duration Some walls partly collapsed	5-6
Divri	17:00	Two strong shocks	4?
Volos	17:00	Very strong shock (or two shocks) with vibration, direction N-S	4?
Ayia Anna	17:00	Strong shock of 5 sec duration, subterranean noise 30 houses collapsed Several houses were cracked	9
Khalkis	17:00	Shock with vibration Many houses destroyed Most houses came tumbling down Some houses collapsed Serious damage	8-9
Molos	17:10	Very strong shock of 4 sec duration Some houses were cracked	5
Pireus		Some roofs, chimneys and walls fell down The bells of two big churches rang	6
Skala (Kato Pelli)		Four people dead Almost all of the 25 houses along the coast collapsed The 50m long and 8m wide pier partly submerged The houses were destroyed from their foundations or suffered serious damage	11
Atalanti	16:50?	Very strong shock The houses were destroyed from their foundations or suffered serious damage	10
Ano Pelli		The houses were destroyed from their foundations or suffered serious damage	10
Skender Agas		The houses were destroyed from their foundations or suffered serious damage	10

Arkitsa		The houses were destroyed from their foundations or suffered serious damage	10
Livanates		The houses were destroyed from their foundations or suffered serious damage, Great damage Out of 1021 inhabitants 5 dead and 20 injured	10
Kiparissia		The houses were destroyed from their foundations or suffered serious damage Great damage Out of 183 inhabitants 4 dead	10
Proskinas		The houses were destroyed from their foundations or suffered serious damage Out of 516 inhabitants 45 dead. Terrible subterranean noise coming from the coast The church of the village collapsed Complete destruction	11?
Malesina		The houses were destroyed from their foundations or suffered serious damage Out of 951 inhabitants 131 dead Not one of the 300 houses was left intact Complete destruction	11?
Ayios Yeorgios Monastery (Malesina)		Subterranean noise coming from the sea The eastern and western walls of the church and of the monastery cells partly collapsed	9?
Mazi		The houses were destroyed from their foundations or suffered serious damage	10
Martino		All the 450 houses were destroyed from their foundations or suffered serious damage Out of 1434 inhabitants 33 dead Great damage, complete destruction	11?
Livadhia		Serious damage	8?
Kastri		Terrible subterranean noise Collapse of walls and houses	8?
Limni	16:50?	Strong shock of 6 sec duration with vibration Some houses were cracked Serious damage	5
Aidhipsos		Serious damage	8?
Yialtra		Serious damage	8?
Petromagoula		Many houses collapsed	9?
Karia		Many houses collapsed	9?
Vrantza		Many houses collapsed	9?
Ayios Dhimitrios		Many houses collapsed	9?
Topolias		Two rail workers were killed	8?
Drakhmanio		Few houses collapsed	8
Dadhi		Shaken but no damage	4
Loutra Aidhipsou		Shaken but no damage	4

Table I: List of localities, related effects and assessed intensities of the April 20, 1894 earthquake

LOCALITY	TIME	EFFECTS	I_{EMS92}
Athens	19:21:06	Some persons standing outdoors were shaken strongly Ground shaking largely observed Rocking of buildings Minor and major cracks were observed in some governmental buildings	6
Thivai	19:20	Destructive earthquake	9?
Trikala	19:20	Very strong shock	4?
Ayia	19:25	Shock of 5 sec duration	3-4
Atalánti	19:30	Very strong shock Major tectonic effects 16 houses collapsed Was turned inhabitable, terror	11
Nafplion	19:30	Shock with vibration at a N-S direction and a medium duration	3-4
Ayia Anna	19:30	Strong shock Almost all houses suffered serious damage	8-9
Livadhia	19:30	Very strong shock	4?
Acrata	19:30	very strong shock of 5 sec duration	4?
Drakhmani	19:30	Strong shock Several houses collapsed or were cracked	8
Aitoliko	19:30	Very strong shock of 11 sec duration	4?
Santorini	19:30	Weak shock	3
Andros	19:35	Two shocks, the second stronger than the first	3-4
Megara	19:40	Very strong shock	4
Khalkis	19:30	16 houses collapsed, the church of Ayia Paraskevi came tumbling down Houses were cracked	8
Lamia	19:10?	Many houses were cracked	6
Ayios Konstantinos & Monastery		Completely destroyed Four people dead	11
Akhladi		At least two houses suffered serious damage	7
Aidhipsos		Great damage	9?
Yialtra		Great damage	9?
Loutra Aidhipsou		No damage	4
Molos		Houses were cracked	5
Stylida		Houses were cracked	5
Dilesi		Houses were cracked	5
Regginio		Houses were cracked	5
Komnina		Houses were cracked	5
Livanates		Houses were cracked, some houses collapsed	8
Skender Agas		Completely destroyed	11

Table II: List of localities, related effects and assessed intensities of the April 20, 1894 earthquake

In the column "effects" the summary of description appears to be repeated in some cases (e.g. in Khalkis, for the event of April 20). This is due to the different description of damage in the different sources, and the intensity is then assessed using the total available information.

The macroseismic intensity assessment was based mainly on damage reports, when these were considered enough to estimate the degree of intensity. The scale used was EMS92 (Gruenthal et al.; 1993), according to which the vulnerability class of the buildings near the epicentre usually did not exceed B in the best case. This was derived from the description of the buildings by Mitsopoulos (1895), which were built with bricks and mortar, with a rather unstable primitive wooden frame. Only the governmental buildings in Athens that have been reported for damage might reach class C. The geological and tectonic observations were used for calibration of the assessed intensities in some localities near the epicentre.

For remote localities the information on how the earthquake was felt was not satisfactory in all cases. For example, the duration of shaking was of no importance for the intensity assessment. On the contfary, information such as " ... many people were frightened ... run outdoors ..." etc., are included in the description of EMS92, and therefore useful for analysis.

In the cases where the information was not considered enough for the assessment of an intensity, or it gave a rough idea of the degree of intensity, a value between two intensity degrees or the symbol ? was used in the column I_{EMS92} of the tables.

Figures 2a,b and 3a,b show the intensity distribution of the two studied earthquakes a: in the whole felt area, b: in the epicentral area.

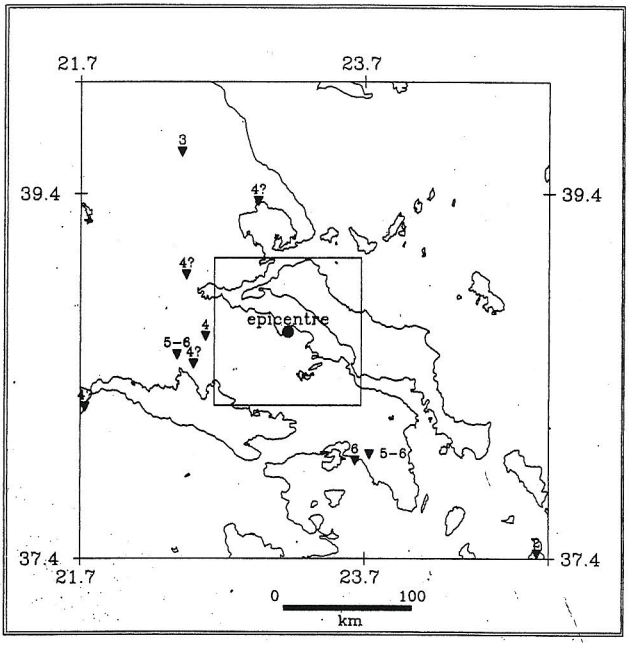

Figure 2a: Distribution of the regional effects of the April 20, 1894 earthquake

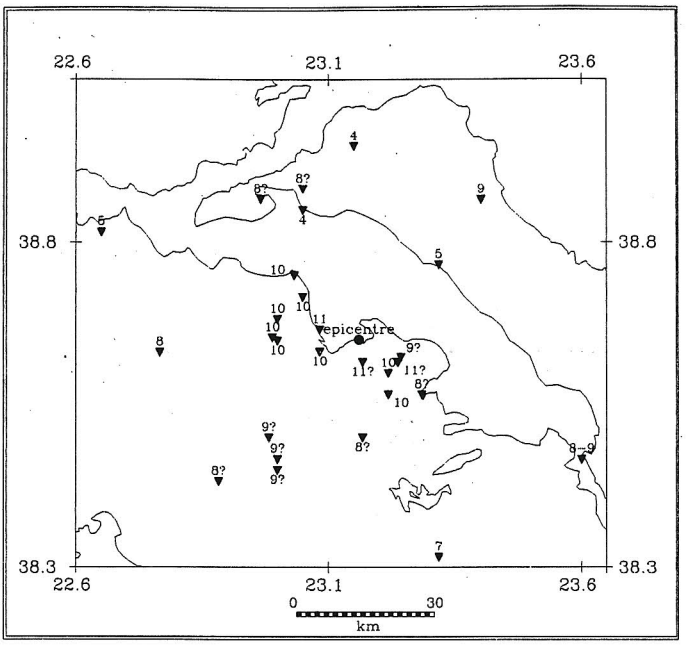

Figure 2b: Distribution of the effects in the epicentral area of the April 20, 1894 earthquake

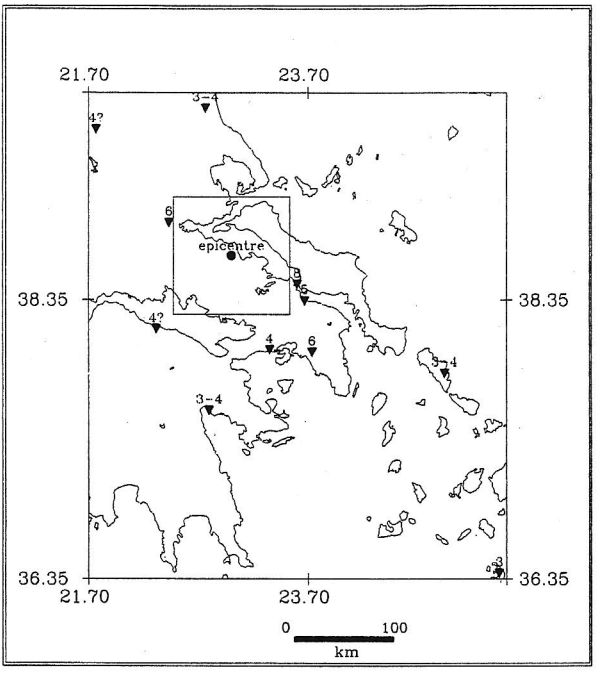

Figure 3a: Distribution of the regional effects of the April 27, 1894 earthquake

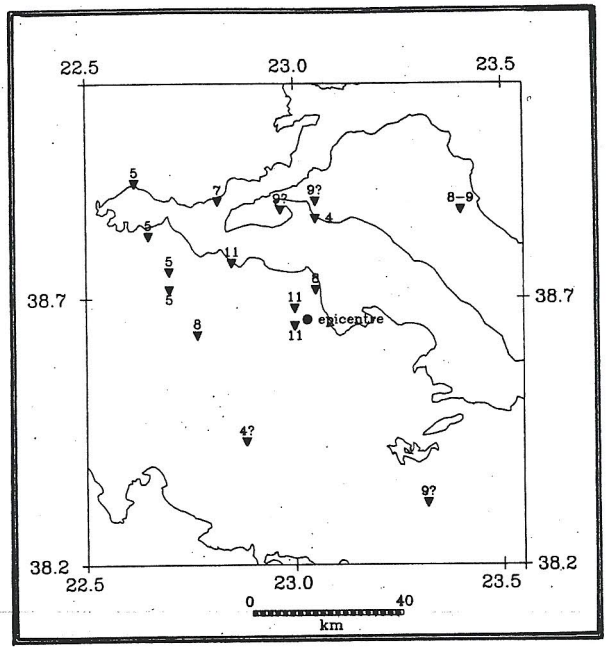

Figure 3b: Distribution of the effects in the epicentral area of the April 27, 1894 earthquake

Impact of the 1894 earthquakes to Athens

Both 1894 earthquakes had a considerable impact on the capital, which, at that time was considered to be a large town (population 140,000), rather than a city. Most of the houses were distributed around the Acropolis and Plaka, and Constitution Square was the most frequently visited place. All these sites are situated on limestone, and perhaps this is the reason why the centre of town has not suffered significant damage from earthquakes in its long history. On the contrary, Piraeus, the port, is located on alluvial coastal deposits, where the earthquakes were more felt.

As it is assumed from tables I and II, the intensity of these two earthquakes in Athens, i.e. at 89 and 75 km distance respectively, did not exceed degree 6 of EMS. However, the changes that have occurred within the 100 years between 1894 and a supposed earthquake with the same parameters today, can imply that the intensity of such an earthquake would be higher.

Within this time period Athens has expanded on unhealthy soils in the north, south and west of the centre, due to the increase of its population. In addition, several high rise buildings have appeared in the last 20 years, more vulnerable to distant earthquakes as their natural frequencies are very near to those of seismic waves expected from this distance from major earthquakes.

The average peak ground accelerations (in cm/sec^2) that would have been recorded in Athens due to the two Atalanti earthquakes, can be derived from the empirical equation:

$$PGA = 2164e^{0.7M}(R+20)^{-1.8} \quad (1)$$ (Makropoulos and Drakopoulos, 1984)

In this equation, using the magnitudes of the studied earthquakes assessed from maximum intensities, as well as the depth of the earthquakes (R refers to hypocentral distance, the depths of the foreshock and mainshock were assessed from macroseismic data at 10 and 6 km respectively, after Ambraseys and Jackson; 1990), the obtained values of PGA for Athens are

given in table III. The equation provides values of peak ground acceleration referring to hard rock conditions, i.e. the centre of Athens. In soft soils the average amplification reaches 20% of PGA, and therefore the estimated values for soft soils are also presented in table III.

Event	M	I	a_{hard}	a_{soft}	a_I
20 April 1894	6.7	5-6	50	60	52
27 April 1894	7.0	6	80	96	76

Table III: Estimated values of average peak ground acceleration and average acceleration (in cm/sec^2) using equations (1) and (2) for the two Atalanti earthquakes

Acceleration related to a certain degree of intensity can also be derived from empirical equations relating the above two quantities, supposing that such equations are reversible. Thus, the accelerations in Athens corresponding to intensities 5+ and 6 (table III), can be obtained from:

$$\log a = -0.04 + 0.32I \quad (2) \quad \text{(Papaioannou; 1984)}$$

Discussion

Earthquakes of the same size as the 1894 events from the same epicentral area have not been repeated. However, their study provides interesting points that need to be taken into consideration when dealing with historical earthquakes.

For the intensity assessment of these earthquakes it is assumed that for the lower degrees of intensity (up to degree 7), few or negligible differences were found between the two macroseismic scales (MSK-64 and EMS92). In the higher intensities a difference of one degree was found in many cases. It is stressed here that one should be conservative when dealing with such intensities, as the information on damage and the vulnerability of buildings should be very detailed, a fact not common in all historical earthquakes. In tables I and II intensities 10 and 11 may be close to reality, but they may also be an overestimation of the effects, especially when cumulative damage is evaluated. The question mark was inevitable in many cases, and usually it suggests that probably the intensity was lower.

The tectonic and geological effects used for calibration were found in agreement with the intensity values assessed in the area where they were observed. The distribution of these effects parallel to the coastline follows the distribution of the high intensities. The intensity distribution of both earthquakes form an epicentral area of a strongly elliptical shape, elongated in a NW-SE direction approximately (figures 2a,b and 3a,b). These distributions are in accordance with the existing isoseismals of the two earhtquakes published in the Unesco atlas of isoseismals (1974).

Intensities 5-6 and 6 in Athens imply values of acceleration near 100 cm/sec^2. The differences in the acceleration values obtained for Athens can be explained be the fact that both equations (1) and (2) take into consideration a uniform release of energy in all directions from the epicentre, and therefore the obtained values of PGA and a_I respectively are average values. In any case, if the earthquakes occurred today, in some parts of the city accelerations would be at least 20% higher than the accelerations that would have been recorded 100 years ago.

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