World Housing Encyclopedia Report

Country: Greece

Housing Type: Multi-story reinforced concrete frame building

Contributors:
T. P. Tassios
Kostas Syrmakezis

Primary Reviewer:
Craig Comartin

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Table of Contents

1 General Information

1.1 Country
Greece

FIGURE 1: Typical Building

1.3 Housing Type
Multi-story reinforced concrete frame building

1.4 Summary
These buildings represent a typical multi-family residential construction, mainly found in the suburbs of Greek cities. This housing type is very common and it constitutes approximately 30% on the entire housing stock in Greece. Buildings are generally medium-rise, typically 4 to 5 stories high. The main lateral load-resisting structure is a dual system, consisting of reinforced concrete columns and shear walls. A relatively small-size reinforced concrete core usually exists, serving as an elevator shaft. The roof and floor structures consist of rigid concrete slabs supported by the beams. Seismic performance of these buildings is generally good, provided that the seismic design takes into account the soft ground floor effects e.g. by installing strong RC shear walls. Failure of the soft ground floor is the most common type of damage for this type of structure. Some buildings of this type were damaged in the 1999 Athens earthquake.

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	X
< 50 years	
< 75 years	
< 100 years	
< 200 years	
> 200 years	

Is this construction still being practiced?	Yes	No
	X	

1.6 Region(s) Where Used
This type of building appears in the main cities of the country, at an estimated percentage of 30% on the entire housing stock.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	X
In rural areas	
In suburban areas	
Both in rural and urban areas	

2 Architectural Features

2.1 Openings

Such a building has 12-15 openings per floor, of an average size of 3.0 m^2. Estimated percentage of opening area to the total wall surface is 25%. Infill walls are generally not considered in the design.

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?	X	
Is this type of construction typically found on sloped terrain? (hilly areas)	X	
Is it typical for buildings of this type to have common walls with adjacent buildings?		X

The typical separation distance between buildings is 10 meters

2.3 Building Configuration

Typical shape of a building plan is rectangular.

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	
Multiple housing units	X
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

2.5 Means of Escape

Commonly an additional exit stairway for the emergency escape does not exist.

2.6 Modification of Buildings

Usually demolition of interior infill walls.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

1 family per housing unit.

3.2 Number of Housing Units in a Building

16 units in each building.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5		
5 to 10	X	
10-20		
> 20		X
Other		

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 2
Number of Latrines: 0

Additional Comments: In some housing units there is only 1 bathroom.

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor		/
Middle Class	X	4/1
Rich		/

Additional Comments: Ratio ' House Price/Annual Income' is usually more than 4.

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	
Personal Savings	X
Informal Network: friends and relatives	
Small lending institutions/microfinance institutions	
Commercial banks / mortages	X
Investment pools	
Combination (explain)	
Government-owned housing	
Other	

3.7 Ownership

Type of Ownership/Occupancy	
Rent	X
Own outright	
Own with Debt (mortgage or other)	
Units owned individually (condominium)	X
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

The main lateral load-resisting system consists of reinforced concrete shear walls. The stiffness of brick infill walls is generally not considered in the design, however self-weight of brick walls is taken into account. The lateral drift of the structure is governed by the stiffness of its columns and walls. The 3-D response of the frame under earthquake actions is strongly affected by the column and wall layout. The walls located at the perimeter of the building in both directions contribute to minimizing the torsional effects. Floor slabs behave as diaphragms during a seismic event.

4.2 Gravity Load-Bearing Structure

The gravity load-bearing structure consists of RC solid slabs, transferring the gravity loads to the beams and columns and finally to the footings.

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Massive stone masonry (in lime or cement mortar)	
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	X
		20	Precast prestressed frame with shear walls	
	Shear wall structure	21	Walls cast in-situ	
		22	Precast wall panel structure	
Steel	Moment resisting frame	23	With brick masonry partitions	
		24	With cast in-situ concrete walls	
		25	With lightweight partitions	
	Braced frame	26	Concentric	
		27	Eccentric	
Timber	Load-bearing timber frame	28	Thatch	
		29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers	
	Other	35		

4.4 Type of Foundation

Type	Description	
Shallow Foundation	Wall or column embedded in soil, without footing	
	Rubble stone (fieldstone) isolated footing	
	Rubble stone (fieldstone) strip footing	
	Reinforced concrete isolated footing	X
	Reinforced concrete strip footing	
	Mat foundation	
	No foundation	
Deep Foundation	Reinforced concrete bearing piles	
	Reinforced concrete skin friction piles	
	Steel bearing piles	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)	X	X
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
Timber	Rammed earth with ballast and concrete or plaster finishing		
	Wood planks or beams with ballast and concrete or plaster finishing		
	Thatched roof supported on wood purlins		
	Wood single roof		
	Wood planks or beams that support clay tiles		
	Wood planks or beams that support slate, metal asbestos-cement or plastic corrugated sheets or tiles		
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls		
Other			

4.6 Typical Plan Dimensions

Length: 10 - 10 meters
Width: 10 - 10 meters

4.7 Typical Number of Stories

4 - 6

4.8 Typical Story Height

3.0 meters

4.9 Typical Span

4 meters

Additional Comments: Span variation is 3.5-4.5 m

4.10 Typical Wall Density

Total wall area/plan area (for each floor) 3-4%

4.11 General Applicability of Answers to Questions in Section 4

The building is typical

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	True	False	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces form the building to the foundation.	X		
Building configuration	The building is regular with regards to both the plan and the elevation.	X		
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e.. shape and form, during an earthquake of intensity expected in this area.	X		
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity, during an earthquake of intensity expected in this area.	X		
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	X		
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	X		
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2)Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).	X		
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	X		
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.		X	
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.			
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).	X		
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	X		
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	X		
Other				

Additional Comments: Building configuration - buildings of this type are considered to be regular in elevation due to the uniform column and wall sections throughout the building height. According to the Code, it is not acceptable to have stiffness variation of over 30%.

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake-Resilient Features	Earthquake Damage Patterns
Wall	Clay brick infill with low tensile strength. Non-uniform wall distribution (in elevation or in plan) may create problems related to seismic performance.	The presence of minimum RC shear walls (a Code requirement) led to an improved structural performance	Cracking in shear walls of the elevator shaft (1999 Athens earthquake), see Figure 5F.
Frame (columns, beams)	-Lack of lateral confinement (stirrups) in the columns.	-Capacity design of beam-column joints ensures ductile behavior of the structure -Good seismic performance on condition of careful detailing during design and construction after the application of the 1985 Code.	Joint failure in poorly constructed structures. Damage to column-beam joints due to bad concrete quality and insufficient reinforcement was observed in the 1999 Athens earthquake (EERI). In many cases, stirrup reinforcement was almost nonexistent (see Figures 5D and 5E).
Roof and floors		Rigid diaphragms (insignificant relative in-plane displacements).	
Irregular Stiffness Distribution - Soft Ground Floor	Soft story at the ground floor level. Buildings with a soft ground floor are a common practice in Greece. Significantly less rigidity in this floor, compared to the rest of the building, leads to large deformations of the soft story (EERI).	In the 1999 Athens earthquake, the soft-story effect was more pronounced in buildings without shear walls (EERI).	Soft ground floor (where there is an absence of infill walls at the ground floor) may cause damage, leading to the development of collapse mechanisms. In the 1999 Athens earthquake, the damage occurred mainly to the joints, which were totally destroyed in a number of cases. As a result, the structural system became a mechanism, and large permanent horizontal displacements were observed. In some cases, collapse of the soft story was occasioned by P-d effect, combined with high vertical accelerations (EERI).

5.3 Seismic Vulnerability Rating

	Vulnerability					
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performace) F
Seismic Vulnerability Class				<	0	>

0 - probable value
< - lower bound
> - upper bound

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
1999	Athens	5.9	IX (MSK)
1996	Aegion	6.1	MSK
1981	Athens		

Additional Comments: On September 7, 1999, at 14:56 local time, a strong earthquake occurred 18 km northwest of the center of Athens. The earthquake was magnitude ?s =5.9 and the coordinates of the epicenter were located at 38.12?-23.64?, in the area of Parnitha mountain. This earthquake came as a surprise, since no seismic activity was recorded in this region for the last 200 years. According to strong-motion recordings, the range of significant frequencies is approximately 1.5-10 Hz, while the range of the horizontal peak ground acceleration were between 0.04 to 0.36g. The most heavily damaged areas lie within a 15 km radius from the epicenter. The consequences of the earthquake were significant: 143 people died and more than 700 were injured. The structural damage was also significant, since 2,700 buildings were destroyed or were damaged beyond the repair and another 35,000 buildings experienced repairable damage. According to the EERI Reconnaissance Report, a number of RC buildings sustained severe structural damage and some of them collapsed, totally or partially. Most of the severely damaged structures were designed according to older seismic codes, with significantly lower seismic forces than those experienced during the earthquake. The overall behavior of RC structures was satisfactory. Some of the recorded ground accelerations show elastic spectral accelerations on the order of 0.6 to 0.8 g for structures with periods in the range of 0.15 to 0.3 sec, corresponding to two- to five-story buildings in Athens. Most of these buildings were designed according to the old code, with about ten times lower seismic forces. This factor is expected to be significantly higher in the epicentral area, where the effective ground acceleration should have exceeded the value of 0.5 g. The majority of the RC structures in the broader area of Athens suffered only minor structural damage because they had strength reserves such as infill walls, over-strength and redundancy.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		
Foundations	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		
Frame (columns, beams)	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		
Roof and floors	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

These buildings are usually built by developers.

7.3 Construction Process

Developers are usually builders of this type of construction. Ready-mixed concrete is usually used. Concrete pumps and concrete vibrators are used in situ.

7.4 Design/Construction Expertise

Structural Engineer (five years University studies and minimum 5 years experience)
Experienced professionals for the construction. Occasional low quality construction is observed.

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

Title of the code or standard: Greek Code for Earthquake Resistant Design (NEAK)
Year the first code/standard addressing this type of construction issued: 1955
National building code, material codes and seismic codes/standards: Greek Code for Earthquake Resistant Design (NEAK), Athens 1995. Greek Code for Reinforced Concrete Design (NKOS), Athens 1995.
When was the most recent code/standard addressing this construction type issued? 1995

7.6 Role of Engineers and Architects

Architects are responsible for architectural drawings and civil engineers for the structural design.

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required	X	
Informal construction		X
Construction authorized per development control rules	X	

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)		X
Building originally designed for its final constructed size	X	

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
Owner(s)	X
Renter(s)	X
No one	
Other	

7.10 Process for Building Code Enforcement

Building design must follow the National Building Code and EuroCodes.

7.11 Typical Problems Associated with this Type of Construction

Special attention is due to the construction of joints and reinforcement detailing.
Uniform distribution of over strength throughout the building elevation is not always achieved.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

250000 GRD/m^2 (600 US$/$m^2$)

8.2 Labor Requirements (estimate)

1 month per floor
50 man-months per floor

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available		X
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		

Additional Comments: Earthquake insurance for this construction type was only recently imposed.

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

Repair works

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	Reinforced concrete columns: deficient reinforcement and concrete strength	Installation of reinforced concrete jackets For the construction of reinforced concrete jackets, concrete quality (strength) must be greater or equal to the existing concrete. New and existing reinforcement must be connected at least at the corners of the columns by using steel plates at 500 mm spacing. Connection between reinforced concrete jackets and existing columns is provided by steel dowels (about 5 dowels /m^2). Seismic strengthening using the concrete jackets is illustrated in Figure 6 (Source: UNIDO).

Additional Comments: Strengthening of damaged concrete columns using the reinforced concrete jackets was used in Greece after the 1981 Athens earthquake. More details on this technique can be found in UNIDO (1983).

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?

Yes, to a great extent.

10.3 Was the work done as a mitigation effort on an undamaged building, or as repair following earthquake damage?

Repair following the earthquake damage.

10.4 Was the construction inspected in the same manner as new construction?

Yes

10.5 Who performed the construction: a contractor, or owner/user? Was an architect or engineer involved?

The construction was performed by a contractor, with the involvement - supervision of an architect and a civil engineer.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

The performance was satisfactory.

11 References

ITSAK Report on the 1999 Athens Earthquake, Institute of Engineering Seismology and Earthquake Engineering, Thessaloniki, Greece (www.itsak.gr)

EERI. Special Earthquake Report: The Athens, Greece Earthquake of September 7, 1999 (www.eeri.org/earthquakes/Reconn/Greece1099/Greece1099.html)

EQE. September 7, 1999 Athens, Greece Earthquake (www.eqe.com/revamp/greece1.htm)

UNIDO. Repair and Strengthening of Reinforced Concrete, Stone and Brick Masonry Buildings. Volume 5, Building Construction Under Seismic Conditions in the Balkan Region, UNDP/UNIDO Project RER/79/015, United Nations Industrial Development Organization, Vienna, Austria, 1983.

12 Contributors

Name	T. P. Tassios	Kostas Syrmakezis
Title	Professor	Professor
Affiliation	National Technical University of Athens	National Technical University of Athens
Address	9 Iroon Polytechniou	9 Iroon Polytechniou
City	Zographou, Athens	Zographou, Athens
Zipcode	15780	15780
Country	Greece	Greece
Phone	+301 6424551	+301 7721590
Fax	+301 8045139	+301 7721582
Email	tassiost@central.ntua.gr	isaarsyr@central.ntua.gr
Webpage		

13 Figures

FIGURE 1: Typical Building

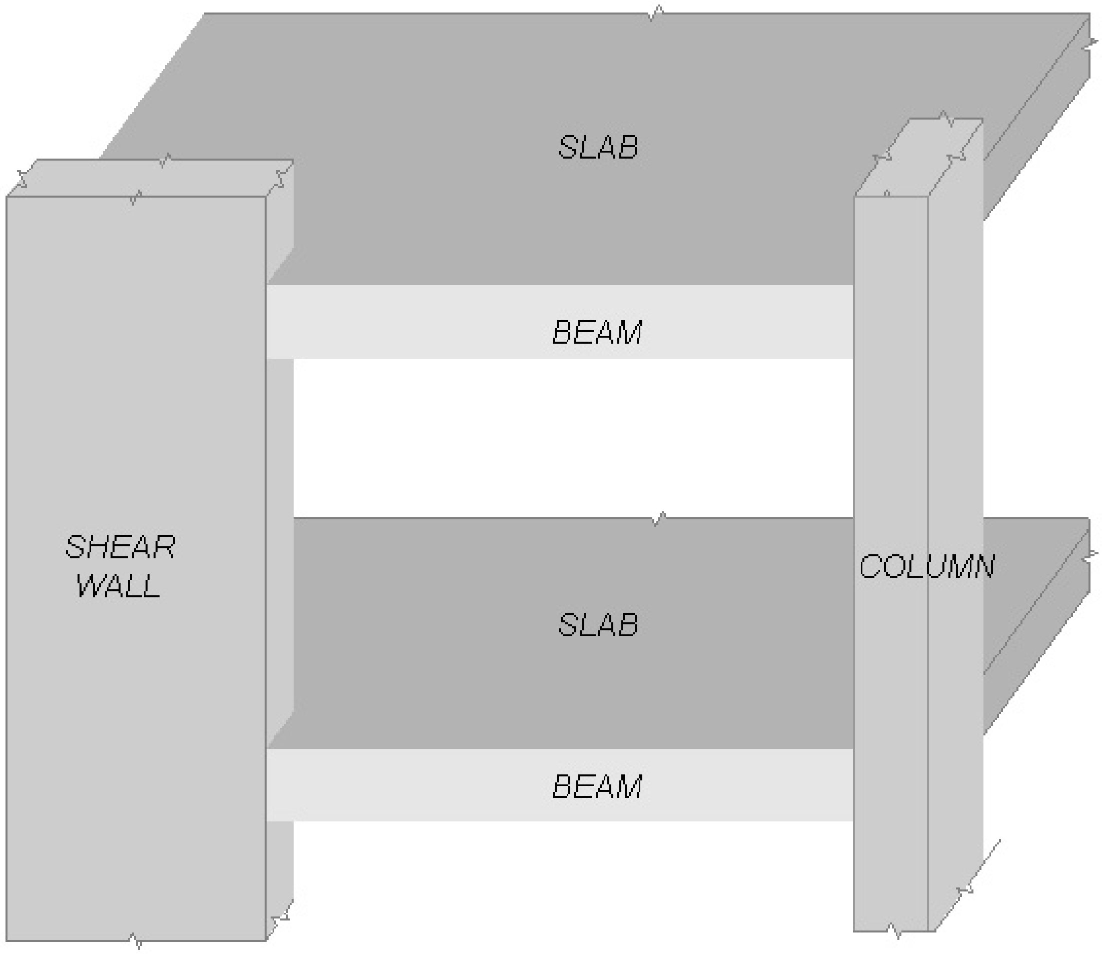

FIGURE 2: Key Load-Bearing Elements

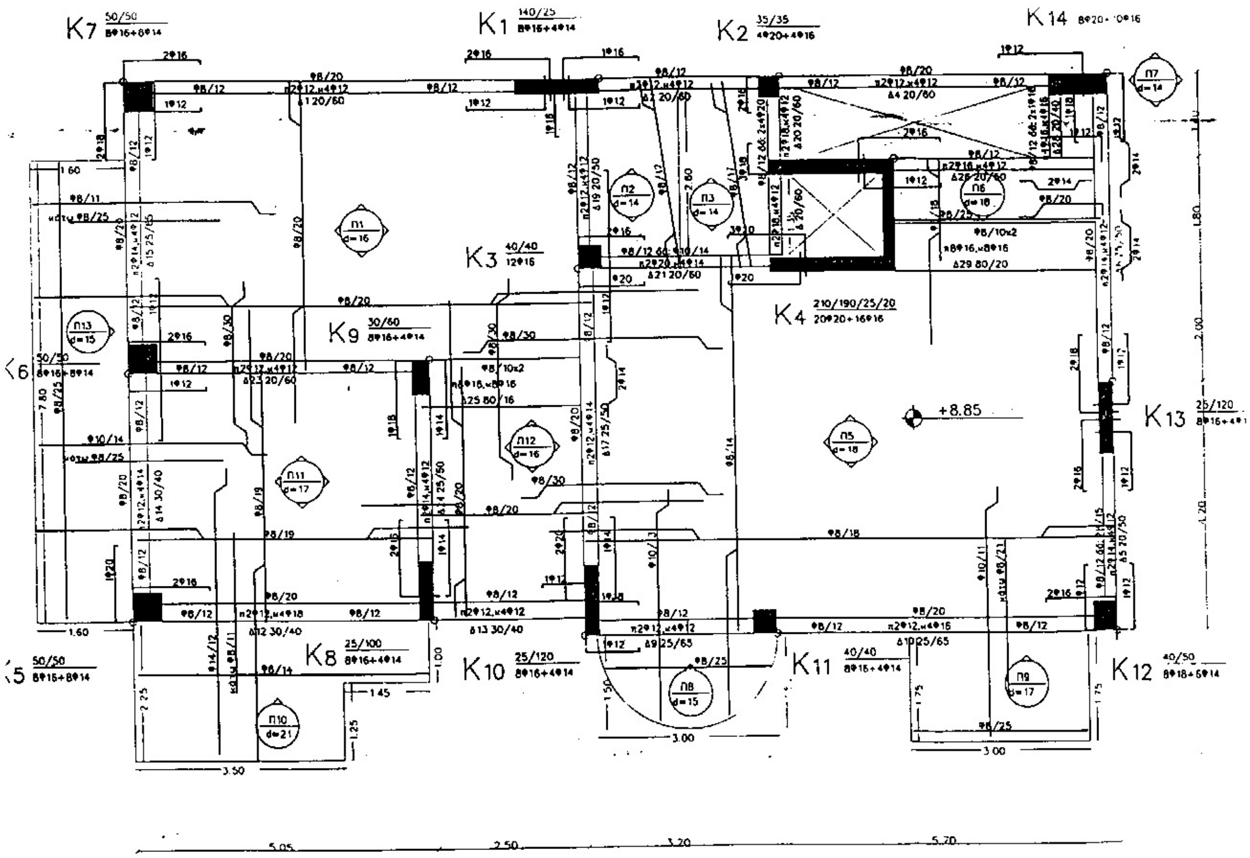

FIGURE 3: Plan of a Typical Building

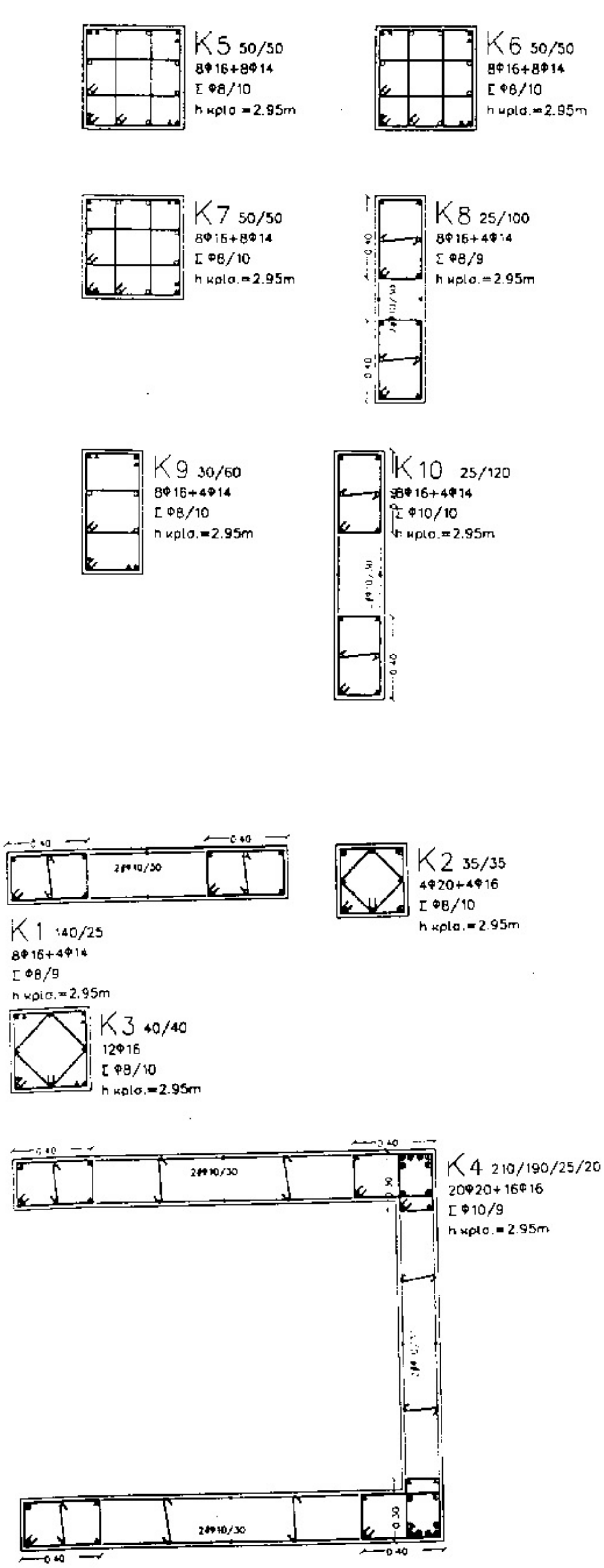
K5 50/50
8Φ16+8Φ14
Σ Φ8/10
h κρίσ.=2.95m
K6 50/50
8Φ16+8Φ14
Σ Φ8/10
h κρίσ.=2.95m
K7 50/50
8Φ16+8Φ14
Σ Φ8/10
h κρίσ.=2.95m
K8 25/100
8Φ16+4Φ14
Σ Φ8/9
h κρίσ.=2.95m
K9 30/60
8Φ16+4Φ14
Σ Φ8/10
h κρίσ.=2.95m
K10 25/120
8Φ16+4Φ14
Σ Φ10/10
h κρίσ.=2.95m
2Φ10/30
K2 35/35
4Φ20+4Φ16
Σ Φ8/10
h κρίσ.=2.95m
K1 140/25
8Φ16+4Φ14
Σ Φ8/9
h κρίσ.=2.95m
K3 40/40
12Φ16
Σ Φ8/10
h κρίσ.=2.95m
K4 210/190/25/20
20Φ20+16Φ16
Σ Φ10/9
h κρίσ.=2.95m
2Φ10/30
0.40

FIGURE 4: Critical Structural Details

FIGURE 5A: Typical Earthquake Damage (1999 Athens earthquake)

FIGURE 5B: Building Collapse in the 1999 Athens earthquake

FIGURE 5C: Earthquake Damage- Dislodged Column due to Soft Ground Floor Effect (1999 Athens earthquake)

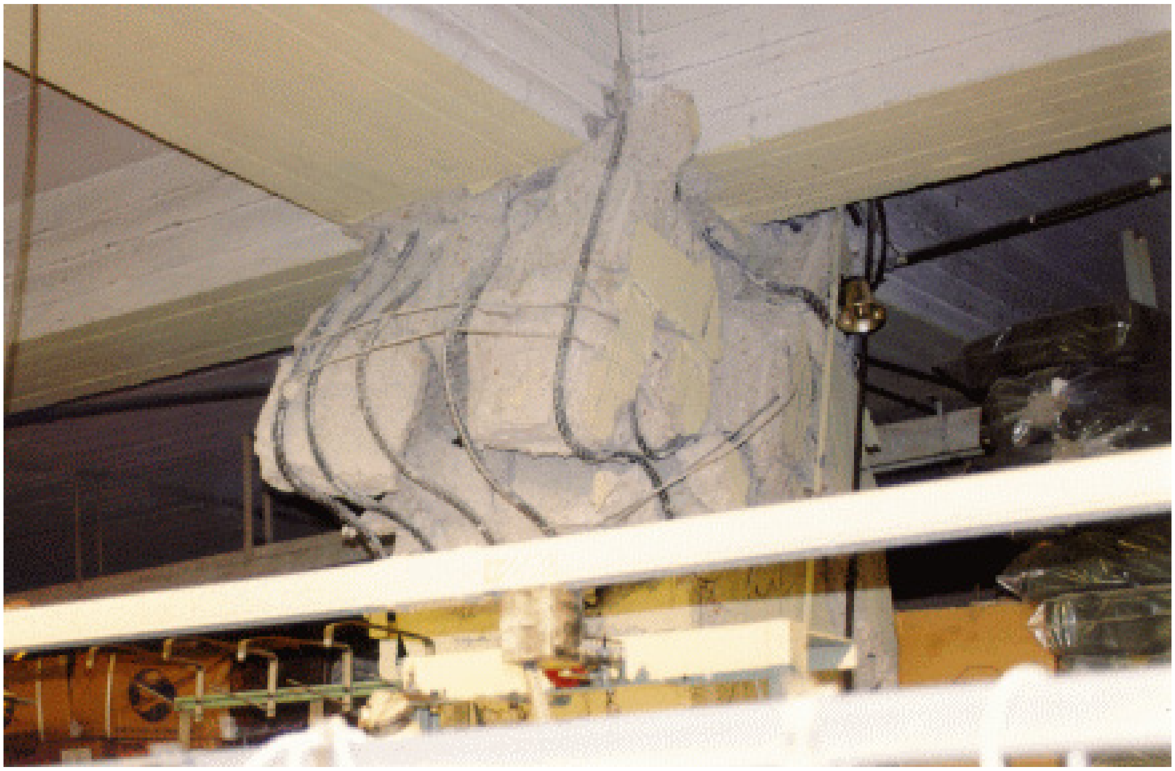

FIGURE 5D: Typical Earthquake Damage-Column Failure (1999 Athens Earthquake)

FIGURE 5E: Failure of column, due to short column effect, of a 5-storey building in Ano Liosia, which was built in 1997 according to the new Greek Seismic Code (1999 Athens earthquake); Source: ITSAK

FIGURE 5F: Typical damage to the shear wall surrounding the stairwell in an apartment block in the 1999 Athens earthquake (Source: EQE)

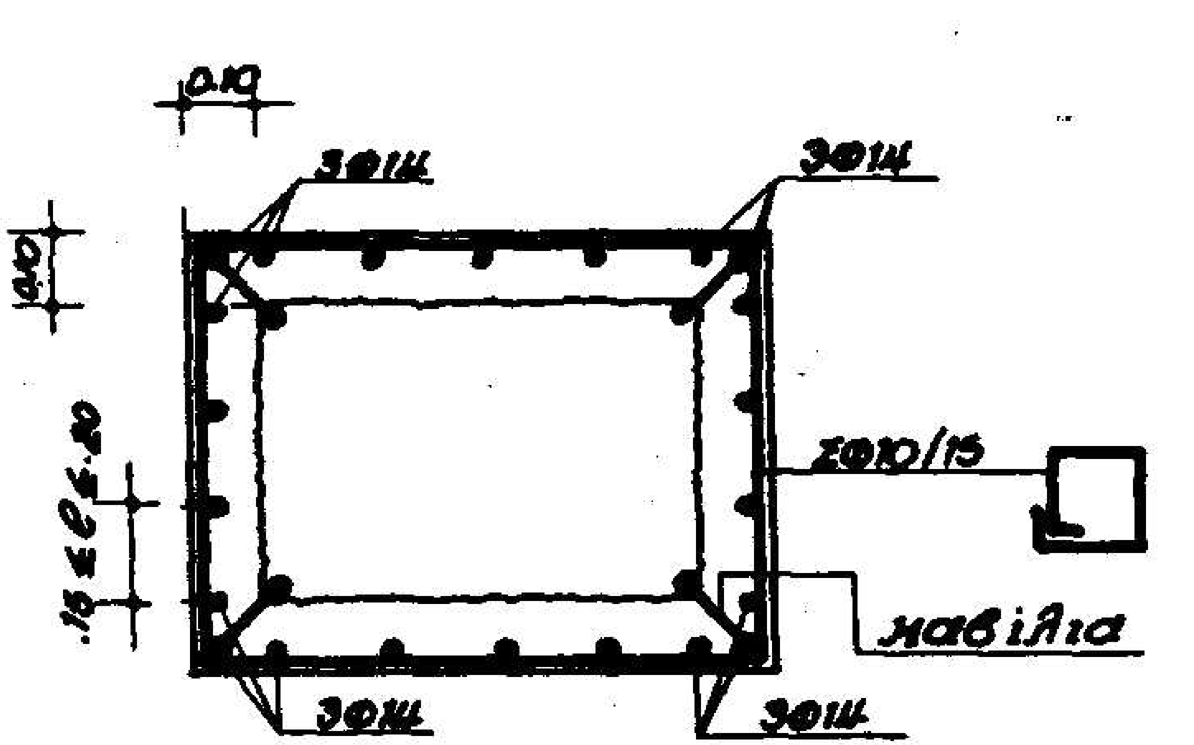

FIGURE 6: Illustration of Seismic Strengthening Techniques