# International Workshop Earthen Buildings in Seismic Areas

## Conference Proceedings Volume I


The University of New Mexico

Intertect

Prepared for
The National Science Foundation

# INTERNATIONAL WORKSHOP

# EARTHEN BUILDINGS IN SEISMIC AREAS

PROCEEDINGS OF INTERNATIONAL WORKSHOP
held at the University of New Mexico,
Albuquerque, New Mexico, May 24-28, 1981

VOLUME I

Edited by:

Gerald W. May
College of Engineering
The University of New Mexico

Sponsored by:

The National Science Foundation
Washington, DC 20550

Appropriate Technology International (ATI)
Washington, DC 20036

Office of Foreign Disaster Assistance (OFDA)
Washington, DC 20523

Issued September 1981

# THE EXTENT OF THE PROBLEM OF EARTHEN BUILDINGS IN GREECE

Panayotis Gr. Carydis

Professor, Chair for Earthquake Engineering, National Technical University, 42 Patission Str., Athens 147, Greece.

ABSTRACT

The present paper deals with "Earthen Buildings" that have a load carrying system of clay with various admixtures. The same term may also include structures with an initial wooden load carrying system filled in with clay. The clay is used either in the form of cast in place material or in the form of raw bricks.

Earthen buildings in Greece have been constructed since the protoneolithic period, and they have been considered superior than the baked brick wall construction, according to the use.

If well maintained and waterproofed, the earthen buildings show a very good earthquake resistance. There are cases that this type of buildings have suffered several strong earthquakes during their life, which in most cases reaches 100 years up to now.

# Introduction

## Terminology

In the present paper the term "Earthen Buildings" means the structures the main load carrying system of which is constructed out of clay with various admixtures. The same term may also include structures with an initial wooden load carrying system filled in with clay.

## Extent of the problem in Greece

In Greece, a considerable number of people still use earthen buildings and in some cases serious problems may arise after damage of these type of structures due to an earthquake. During the last earthquakes a great percentage of this buildings were damaged.

There are no provisions for the aseismic construction of earthen buildings in Greece. There are provisions only for masonry (stone and brick) and reinforced concrete structures.

Earthen buildings have not been constructed in Greece in the last 30 years as main structures for habitation, and most likely this type of structures will not be constructed any more in Greece, according to the present state of practice.

The repair and strengthening of this type of buildings is a problem in most cases. There are also cases where alterations, additions and renovations must be done to earthen buildings due to various reasons (use, archaeological,traditional) and the required technology it is not very well known.

In addition, the maintenance and waterproofing of the material of the walls of earthen buildings present considerable difficulties.

# Historical Background

About the Protoneolithic age (6500 - 6000 b.C.) the inhabitants of Greece left the caves and settled in plains or on the shores of lakes, rivers and smooth bays. They wanted to have more permanent homes near the places of their work (pastures and farming fields), and they created the first communities in the plains of Thessaly, Argolis and Thrace.

Using techniques similar to those used for the knitting of baskets the early builders could create large spaces, of a rather circular form, for their houses using branches of trees driven into the ground. The branches were then smeared with mud on the outside. Later, clay (grayish or red) was used instead of mud and the houses were smeared with clay on the outside and even later on the inside as well.

Next, they used trunks or piles of wood for the skeleton of the houses and raw bricks to fill in the gaps between the wood. The piece of the wood that was driven into the ground was smeared with clay in order to protect it from humidity and other effects, Choremis (1981).

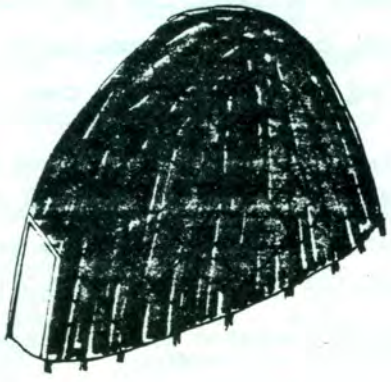

FIG. 1

The early builders created large round spaces, using branches and a cover out of mud.

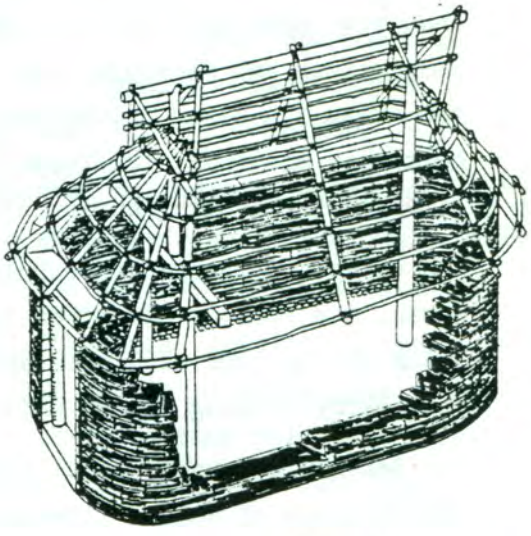

FIG. 2

Later, wooden frames and raw bricks were used, Schefold (1930).

Ruins of this kind of structures have been found in Sesklon-Thessaly-and in New Nicomedea. The houses had a rather rectangular shape with round edges, with partitions inside.

Various admixtures were used in the clay, according to the availability of local materials, the existing practice related to the construction of other similar objects (earthen casks etc), and the prevailing climatic and topographic conditions. These materials were: asbestos, sand, mica, and - what was very popular--the ground straw. In the island of Syros asbestos was used, although this mineral was not found in the island itself.

Bull's excrements or hair of animals were used, as an admixture to the mass of the clay, against high temperatures and as waterproof materials.

In some cases, instead of clay light (porous) and waterproofing material was used (Asia Minor, Spain, Greece). This light material was very useful for the upper parts of domes.

The clay with the other admixtures was used as a material that was cast in place, as a mortar and for the construction of raw bricks.

The latter case is the most popular. Greeks, Babylonians, Egyptians, and Romans extensively used the raw bricks out of clay and ground straw. They did not yet know the baked bricks, but when the latter ones were discovered and used by the Babylonians and Persians, the Greeks and Romans believed the raw bricks to be better than the baked bricks and natural stones, because the raw brick walls were better in absorbing the impacts of the sieging rams, and thus they were more slowly deteriorating during sieges.

The effect of the water is ruinous. It is reported, Orlandos (1955) that in some cases, the ruinous effect of the water was used as a weapon by the besiegers. The walls of the city of Iionos and those of Mantinea were destroyed by the water of the nearby flowing rivers which were on purpose deviated by the besiegers.

The Babylonians used asphalt as gluing material between the raw bricks in the construction of walls. Elsewhere, smaller pieces of crushed stones or baked bricks for wedging the raw bricks among each other were used.

Many ancient writers like Plato, Xenophon, Herodotus, Aristophanes, Thucydides, Strabo and Vitruvius, referred to the way of preparation of the admixtures of the clay, the way of molding in order to form raw bricks, as well as the way of drying, transportation, and cost of the raw bricks. The bricks were made by specialized technicians and workshops. A kind of trade mark like a seal was usual among Ba-

bylonian raw brick makers, by which the date and place of construction was stated.

This was by law imposed on the Roman raw brick makers who should also indicate the name of the maker.

The shape of the bricks was in general that of an orthogonal parallelepipedon except in some rare cases were the base was a trapezoid (like in Delphi), Orlandos (1955).

The height of the bricks was relatively small, compared to the other dimensions. The height rarely was more than 10 cm , while the other two dimensions were more than 30 and 40 cm. The dimensions were, more or less, standard. The base had dimensions multiple of the "foot" in ancient Greece (= 0.308 m). The height was a multiple of the "finger" (= 1.92 cm), Smith and Tsivanopoulos (1890).Dimensions that were measured in ruins were 0.308 m in the walls of the city of Athens;0.45 m in the walls of the sanctuary of Elefsis; 0.38 m in the walls of the city of Apollonia; 0.39 m in the walls of the houses in Olynthus, Orlandos (1955).

Half bricks were used in order to braid the bricks for better construction of the walls. It is interesting to notice here that the smaller dimension was less than the half of the other dimension in order to leave space for mortar.

The dimensions of the base of the bricks depended on the particular use. For private houses, for example, smaller dimensions were used, while for public works the larger dimensions were preferred, Smith and Tsivanopoulos (1890).

Interesting ruins in Greece are among others, Choremis (1981): The west gate of Eretria since 600 b.C. A part of the wall still remains, because the fire that turned the construction into ruins baked in the same time this part and made it more durable; The palace of Nestor in Pylos, built about 1250 b.C., was timbered. Its height was at least 2 stories. Thick plaster out of clay was placed on both sides of the timbered walls. The palace in the island of Santorini,that was destroyed from the eruption of the volcano at 1500 b.C., was timbered and plastered with clay and pumice.

A part of the walls of the city of Gela in South Italy was found intact, Choremis (1981), because it was buried in the surrounding sand and clay and the water could not destroy it.

## Present Condition of Earthen Buildings in Greece

The various Governmental programs for rehabilitation of refugees (1920-1930) and of population striken by the war (1940-1949), although they were very big (about 200000 dwellings) and provided for a variety of relatively cheap building types, did not include the construction of buildings with earthen raw bricks,except in one or two settlements, where the earthen raw bricks were used as a filling material to the wooden load carrying system, Papaioannou (1975). This, in spite of the traditional reasons that might impose the construction of earthen buildings, was due to the relative difficulties for mass production of this type of buildings and to the high cost of their maintenance.

In the city of Kiation, noth Peloponnesus, a settlement of 100 one storied units has been constructed in 1930 within the frame of the habitation program for refugees. The load carrying system of each unit is a wooden frame with diagonal beams. The gaps are filled with earthen raw bricks, Fig. 3.

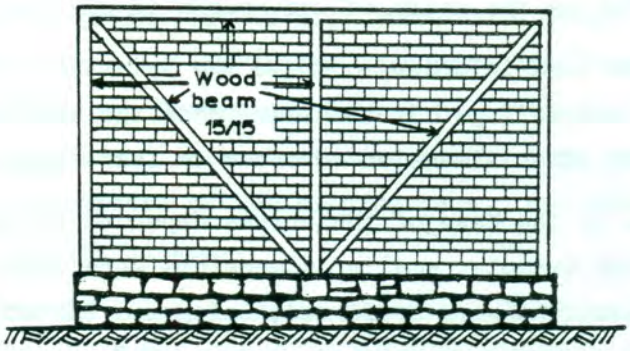


FIG. 3

Elevation of a wooden frame for houses. The gaps are filled with earthen raw bricks. The base is out of stone masonry.

All the well maintained buildings out of wood frame and earthen raw bricks in Kiaton withstood the various earthquakes quite well, Fig. 4. If we assume a rather strong shock every 20 ÷25 years that happens in this region, this type of buildings has been tested by the earthquakes two to three times quite successfully.

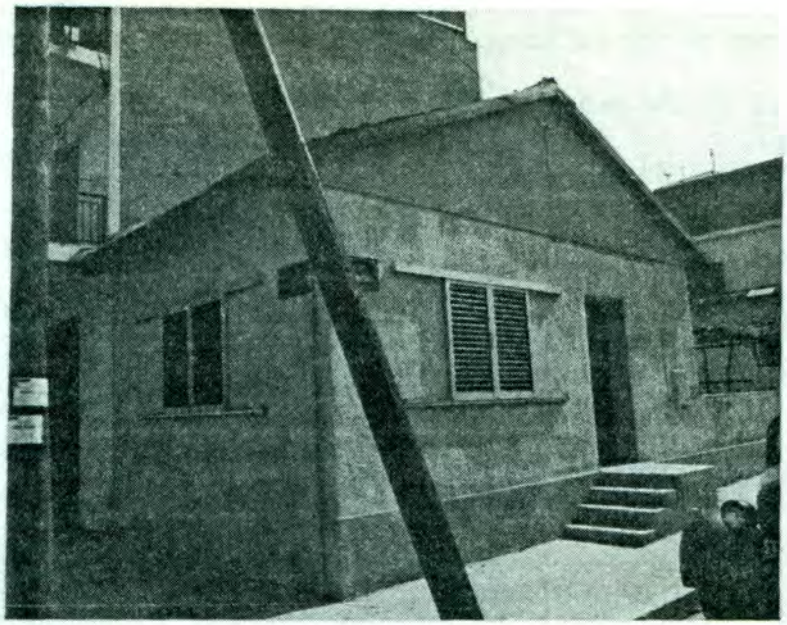

FIG. 4

Well maintained earthen buildings stand the test of time and of earthquakes very well.

Most of the buildings of this type, constructed in Kiaton, have been renovated and extended by adding more rooms in the horizontal and vertical direction using other materials, like stone or baked bricks and reinforced concrete. It has been observed that stone masonry structures and this type of structures of equal height had the same movement during the recent series of earthquakes of February 24 and 25, 1981. The same movement of adjoined buildings means same dynamic characteristics of these two types of structures. Many of this type of buildings have been demolished in order to build modern houses, propably, because the wooden frame and roof rotted.

In earthquake areas wood was used up to the late fifties as a strengthening element to the load carrying system, regardless of the material from which the latter was made. The wood is placed in the corners, in the sills of the windows,in the lintels, in any intermediate height if required, and under the roof. There are vertical, horizontal and x-braced wooden beams. In most cases they do not form any kind of frame.

In some cases, like in the island of Lefkas massive wooden corners were used to strengthen the corners of the buildings. These corners, each one of which was carved in one piece of root - usually of olive tree - were forming the end of

the corner of the building, Fig. 5.

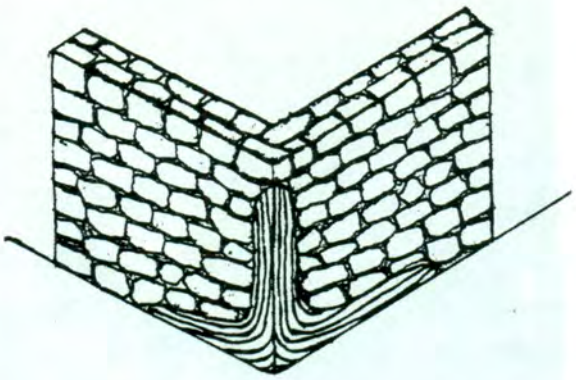

FIG. 5

Massive one-piece carved wooden corner (island of Lefkas).

Some cities and villages in Greece have many one or two storied earthen buildings, with a load carrying system out of earthen raw bricks. Thise buildings are 80-100 years old. There are wooden beams as strengthening elements and for the distrubution of loads, Fig, 6.

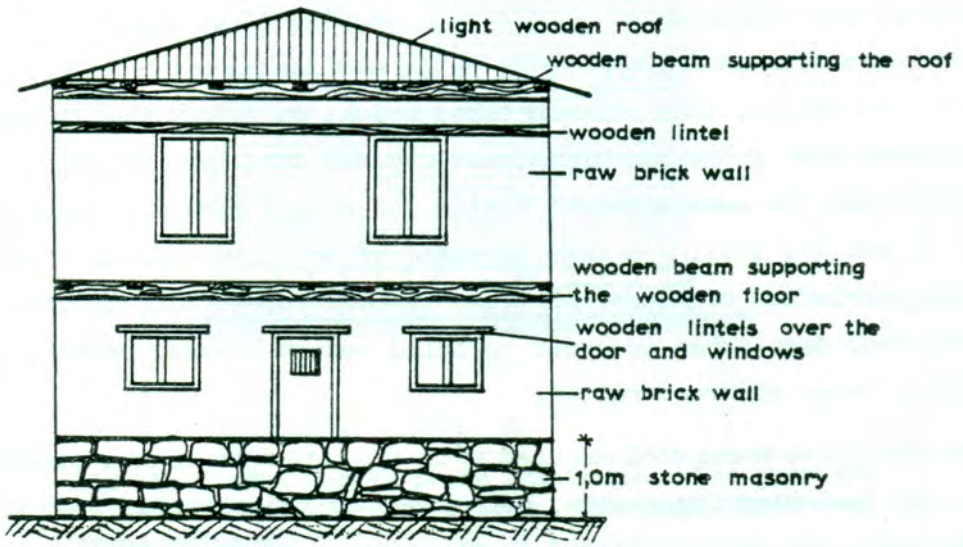


FIG. 6

Typical two storied earthen building

The "modern" raw bricks have dimensions 40*20*20 cm, and they out of clayey soil with ground straw.The pieces of straw have a length of 1-4 cm. Some times the clayey soil has small stones,fragments of tiles and sand.The same material is used

as mortar between the bricks.

In rare cases the mortar of the vertical joints between bricks is missing.

The thickness of the walls depends on the loads carried by them. Typical thickness for a bearing wall of a two storied building is 60 -70 cm.The internal partitions of the buildings are of a light timber construction (bagdhadi).

The percentage of earthen buildings in the various cities and villages in Greece constantly decreases. Table 1, for example, shows the results of relavant statistics for the city of Kiaton from 1920 up to this year.

TABLE 1

| Year | Earthen raw brick masonry | | Stone masonry | | Wood.fr./raw brick fill. | | R/C with baked brick fill. | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Num. | % | Num. | % | Num. | % | Num. | % | Number |
| 1920 | 500 | 100.0 | - | - | - | - | - | - | 500 |
| 1928 | 650 | 92.9 | 50 | 7.1 | - | - | - | - | 700 |
| 1940 | 1000 | 75.7 | 200 | 15.2 | 80 | 6.1 | 40 | 3.0 | 1320 |
| 1971 | 1300 | 56.6 | 470 | 20.4 | 30 | 1.3 | 500 | 21.7 | 2300 |
| 1981 | 1300 | 52.9 | 60 | 2.4 | 20 | 0.8 | 1080 | 43.9 | 2460 |

These statistics may be conidered as a typical example for other Greek cities that had also many earthen buildings in the past.

During the recent earthquakes 70% of the earthen buildings with raw brick masonry in the city of Kiaton were seriously damaged and have been condemned. This is attributed to: bad maintenance, due to which the water or the high humidity deteriorated the walls; damage of the roof; the rotten wooden beams that were initially used for strengthening; lack of or bad foundation; no, or inadequate repair of damages due to previous earthquakes. Numerous buildings almost 80 years old belong to the latter case. Some additional reasons for serious damages were the creation of big openings in the walls-resulting from a change of use mainly in the center of the old city- as well as the addition of more closed space with the constuction of reinforced concrete slabs and beams which are supported by the raw brick walls. Example of this type of mixed construction is the plan in Fig. 7, which, however, remained intact during the recent earthquakes.

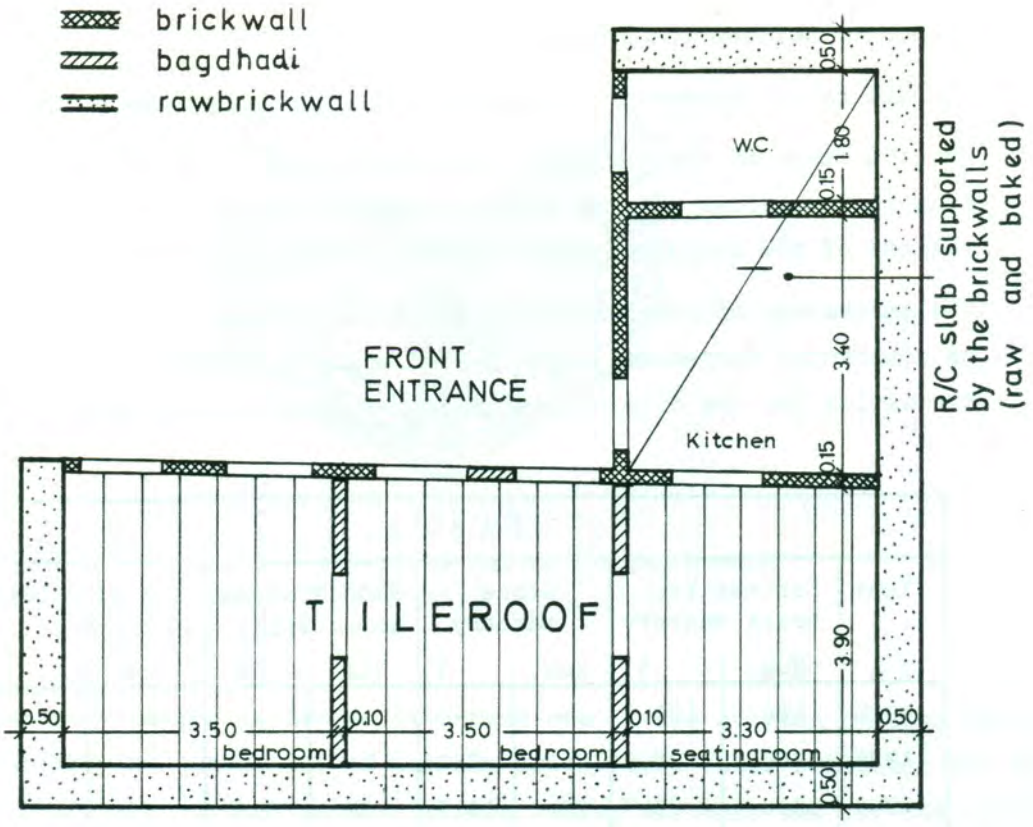


FIG. 7

One storied Earthen building since 1900,with new facade and partially new roof out of R/C, in Aghios Ioannis Rentis/Athens.

FIG. 8

Two storied earthen building in the center of the city of Kiaton. In the front of the first storey,a R/C construction replaces the existing wall: beam with balcony on slender columns. The building was seriously damaged by the recent earthquakes.

Other examples of renovations, additions etc, to this type of buildings are shown in Fig. 8 through 11.

FIG. 9

Two storied earthen building in the center of the city of Kiaton. Details of the construction of the roof and of the light partitions. Alterations in the front of the first storey.

FIG. 10

Two storied earthen building in the center of the city of Kiaton. Beam on columns out of R/C replaces the biggest part of the front wall of the first storey,for larger openings for the windows.

FIG. 11

An one storey old earthen building has been renovated with the addition of R/C columns and R/C beams, and of a second storey, out of R/C load carrying system and baked brick walls for partitions.

FIG. 12

A modern construction out of R/C and baked brick walls is added to an old two storied earthen building.

In Fig. 12 through 14 other damages of two storied earthen buildings are shown after the recent earthquakes in the city of Kiaton. These buildings have suffered several strong earthquakes. Most of them have not been repaired during the last 50 years.

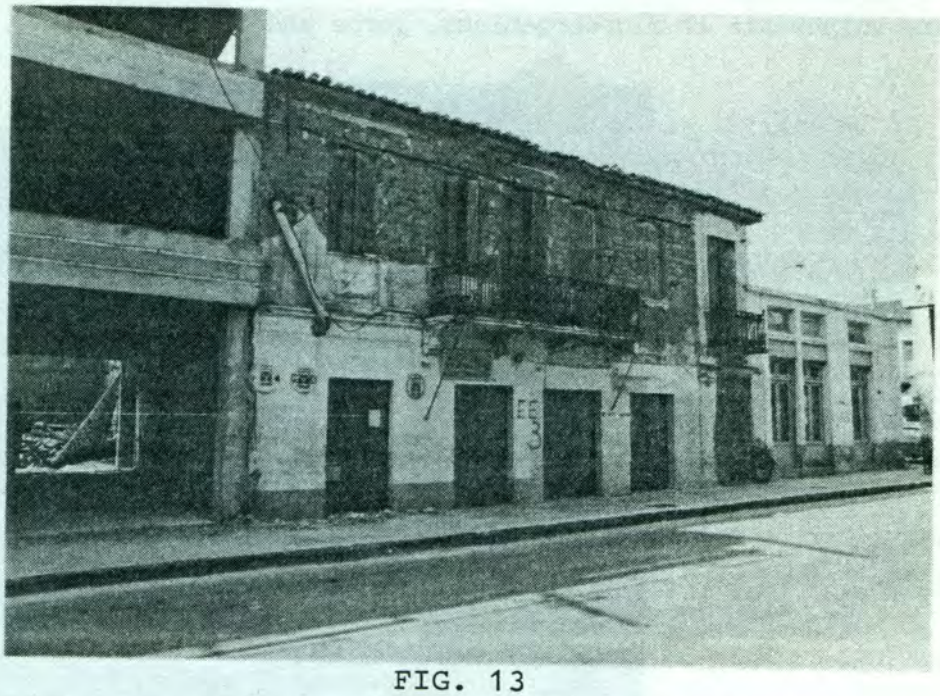

FIG. 13

Old earthen building near the sea shore. The separation of the mortar is typical.

FIG. 14

A two storied earthen building,100 years old. This building has suffered at least 3 strong earthquakes, while it was not repaired after the second one.

The rain water, the ground water or the humidity are destructive for the raw bricks. For this reason a waterproofing mortar is one of the best means to make the earthen buildings more durable.

The wooden beams which are put for strengthening the walls of earthen buildings are vulnerable to microorganisms, worms and insects.

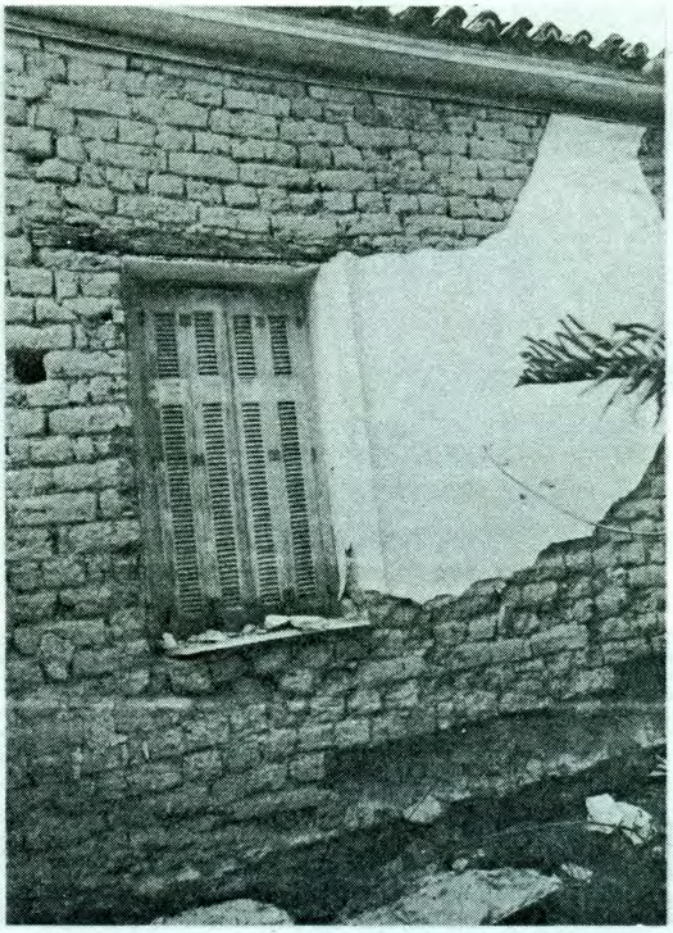

FIG. 15

Humidity and ground water is coming from the body of the foundation. The uncovered raw bricks loose their strength. The wooden beams of the lintel and roof have been moth--eaten.

It is interesting to notice here that many earthen buildings collapsed slowly. The remaining parts did not move one in relation to the other,which means that during the collapse of the building there was no shock or any high acceleration of the particular parts. Some observers say that the buildings sat slowly on the ground.

FIG. 16

Collapsed two - storied earthen building

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