World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Reinforced concrete frame building with an independent vertical extension

Report #	17
Report Date	05-06-2002
Country	GREECE
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for seismic effects, with URM infills
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Summary

This is a typical residential construction found in the suburbs of large Greek cities and in smaller towns. Buildings are three stories with a warehouse on the ground floor level, and typically, two apartments on the upper floor levels. The peculiarity of this building type is that

it consists of two independent structures built over a period of 20 years. The two lower stories were constructed in the 1960s as a reinforced concrete frame structure, without provisions for vertical extension. In the 1980s, an additional floor was built on top of the existing structure and an independent elevator core and staircase added to expand the building horizontally. Columns and shear walls at the perimeter of the 1980 portion of the building were built on separate footings, whereas the interior columns and shear walls were constructed by drilling openings through the slabs of the 1960 portion in order to achieve continuity from the top floor down to the new foundations. Floor structure for the 1980 portion was constructed at an elevation 400 mm higher when compared to the roof level of the 1960 portion. The entire layout results in a tight connection of the new and the old structure. Due to the anomalous position of the channel-shaped elevator shaft, seismic response of this structure is characterized with significant torsional vibrations in the newer 1980 section, thus resulting in excessive lateral displacements in the 1960 structure. Some buildings of this type were damaged in the 1999 Athens earthquake and were strengthened after the earthquake.

1. General Information

Buildings of this construction type can be found in many suburbs of large cities and as apartment building in smaller cities with older houses with no provisions for vertical extension. This contribution describes a typical building located in the Central Greece (Thrakomakedones - suburb of Athens). This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. The traditional concrete construction of the 1960's and 1980's with increasing quality assurance and improved construction practices.

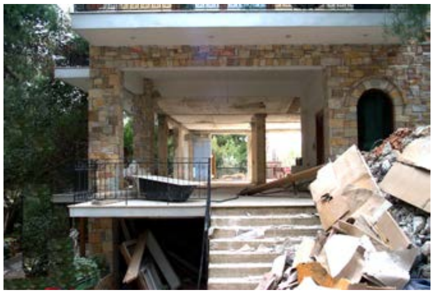

Figure 1: Typical Building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. This is also the typical separation distance for up to three-story high buildings When separated from adjacent buildings, the typical distance from a neighboring building is 0.04 meters.

2.2 Building Configuration

The plan shape for this building is generally rectangular. Typical openings for reinforced concrete buildings: window and door widths range from 0.80 m to 1.5 m. A gross estimate of the overall window and door area is about 20% of the exterior wall surface area.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There are typically two exits for this building type: a main staircase at the front and an auxiliary entrance and exit at the back of the building.

2.4 Modification to Building

The top floor has been added as a vertical extension to the existing building.

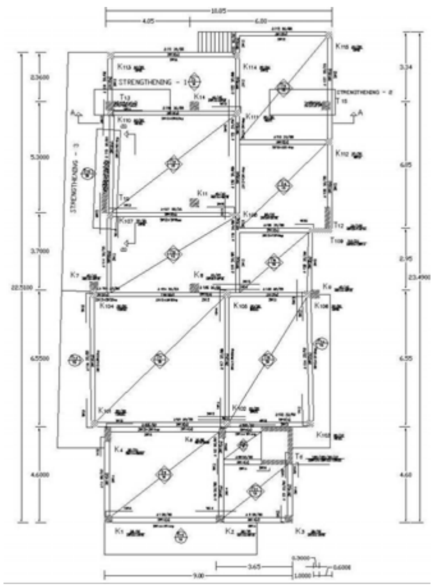

Figure 2A: Plan View at the Elevation 3.50 m Showing Slabs and Beams of te 1960 Structures and the Vertical Elements of Both Structures

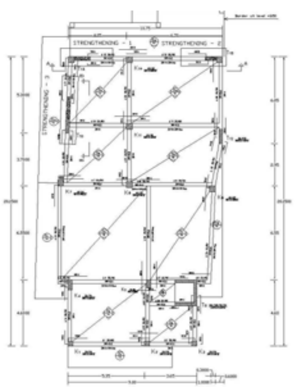

Figure 2B: Plan View at the Elevation 7.00 m Showing Slabs, Beams, and Vertical Elements of te New (1980) Structure

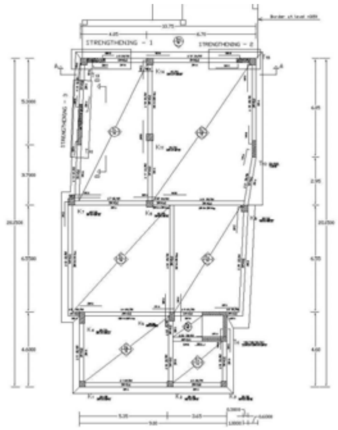

Figure 2C: Plan View at the Elevation 10.50 m Showing Slabs, Beams, and Vertical Elements of the New (1980) Structure

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐

		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☑
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

The older (1960s) portion of the building is a RC frame with limestone masonry infill walls designed to seismic requirements of the current building code of the period. The newer (1980s) portion was designed with seismic provisions. The 1980 portion is a dual system - RC frame with shear walls.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete structural walls (with frame). Reinforced concrete slabs on beams supported by columns and shear walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. The main lateral load-resisting system consists of reinforced concrete moment-resisting frame with shear walls. The lower two stories were constructed in 1960's as a reinforced concrete frame structure, without any provisions for the vertical extension. The frame is infilled with unreinforced limestone masonry infill walls 400 mm thick. The column layout is quite regular and there are no shear walls in this portion (see gray-shaded column sections in Figure 3A). The building was expanded in the 1980's by constructing an additional floor atop the existing structure with an independent elevator core (see Figures 3A, 3B and 3C). The columns and shear walls located at the perimeter of the 1980 portion were built on the separate footings, whereas the interior columns and shear walls were constructed by drilling the openings through the slabs of the 1960's portion in order to achieve continuity from the top floor down to the new foundations. Floor structure for the 1980 portion was constructed at an elevation 400 mm higher as compared to the roof level of the 1960 portion.The entire layout resulted in a tight embracement of the 1960 and 1980 portion of the building.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 11 and 11 meters. The building is 3 storey high. The typical span of the roofing/flooring system is 4 meters. In some cases the typical span can be up to 5 meters. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is none. 0.06% - 0.08%.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☑	☑
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☑	☑
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
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 shingle roof	☐	☑
	Wood planks or beams that support clay tiles	☐	☐
	Wood planks or beams supporting natural stones slates	☐	☐
	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	Described below	☑	☑

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☐
	Reinforced-concrete isolated footing	☑
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

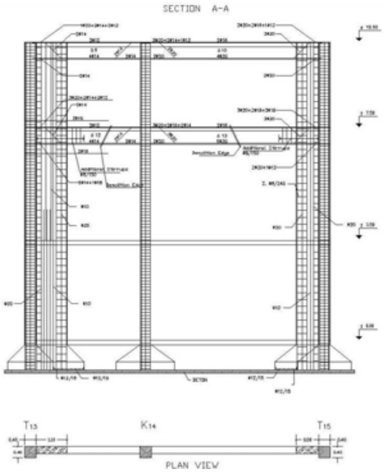

Figure 3: Vertical Section Through the Building Showing the Lower (1960) Portion and the Extended (1980) Portion

Figure 4: Critical Structural Elements: Column-Floor Slab Connection (1980 Structure)

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 2 housing unit(s). 2-3 units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

4.2 Patterns of Occupancy

Two to three families per building.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☐
c) middle-income class	☑
d) high-income class (rich)	☑

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐
1:1 or better	☑

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☑
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

In some cases there are 2 bathrooms in each housing unit. .

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☐
outright ownership	

	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		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 from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
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.	☑	☐	☐
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.	☑	☐	☐
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.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☐	☑
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 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 the requirements of national codes and standards (an estimate).	☑	☐	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Infill Masonry Walls - 1960 frame	-Limestone masonry walls 400 mm thick; very stiff as compared to the 1960 portion of the RC frame.		- Minor cracks in the walls.
Frame - 1980 portion Frame - 1960 portion	-Designed for adequate strength but not checked for excessive lateral displacements due to torsion -Low capacity for lateral loads		-Minor cracks in the columns of the 1980 portion. -Moderate cracks in the columns of the 1960 portion.
Roof and floors	- Adequately designed		
Integral structural/seismic response of the 1960 and 1980 portion of the building	- Both the 1960 and 1980 portion of the building were designed for seismic effects, however the different (incompatible) dynamic characteristics of these two structures were not considered in the design.		-Incompatible dynamic characteristics of the old and new portion of the building were the major cause of the damage in the 1999 Athens earthquake.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☐	☑	☐	☑	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1981	Korinth, Greece	6.6	VIII (MMI)
1999	Athens, Greece	5.9	IX (MMI)

Due to the eccentric position of the elevator shaft (a "U"- shape open core) in the 1980s portion, the dynamic response of this building showed intensive torsional vibrations in the 1980 structure causing excessive displacements to the old

(1960) structure. The torsional eccentricity (distance between the centers of mass and stiffness) was equal to 7m in a building of 20 m maximum plan dimension. In the 1999 Athens earthquake, the building described in this contribution experienced severe damage caused by the tight connection of two structures with rather different dynamic properties. The damages included the extensive cracking in the exterior limestone masonry infill walls and the interior brick masonry infill walls, and the minor cracks in the flexible 1960s frame structure. More information on the 1999 Athens earthquake is available on the Internet at www.itsak.gr.

Figure 5: Typical Earthquake Damage to a Column of the Older 1960 Atructure (1999 Athens Earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced concrete.	Concrete: C12/16 (16 MPa cube compressive strength) Steel: S400 (400 MPa characteristic tensile strength).		
Foundation	Reinforced concrete.	Concrete: C12/16 (16 MPa cube compressive strength) Steel: S220 (220 MPa characteristic tensile strength).		
Frames (beams & columns)	Reinforced concrete.	Concrete: C12/16 (16 MPa cube compressive strength) Steel: S220 (220 MPa characteristic tensile strength). This is for 1960 portion. Concrete: C12/16 (16 MPa cube compressive strength) Steel: S400 (400 MPa characteristic tensile strength).This is for 1980 portion.		
Roof and floor(s)	Reinforced concrete.	Concrete: C12/16 (16 MPa cube compressive strength) Steel: S220 (220 MPa characteristic tensile strength).		

6.2 Builder

Typically the owner lives in the house. The house is built by the technicians.

6.3 Construction Process, Problems and Phasing

The owner manages the construction under the supervision of a civil engineer who has the complete technical responsibility. Different phases, i.e. excavation, concrete construction, brick construction etc., are subcontracted to technicians. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

In general, the level of expertise is good, but the quality of construction and the design needs to be improved. In the case of the building described in this contribution, the designer of the newer (1980s) building portion did not try to separate the motion of the two structures allowing excesive torsional vibrations. Engineers and architects play a major role in the design, however they play a minor role in the construction.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Greek Aseismic Code. The year the first code/standard addressing this type of construction issued was 1959. Greek Aseismic Code (EAK 2000), Greek Concrete Code (NKÙÓ). The most recent code/standard addressing this construction type issued was 2000. Title of the code or standard: Greek Aseismic Code Year the first code/standard addressing this type of construction issued: 1959 National building code, material codes and seismic codes/standards: Greek Aseismic Code (EAK 2000),Greek Concrete Code (NKÙÓ) When was the most recent code/standard addressing this construction type issued? 2000.

Building inspections performed by the engineer in charge.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules.

The authorities that issue the permits do not check these cases adequately. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s) and No one.

6.8 Construction Economics

300-500 \$US/m^2. 14-18 months for a 3-storey RC Building of 20 X 11 m plan dimensions. Groups of 10-15 technicians are responsible for the RC frame construction and the infill walls and the plaster, while smaller groups take care of the remaining parts (finishing).

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. It covers the maximum cost agreed in the contract and the premium is a fixed percent of that.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Minor cracks in concrete columns and shear walls	Sealed with epoxy resins following standard practice
Strengthening of the footings	Anchoring of the new reinforcement, installation of dowels in the interface, preparation of the concrete interface for improved bonding, cast in situ concrete (see Figure 6D)
Installation of new shear walls	Welding of new reinforcement to the existing reinforcement at several (3 to 5) locations within a storey-height, preparation of concrete surface for improved bonding, pouring of concrete in-situ (see Figures 6A, 6B and 6F).
Demolition and partial reconstruction of beams	Careful support (underpinning) of the adjacent structure, partial demolition of the beams, installation of additional reinforcement adequately anchored, preparation of the concrete interface, pouring the concrete.

The problems associated with the seismic performance of this building type are due to the tight connection of two structures with quite different dynamic properties. Since it is not possible to separate these two structures (i.e. the 1960 and 1980 portion of the building), the strengthening is required. The following options have been considered: a) strengthening of the 1960 frame, b) strengthening of the 1980 frame, or c) strengthening of both structures. The purpose of strengthening is to achieve an acceptable performance for the entire structure, to control the lateral displacements (drifts), and also to avoid excessive damage of the exterior and interior infill walls in future earthquakes. Strengthening of the old 1960 RC frame has appeared to be impractical and unreliable due to the poor quality of concrete and the lack of seismic detailing (inadequate amount of reinforcement, lack of stirrups, etc). Strengthening of the newer, 1980 frame, with the objective to reduce the excessive torsional effects in the structure and control the response of the old 1960 structure was considered. This option seemed to be very expensive, as it required strengthening of almost all columns and shear walls. Finally, it was decided to demolish all severely damaged infill walls and the frame at the first floor level (1960 structure), including the columns, beams and the floor slab, and to rebuild the brick infill walls at this floor level within the frames of the new structure. In addition, all cracks in the vertical elements were sealed with epoxy resins. Finally, three columns or shear walls in the new structure were strengthened to increase the torsional rigidity (locations STR 1-3 in Figures 3A, 3B and 3C). Beams at the first floor level had to be partially demolished and rebuilt with additional reinforcement (see Figures 2 and 6F). These strengthening measures were effective in ensuring the overall seismic performance of the strengthened building (including the 1960 and 1980 portion) in accordance with the requirements of the current Greek design code.

8.2 Seismic Strengthening Adopted

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

Yes. Seismic strengthening is a common practice for this type of construction.

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

The work was done as a repair following damage due to the September 7, 1999 Athens earthquake.

8.3 Construction and Performance of Seismic Strengthening

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

The inspection on the retrofit of this construction was more thorough than it would be for a new construction.

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

The construction was performed by a contractor, who was chosen by the owner, and the construction was supervised by the designer.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

The performance was good in the aftershocks of Richter magnitude 4.5.

Figure 6A: Seismic-strengthening Techniques - Installation of a New Shear Wall

Figure 6B: Seismic Strengthening - Connection of the Old and New Concrete (Welding of Rebars)

Figure 6C: Seismic Strengthening - Extension of te New Shear Wall Through the Floor Slab

Figure 6D: Seismic Strengthening of hte Footing

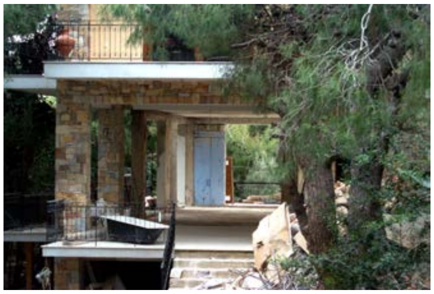

Figure 6E: Demolition of hte Damaged Infill Walls at the Ground Floor Level

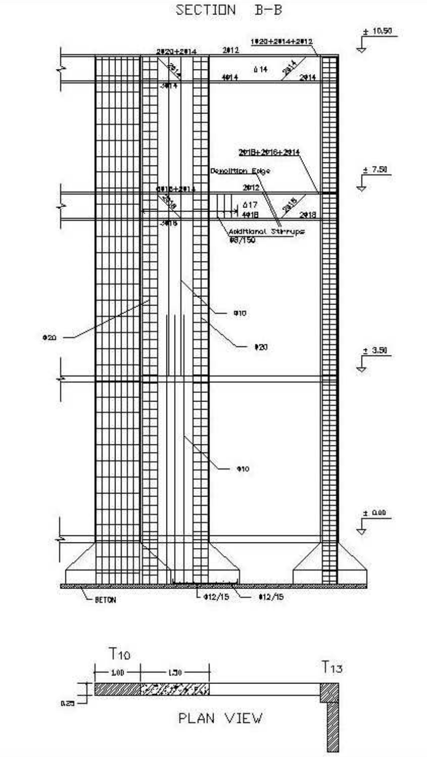

Figure 6F: Seismic Strengthening - Installation of a New Shear Wall

Reference(s)

1. Greek Code for Earthquake Resistant Design (NEAK)
   Athens 1995

2. Greek Code for Reinforced Concrete Design (NK
   Athens 1995

3. Report on the 1999 Athens Earthquake

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