P.G. Touliatos

TRADITIONAL ASEISMIC TECHNIQUES IN GREECE

Abstract

Living in a country of frequent and high seismic activity and observing the disastrous influence of that activity on the construction for several thousands of years, people recognised from the very early stages of the history the necessity of the aseismic behaviour of the buildings.

Many related techniques have been developed for at least 35 centuries and are still developing under the impetus of modern technology.

This paper is trying to describe some characteristic aseismic traditional techniques in Greece and to formulate their basic principles.

1. Introduction

All the people living in Eastern Mediterranean have sometimes and in some degree felt the phenomenon of an earthquake and have observed its consequences.

From ancient times, Greek philosophers (as Aristoteles, Pythagoras, Hepicouros) have dealt with the earthquake phenomenon and tried to interpret.

It's estimated that today, a 50% of the annual seismic energy of Europe and 2% of the annual world seismic energy, is released in Greece.

In this country, people live developing civilisations and constructing their monuments and buildings for many thousands of years. Surviving frequent and disastrous earthquakes they got familiar with the act of observation of the damages on their constructions and so understood, more or less, their behaviour during seismic action. Rebuilding them in better ways, truing to improve their resistance against dynamic loading, the ancient constructors experimented with different materials, construction systems and, sometimes, sophisticated detailing. Following long hard paths of observation, experiments, failures and inventions they created local or more spread around aseismic techniques concerning basic members of a building (masonry, roof *etc.*), or even a complete building system.

It is a fact that it is impossible to protect completely a construction against the, sometimes out of the human capabilities limit, seismic force. In Greece, monuments, buildings, cities or even whole civilisations has been lost due to seismic and/or volcanic activities, since prehistoric times to our days (i.e. Thira, volcano eruption 1500 B.C., City of argostoli, complete destruction, 1953, Kalamata severe damages, 1986, etc.).

On the other hand many architectural monuments stand still after more then thousand years (i.e. Parthenon, 483 B.C., Hagia Sophia 537, A.D., Hosios Lukas Monastery, 955 A.D., etc.) in areas with, some times, high seismic risk. Traditionally constructed buildings and settlements, all over Greece, exist and are used for hundreds of years surviving repeatedly seismic action.

2. The experience of the past

We should accept today the principle that the design of an aseismic building must be based on the right conception and inspiration from the very beginning. It is wrong to design a building in a seismic area without taking into account the seismic factor and then try to correct the various errors by using complicated calculations and strengthening methods. Today the correct structural and dynamic analysis and dimensions are very powerful and valuable weapons in our hands, in order to design aseismic structures. But, it is well known, that a structure which is based on a fault conception cannot be totally corrected by any calculation.

On the contrary, when the proper crucial decisions concerning the materials, the load bearing systems, the joints and the forms are taken from the first steps of the design procedure, the correct behaviour of the structure can be guaranteed. It is evident, today, that the designer must develop (trough education and praxis) an aseismic perception based on the main principles of aseismic design.

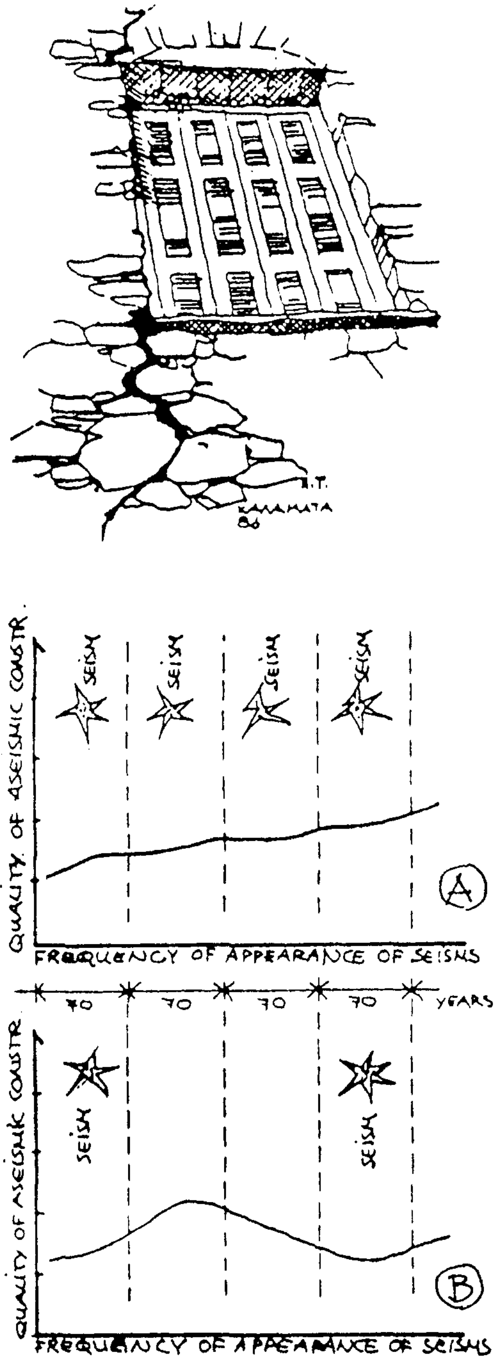


FIG 1. THE EVOLUTION OF THE ASEISMIC CONSTRUCTION IN RELATION WITH THE FREQUENCY OF THE APPEARANCE OF SEISMS.

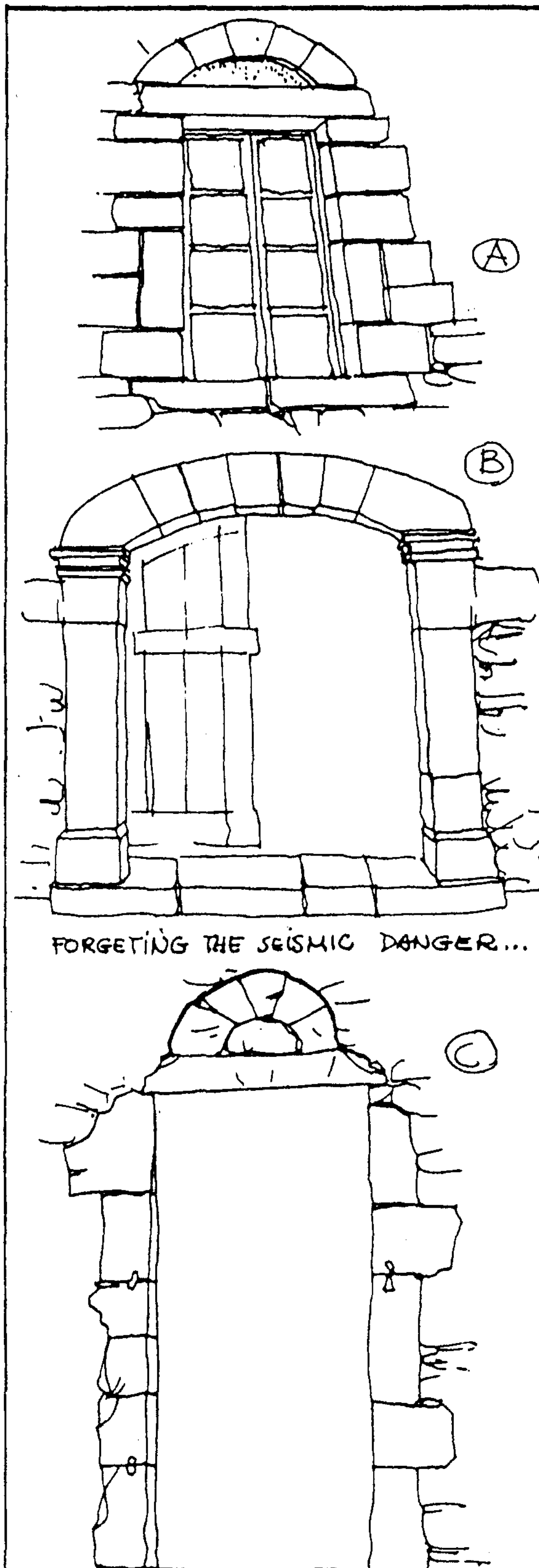


FIG. 2 KARITENA - GREECE

In older times and despite the fact that the structural and dynamic analysis methods were totally unknown, some very efficient aseismic methods and techniques were developed by local craftsmen. Nevertheless, these skilled workmen had a very deep knowledge of the materials and the building systems of that time, which stayed the same and kept developing for centuries, passing on from one generation to the other. They also had a very good conception of every small detail as well as of the whole of the construction. This deep knowledge together with observation of the behaviour of the structures during earthquakes and the examinations and repairs of the damages led to the invention of very interesting and efficient aseismic systems.

Perhaps the following remark can help to detect, study and support such aseismic construction systems:

It is obvious that the evolution of more complete aseismic systems took place in areas where earthquakes were a frequent phenomenon. There is at least one important seismic action during the life period of a generation. Consciousness of danger and personal experience lead traditional constructors not only to the invention of aseismic techniques, but also to their evolution and conservation, as happened in Santorini, Lefkas etc. (Fig 1, A).

On the contrary, in places where earthquakes are a rare phenomenon and the period of calm between two important seismic actions is larger than the average generation life time , the attention of constructors tends to diminish during the long periods of calm (Fig. 1, B). That happened in Athens where nobody expected the 1981 earthquake and where since that time the reinforced concrete aseismic code has been improved repeatedly several times. That also just happened in Cairo (October 1992) and I am very afraid it can happen any moment in Cyprus (Nicosia). A small, representative example can be taken from the diminishing quality of the construction of the openings in the masonry of the buildings in the village of Karitena in Peloponese (Fig 2). After a long calm period from the last significant seismic action the careful, aseismic construction of the perimeters of the openings is forgotten or degenerated into morphocratic repetitions (Fig. 2, C).

It would be very interesting to compare maps of the frequency of the repetitions of the earthquakes over the country to those of the quality of the aseismic techniques, from place to place. A map of the level and kind of damages can be added.

3. Weakening of an old structure

When, during an earthquake, an old structure in severely damaged, or even destroyed, a quick judgement about improper materials or a wrong building system is not always correct. When we examine an old construction in order to maintain, repair or strengthen it, we should always try to determine its initial condition of strength and ability to resist seismic action. It is easy to observe that the quality of a structure seismic behaviour usually is weakened through the ages.

The descendant of resistance to seismic action is due to ageing, abandonment, unsuccessful interventions and the seismic events themselves (Fig. 3). We must also add the frequent non compatibility of today's materials and techniques, which we have used carelessly in various interventions and repairs. Also there are great difficulties in modelling and structural analysis of the old structures and a lot of research must be done on this subject (Fig. 3).

So, it is obvious that almost any construction, even with marvellous aseismic technique applied, reaches a point throughout time when it cannot face successfully the earth quake. Many old, famous monuments, resisting for centuries the dynamic actions at some moment have proved this hypothesis by a local or more general failure. The Parthenon and Hagia Sophia are among them.

In order to intervene at such a moment and bring the construction at least to its initial condition of strength and seismic resistance with the minimum changes of its original construction conception, it is necessary to detect, study and analyse its construction system and, of course, any existing aseismic method or technique.

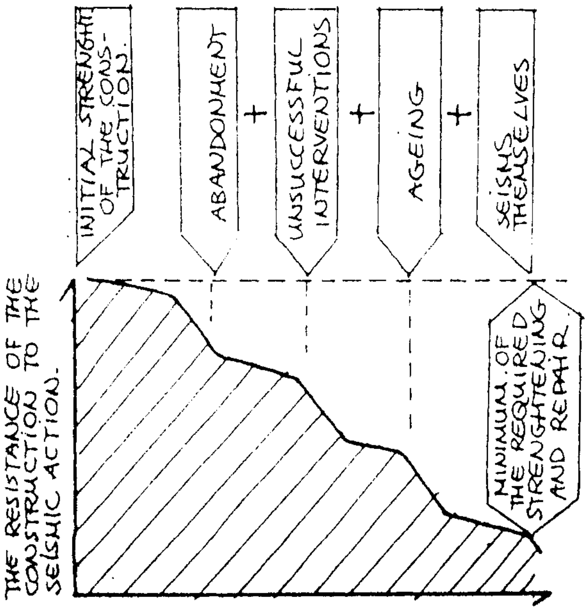
4. Load bearing walls

Many factors play a crucial role in the determination of a wall's seismic resistance. Basic factors are the materials, which are used, and the construction system(s). Many times the old constructors, building in areas with seismic risk tried to improve both. Accordingly, of course, to the building importance, best materials were chosen for the wall elements (i.e. perfectly curved marble components, high quality bricks, etc.). Better co-operation between the wall elements has been achieved by special (i.e. iron embedded in lead) connectors (i.e. classical period monuments). High quality mortars served the same goal (i.e. Byzantine era monumental constructions).

It is very important to mention here that a principle, which is modern today, was known and carefully applied at least 2500 years ago, during the construction of the Parthenon on the Athens Acropolis. The principle that the connector must be weaker than the connected members.

At least since the Minoian civilisation time (about 3700 years ago) serious attempts have been made to reinforce the masonry, improving its bending capacity and the ability to undertake tensile forces, by horizontal and, more seldom, vertical reinforcement zones. Usually wood was used, sometimes in a very sophisticated ways, as for an example in the settlement of Akrotiri on the Island of Santorini (1500 B.C.) (Fig. 10), (Fig. 4.).

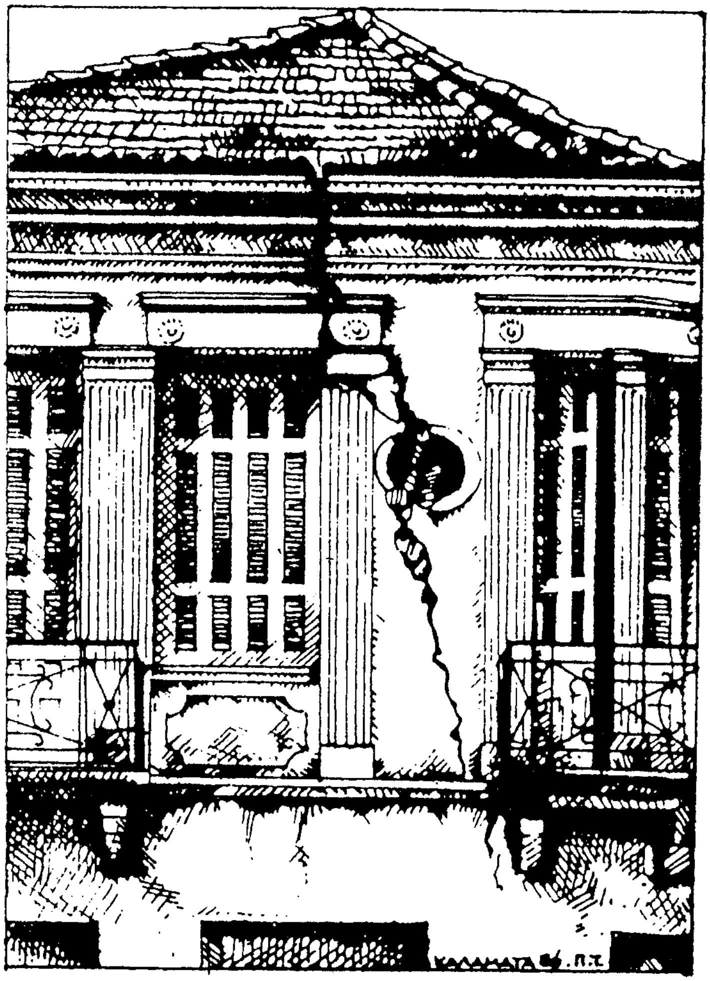
SOME OF THE REASONS OF THE WEAKENING OF THE CONSTRUCTION.



OTHER POINTS OF DANGER FOR AN OLD CONSTRUCTION ARE:

- THE CARELESS USE OF NEW, NOT EXPERIENED MATERIALS OR CONSTRUC-TION SYSTEMS WHICH ARE NOT COMPATIBLE TO THE STRUCTURE.
- CARELESS ADDITIONS OVER OR BESIDE THE OLD CONSTRUCTION.
- UNCORRECT MODELING AND/OR DIFFICULTIES IN ANALYSIS.
- LUCK OF KNOWLEDGE ABOUT THE TRADITIONAL MATERIALS OR TECHNI-QUES.

FIG 3. THE PROCESS OF THE WEAKENING OF AN OLD CONSTRUC-TION.



OLD BUILDING IN KALAMATA CITY HEAVILY DAMAGED BY THE EARTH-QUAKE OF 1986.

Trying to minimise the weight (and the mass) at the upper parts of the buildings the external and the internal, load bearing and separating walls of the higher floors started to be constructed in timber frame (Fig. 5). Those timber framed walls became more stiff by diagonal (and other) bracing's, more carefully developed in places with high probability of dynamic action as, for example, the mountains of Pelion in central Greece, with landslides and earthquakes, or the island of Lefkas with very high seismic activity (Fig. 13).

4.1. Morphology and seismic risk

It is very characteristic that the choice of the same material and the same construction system didn't produce same architectural and morphological types of buildings. In central and north Greece the lower floors have stone masonry reinforced by wood and the upper floor has timber framed external and internal walls. The light timber frame, the diagonal timber bracing , the careful interbonding of the timber members, etc., permitted more freedom in the design.

So the upper floor very often projects over the street enlarging or/and correcting the plan and the space of the rooms. On the other h and the upper floor acquired the privilege of many and large windows (Fig. 6).

On the island of Lefkas the same system , in general was applied. This island is subjected to very strong and frequent earthquakes. Only the ground floor remained in stone. The upper (one or two usually) floors although built in a very sophisticated timber framed construction system, keep the strict and conservative morphology of a stone masonry: no projections at all and small openings placed strictly one over the other (Fig. 6,13).

4.2. The co-operation of the walls

From very early stages of the construction activity in Greece it was also observed and understood that the load bearing stone or brick walls can resist loads in their plane quite successfully but become very weak in the case of accepting forces perpendicular to their surface.

These walls parallel to the main direction of the earthquake have a better seismic behaviour than the perpendicular ones, where we observe cracks from bending stresses and in some cases these walls collapse after overturning.

Since prehistoric times many efforts have been done to establish a reliable co-operation between the walls of a building.

Better interbonding of the stones at the corners, continuity of the horizontal reinforcement zones (usually in timber) by careful connections at the corners and the use of special iron tie-rods took place during the centuries (Fig. 4).

In more developed aseismic techniques the builders used the horizontal construction of a floor or a roof (with higher or lower diaphragmatic behaviour) to connect the walls (Fig. 7).

5. Horizontal load bearing structures (floors-roofs)

Traditional roofs and floors are usually made of wood. Sometimes we find horizontal load bearing structures of stone and bricks (vaults, domes, arches) metal beams (neo-classical buildings) even reinforced concrete. Especially during seismic action, horizontal load bearing structures, (partially or in the whole) transfer horizontal forces to the vertical load bearing system (Fig. 8).

A general goal is not only to extinguish the transferring of horizontal forces but also to transform these horizontal structures into diaphragms. In this way, with adequate anchoring and joints, the horizontal structures become rigid and connected and strengthen the walls during seismic action (Fig. 7).

In general, there are two large groups of roof construction. The first is a post and beam system. That means that vertical or inclined posts on horizontal beams support other horizontal or inclined beams creating the desired shape of a roof. Usually there is no any special geometric rule of components in that roof system. The advantage of that roof is its significant flexibility and as a result the ability to deform absorbing energy during seismic action. In that system usually the first horizontal layer of beams undertake the task of connecting the walls and creating the box-frame action. Also a diaphragm action, if any, is performed by the ceiling construction (Fig. 7,8).

The second group is using more geometrically defined components (as trusses, etc.). Here the energy absorbing capacity is much lower, the rigidity higher and the diaphragmatic behaviour of the upper levels of the more frequent (Fig. 8).

6. Examples of the aseismic techniques (and constructions) in Greek history.

6.1. Parthenon

The temple of Parthenon, on the top of Acropolis of Athens, built in the unbelievably short time of eight years (447-438 B.C.), has experienced during the last 2500 years many earthquakes, some quite severe, leaving on the structure unmistakable prints.

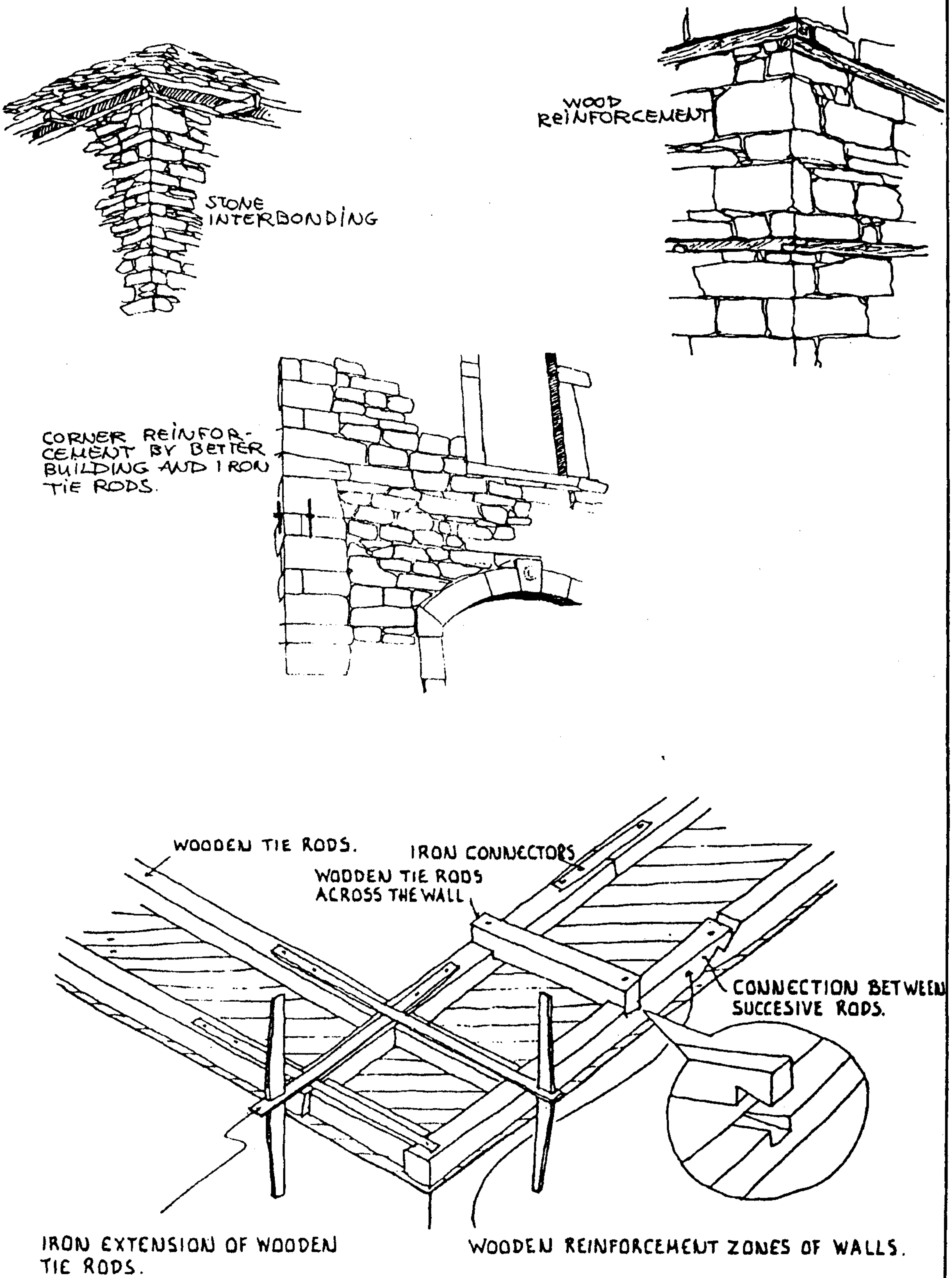


FIG. 4 - CONNECTION OF THE WALLS AT THE CORNERS OF THE BUILDING.

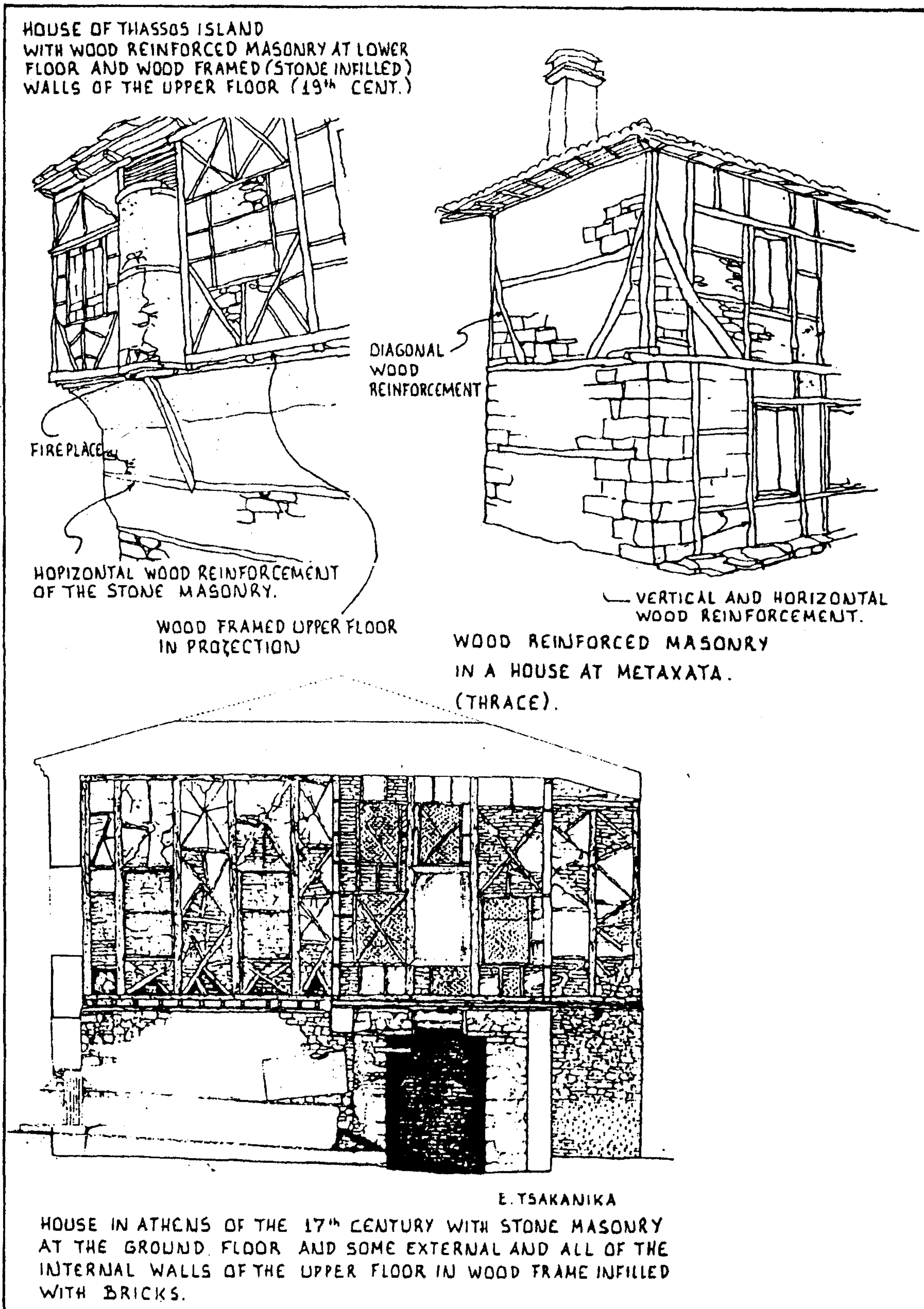
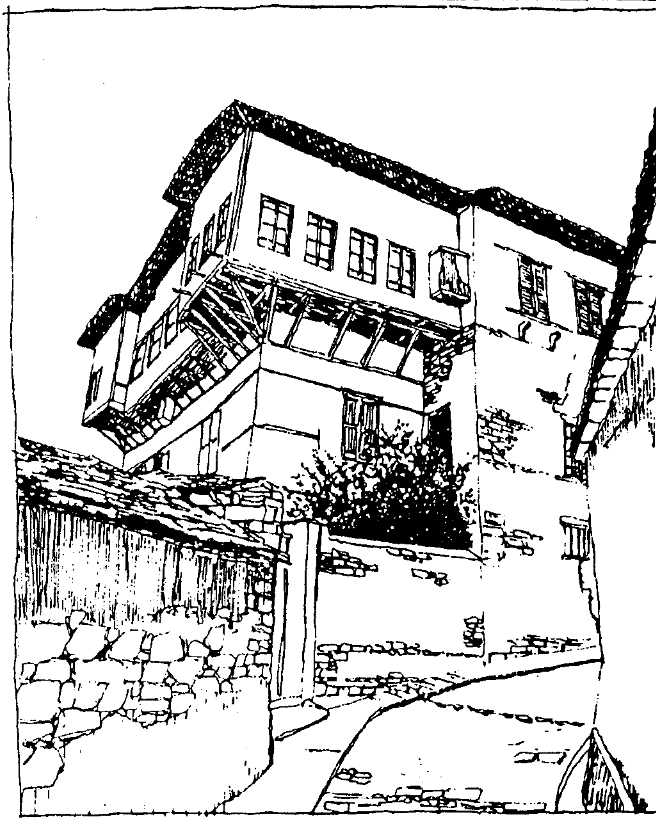
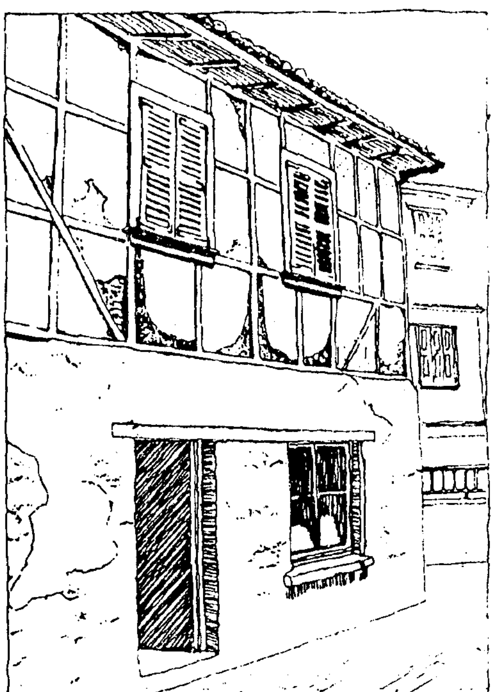


FIG. 5. WOOD REINFORCED MASONRY. –
· WOOD FRAMED WALLS AT THE UPPER FLOORS OF THE BUILDINGS.

TYPICAL CONSTRUCTION OF THE HOUSES IN PILION.
(CENTRAL GREECE WITH SEISMIC RISK AND LANDSLIDINGS).

THE LIGHT WOOD FRAMED UPPER FLOORS HAVE SIGNIFICANT FREEDOM IN THEIR DESIGN:
FREE COMPOSITION IN PLAN, DARING PROJECTIONS AND HIGH PERCENTAGE OF OPENINGS IN THE WALLS.





TYPICAL CONSTRUCTION OF THE HOUSES IN LEFKADA ISLAND WITH VERY POOR SOIL AND VERY HIGH SEISMIC RISK.

THE LIGHT WOOD FRAMED UPPER FLOOR DESIGN, FOLLOWS THE STRICT AND CONSERVATIVE FORMS OF THE GROUND FLOOR MASONRY:
NO PROJECTIONS AT ALL AND SMALL OPENINGS PLACED USUALLY ONE OVER THE OTHER.

FIG 6. THE INFLUENCE OF THE HIGH SEISMIC RISK ON THE MORPHOLOGY OF THE BUILDINGS.

Recent works of restoration revealed more details about the perfect work of the architects and craftsmen. Just the description of one such detail, from the work of H. Bouras and M. Korres about Parthenon restoration, can determine the level of aseismic technique knowledge 2500 years ago.

Time Parthenon has all the features of the Doric Order in their perfection. Designed by Ictinos and Callicrates it was the wider and longer than any other temple of the time with eight - column (octastyle) portico rather then the usual six-column (hexastyle) one.

Along the long sides of the temple the marble components, which cover the space between the colonnaded and the wall are also connecting them by means of special iron joints. In this way the colonnade (with its entablature) has to behave as a whole together with the wall of the nave, during dynamic action. This is performed successfully for 25 centuries because of the similarity of their masses (Fig. 9).

On the contrary, along the other two short sides (the East and the West ones) of the temple, the marble beams, as well as the marble plates, which cover the space between the colonnades and the wall are connecting them at a fixed distance only by means of the friction. That means that the ceiling components of those territories of the temple are simply placed on the entablature of the colonnade and the nave, without any joint element, permitting independent movement. This happens because the mass and the geometry of the colonnade at that point is quite different of those of the wall of the nave. During strong dynamic loading the movements (deflections) of the nave wall have different characteristics from those of the colonnades at the front. The beams would not be able (as the calculation also showed) to keep the distance between the nave wall and the colonnades fixed, even if they were connected by means of the heaviest types of joints, which have been found on the Parthenon.

6.2. "Akrotiri" example (1500 B.C.)

In the two or three storey buildings that were excavated at the settlement of Akrotiri on the island of Santorini in Greece, destroyed by a volcano eruption in 1500 B.C. heavy and complicated wooden, load bearing construction was uncovered. This construction not only reinforced the stone walls and the perimeters of the openings, but it was used as a load bearing wall itself. The design of this construction and especially the details of the joints, which are capable for strong tension actions, prove the effort for survival of a people who, living on the slopes of an active volcano, was familiarised with the constant seismic risk (Fig. 10, 11).

6.3. "Lefkas" example (1825 A.D.)

Lefkas is one of the Greek islands with very high seismic risk. In 1825 the city of Lefkas was destroyed by a severe earthquake. After that, the English who occupied the island (1810-1864) established the first Aseismic Code. In 1827 new regulations about materials and buildings systems to be used were formulated. Today these system of wood framed constructions are still in common use responding very satisfactorily to the frequent strong earthquakes.

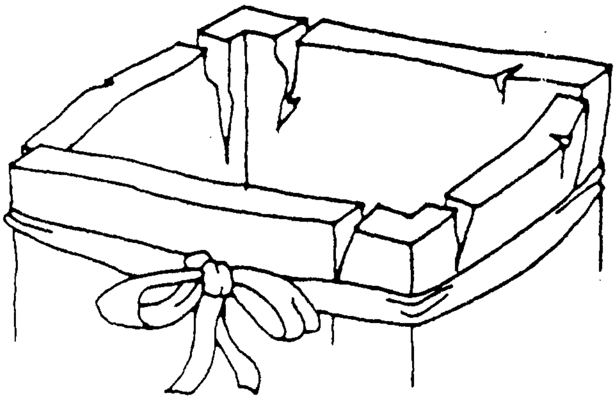
Multi-storey buildings are based upon a foundation which consists of a heavy wood grill covered by sand, stones and purcolana. The ground floor, is surrounded by stone walls. The timber frame of the upper floors is supported by this walls. A secondary, load bearing system of wooden columns, like a second line of defence, is constructed in parallel line to the internal side of the stone walls, also supporting the same timber frame of the upper building. During severe earthquakes, parts of the stone walls can fall outside leaving the whole wood frame of the multi-storey building untouched and temporarily supported by the wooden columns until the masonry is repaired. (Fig. 12). While taking advantage of the obvious properties of a stone wall, such as strength, diaphragmatic behaviour, traditional appearance, prestige, security, etc. this type of construction system, by means of redundancy does not transfer the severe deformations or possible failures of the weaker parts, which in this case are stone walls, to the light timber structure (Fig. 13).

There it can be argued, that the principle of independently deformed but collaborating parts of a building was established at least two centuries ago, when it was realised that different constructions using various materials present different behaviour under seismic loading. A principle that is very important in the modern aseismic construction as well.

The wood frame, consisting of modulated vertical studs and horizontal beams and girders, is carefully stiffened by slanting wood rods and by wooden corner reinforcements curved out of a whole pieces of wood (usually brunches or roots, in right angle, of an olive tree) (Fig. 13).

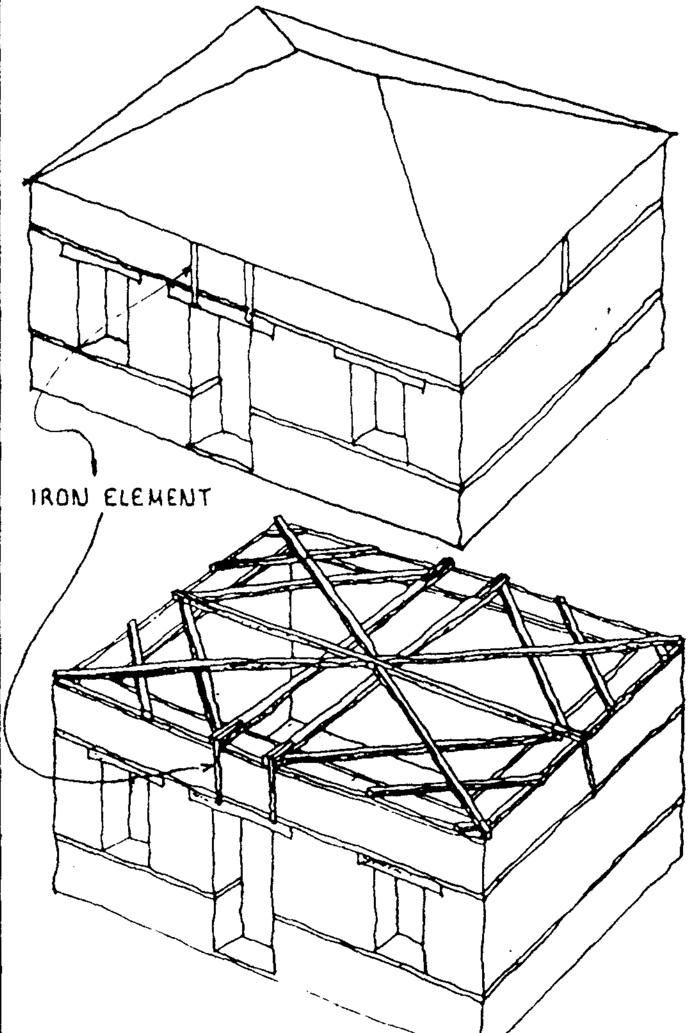
Sophisticated systems of interbonding of the timber parts are also found. The timber components, properly curved out and using nail, timber dowels and wedges, present resistance to tensile action and a ductile behaviour always avoiding a too stiff composition (Fig. 14, A). Thus a second basic principle is recognised: the advantage of using strong timber joints with adequate ductile (or/and energy absorbing) behaviour (Fig. 14, B). The similarity of the described interbonding of the timber parts in Lefkas with those of the constructions of Akrotiri township in Santorini (13 centuries earlier) is noteworthy.

FIG. 7. THE COOPERATION OF THE WALLS IMPROVED BY THE ROOF FRAME CONSTRUCTION.



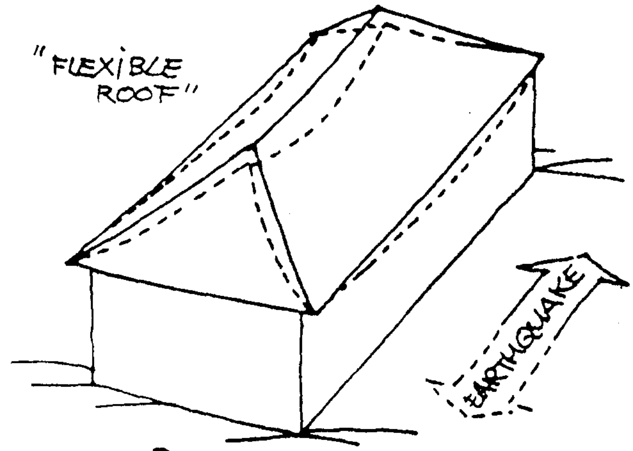
DUE TO SEISMIC ACTIONS THE WALLS CAN BE REMOVED FROM THEIR VERTICAL POSITION, SEPARATED FROM EACH OTHER, CURVED, CRACKED OR EVEN OVERTURNED.

THEREFOR THE BUILDING CAN BE "TIED" AT THE PLACE OF HORIZONTAL PLANES OF ROOFS AND FLOORS BY...

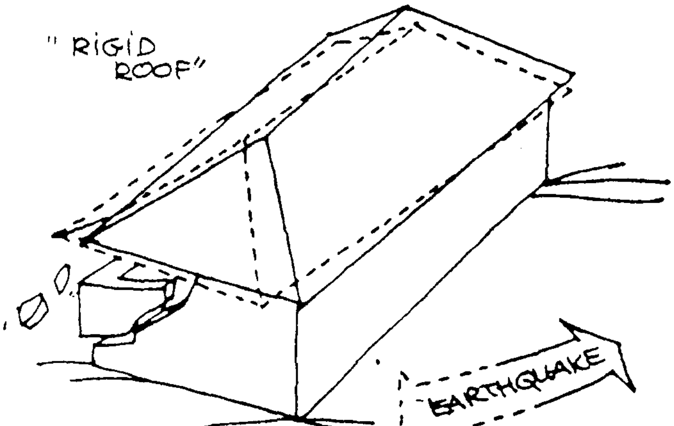


... THE CONSTRUCTION OF THE FLOOR OR THE ROOF AS THIS EXAMPLE FROM GALAXIDI ON THE KORINTHIAN BAY WITH HIGH SEISMIC RISK.

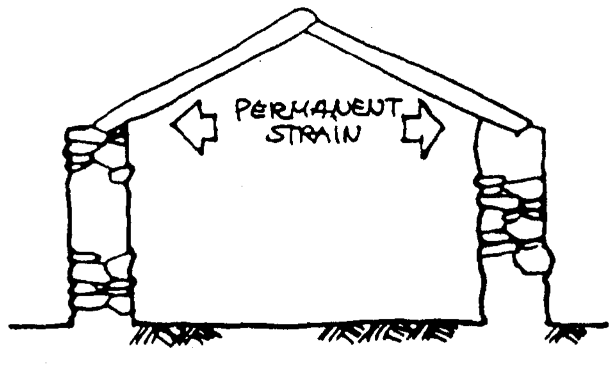
FIG. 8. ROOFS

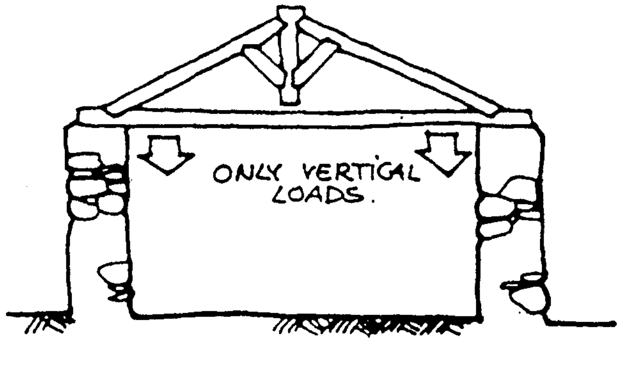


ROOF FRAME THAT ABSORBS THE SEISMIC ENERGY.



ROOF FRAME WITH NO ABSORPTION OF THE SEISMIC ENERGY.





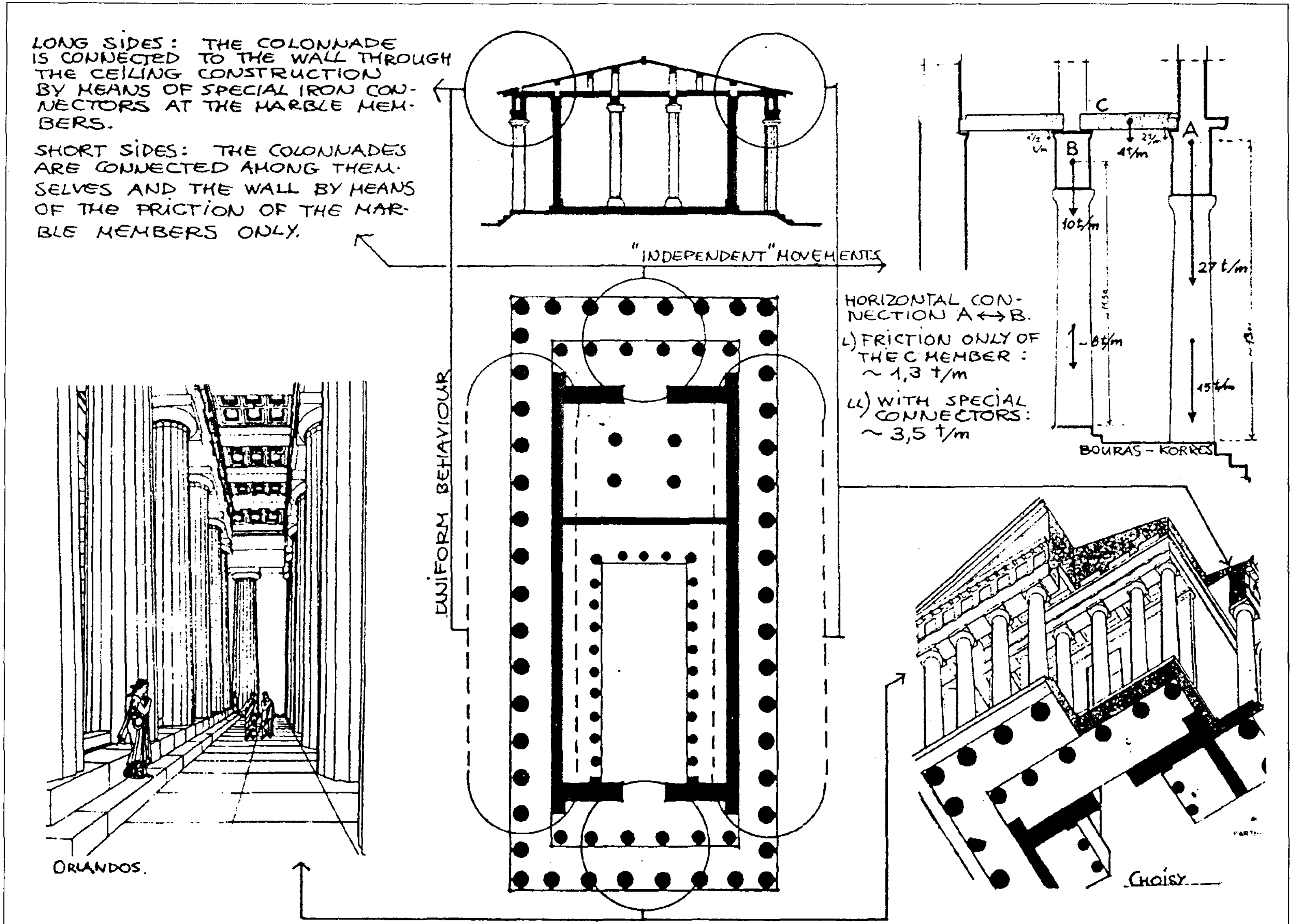
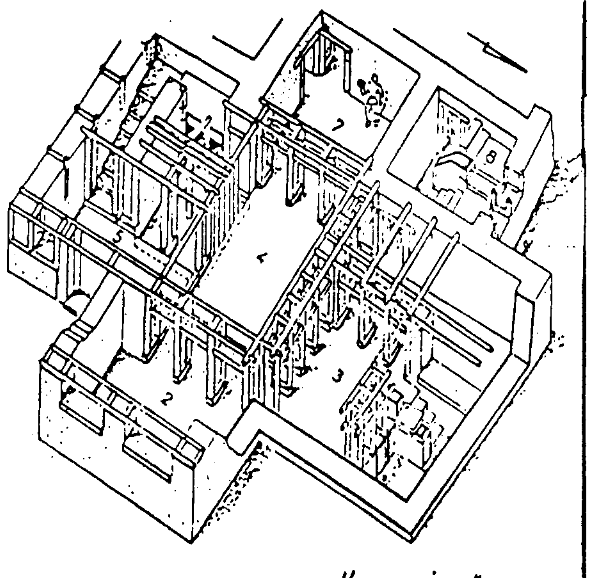


FIG. 9. DYNAMIC BEHAVIOUR OF SOME PARTS OF THE PARTHENON.



GROUND FLOOR OF "XESTI 3"
(KLAIRI PALYVOU - 1988)

WINDOWS (TYPE D)
(KLAIRI PALYVOU - 1988)

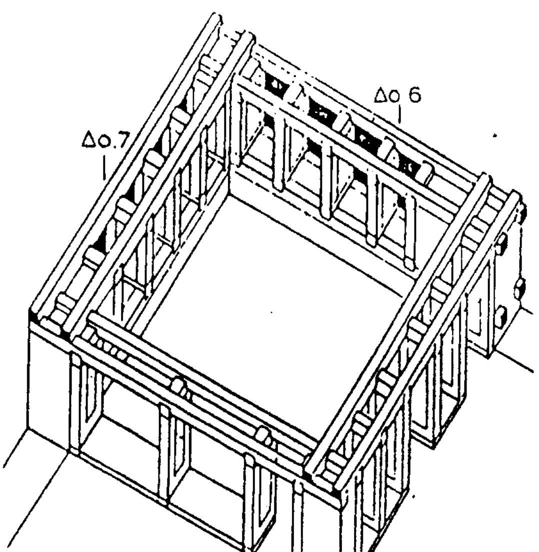
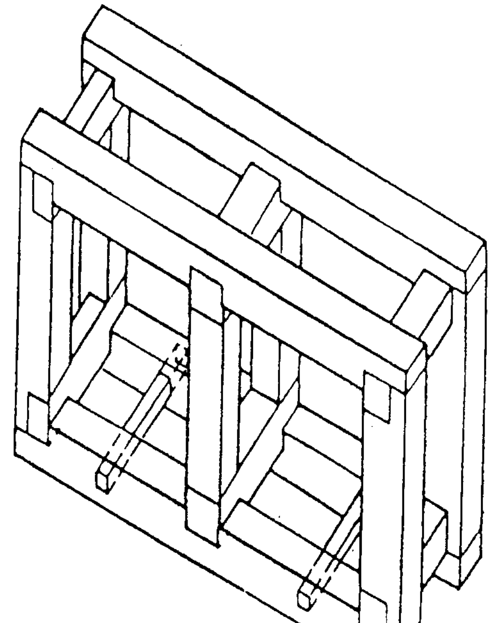


FIG 10. HEAVY WOODEN CONSTRUCTIONS OF THE EXCAVATED BUILDINGS IN AKROTIRI OF SANTORINI (THIRA) 1500 B.C.



THE WOODEN FRAME OF THE WINDOW. (TYPE C)
(By KAIRI PALYVOU - 1988)

THE WOODEN FRAME OF A WINDOW FROM "XESTI 3"
(BY KL. PALYVOU. - 1988)

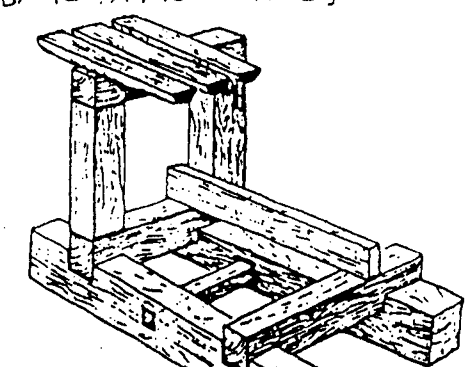


FIG 11. HEAVY WOOD FRAMES OF THE WINDOWS OF THE EXCAVATED BUILDINGS IN SANTORINI (AKROTIRI 1500 B.C.)

7. Epilogue

It is a well established principle that today we must strive to preserve the aseismic behaviour of those old buildings without changing the initial architectural, static and dynamic conception in any restoration or conservation project because the correctness of the chosen solutions has been proved several times during the existence all those years.

Our goal should be the re-establishment of their initial (at least) strength and resistance to the earthquakes in the most compatible and simple way. In this procedure the best possible knowledge of the relevant aseismic technique which has been used and the aseismic design principles is necessary.

REFERENCES

1. J.Ederhard, "Architects and Earthquakes". New York 1975.
2. Chr. Arnold, R.Reitherman, "Building Configuration and Seismic Design", New York 1982.
3. M. Korres, Ch.Bouras, "Study for the restoration of Parthenon", Athens 1983.
4. C.Palyvoy, "Akrotiri, Thera: Building Techniques and Morphology in late Cycladic Architecture", Ph.D. Thesis N.T.U.A Athens 1988.
5. Rowland Mainstone, "Hagia Sofia", London 1988.
6. P.Touliatos, "Interventions on Architectural Monuments and Historical Settlements. Seismic behaviour of Traditionally constructed Buildings. Repairs and Reinforcements", Heraklio, Crete 1988.
7. E. Tsakanika, S. Lasouras, "Traditionally Built Structure of the 16th Century", Diploma Thesis N.T.U.A. Athens 1988
8. D.Gante, M. Mitropoulos, "Lefkas Earthquake-Resistant Building Technology of the 17th Century". Research N.T.U.A Athens 1990.
9. "Greek Traditional Architecture", Published by "Melissa", Athens 1991.
10. P. Touliatos, "The aseismic design of the timber construction of the Past and Today", 1st Greek Conference on Aseismic Engineering and Seismology, 2nd Volume, Athens 1992.
11. P. Carydis, O. Vagelatory, I.Vlachos, M. Xinostathi, P. Touliatos, K.Holevas, "Research for the Constructional Seismic Regulation", Athens 1985.

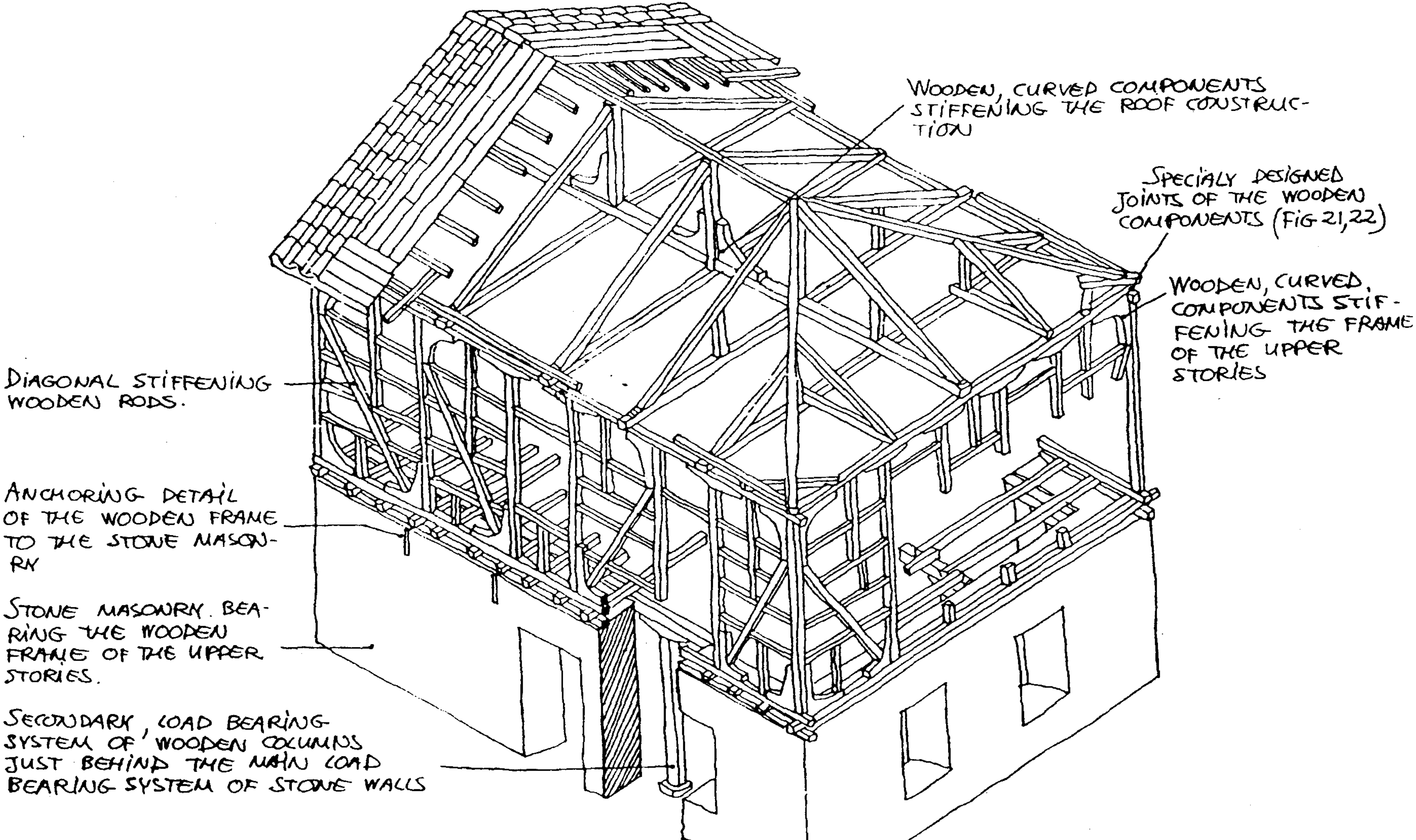


FIG. 13. GENERAL ISOMETRIC VIEW OF THE TRADITIONAL WOOD-FRAMED ASEISMIC CONSTRUCTION OF THE GREEK ISLAND OF LEFCAS.

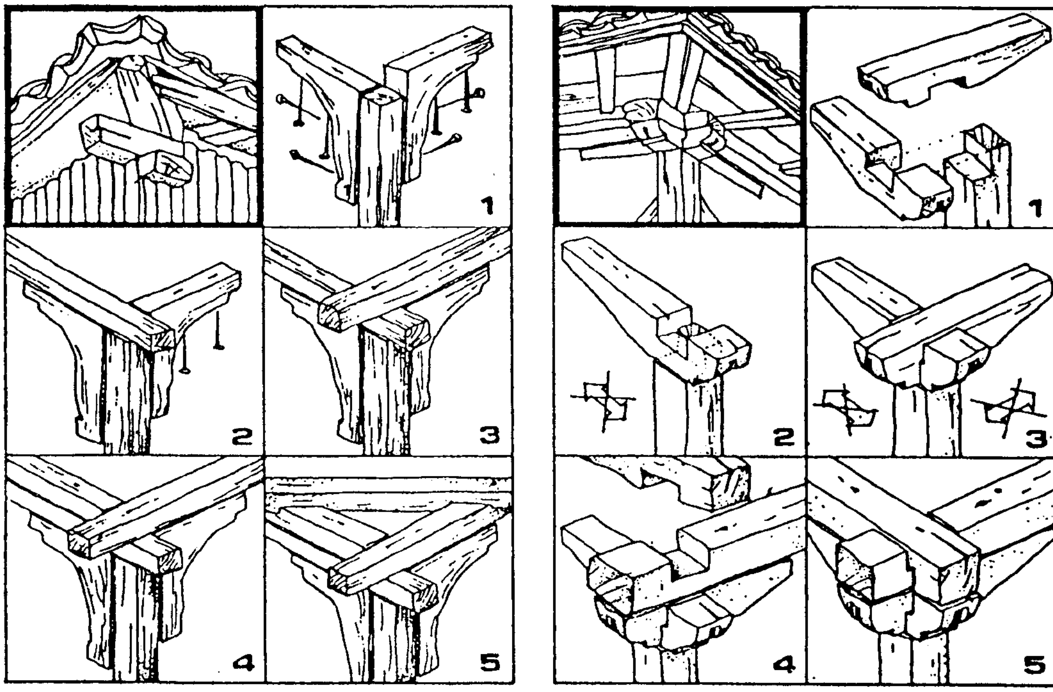


FIG. 21. ISLAND OF LEFCAS - GREECE.
CHARACTERISTIC EXAMPLES OF THE JOINTS OF THE WOODEN COMPONENTS IN THE TRADITIONAL WOOD FRAMED ASEISMIC CONSTRUCTION OF THE ISLAND.

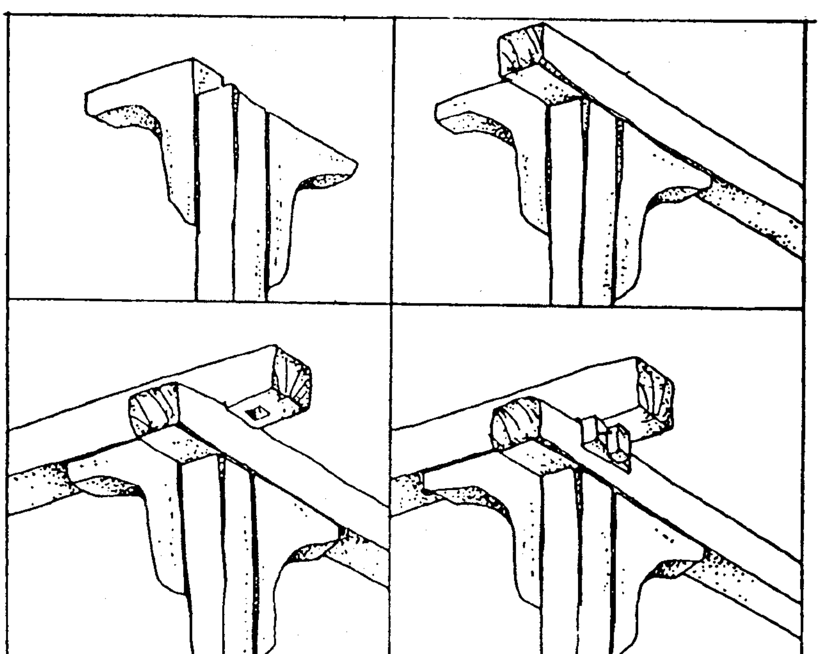


FIG. 22. ISLAND OF LEFCAS - GREECE.
CHARACTERISTIC EXAMPLE OF A JOINT WITH A SIMPLE ENERGY ABSORBING MECHANISM. WHEN BROKEN THE WOODEN DOWEL CAN BE EASILY INSPECTED AND QUICKLY REPLACED.