

SEISMIC HISTORY OF PELLA AND THE 1ST CENTURY B.C. EARTHQUAKE

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Abstract

Research and evaluation of past and recent seismic records is required in order to obtain an overall picture of the seismic history of a given region. To this aim, important information can be collected through the study of monuments and the damage that they may have experienced during their history. Consequently, the archaeological reports on a hitherto unknown earthquake of the 1st century B.C. in Pella (northern Greece) are particularly interesting. These reports are based on the findings that came to light after the excavations of I.Akamatis in the region where the ancient town of Pella was laying. Beginning with this earthquake, this study tries to reach useful conclusions on the seismicity of Pella, in terms of macroseismic intensities from all earthquakes that have affected the town. For all these events, the intensity attenuation relations were used to calculate the macroseismic intensity in Pella. Although it is known a priori that the area is characterized as a relatively low seismicity area, the picture of its seismic history indicates the existence of damaging earthquakes with relatively large return periods. More specifically, in Pella the maximum observed intensity was found to be 7/8 during its seismic history, indicating the picture of low-to-moderate seismic hazard in the region.

Key words: historical earthquakes, seismicity, Pella.

Περίληψη

Η έρευνα των παλαιότερων και πρόσφατων σεισμικών καταγραφών και η εκτίμησή τους είναι απαραίτητη για την ολοκληρωμένη εικόνα της σεισμικής ιστορίας μίας περιοχής. Σημαντικά στοιχεία για τέτοιου είδους μελέτες προέρχονται από τη μελέτη των ιστορικών μνημείων και τα πιθανά αίτια των καταστροφών τους κατά τη μακρόχρονη διάρκεια ζωής τους. Τα ιστορικά στοιχεία που αποκαλύφθηκαν σχετικά με ένα πιθανό σεισμό στην αρχαία Πέλλα τον 1^ο αιώνα π.Χ. περίπου αποκτούν ιδιαίτερο σεισμολογικό ενδιαφέρον. Τα στοιχεία προέρχονται από ανασκαφές που πραγματοποίησε ο Ι. Ακαμάτης στην Αρχαία Πέλλα. Στην παρούσα εργασία η έρευνα ξεκινά με το σεισμό αυτό και, ακολουθώντας σύγχρονες μεθόδους έρευνας ιστορικών σεισμών σε συνδυασμό με την ανάλυση των σεισμών της περιοχής κατά τον 20^ο αιώνα, υπολογίστηκαν οι μακροσεισμικές παράμετροι των ιστορικών σεισμών και η αντίστοιχη ένταση στην πόλη της Πέλλας. Η μεθοδολογία περιελάμβανε τον υπολογισμό της μακροσεισμικής έντασης στην Πέλλα για κάθε σεισμό της ευρύτερης περιοχής που μελετήθηκε, με τη χρήση των μακροσεισμικών σχέσεων εξασθένησης. Παρότι είναι γνωστή εκ των προτέρων η σχετικά χαμηλή σεισμική επικινδυνότητα της

The seismic activity in northern Greece is related to an extensional deformation in N-S direction that causes strike faulting in E-W direction, dipping to the north or south. However, the faulting pattern in Central Macedonia is complicated, including strike faults of significant dip and different directions: (a) strike faults in a general E-W direction with branches deviating in ENE-WSW to ESE-WNW directions (e.g. seismic faults of Sohos, Stratoni, etc), (b) SE-NW strike faults (e.g. Assiros-Analipsi-Scholari fault zone) and, (c) NE-SW strike faults (north Almopia fault zone, seismic fault of Griva-Goumenissa). It should be mentioned that the E-W faults are the most active.

In particular, in Pella district, the fault of Edessa with direction NE-SW is related to two strong earthquakes in 1395 ($M=6.7$) and in 1990 ($M=6.0$). In addition, the Anthemountas fault zone, located to the southeast of Pella in direction SE-NW, was activated during the earthquakes of 1677 ($M=6.2$) and 1759 ($M=6.3$), which also caused damage to the town. Finally, the earthquakes of 896 ($M=6.0$) and 1211 ($M=6.4$) are related to Veroia fault, to the southwest of Pella (Papazachos and Papazachou 2003).

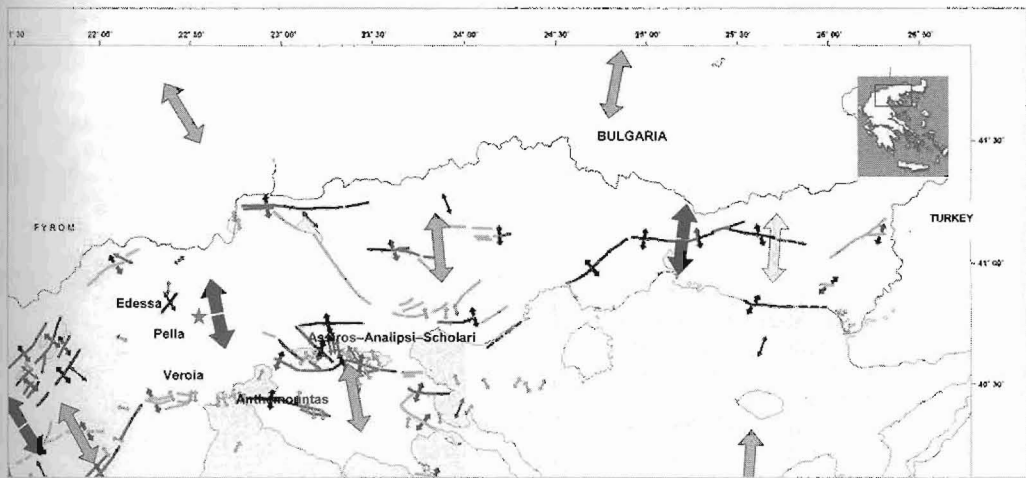


Figure 2 - Major faults in N. Greece, directions of tensional stresses from seismological data (green arrows) and tectonic data (black arrows) (www.geo.auth.gr/871/, modified)

3. Historical background: Pella, Capital of the Macedonian Kingdom

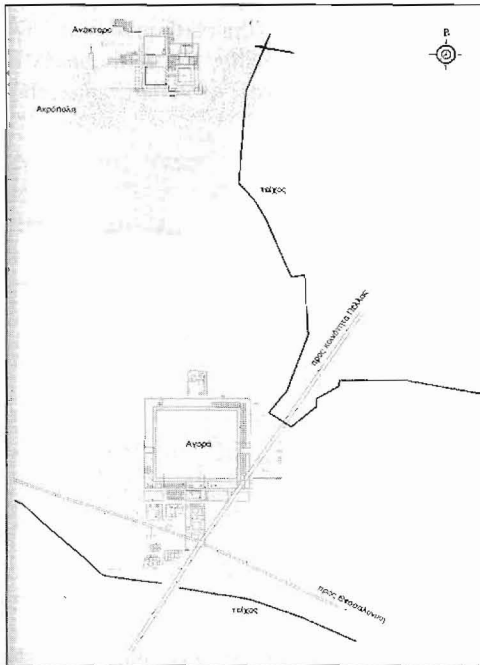
In the beginning of 4th century B.C. Pella was the capital of the glorious Macedonian kingdom. Birthplace of King Philippos II, Pella was expanded and flourished during his reign, becoming the cultural centre of the Greek world. In 168 B.C. it was surrendered to the Romans, but remained one of the most illustrious towns of Macedonia even after the dissolution of Macedonian Domain.

Earthquakes, the intense economic crisis at the time, but, mainly, the foundation of Colonia Pellensis, i.e. the roman county of Pella to the west, where today Nea Pella can be found, contributed to the demise of the Hellenistic kingdom capital. During the Ottoman domination, the ruins of the ancient town became the ideal source of building material for the construction of nearby Giannitsa town.

The first excavations began in 1914, but were halted due to the outbreak of World War I. In 1957 an accidental dig revealed the ruins of the Macedonian capital and since then research has continued until today. Some of the early discoveries were the Pella famous mosaics, which, today, are exhibited in the local Museum. Progressively an entire Hellenistic town was revealed with its palace, private residences, temples and cemeteries.

3.1. The Agora of Ancient Pella - Reports on the 1st Century B.C. Earthquake According to Archaeological Excavations

In ancient Greek world, the Agora represented the centre of political, economic, religious and cultural life of every town. The building complex of the Agora of ancient Pella was discovered in 1980 during the widening of the road that leads from the archaeological area to the town of Nea Pella. The excavation, which has been carried out until now under the surveillance of professor Akamatis, revealed an imposing complex of buildings and galleries situated around a square, occupying an area of ten building blocks in the ancient town (Figs 3, 4).



Figures 3, 4 - Plan of Ancient Pella. The Agora is located in the centre, while the acropolis and palace are situated to the north (left). Part of the Agora (right) (Touratsoglou 1995)

The discovered remnants, and the place where they were found, led the archaeologists to the conclusion that the destruction of ancient Pella complex was the result of a violent natural cause, probably an earthquake. In particular, the configuration of the destruction layer in many places shows a hasty abandonment and researchers assume that the owners did not have the time to salvage their precious belongings, which were found irregularly stacked on the floors. Moreover, these objects did not bear any signs of burning, so a fire disaster could not be justified. Sealed handholds, roman currency and a treasure of a hundred Athenian four-drachma coins buried under the lower floor of an ancient building helped the archaeologists to place the event towards the end of the first decade of 1st century B.C. More recent discoveries of sealed amphora justify this interpretation (Akamatis 1992). Finally, in the Pella Agora, a small kiln was also found, which was full of Venus statuettes and busts, and was later related to the 90 B.C. earthquake (Akamatis 1999).

An independent testimony that supports the above dating of the earthquake at around 90 B.C. comes from the archaeologist M. Siganiidou, according to whom, a group of eleven people was found buried under the ruins next to the entrance of a residence in the ancient town (Steiros and Jones 1996).

The following study of Pella seismic history will help us to correlate all the seismic records and to verify whether an earthquake capable of causing such destruction, is really possible to be generated in that area or not.

4. Methodology for the Analysis of Seismic Data

In order to study the seismic history of Pella, all the available earthquake records with sufficient data were collected and analysed. The data assembled were distinguished in two groups:

- Historical earthquakes from antiquity up to the end of 19th century.
- 20th century earthquakes, which were separated in two subclasses,
 - Earthquakes of first half of 20th century (1900-1950) and,
 - Earthquakes of second half of 20th century (1951-2000)

In each case we applied a different method of analysis in order to achieve the best possible accuracy of results. However, it should be stressed that seismic records of strong and destructive earthquakes with their epicentre in Pella are very rare, at least so far. Therefore, earthquakes with epicentres in a broader area around Pella, (i.e., an area of 90-km radius), but likely to have damaged the town of Pella were taken also into account. Thus, the epicentres of the earthquakes that have occurred in the study area lie within the coordinates 40°-41.5° and 21.2°-23.5°.

4.1. Analysis of 20th Century Earthquakes in the Region of Pella

For practical purposes, the processing commenced with the second half of 20th century earthquakes, which present a considerable number of macroseismic observations, in order to obtain the necessary empirical relations that will be used for the analysis of the other groups of earthquakes. Macroseismic intensities and information was collected from the seismological bulletins of Geodynamic Institute of National Observatory of Athens.

4.1.1. Earthquakes of the Second Half of 20th Century (1951-2000)

In order to study the earthquakes of this period the following process was applied:

- For each earthquake the coordinates of the locality with maximum intensity were adopted for the epicentre (when more localities with maximum intensity appeared, their spatial mean represented the epicentre).
- Distance Δ of each locality from the macroseismic epicentre was calculated, taking into consideration both the geoid and Earth curvature.
- The intensity attenuation relations $\psi = f(\Delta)$ or $I - I_{max} = f(\Delta)$, were constructed (I_{max} being the maximum intensity of each earthquake), as follows (equation 1):

$$I = I_{max} + [\alpha * \ln(\Delta) + \beta] \quad (1)$$

- Through the above relation, by replacing Δ with the epicentral distance of Pella, the expected intensity of each earthquake in Pella itself was calculated.

It should be noted that the foreshocks and aftershocks of the main events were not included in this analysis.

The date and origin time of each mainshock, macroseismic epicentre coordinates, latitude and longitude, the epicentral distance, Δ , of Pella, the macroseismic intensity attenuation equation and, finally, the calculated macroseismic intensity in Pella I_{Pcal} are listed in Table 1. R^2 is the correlation coefficient. When available, the observed macroseismic intensity in Pella I_{Pobs} is also included.

Taking into account the results of the above analysis, equation 2 was obtained; it indicates the general attenuation relation of macroseismic intensity for the earthquakes of the study area in the second half of 20th century:

$$I = I_{max} + [-1.085 \cdot \ln(\Delta) + 1.076] \quad R^2 = 0.501 \quad (2)$$

The above relation will be used for the analysis of the earthquakes of the first half of 20th century (1900-1950), as well as the historical earthquakes.

Table 1 - Intensity Attenuation Relations (1951-2000) and Pella Macroseismic Intensities

Date	Time	Lat°	Lon°	Δ[km]	$I = I_{max} + [\alpha \cdot \ln(\Delta) + \beta]$	R ²	I _{Pcal}	I _{Pobs}
1955 JUN 09	23:54	40.83	22.28	10.3	8.0+[-0.80·ln(Δ)-0.04]	0.61	6.0	
1958 MAR 15	06:28	40.63	21.26	108.79	7.0+ [-0.88·ln(Δ)+0.92]	0.58	3.8	
1958 JUL 17	05:37	40.72	23.39	72.62	7.0+[-1.27·ln(Δ)+2.14]	0.68	3.7	
1960 JUL 13	13:01	40.52	23.45	82.13	8.0+[-1.06·ln(Δ)+0.94]	0.76	4.3	
1974 JUN 22	23:30	41.22	22.93	60.44	6.0+[-0.71·ln(Δ)+0.66]	0.56	3.7	
1978 MAI 23	23:34	40.66	23.32	67.60	7.0+[0.83·ln(Δ)+0.73]	0.67	4.2	
1978 JUN 20	20:03	40.66	23.26	62.37	8.5+[-1.12·ln(Δ)+1.12]	0.63	5.0	4.0
1979 SEP 25	01:41	40.82	22.35	16.44	6.5+[-0.32·ln(Δ)-1.41]	0.35	4.2	4.0
1980 JUN 02	04:22	40.83	22.33	18.58	6.0+[-0.90·ln(Δ)+0.96]	0.59	4.3	3.5
1980 AUG 24	17:38	40.83	22.35	17.13	5.0+[-0.08·ln(Δ)+0.82]	0.99	3.9	
1984 FEB 19	03:47	40.63	23.35	70.65	6.0+[-0.53·ln(Δ)+0.49]	0.34	4.2	
1984 JUL 09	18:56	40.78	21.95	49.63	7.0+[-0.75·ln(Δ)+0.52]	0.44	4.6	
1984 OCT 25	14:38	40.18	21.72	95.41	7.0+[-0.56·ln(Δ)+0.25]	0.30	4.7	
1986 FEB 18	14:33	40.80	22.05	40.99	6.0+[-0.20·ln(Δ)-0.89]	0.28	4.4	4.0
1990 DEC 21	06:57	40.92	22.36	22.45	7.0+[-1.09·ln(Δ)+1.08]	0.50	4.7	5.0
1994 SEP 01	16:12	40.84	21.33	102.16	6.0+[-0.83·ln(Δ)+1.36]	0.46	3.5	4.0
1995 MAI 13	08:47	40.10	21.60	108.33	9.5+ [-0.96·ln(Δ)-0.80]	0.58	4.2	4.0

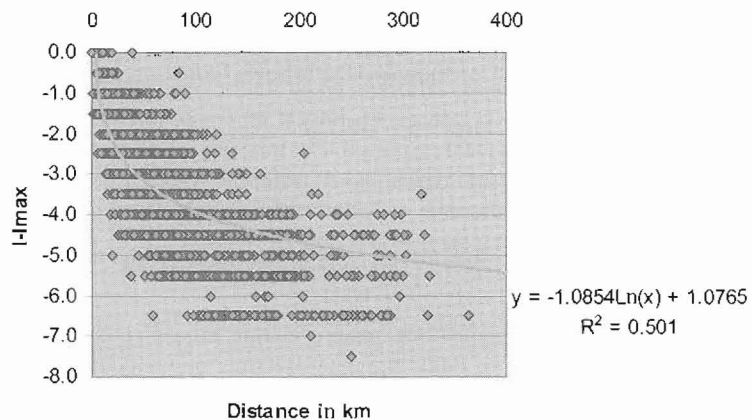


Figure 5 - Relation $\psi = f(\Delta)$ or $I - I_{max} = f(\Delta)$ for all Earthquakes of period 1951-2000

4.1.2. Earthquakes of the First Half of 20th Century (1900-1950)

For the earthquakes of this period, a smaller number of macroseismic data is available and intensities are given either descriptively or numerically, in the Rossi-Forel scale. In the latter case, before proceeding to the analysis, it was considered necessary to convert the RF values into the MSK-65 scale (Sakkas 2006), in order to obtain a homogenous data set.

For the earthquakes of the period 1900-1950, the following method was applied:

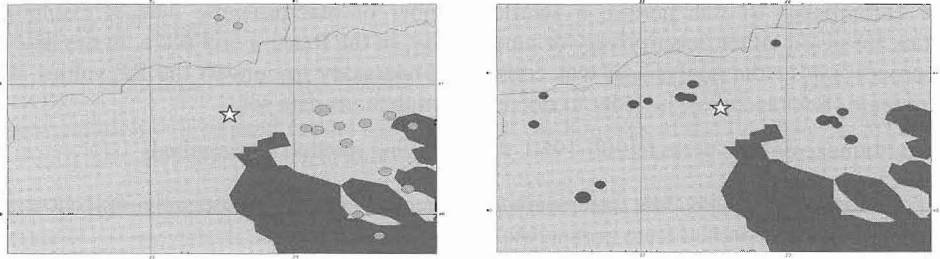
- For each earthquake, the microseismic epicentre (the macroseismic epicentre is not available) was adopted from parametric earthquake catalogues.
- Distance Δ of each locality from the epicentre was calculated, taking into consideration the geoid and the curvature of the Earth.
- The distance, Δ , of Pella from the epicentre was replaced in Equation 2, in order to evaluate the expected intensity in Pella. The use of attenuation relation (2) was considered necessary, due to the lack of adequate macroseismic data in this period.

It should be noted that, as the main events of the study area in the period 1900-1950 were relatively few, the foreshocks and aftershocks with maximum intensity $I_{max} \geq 5.5$ were also included in the analysis.

Date and origin time of each event, microseismic epicentre latitude and longitude, the epicentral distance, Δ , of Pella, maximum intensity I_{max} and the corresponding calculated microseismic intensity in Pella I_{Pcal} , resulting from eq. (2), are listed in Table 2.

Table 2 - Parameters of the Earthquakes of the period 1900-1950 and intensities in Pella

Date	Time	Lat°	Lon°	Δ (km)	I_{max}	I_{Pcal}
1902 JUL 05	14:32	40.80	23.20	56.50	9.0	5.7
1923 DEC 05	20:57	39.84	23.60	137.07	6.8	2.5
1929 DEC 20	20:19	40.20	23.80	124.32	7.1	2.9
1931 MAR 07	0:18	41.50	22.48	81.74	5.7	2.0
1931 MAR 08	1:51	41.44	22.61	75.22	5.9	2.3
1932 APR 23	9:59	40.70	23.50	82.07	7.4	3.6
1932 SEP 26	19:21	40.39	23.81	115.81	11.0	6.9
1932 SEP 29	3:58	40.83	23.46	78.67	11.0	7.3
1932 OCT 09	6:24	40.00	23.45	115.33	6.3	2.0
1932 NOV 01	16:20	40.55	23.37	74.76	7.7	4.1
1933 MAI 08	1:13	40.65	23.17	55.39	7.0	3.7
1933 MAI 11	19:10	40.76	23.67	96.11	7.4	3.5
1933 JUN 01	2:40	40.68	23.83	110.05	6.7	2.7
1935 FEB18	6:40	40.33	23.64	105.46	7.0	3.0
1936 APR 08	4:17	40.66	23.09	48.56	6.0	2.9
1952 JUN 27	13:09	40.68	23.32	67.22	6.0	2.5



Figures 6, 7 - Earthquake epicentres of the Periods 1900-1950 and 1951-2000 (Tables 2 and 1, respectively). The size of the circle represents maximum intensities. The star on the map depicts the location of ancient Pella

4.2. Analysis of Historical Earthquakes in the Region of Pella

In historical seismology, the study and analysis of historical earthquakes are based on the written testimonies. However, taking into consideration each writer's subjective view of a seismic event, a certain attention is required in order to locate any inaccuracies in the presentation of the facts in each source. Thus, the precise epicentre and maximum intensity of each earthquake cannot always be assessed with certainty. A more accurate assessment of macroseismic parameters can be achieved through cross-correlation of the available historical information and exploitation of all available elements.

As it has already been stressed, the region of Pella is generally considered of low seismicity, with very few damaging earthquakes, compared to the higher seismicity of other regions of Greece. Moreover, the poor amount of historical data on earthquakes in Pella itself, leads to the investigation of a broader area around Pella, with earthquakes that are likely to have caused damage in Pella. Consequently, the historical reports assembled are mainly related to earthquakes of Thessaloniki, Veroia and Edessa.

After extensive research in historical earthquake catalogues, seismological and historical studies, archaeological studies and published sources, a catalogue of historical earthquakes was created, which covers the time period from antiquity up to the end of the 19th century. For these earthquakes a considerable amount of material was accumulated.

For each historical earthquake three steps were followed:

- The dendritic plan of the sources that report the earthquake was constructed, in order to correlate all the information coming from more sources, at least in the majority of cases and to locate the original or primary ones.
- A description of macroseismic parameters of each earthquake with addition of other related information obtained from the primary sources, was then made.
- The macroseismic parameters of the earthquake (origin time, place, geographic coordinates of epicentre, magnitude and maximum macroseismic intensity) were listed in tables. This data originated from the relative earthquake catalogues. After the correlation of all information, a reassessment of macroseismic parameters for each earthquake was attempted.

Having the table of parameters, the epicentral distance of Pella, Δ , was calculated and, using the general attenuation relation (Equation 2), the expected intensity in Pella was calculated.

Thus, as in the case of the 20th century earthquakes, Table 3 was constructed; it includes the macroseismic parameters of each earthquake (origin time, area of seismic event, coordinates of macroseismic epicentre, maximum intensity I_{max}), as well as the epicentral distance Δ of Pella and

the calculated macroseismic intensity I_{Pcal} in Pella (in the EMS-98 scale). It is noteworthy that some of the historical earthquakes studied (marked with * in Table 3) were not included in the existing parametric historical earthquake catalogues.

Table 3 - Reassessed Macroseismic Parameters of Historical Earthquakes in Pella

Date	Time	Area	Lat°	Lon°	Δ(km)	I_{max}	I_{Pcal}	References
1 st century B.C.*		Pella	40.77	22.53	0	7.5	7.5	1,3,44
677/667		Thessaloniki	40.63	22.93	36.96	6.5	3.7	14,21,28,30,31,32,36,37,39,40,46
700		Thessaloniki	40.63	22.93	36.96	7.0	4.2	30,31,32,46
896 FEB		Veroia	40.52	22.20	39.59	8.0	5.1	7,14,30,31,32,36,37,39
Beginning of 1200		Veroia	40.52	22.20	39.59	8.0	5.1	7,31,32
1395 SEP		Edessa/Vodena	40.80	22.05	40.99	8.5	5.5	7,12,31,32,38,43
1420 JUL		Thessaloniki	40.63	22.93	36.96	7.0	4.2	12,31,32
1430 MAR 26		Thessaloniki	40.63	22.93	36.96	6.0	3.2	12,14,15,28,30,31,32,37,43,46
1677		Vassilika	40.47	23.13	60.73	8.0	4.6	30,31,32,39,43
1759 JUN 22	1.00	Thessaloniki	40.63	22.93	36.96	9.0	6.2	17,21,28,30,31,32,34,43
1760 SEP 14		Thessaloniki	40.63	22.93	36.96	4.5	1.7	21, 34
1768 MAR 27*	3.00	Thessaloniki	40.63	22.93	36.96	6.5	3.7	23,43
1783 SEP 08		Thessaloniki	40.63	22.93	36.96	8.0	5.2	21,39,48
1829 MAR 30*	22.00	Veroia	40.52	22.20	39.59	5.5	2.6	23
1839 JAN 16-17*	Night	Thessaloniki	40.63	22.93	36.96	6.5	3.7	21
1843 MAR 09*		Thessaloniki	40.63	22.93	36.96	4.5	1.7	34
1845 JAN 16*		Thessaloniki	40.63	22.93	36.96	4.0	1.2	34
1858 DEC 27*		Thessaloniki-Serres	40.63	22.93	36.96	4.5	1.7	37
1860 MAR 05*	06.10	Thessaloniki	40.63	22.93	36.96	4.5	1.7	37
1890 MAI 05*		Thessaloniki	40.63	22.93	36.96	5.0	2.2	26

5. The Seismic History of Pella

Figure 7 presents the seismic history of Pella in terms of its macroseismic intensity due to all studied earthquakes, vs time.

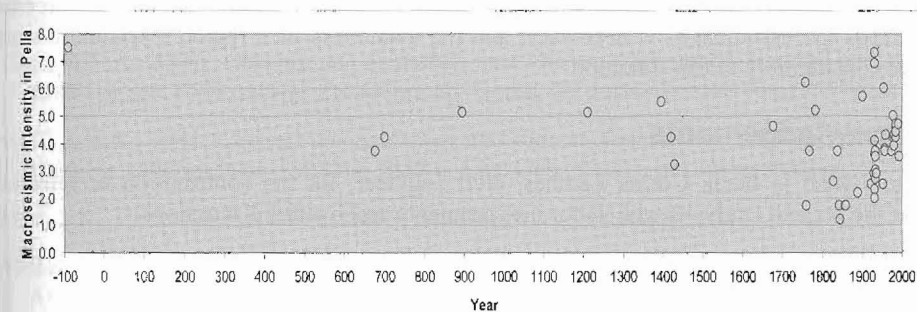


Figure 7 - The Seismic History of Pella

From this diagram, the following can be noted:

- In its long history, the area has rarely been affected by strong earthquakes. The calculated maximum intensity in Pella is $I_{Pcal}=7.5$ (Table 3), but I_{max} in the broader area around Pella reached 11 in Sept. 1932 (Table 2).
- The data set is richer in 20th century, due to systematic collection of macroseismic and instrumental data.
- Between the years 650 and 1700 a certain periodicity of earthquake occurrence could be observed, with intervals of seismic quiescence of approximately 200-300 years.
- The majority of calculated intensities in the city of Pella vary within values 3.5-5.5.
- In two cases, particularly high macroseismic intensities are noted: in 1st century B.C. earthquake ($I_{Pcal}=7.5$) and in 1932 earthquakes ($I_{Pcal}=6.9$ and $I_{Pcal}=7.3$ on September 26 and 29, respectively). It is observed that the high intensity value of the 1st century B.C. earthquake matches approximately the corresponding higher values of intensity in Pella in the 20th century. Although the ancient earthquake was a local event, while the 1932 events originated from Ierissos region, macroseismic intensity 7/8 seems to be a rare, however realistic value for Pella.
- In the case of Pella ancient earthquake, the assessment of macroseismic intensity was based on detailed information on damage and vulnerability of the buildings, according to the European Macroseismic scale EMS-98.

6. Conclusions

According to the results of this study, a maximum intensity $I_{max}=7/8$ in Pella is a rather realistic, although rare case. Since 700 A.D., damage ($I_{max}\geq 5$) was observed periodically in the town from local or neighbouring seismogenic sources. In this sense, the possibility of a destructive earthquake in 1st century B.C., as dated by the archaeologists, is considered here as a reasonable assumption.

The seismic history of Pella creates a picture of low-to-moderate seismic hazard in the region, but this should not comfort neither the residents, nor the local authorities. A similar, characteristic example is the 1995 Grevena earthquake ($M=6.6$), in an area that was previously considered of low seismicity. This earthquake also caused some damage in the city of Pella. Consequently, the recent shift of Pella Prefecture from "old" category I to "new" category I of seismic hazard, including an increase of its seismic risk of 33% is justified (according to Greek Antiseismic Code of 2000, Category I: $PGA=0.12g$. After the 2003 modification, Category I: $PGA=0.16g$).

What should always be kept in mind is the fact that the seismic activity is perhaps the most "uncertain" hazard as concerns time and place where it may occur. Therefore, the reinforcement of cities towards the earthquakes is necessary, and the awareness of a region's seismic history can contribute considerably to this direction.

7. Acknowledgements

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**eq: earthquake