ANNALI DI GEOFISICA, VOL. XXXVIII, N. 5-6, November-December 1995

Archaeological evidence of antiseismic constructions in antiquity

Stathis C. Stiros
Institute of Geology and Mineral Exploration (IGME), Athens, Greece

Abstract
While there is no doubt that antiseismic cultures existed in antiquity, there is much debate as to whether clear antiseismic construction techniques existed as well. Reports of foreign visitors indicate that from the 15th to early 19th century not only were people aware of such techniques, but they effectively used them on a town-wide and region-wide scale, probably under the control of a central authority. Archaeological studies also reveal the extensive use of certain construction techniques (timber beam frames, metal reinforcement, etc.), the aim of which, according to our present knowledge, could be the support of buildings affected by dynamic loads. Such techniques were adopted, introduced, tested and evolved by ancient architects, who were certainly aware of the effects of earthquakes on their constructions and had much freedom in their planning; the latter, however, was dominated by the cost-benefit analysis principle. These data indicate that antiseismic construction techniques, possibly even as a state policy, existed in ancient times, and that for certain periods and areas, seismicity appears as the main factor controlling building style.

Key words *Greece – archaeoseismology – seismic culture – antiseismic construction techniques*

1. Introduction

In recent years there has been much interest in the seismological history of ancient monuments and remains; this interest stemmed from the need to protect and reinforce them against future earthquakes, and to better understand the seismic history of certain regions.

It is in this framework that there have been efforts (1) to develop a methodology for the identification of palaeoseismic events from the examination of archaeological data, (2) to enrich the seismological catalogues, and (3) to study the implications of the collected information in the earth sciences, humanities and engineering. This research led to the birth of *Archaeoseismology*, a new discipline, or better an interdisciplinary field of earthquake studies (Karz and Kafri, 1978; Nikonov, 1988; Stiros, 1988; Guidoboni, 1989; Stiros and Jones, 1995).

A particularity of this discipline is that it is focussed on human constructions. The latter are not simply passive markers of a sudden geomorphological change (for instance, the uplift of a harbour), but reflect also the efforts of man to face earthquakes, to survive with earthquakes, and to reduce their effects. Was this effort deliberate and systematic, at least for some periods in antiquity? This is a question I shall try to answer in this paper.

2. Seismic cultures in antiquity

Recent studies clearly indicate that some of the earthquakes were not simply catastrophic events, but also played a catalyzing role in the evolution of the urban, architectural and pottery style of certain areas or sites, both in prehistoric and more recent periods (for example, La Rosa, 1995; Marthari, 1990; Kilian, 1990, 1995; Stiros, 1995a). This response to earthquakes was obviously «passive», in the sense that the earthquakes simply gave the opportunity for new houses, palaces or churches to be built, usually with a «modern» style. Except for this «passive» response to earthquakes, there existed active, deliberate responses as well, usually called *seismic cultures.*

Seismic cultures included the perception of the physical phenomenon (a rarely «scientific» and usually religious/idelogical and political approach, see Helly, 1989; Evangellatou-Notara, 1993; Polymenakos, 1995), as well as post-seismic recovery and earthquake prevention techniques. While the post-seismic recovery techniques proved very practical and effective (for example funding from other communities or the national administration and private donations, see Helly, 1989; Guidoboni, 1989, for example p. 659; Di Vita, 1995) certain earthquake prevention techniques were dominated by ideology. Religious processes were in various periods and areas considered the only remedy against the expected earthquakes. Christian practices are the most common, but probably the most glossy example comes from Minoan Crete.

In an excavation not far from Knossos, near Herakleion (fig. 1), Sakellarakis and Sapouna-Sakellarakis (1981) brought to light skeletons of people killed and buried by earthquake debris in a Minoan shrine. According to the excavators, the fatal earthquake followed a human sacrifice and the collapsed shrine buried the «priests» and the victim of the sacrifice. Since this seismic destruction took place in a turbulent period, during which the Minoan palaces in much of Crete were destroyed, this pre-seismic sacrifice was interpreted as an ultimate, yet unsuccessful effort to prevent the fatal earthquake.

Obviously, although ineffective religious earthquake-prevention techniques are still in use, people were forced to develop more effective techniques, *i.e.* the construction of buildings resistant to seismic shocks.

3. Antiseismic techniques in antiquity: the debate

The existence of a deliberate antiseismic technique in antiquity, is, however, a matter of debate among specialists. Two recent opinions in this subject are those of Kirikov (1992), whose verdict is that the ancient builders did not think of earthquake resistance of their megalithic monuments in particular, and Yavuz (1993) who presented evidence of building styles undoubtly testifying to the fear of seismic shocks in various periods and areas.

I am of the opinion that this debate reflects our imperfect and fragmentary knowledge of the ancient building style and its evolution, as well of the way of thinking of ancient architects and builders. This is to a large degree due to the lack of clear written statements explaining why specific types of structural design were selected (or developed) to prevent the failure of constructions due to seismic shocks; a point I discuss in a latter section of this paper. This lack of knowledge had important consequences: in his famous painting «The School of Athens», exhibited in the Vatican Museum, Raphael, famous as an architect as well, imagined cupolas and arches in the buildings of classical Athens. Of course, such forms were developed only after the introduction of high quality mortars in the Roman period!

This misconception or ignorance of the previous experience in a period during which engineering and architecture were still based on the principles of cumulative experience and trial-and-error techniques is especially important: Raphael was for some time in charge of the Saint Peter's project in Rome, and was obliged to solve the problem of the construction of the Basilica's dome!

A second example is the restoration of the Parthenon, early in this century. The iron clamps and dowels used were not resistant to corrosion, nor covered by lead that protected them from corrosion and provided them with plasticity, as was the case with the ancient material. This ignorance and disregard of the techniques of the ancient builders had important consequences for the monument (Korres and Bouras, 1983; Zambas, 1988; Varoufakis, 1992).

Fortunately, in recent years a bulk of historical, archaeological and structural data has been made available and permits a better understanding of this matter. Based on such data, I shall try in the following to show that the ancient architects and builders, at least for some periods and areas, were conscious of the ef-

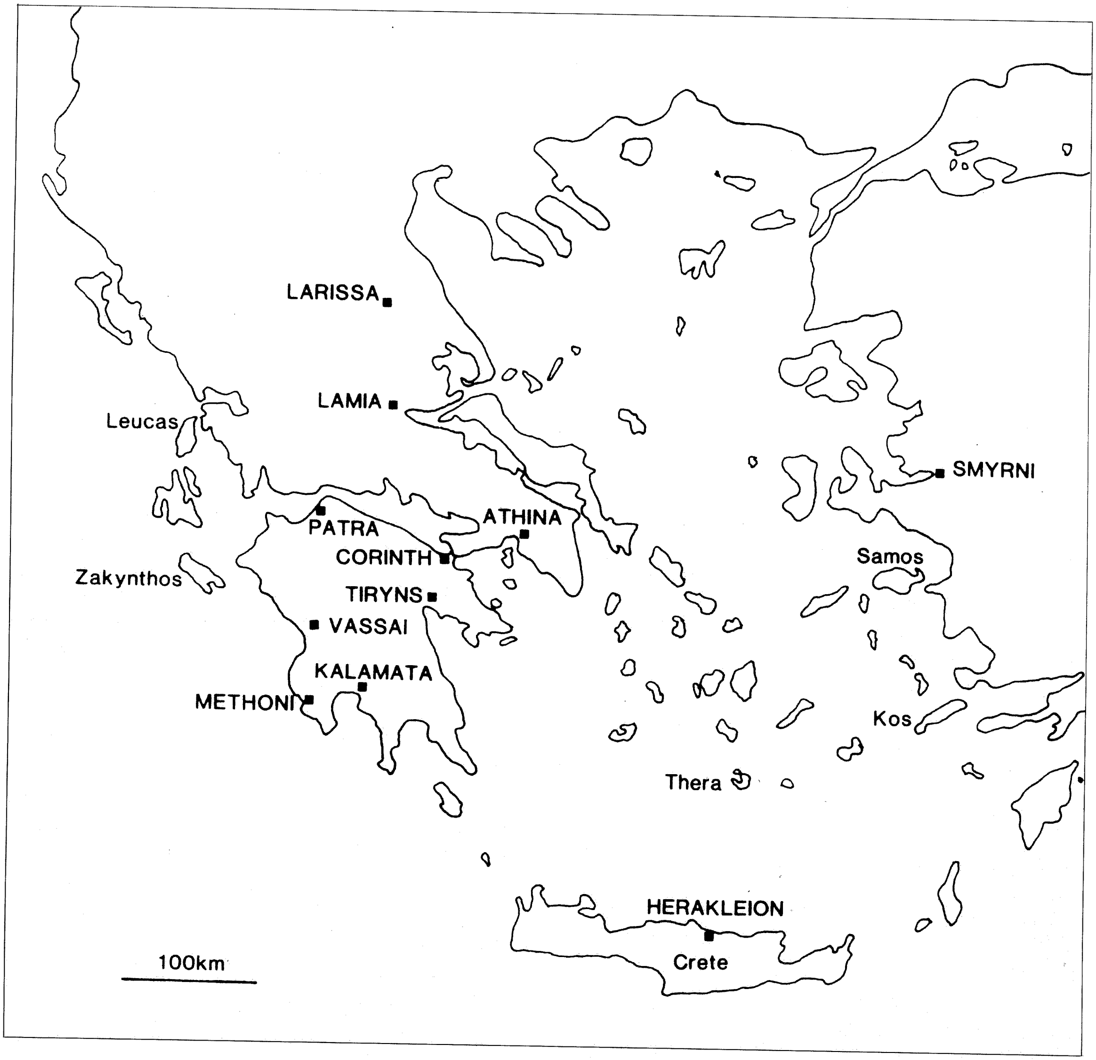

Fig. 1. Location map.

fects of earthquakes on buildings, of their weaknesses and of the measures to be taken for their reinforcement.

4. Historical evidence of antiseismic techniques in antiquity

In Appendix, I cite reports of 15th to early 19th century travellers who clearly indicate that in Greece and nearby regions people were able to recognize which building techniques and materials offered strength against seismic shocks, and to adopt new and effective earthquake-safe styles of construction on at least a city-wide scale: houses were built low and wooden-framed to resist frequent earthquakes (Larissa, Zakynthos); after a destructive event, special effective building techniques, probably developed elsewhere, were adopted (Smyrni);

building techniques that are recognized as antiseismic were widely used (Methoni).

Such ideas and practices survived till the last decades (figs. 2 and 3), just before reinforced concrete was introduced. This experience is reflected in the following proverb from the Kalamata area (SW Greece), characterized by the construction of mudbrick houses reinforced with a timber frame: a mudbrick house says to its owner «*Do protect me from the water and I shall protect you from the earthquake*».

The most important conclusion, however, is that in certain cases the post-seismic recovery and rebuilding of whole cities was dominated by clear, possibly imported antiseismic techniques, indicative of central planning and absolute consensus of citizens. Some workers emphasize the rebuilding of Leucas after the 1825 earthquake under strict regulations and brilliant techniques (fig. 4) which are assigned to an antiseismic code compiled and directed by the British Administration (Galanopoulos, 1954; Touliatos, 1993). Obviously, the British code was (and could only be) nothing more than a generalization of techniques and practices

(2)

(3)

Fig. 2. Two styles for wood-framed houses (from Aghios Constantinos village, Samos Island). The bearing system, at least for the upper floor, consists of a wooden frame, and the voids are filled either with brick, or with a secondary, non bearing wooden frame («tsatma»). The walls are then covered with stucco.

Fig. 3. A more daring, though statically and dynamically efficient construction style, from Samos. The upper levels are made of wood.

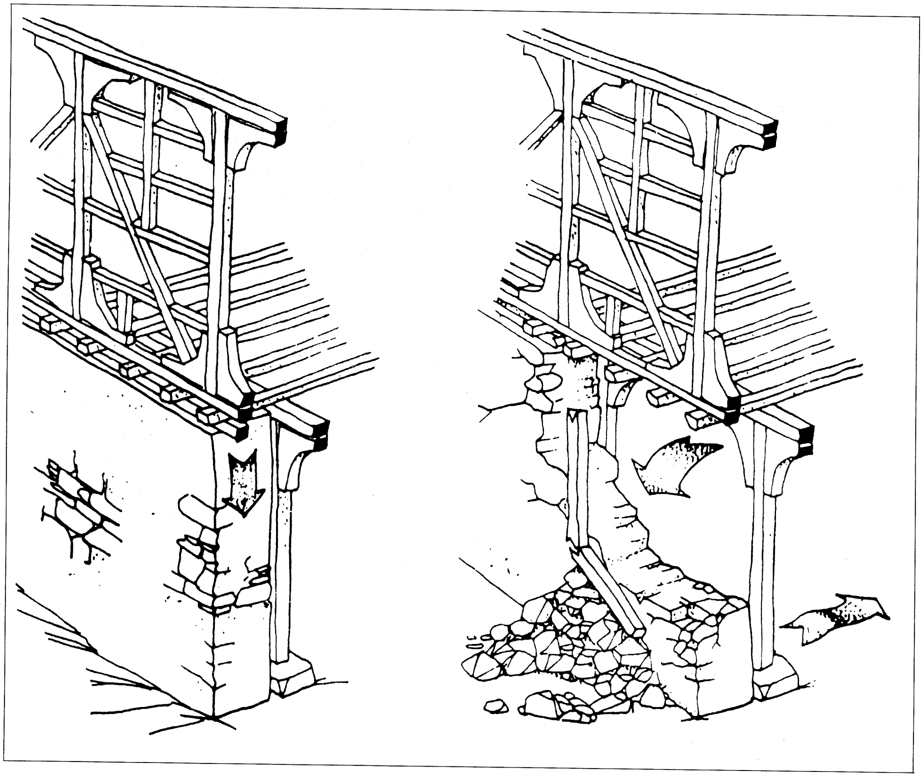

Fig. 4. Antiseismic techniques at Leucas (after Touliatos, 1993). Even after the collapse of the walls the roofs do not fall.

which had proved effective and had long been in use in the wider area (the case of Zakynthos at 1600 and of Patra in 1805). Even as a state policy, the Leucas experience is probably a repetition of the rebuilding of Smyrni in 1688 (see Appendix).

More recent similar examples are the reconstruction of Corinth and Kos after the 1928 and 1933 earthquakes, respectively.

5. Archaeological evidence

Martin (1965), Kirikov (1992), Yavuz (1993) and Stiros (1995b) have, among others, presented numerous cases of building features and techniques, the main function of which would be, according to present-day experience, to resist to dynamic loads. In this section, I focus on three cases of building features that provide evidence of a deliberate antiseismic construction.

5.1. *Tiryns, post-earthquake alterations in the foundations style*

Extensive excavations in the Mycenean centre of Tiryns revealed various types of building foundations (Kilian, 1990). Kilian (1995) observed that special precautions were taken for the foundations built after a damaging earthquake. This innovation was explained as an effort to reinforce houses against future shocks

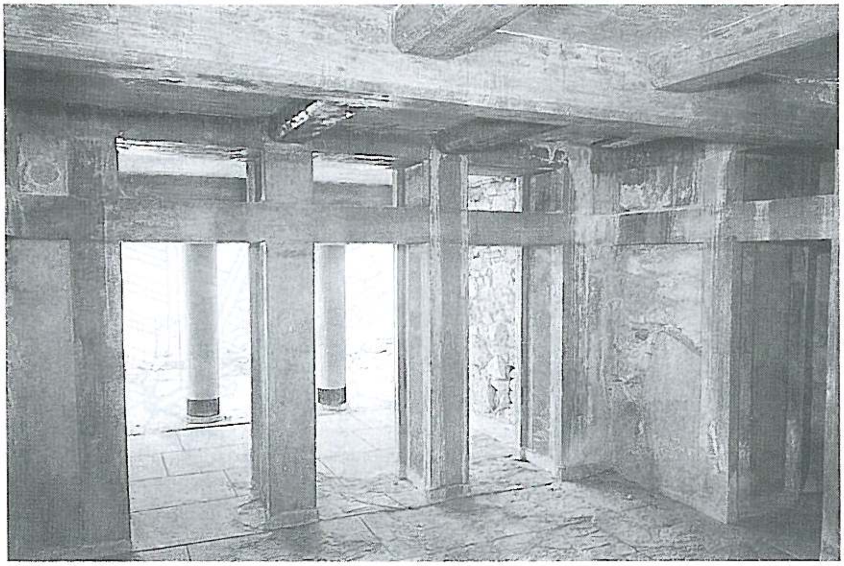

Fig. 5. Part of a Minoan villa at Knossos. The statically and dynamically daring style is counterbalanced by the extensive and sophisticated use of wood.

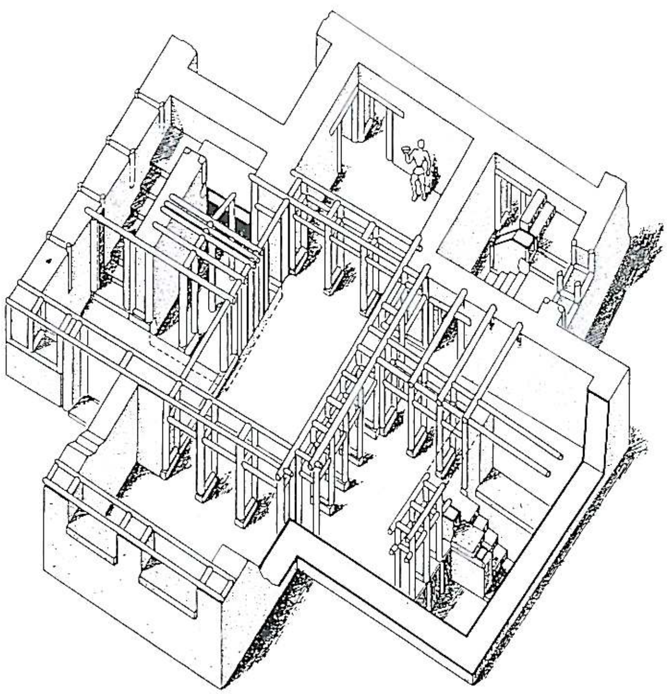

Fig. 6. The wooden frame bearing system at Akrotiri (Xeste 3, east compartment; after Palyvou, 1988).

but was limited to the houses of the upper class. The lower classes, obviously, were aware of the new technique as well, but could not afford them.

5.2. *Minoan palaces and houses*

Excavations of palaces and villas in Crete and of houses at Akrotiri at Thera provide a clear picture of last stages of the Minoan architecture. From a structural point of view, the architectural style is daring: huge openings, many floors, etc. (fig. 5). But in compensation, there have been adopted special techniques, for example wooden frames in the openings, the walls, etc. (fig. 6), careful construction of the corners (with well-hewen interbonding blocks), and probably better foundations (Evans, 1928; Palyvou, 1988, 1990).

Since timber was imported, and its cost high, the inhabitants of Akrotiri, for instance, who had rebuilt their city after a probably seismic destruction (Marthari, 1990), were not simply fashion-victims, but cautious not to become earthquake victims again. While the concept of the antiseismic, timber-framed construction is ubiquitous in Akrotiri (and the other Minoan buildings), «weak points» are found everywhere. The fate of this city, however, was not to be hit by another destructive earthquake, but to be buried under pumice, and preserved.

5.3. *Metal reinforcement of stonework in classical times*

It has long been recognized that the classical Greek constructions should not be regarded «as a simple piling up of stones, and their superstructure as a simple piling up of beams» (Dinsmoor, 1922), and that wooden or metal clamps, dowels and anchor bars were added for the reinforcement of their walls (fig. 7), but also of columns, roof beams, even of their foundations (Livadefs, 1956; Martin, 1965). Until recently, however, it was believed that the only functions of these reinforcements were to enhance the static efficiency of the

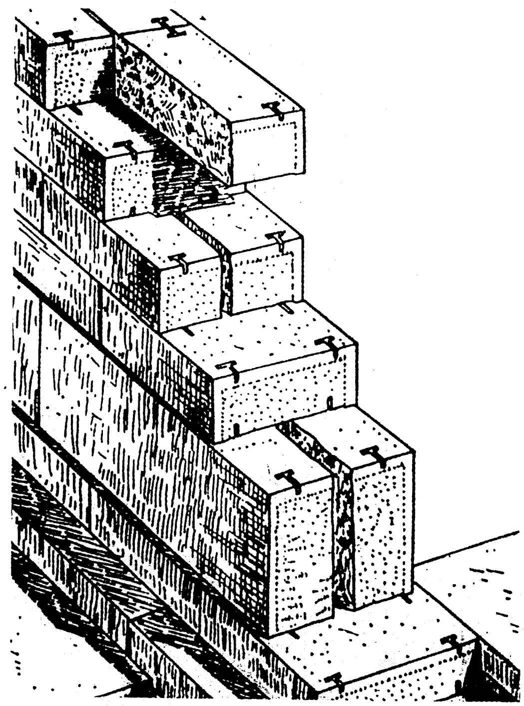

Fig. 7. Clamps and dowels in the Parthenon (after Martin, 1965).

buildings, and to prevent the opening of joints (due for example to dilatation of frozen water, etc.). However, there is evidence that clamps and dowels had a different function as well:

1) the level of stresses in classical Greek and other constructions is small, and the strength of building materials (usually marble) high (Sinopoli, 1989, 1991), so that no additional reinforcement was necessary to eliminate static stresses;

2) metal and wood reinforcement were more usual in the higher parts and corners of buildings (Martin, 1965, p. 240), *i.e.* their parts most vulnerable to earthquakes. Certainly, the upper parts of buildings are most affected by tilting due to partial foundation settlements; yet, settlements of foundations were not usual in ancient monuments to justify the generalized use of metal or other reinforcement, while it is questionable whether metal reinforcement in the upper parts of constructions could balance

the corresponding stresses, or why the architect would focus on reinforcing the walling and not the foundations; techniques for reinforcement or improving of the latter were certainly not unknown to the ancients (Dinsmoor, 1922; Martin, 1965);

3) recent studies reveal that the role of lead mantling iron clamps and dowels was not simply to protect them from corrosion, for sulphur-free, corrosion-resistant iron was used (Varoufakis, 1992). Korres and Bouras (1993) and Zambas (1988) explained that the role of lead was to permit a plastic deformation after a certain stress level and prevent a brittle failure of the marble elements; a principle implemented in the design of the new Titanium reinforcement of the Acropolis. Consequently the

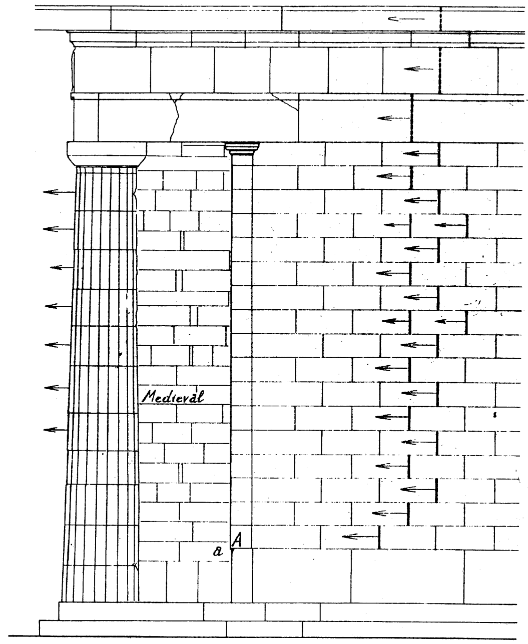

Fig. 9. Seismic displacements at the south wall of the Parthenon; the offset at Aa already existed when the wall marked «Medieval» was built during the Frankish occupation (after Korres, 1995).

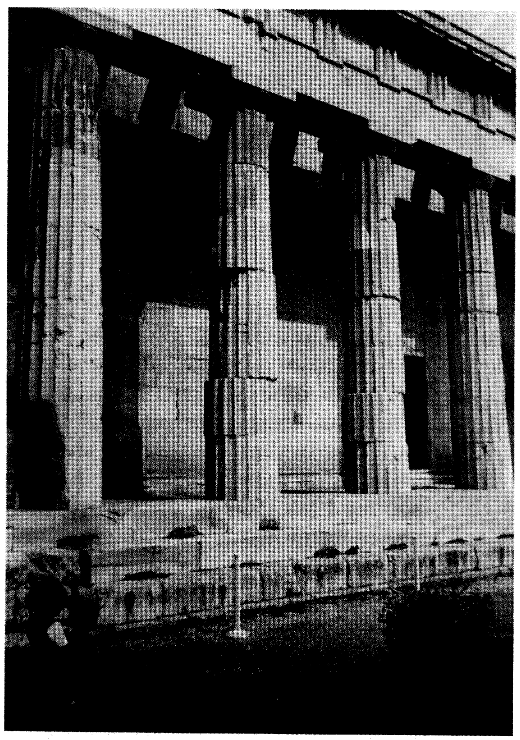

Fig. 8. Offset drums in the columns of the Hephaisteion Temple (Thisseion) Athens. Based on such observations, two early seismologists (A. Sieberg and N. Criticos) proposed that Athens is not an earthquake-free area (see Galanopoulos, 1956).

ancient builders were familiar with, and expected horizontal sliding of drums in columns or rows of blocks in walls, like those observed today in the majority of surviving classical monuments (figs. 8 and 9; Sinopoli, 1989).

Simple statistics can support this conclusion. At least two reports of recent earthquakes that caused relative movements of structural elements of classical temples along horizontal discontinuities are available (Vassai Temple, Andronopoulos *et al.*, 1976; Parthenon, Korres, 1995). This means that the corresponding examples in antiquity would be numerous, especially since such constructions were far more common than today.

Consequently, it was a common knowledge that earthquakes produce such effects and it is difficult to imagine that the ancient Greek architects who inherited and developed the metal reinforcement techniques from the East and

Egypt (Martin, 1965, p. 238) were not conscious of their antiseismic role, especially since any modern engineer would indicate that such devices are necessary to prevent the failure of a structure due to dynamic loads.

6. Discussion

There is therefore no doubt, as historical data reveal, that at least in the last centuries an antiseismic construction technology and a genuine seismic culture in the broader sense ex isted, at least in areas and periods characterized by short recurrence intervals for catastrophic earthquakes. The interesting point is that the information about this technology is due to foreign travellers coming from earthquake-safe countries. Local sources on the contrary are confined to notifying (some of) the events, and occasionally to give some information on the economic, social etc. impacts of the earthquakes, but no reference to antiseismic techniques was made.

Concerning previous periods, the reports of travellers are few, if any, and even geographers like Strabo (who had much interest in the seismic history of various areas), avoid any reference to antiseismic technologies. Yet, the fragmentary and mute architectural remains of antiquity clearly indicate the widespread use of techniques which a modern structural engineer can recognize as remedies against earthquake damage. Surprisingly, the function of such techniques has not, until recently, been recognized. Two possible explanations can be proposed:

1) the archaeological research had different priorities, the archaeologists and architects involved in the study of ancient remains were not familiar with dynamic effects, while structural engineers had little, if any, connection with archaeology;

2) although the post-seismic rebuilding of certain cities was centrally administrated at least during certain periods (for example reconstruction of several cities in Asia Minor destroyed by earthquakes during Hadrian's times), ancient architects were based on the cumulated and personal experience and the trial-and-error technique, but no strict nor bureaucratic regulations existed.

There existed certainly some generally accepted principles (for example metal reinforcement of stone constructions, Dinsmoor, 1922; Martin, 1965), but the architect had the liberty to decide about their distribution and extent. The architect had also to decide about the aim of his construction: a construction that was planned to last long and survive earthquakes was made carefully, the Parthenon for instance. A construction whose function was limited (for example the walls made to offer quick protection during a war, Varoufakis, 1992), was from the structural point of view poor, and not characterized by an antiseismic technology. The cost-benefit principle dominated the ancient construction style.

7. Seismicity and evolution of the building style

Building style and its evolution in various areas is usually considered to depend on factors like the availability of construction material (for example, Roman mortar required certain volcanics, which are not available in the east, and after the division of the Roman Empire, a new mortar was introduced, while the lack of wood in the Cycladic islands led to the evolution of a timber-free architecture); security conditions (development of houses or town fortresses during certain periods); economic trends (a tendency towards large buildings in periods of prosperity); the cosmopolitanism of society (possibility to be acquainted with and adopt foreign styles); tradition (for example adaptation of ancestral styles in colonies, etc.); the continuity of inhabitation (any discontinuity in the inhabitation history of a site erases the memories of destructive shocks); but also political and ideological reasons (*e.g.* Tsausescu's efforts to rebuild Bucarest), etc. To these factors, we must add the earthquakes, as the experience from the Ionian Islands, Larissa or Smyrni (see above), indicate.

Especially important is the length of the recurrence intervals between major shocks: if their length is longer than one generation, the seismic risk is usually forgotten, and no special prevention measures are taken. But if the recurrence intervals are short, as for example is the case of the Ionian islands, the memories of the earthquakes are strong, and do not permit the antiseismic construction techniques to be forgotten or ignored. Seismicity therefore can be a factor that controls building style and history in certain areas.

This result has important implications for the study of the architectural history of certain areas, as the following two examples indicate.

7.1. *Samos: structural conservatism*

The evolution of the building style of houses on Samos island (east Aegean) is something of an enigma for architects: in spite of the fluctuations of the economy, the drastic changes in the political situation, the proximity to a major urban and commercial centre (Smyrni-Izmir), the contacts with Europe (where Samos wine was exported and used for communion), and the availability of nearly all types of building material (limestone, schists, clay, wood, etc.), the structural style and size of houses remained remarkably unchanged for 4-5 centuries, at least till the 1920's (see Papaioanou, 1982).

Our explanation for this structural conservatism in the traditional architecture of the island is that short intervals of moderate earthquakes continuously recalled the seismic risk, and did not permit the evolution of the structural style, or new, more daring structural forms to be introduced (figs. 2 and 3).

In fact, from the catalogue of Papazachos and Papazachos (1989) and the study of historical archives we found that between 1804 and 1904 (a period for which the historical archives are complete and there is no reason to believe that they were not representative of the situation in the 3-4 previous centuries), Samos was affected by 10 earthquakes: in 1804 (Stavros Monastery code, Samiaka C, p. 371-373 or B 75), 1831, 1846, 1865, 1868, 1873, 1875, 1877 and 1904. The average interval between the earthquakes was 15 years, *i.e.* an interval compatible with the interval of renovation or rebuilding of houses. The longest interval between the shocks, on the other hand was 30 years, short enough to permit the memories of shocks to survive and be conveyed to the younger generation.

7.2. *Lamia area (Central Greece): waves of church building*

Two waves of church building or repairs have been identified in the wider Lamia area, in the mainland, in the 16th and 18th century, and have been regarded as products of periods of peace and prosperity (Panousakis and Christodoulopoulou, 1992). In a recent paper, however, (Stiros, 1995a), I noted that such large-scale church construction or repair projects were quite unusual during Turkish occupation, and that all but one these projects were carried in the decades following the destructive earthquakes of 1544 and 1740 (Papazachos and Papazachos, 1989); these large-scale church building or reconstruction projects must therefore be regarded as post-seismic recovery.

8. Conclusions

There is historical and archaeological evidence that ancient people were able to identify which structures are resistant to earthquakes, and to build such constructions. For certain periods, there were certainly some efforts at introduction, testing and generalization of such techniques, sometimes under the control of a central authority. Earthquakes therefore were a factor, sometimes the decisive factor in building style. However, as the threat of earthquakes was not continuous, the expensive and architecturally embarassing structural limitations were sometimes ignored or condemned to oblivion. The seismic risk (or better the recurrence intervals between major shocks, and the surviving memories of destructive earthquakes) was therefore one of the factors in the cost-benefit analysis for the planning of new constructions in antiquity.

Appendix

Methoni, 1494 (Simopoulos, 1984, vol. 1, p. 341) – Most houses, either small or large, are wooden in their upper middle parts, especially on the side looking to the street.

P. Casola «Viaggio di Pietro Casola a Gerusalemme», from the autograph in the Biblioteca Trivulzio, Milano, 1855.

Chandax (Herakleion), 1508 (Simopoulos, 1984, vol. 1, p. 360-361) – The extent of the damage (of the 1508 earthquake) is of no surprise: in this town instead of lime mortar they use clay that does not offer strength.

«Voyage du magnifique et très illustre chevalier D. Trevisan...» Paris, 1874.

Zakynthos (Zante) Island, 1600-1749 (Simopoulos, 1984, vol. 1, p. 443, vol. 2, p. 260) – Zakynthos suffers very much from earthquakes. There is no year (especially during September and October) without shocks – I personally experienced three quakes in one week. For this reason they build their houses very low in order not to be destroyed. And when they feel an earthquake, they start ring the bells of churches to pray.

W. Biddulph «The travels of four Englishmen and a preacher into Africa ...» by William Biddulph begunne in the yeere of Jubilee 1600 and by some of them finished the yeere 1611.

The houses in Zante are low because of the earthquakes and the poverty of the inhabitants.

A. Drummond «Travels through different cities of Germany, Italy, Greece...», London, 1754.

Larissa, 1669 (Simopoulos, 1984, vol. 1, p. 629, 630) – Larissa is a big town, but so badly built that you feel you are in a village. The walls of most houses are made of brick and mudbrick. All houses are of one single storey. I asked why they do not build better houses in such a big and commercial town, and they answered that the area suffers from earthquakes and the higher buildings collapse. I observed that many houses in the town were framed with huge timber beams.

R.P. Robert de Dreux «Voyage en Turquie et en Grèce 1665-1669», Paris, 1925.

Smyrni (Izmir), 1688-1715 (Simopoulos, 1984, vol. 2, p. 81) – The disaster from the 1688 earthquake was due to the fact that the houses were built of stone. When the city was built again, stones were used only in the foundations and the base of the walls. The remaining building was made of a wooden frame and bricks. After the rebuilding of the city, strong earthquakes occurred, but no houses were demolished.

Tarillon «Nouveaux mémoires des missions de la Companie de Jésus dans le Levant». Lettre à Monseigneur le compte de Pontchartrain, sécrétaire d'État sur l'état présent des Missions des pères Jésuites dans la Grèce, Paris, 1714.

Patra, 1805 (Simopoulos, 1985, vol. C1, p. 375) – Patra suffers very much from earthquakes; for this reason the house of the British Consul was made of wood.

W.M. Leake «Travels in Morea», 3 vols., London, 1830.

REFERENCES

ANDRONOPOULOS, V., G. KOUKIS and A. TZITZIRAS (1976): Geotechnical study of the Epikourios Apollo temple (in Greek), *Geotechnical Res. IGME*, **3**.

DI VITA, A. (1995): Earthquakes and civil life in Gortyn (Crete) in the period between Justinian and Costante II (6-7th century A.D.), in *Archaeoseismology*, edited by S. STIROS and R. JONES, *Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7**, 45-50 (in press).

DINSMOOR, W.B. (1922): Structural iron in Greek architecture, *Am. J. Arch.*, **24**, 148-158.

EVANGELLATOU-NOTARA, F. (1993): Earthquakes in Byzantium from the 13th to the 15th century Historic examination, *Parousia, Annex*, **24**, 194.

EVANS, A. (1928). *The Palace of Minos*, vol. II i, London.

GALANOPOULOS, A. (1954): Die Seismizität der Insel Leukas, *Gerl. Beitr. Geophys.*, **63**, 1-15.

GALANOPOULOS, A. (1956): Seismic risk of Athens (in Greek), *Prakt. Akad. Athenon*, **31**, 464-472.

GUIDOBONI, E. (Editor) (1989): *I terremoti prima del Mille in Italia e nell'area Mediterranea* (SGA-ING), pp. 768.

HELLY, B. (1989): La Grecia antica e i terremoti, in *I terremoti prima del Mille in Italia e nell'Area Mediterranea*, edited by E. GUIDOBONI (SGA-ING), 75-91.

KARZ, I. and U. KAFRI (1978). Evaluation of supposed archaeoseismic damage in Israel. *J. Archaeol. Sci.*, **5**, 237-253.

KILIAN, K. (1990): Mykenische Fundamentierungsweisen in Tiryns, in *L'Habitat Égéen Préhistorique, Bull. Correspondance Hellenique, suppl.* **19**, Athens.

KILIAN, K. (1995): Earthquakes and archaeological context at Tiryns (LH II period), in *Archaeoseismology*, edited by S. STIROS and R. JONES, *Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7**, 63-67 (in press).

KIRIKOV, B. (1992): *Earthquake Resistance of Structures: from Antiquity to Our Times* (MIR Publishers, Moscow), pp. 240.

KORRES, M. (1995): Seismic damage to the Acropolis monuments, in *Archaeoseismology*, edited by S. STIROS and R. JONES, *Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7**, 69-74 (in press).

KORRES, M. and C. BOURAS (1983): *Study for the Restoration of the Parthenon* (in Greek), Ministry of Culture and Science, Athens.

LA ROSA, V. (1995): A hypothesis on earthquakes and political power in minoan Crete, *Annali di Geofisica*, **38**, 881-891 (this volume).

LIVADEFS, C. (1956): The structural iron of the Parthenon, *J. Iron Steel Inst.*, **188**, 49-66.

MARTHARI, M. (1990): The Chronology of the last phases of occupation at Akrotiri in the light of the evidence from the West House pottery groups, in *Thera and the Aegean World III*, edited by D. HARDY and A. RENFREW, vol. III, 57-70.

MARTIN, R. (1965): *Manuel d'Architecture Grecque*, I. *Materiaux et Techniques* (Picard, Paris).

NIKONOV, A. (1988): On the methodology of archeoseismic research into historical monuments, in *The Engineering Geology of Ancient Works, Monuments and Historical Sites, Preservation and Protection*, edited by P. MARINOS and G. KOUKIS (Balkema, Rotterdam), 1315-1320.

PALYVOU, C. (1988): Akrotiri Thera: Building techniques and morphology in Late Cycladic architecture, *Phd Thesis*, Technical University, Athens.

PALYVOU, C. (1990): Architectural design at Late Cycladic Akrotiri, in *Thera and the Aegean World III* edited by D. HARDY, C. DOUMAS, J. SAKELLARAKIS and P. WARREN (The Thera Foundation, London), vol. 1, 44-56.

PANOUSAKIS, C. and R. CHRISTODOULOPOULOU (1992): An itinerary in the post-Byzantine churches of Phthiotida (in Greek), *Archaeologia*, **45**, 42-57.

PAPAIOANOU, K. (1982): *Samos, Hellenic Traditional Architecture* (Melissa, Athens).

PAPAZACHOS, B. and C. PAPAZACHOS (1989): *The Earthquakes of Greece* (in Greek), (Zitis, Thessaloniki).

POLYMENAKOS, S. (1995): Thoughts on the perception of the earthquake in the Greek antiquity, in *Archaeoseismology*, edited by S. STIROS and R. JONES, *Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7**, 253-257 (in press).

SAKELLARAKIS, Y. and E. SAPOUNA-SAKELLARAKI (1981): Drama of death in a Minoan Temple, *National Geographic*, **159**, 204-222.

SIMOPOULOS, K. (1984-1985): *Foreign Travellers in Greece* (in Greek), 5th ed., 3 vols., Athens.

SINOPOLI, A. (1989): Kinematic approach in the impact problem of rigid bodies, *Appl. Mech. Rev,*, **42**, S233-S244.

SINOPOLI, A. (1991): Dynamic analysis of a stone column excited by a sine wave ground motion, *Appl. Mech. Rev.*, **44**, S246-S255.

STIROS S. (1988): Archaeology, a tool to study active tectonics – The Aegean as a case study, *EOS, Trans. Am. Geophys. Un.*, **13**, 1636 and 1639.

STIROS, S. (1995a): Earthquakes and church construction in Phthiotis in 16th and 18th century (in Greek), *Archaeologia*, **54**, 23-24.

STIROS, S. (1995b): Identification of earthquakes from archaeological data: methodology, criteria and limitations, in *Archaeoseismology*, edited by S. STIROS and R. JONES, *Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7**, 129-152 (in press).

STIROS, S. and R. JONES (Editors) (1995): *Archaeoseismology, Occ. Paper of the Fitch Lab.* (Oxbow, Oxford), **7** (in press).

TOULIATOS, P. (1993): The traditional aseismic techniques and the everlasting principles they reveal, *Stop Disasters*, **12**, 4-5.

VAROUFAKIS, G. (1992): How the iron clamps and dowels of the temples of the Athenian Acropolis have resisted the century-long corrosion? (in Greek), *Archaeologia*, **45**, 14-19.

YAVUZ, A. (1993): Historic buildings and earthquake factor in their design, in *Proceedings of the Seminar Protection of Architectural Heritage Against Earthquakes* (Ministry of Public Works and Settlement, Ankara, Turkey), 101-115.

ZAMBAS, C. (1988): Principles for the structural restoration of the Acropolis monuments, in *The Engineering Geology of Ancient Works, Monuments and Historical Sites*, edited by P. MARINOS and G. KOUKIS (A. Balkema, Rotterdam), 1813-1818.