DESIGN, CONSTRUCTION, BEHAVIOR AND REPAIR PROBLEMS OF RURAL STRUCTURES IN GREECE

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ABSTRACT

Classification of different low-cost construction systems used in Greece is attempted.

Problems and possibilities of design, construction, seismic behavior and repair of rural structures in Greece, with either traditional or recent low-cost construction systems, are presented, with emphasis on observations and conclusions from recent destructive earthquakes (Volvi 1978, Magnissia 1980, Alkyonides 1981).

Need for practical design, construction and repair recommendations, easily available to rural population, is stressed.

Introduction

Greece is one of the most seismically active countries in the world. Mean return period for $M \leq 6,0$ and $M \leq 7,0$ earthquakes is estimated to be 0,4 and 3,0 years respectively (4). During this century, Greece experienced at least 4 shocks stronger than 7,4R, while there is historical evidence of repetetive extremely destructive earthquake action in the past. No part of Greece can be considered as having a low seismicity. During the last four years, three destructive sequences of shocks took place:

(a) In 1978, in Northern Greece, near Thessaloniki (Volvi), 3 main shocks with magnitudes 5.8R (05.24.78), 6.5R (06.20.78) and 5.3R (07.5.78),

(b) In 1980, in Central Greece, near Volos (Magnissia), 3 main shocks with magnitudes 5.4R, 6.3R and 5.9R (07.9 .80), and

(c) In 1981, in Central Greece, near Athens (Alkyonides), 5 main shocks with magnitudes 6.8R (02.24.81), 6.5R(02.25.81), 6.3R(03. 4 .81), 5.8R(03. 5 .81) and 5.7R(03. 7 .81),

causing extensive damage in all types of structures, both in big cities and small settlements. Officially estimated total cost of repairs has been of the order of 1.5 billion dollars.

Urban development and construction tradition has been continuous since 3000BC in Greece, influenced by a variety of environmental resources and constraints, by frequent earthquake actions and by similar traditions of neighboring countries (Albania, Yugoslavia, Bulgaria, Turkey). A large number of different construction systems are still present in ancient, medieval and contemporary monuments, in still inhabited medieval and recent anonymous settlements, in modern villages and in big cities. In fact, a significant percentage of the population still lives in non-engineered structures, a great percentage of which can be classified as earthen structures.

Surprisingly at first, a great number of well constructed non-engineered structures withstood recent destructive earthquakes with more success than many modern seismic-resistant reinforced concrete (R.C.) structures. Moreover, the fact that low-cost is the main characteristic of non-engineered structures, does not necessarily mean that their architectural value is also low. On the contrary, many of them meet high architectural standards.

In spite of the above, there is a lack of reliable data con -

cerning the number and distribution over the country of the existing non-engineered structures, as well as on their seismic behavior. There is also a lack of simple Codes, recommendations and aids for effective methods of construction, repair and strengthening for this type of structures.

Traditional Construction Systems

A continuous 5000 year construction tradition, influenced by a variety of environmental resources and constraints, by frequent earthquake actions and by similar traditions of neighboring countries, produced a wide range of traditional construction systems and forms.

The predominant traditional systems that are still present in dwellings in Greece are classified in fig.1, according to their materials and to their structural use. Distinction is made among vertical, horizontal and roof systems, as well as among systems with surface and linear elements. The mass of the roof system influences materially the overall structural behavior during earthquakes, so, roof systems are classified according to their mass.

In table 1, the extent of use and the areas and types of structures in which the different systems are met are presented. Prevailing construction materials for dwellings and other rural structures are stone in mountainous areas and islands and adobe (and sometimes brick) in plains. Good quality timber is available only in certain areas in Greece. A large number of inhabited small villages and settlements are almost entirely built by traditional construction systems.

In table 2, cost-benefit parameters are given for the different traditional construction systems. Seismic behavior of a structure depends on the combination of its mass, stiffness, strength and ductility. Each system has its advantages and draw-backs, giving the best solution for certain cases. Knowledge of the construction methods for the different systems decreases with time, creating a problem for initial use, or repair and strengthening of these systems.

In figs.2÷7, typical examples of applications and details of traditional construction systems are given. Excellent architectural and structural results have been obtained using "poor" materials , but with the wisdom of a long tradition. Earthquake threat is always a consideration. Earthen structures are extensively used in the islands and in the plains of the mainland. Earth is also used in timber-framed structures, in areas where good quality timber is available.

Present Urban Development Policy and Practice

Today's urban development policy and practice in Greece have been strongly influenced by: (a) construction tradition, (b) frequent long periods of war during this century (1912-1913, 1917-1922, 1940-1949), (c) periods of building construction explosion in between and after war periods and (d) big population movements (Greek-Turk population exchange in 1922, refugee movements during the period of 1940-1949).

Right after 1922 and during the period of 1944-1949, big refugee settlements were hastly erected in and around big cities, almost exclusively with non-engineered structures. During the war period of 1940-1949, many of the existing buildings were completely destroyed due to war actions. Finally, the big demand for housing, as well as the effort for industrialization, created a constructuction boom during the last 30 years, both in big cities and villages.

At present, construction is officially permitted only on owned land, according to town-plan, after official permit, under the supervision of a licensed Civil Engineer or Architect. Rural structures of secondary importance (stables, warehouses, etc) require only a gentarmery permit for construction. In cities (population greater than 5,000), the continuous building system prevails (individual buildings are erected in row without any seismic joint), while in villages (population less than 5,000), individual structures have to be independently erected. A large number of settlements has been declared preserveable and special permit is required to guarantee preservation of the nature of the settlement.

In spite of the official policy, a large number of low-cost non-engineered structures is erected everyday: (a) in the surroundings of big cities as squatter settlements, (b) in remote rural communities as dwellings, and (c) in most villages and small communities as secondary constructions (stables, warehouses, etc.).

Present Construction Policy and Practice

Predominant low-cost construction systems in use today are classified in fig.8,according to their material,structural use and frequency. A comparison between the data of fig.1 and table 1 on one hand and the data of fig.8 on the other,reveals that:

(a) Concrete,reinforced concrete,cement blocks,steel and perforated steel truss elements,are introduced as new materials,unreinforced and reinforced concrete being the most predominant.
(b) The use of brick has increased
(c) Stone,adobe and timber do continue to be used,although to a lesser extent.
(d) Traditional timber frame systems (bagdadi,tsatmas) and stone vault systems have practically disappeared.

New structures have to conform to the General Building Code (29), to the Loading Code for Structural Works (30),and to the Seismic Code for Buildings (31). No structural system except reinforced concrete is covered by a National Code. Recommendations for the EQ Safety of 1-story Rural Dwellings (20) and Recommendations for Construction of Aseismic Dwellings (25) give some guide-lines for low-rise rock and brick masonry construction in seismic areas.

Residential buildings in cities are constructed with R.C.wall, frame,or dual systems.

Rural dwellings are usually constructed with a mixed structural system,consisting of load bearing brick walls + a few reinforced concrete columns + reinforced concrete slabs and roofs. Due to financial problems,the structure is erected in several stages,usually with the houseowner's personal work and supervision. As expected, the end result is a structure of very low quality. Secondary rural structures (stables,warehouses,etc) in most cases do not cover any safety provisions,since least cost and effort is mainly sought at during their construction. Surveys of the type and quality of construction in small villages in Greece show that more than 3/4 of existing structures are either non-engineered,or of the mixed(brick masonry + RC columns) construction system. Non-engineered structures are usually built with stone,brick,or concrete block masonry with a light roof,or with adobe masonry and timber + tiles roof (fig.9).

Dwellings in squatter settlements follow the same general trend of construction,but since they are usually built in areas of poor soil conditions and in a big hurry (usually during night-time),they end to a still less efficient result. Materials mostly in use are reinforced concrete,and brick or cement block masonry (fig.10).

Construction tradition has been overwhelmed by the explosion of construction needs during the last 30 years. New people entered the construction business as technicians,without having enough time or opportunity to acquire the required knowledge and skill. Exten - sive use of reinforced concrete,which seemed as an easy to handle material,destroyed further the existing tradition. In this way,the long good construction tradition tends to disappear,without being replaced by an equally well known technique. Inflation,increased the demand for cheaper construction and the earthquake threat was forgotten. Finally,the mean quality of construction for low-cost structures seems to be lower than it was a few years ago with the tradi - tional construction systems and materials. We have more and better materials,but we lost construction tradition and structural feeling.

Engineering Remarks from Recent Earthquakes in Greece

A lot of material concerning seismic behavior of traditional or contemporary low-cost construction systems comes into light du - ring each strong earthquake in Greece. Unfortunately,to the writer's knowledge,no rational effort has been made until now for selection and evaluation of this data,mainly,due to lack of financial support. Existing data concerning seismic behavior of low-cost construction systems in Greece is scattered in a number of papers covering mainly seismic behavior of modern reinforced concrete structures.

Mean level of damage during the earthquakes of Volvi,Magnis - sia and Alkyonides is estimated to be rather high,compared with the observed intensities in the affected areas. This can be easily rea- lised if one examines,not so much the overall damage statistics,but the damage of well constructed simple structures with traditional construction systems.

Well constructed and maintained old non-engineered structures with low-cost traditional construction systems survived the earth -

quakes with minor to moderate damage (figs 11,12,13). It is worth noting that many of these structures had already experienced at least one more severe earthquake in their lifes. This good behavior was specially prominent in the cases of lightly roofed adobe masonry structures and of hollow or adobe filled timber framed structures (bagdadi and tsatmas).

Poorly constructed and/or maintained old non-engineered structures with low-cost traditional construction systems,naturally,experienced severe damage during recent earthquakes (fig.14).

Seismic behavior of "modern" RC or mixed system "seismic-resistant" rural dwellings with the usual causes of overstress or understrength(structure to structure interaction,bad morphology,bad reinforcement detailing) was not better than that of bad old non-engineered structures (figs.15,16,17).

It seems that,for normal quality of construction,the percentage of severely damaged structures is higher for modern "low-cost" RC or mixed system rural dwellings,than for non-engineered dwellings with traditional construction systems,although the cost of the latter is much less. This surprising at first conclusion can be explained by the following reasoning:

(a) Good seismic resistance of RC structures can only be obtained through good design and construction,requiring higher knowledge and skills than old systems.
(b) RC gives the feeling of more freedom for overall form selection. This is of course true,provided that appropriate countermeasures will be taken during design and construction of RC structures with a bad morphology,which seldom is the case.
(c) Rural RC dwellings with bad morphology are not as simple structures to analyze and design as is usualy thought. This is especially true in cases of mixed construction systems comprising of brick masonry bearing walls + RC solumns + RC slabs,whose seismic behavior is to a large extent unpredictable.
(d) Heavy reinforced concrete slabs induce far more seismic strains to vertical structural elements,than light old roofs and timber floors induce to their non-engineered structures.

It is concluded that,usually despised non-engineered structures with traditional construction systems can be as good for seismic protection as modern "low-cost" RC or mixed system rural structures. Since structures with traditional construction systems are much less expensive and can usually be self constructed, some thought has to be given to their re-use. Among the old traditional systems, adobe masonry offers the least cost and requires the least skill.

Lack of simple Codes, recommendations and guide-lines for repair and /or strengthening of moderately damaged non-engineered rural structures with traditional construction systems,has been observed during recent earthquakes in Greece,as well as a lack of knowledge of young engineers for relevant appropriate techniques of repair and/or strengthening.

Mass RC construction in cases of destructive damage of old settlements,in many cases led to a destruction of the environment (fig.18).

Conclusions

There is a large number of structures with different low-cost traditional construction systems in Greece. Most of them have passed successfully the tests of time and of more than one strong earthquake shock. Rational classification of these structures,survey of their distribution and careful study of their seismic behavior,will possibly lead to conclusions valuable not only for Greece.

Seismic behavior and architectural possibilities of adobe masonry,together with its low cost and ease of construction,make adobe masonry a very suitable construction system for low-rise,low-cost rural structures.

Simple and practical guide-lines for traditional systems construction, maintenance, repair and/or strengthening and cost-benefit comparisons between existing low-cost and traditional systems,both easily available to rural population are needed. In this respect,adobe masonry should be examined first,so that its use for low-rise,low-cost rural structures will be promoted. Knowledge of the behavior and guide-lines for maintenance,repair and/or strengthening of the rest traditional systems found in Greece,will promote preservation of buildings,monuments and settlements of cultural value.

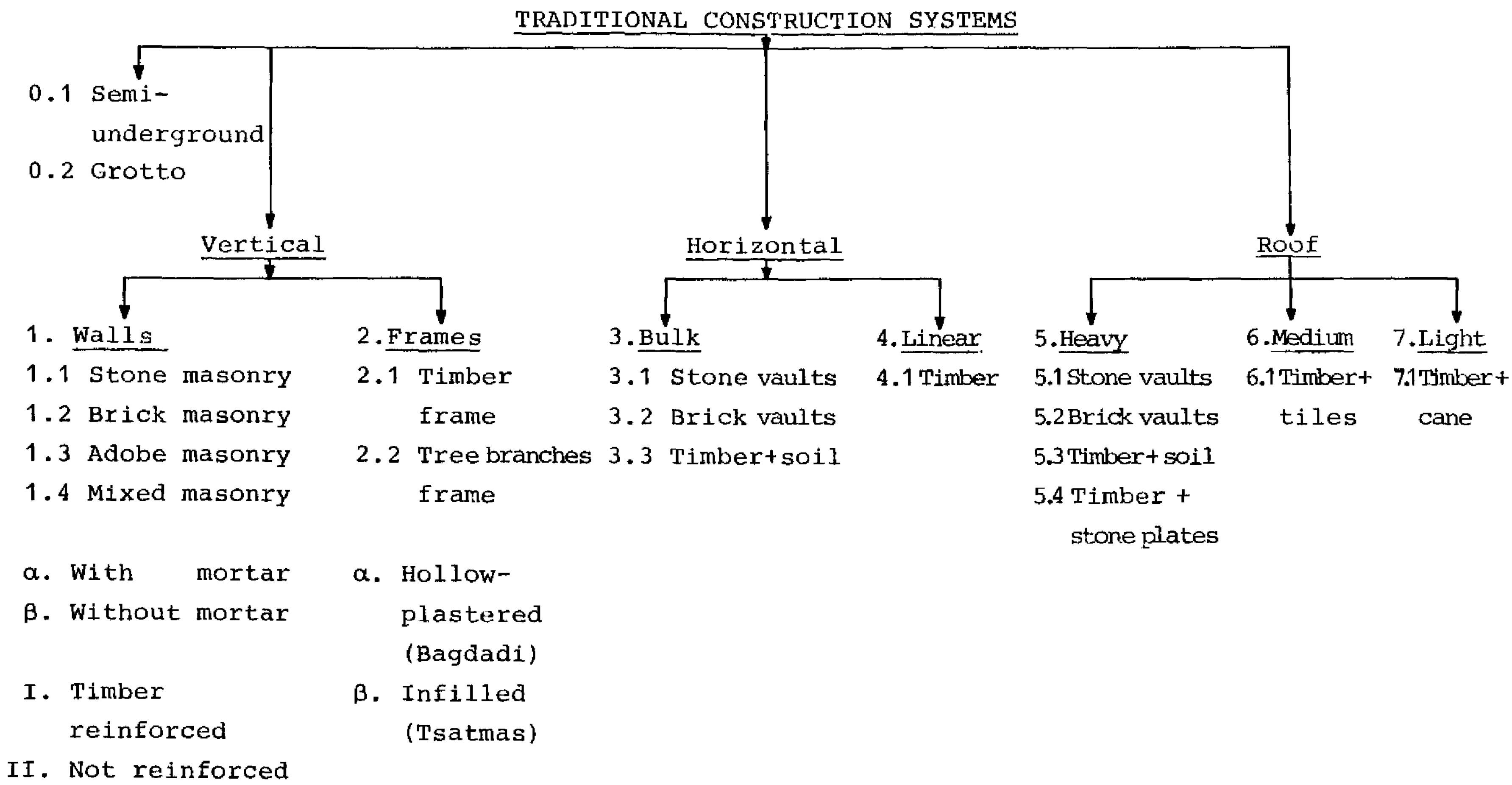


FIG.1 Classification of Traditional Construction Systems in Greece According to Material and Structural Use

TABLE 1

Use of Traditional Construction Systems in Greece

	System	Use	Areas	Type of Structures: Monuments - Churches	Traditional settlements	Squatter settlements	Rural (dwellings)	Rural (secondary)
0.1	Semi-underground	-	I		-			
0.2	Grotto	-	MI	-	-			
1.1	Stone	*	MI	*	*	-	*	+
1.2	Brick	*	P	*		+		
1.3	Adobe	*	P		+		*	*
1.4	Mixed	+	MP	*	-			
α	mortar	+	MP	+	+	+	+	
I	Timber reinf.	*	MP	*	*		-	
2.1	Timber	+	MP		+		+	-
2.2	Tree branches	-	MP					-
α	Hollow	-	MP		-		-	
β	Infilled	+	MP		+		+	-
3.1	Stone vaults	+	MI		+			
3.2	Brick vaults	-	PI	+	-			
3.3	Timber + soil	+	I		+			
4.1	Timber	*	P		*		*	
5.1	Stone vaults	+	MI	-	+			
5.2	Brick vaults	*	PI	*	+			
5.3	Timber + soil	+	I		+			
5.4	Timber + stone	+	M		+		+	-
6.1	Timber + tiles	*	P		*	+	*	-
7.1	Timber + cane	-	P					-

Use: * Extensive
+ Medium
- Small

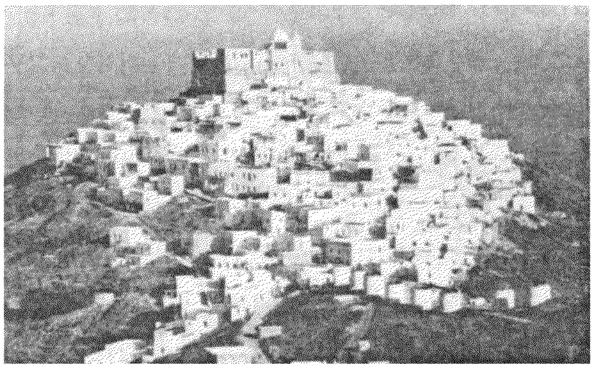
Areas: I Islands
M Mountains
P Plains

TABLE 2

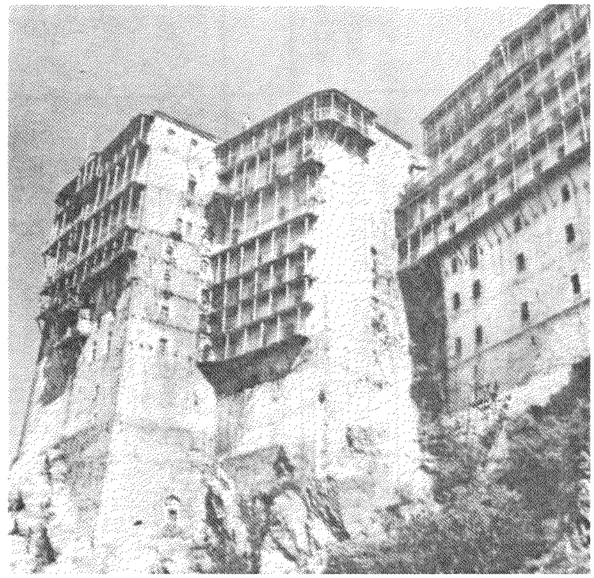
Characteristics of Traditional Construction Systems in Greece

	System	Cost	Water proofing	Thermal insulation	Stiffness	Mass	Strength + ductility		Material availability	Knowledge of construction method
							Vertical loads	Horizontal loads		
0.1	Semi-underground	VL	VL	G						
0.2	Grotto	VL	L	G						
1.1	Stone	L	M	G	H	B	H	L-M	H	M
1.2	Brick	M	G	G	M	M	M	L-M	L-M	M-G
1.3	Adobe	L	L	G	L-M	M	L	L	H	M
1.4	Mixed	M	M-G	G	M-H	M-B	M-H	L-M	L-M	L-M
α	with mortar	(M)	(G)	(G)	(H)	(B)	(H)	(H)		(M)
β	w/o mortar	(L)	(L-M)	(L)	(L)	(L)	(L)	(L)		(H)
I	Timber reinf.	(M)			(H)		(H)	(H)	(L)	(L)
II	Not reinf.	(L)			(L)		(L)	(L)	(M)	(H)
2.1	Timber frame	M	L	G	L	L	M	M-H	L-M	L-M
2.2	Tree branches	VL	VL	M	VL	VL	VL	VL	H	L
α	Hollow	(L)	(L)	(M)	(L)	(L)	(L)	(M)		L-M
β	Infilled	(M)	(M)	(M)	(H)	(B)	(H)	(M)		L
3.1	Stone vaults	M-H				VB	H	M	H	L
3.2	Brick vaults	M-H				B	H	M	L-M	M
3.3	Timber + soil	L				VB	L-M	L-M	H	L
4.1	Timber	M				L	L-M	M-G	L-M	M-G
5.1	Stone vaults	M-H	M	M-G		VB	H	M	H	L
5.2	Brick vaults	M-H	M-G	G		B	H	M	L-M	M
5.3	Timber + soil	L	M-G	G		VB	L-M	L-M	H	L
5.4	Timber + stone	L	L-M	L-M		B	L-M	L-M	L-M	L
6.1	Timber + tiles	M	G	G		M	M	L-M	L-M	M
7.1	Timber + cane	VL	VL	M		VL	VL	VL	H	L-M

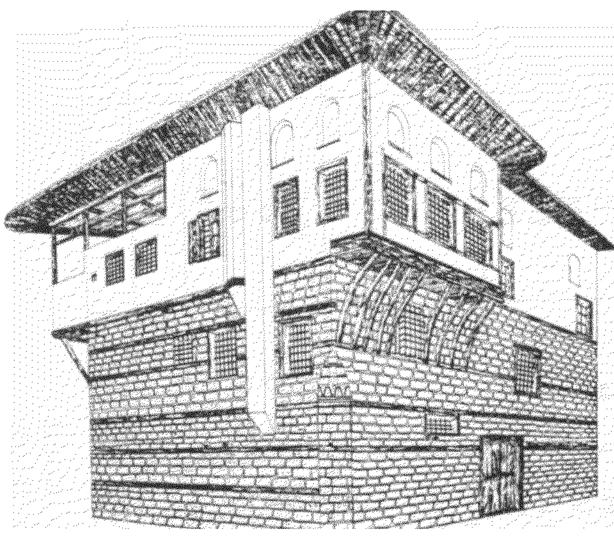
VL: Very low
L: Low
M: Medium
G: Good
H: High
B: Big



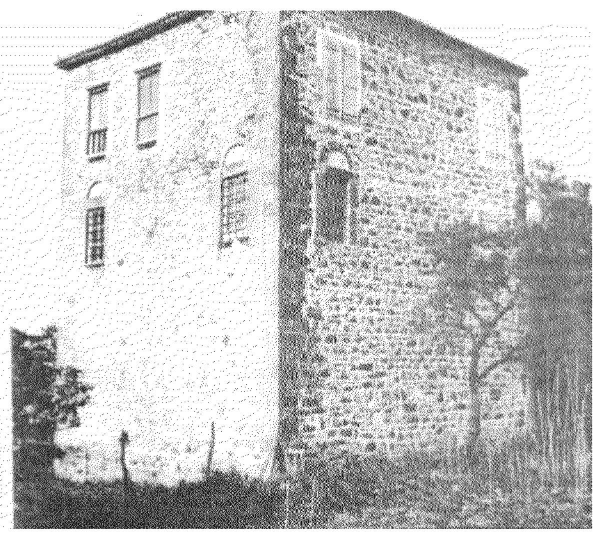
Astypalaia. Aegean Sea (9)



Monastery State of Mount Athos.
Northern Greece



Verria. Northern Greece (22)



Mytilini. Aegean Sea

FIG. 2 Traditional Construction Systems. Stone Masonries. Excellent architectural and structural results with poor materials. Northern Greece and Aegean Islands