World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institue (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Multi-story reinforced concrete frame building

Report#	15
Last Updated	
Country	Greece
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Important

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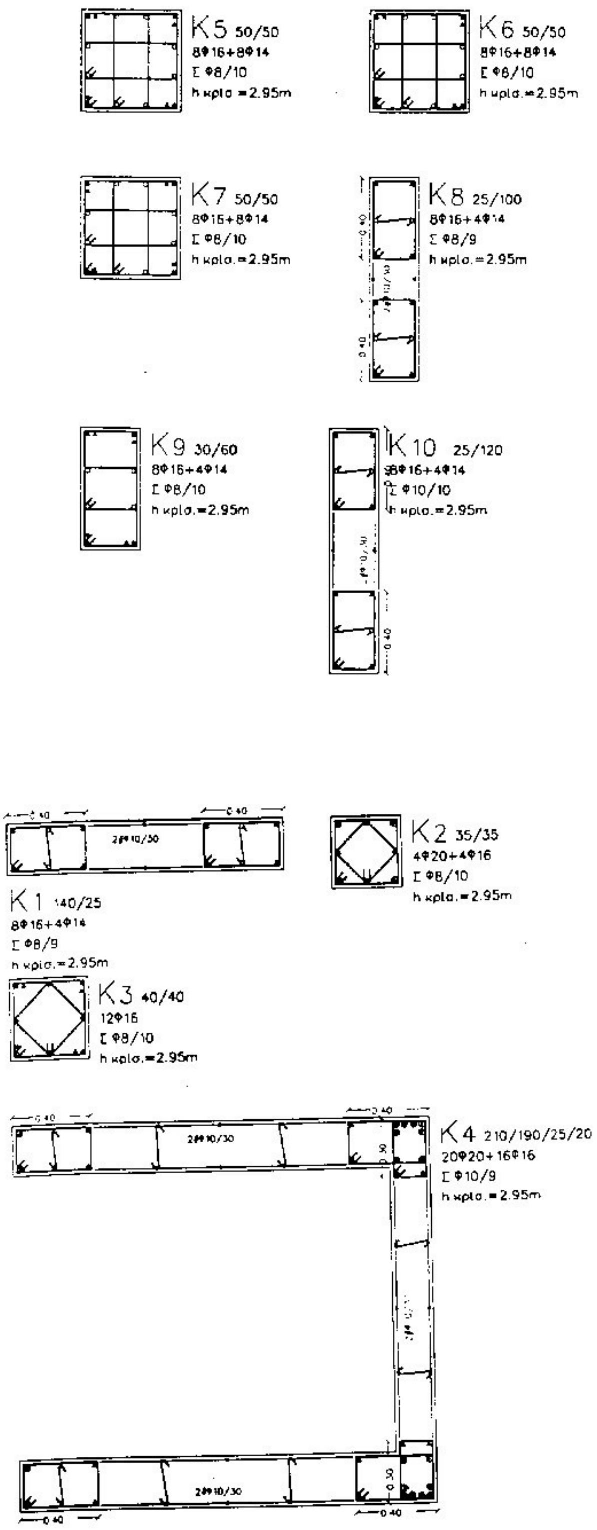
General Information

Building Type:	Multi-story reinforced concrete frame building
Country:	Greece
Author(s):	T. P. Tassios Kostas Syrmakezis
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in the main cities of the country, at an estimated percentage of 30% on the entire housing stock. This type of housing construction is commonly found in urban areas.
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.
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 10-19 units
Typical number of stories:	4-6
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	10
Typical plan width (meters)	15
Typical story height (meters)	3
Type of Structural System	Structural Concrete: Moment Resisting Frame: Dual system Frame with shear wall
Additional comments on structural system	The gravity load-bearing structure consists of RC solid slabs, transferring the gravity loads to the beams and columns and finally to the footings. 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.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	4-5%
Typical wall densities in direction 2	4-5%
Additional comments on typical wall densities	The typical structural wall density is up to 5 %. Total wall area/plan area (for each floor) 3-4%.
Wall Openings	Such a building has 12-15 openings per floor, of an average size of 3.0 m.sq. Estimated percentage of opening area to the total wall surface is 25%. Infill walls are generally not considered in the design.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Usually demolition of interior infill walls.
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footing
Additional comments on foundation	

Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: cast-in-place and precast solid slabs
Type of Roof System	Roof system, other
Additional comments on roof system	Structural concrete: cast-in-place and precast solid slabs
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	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)
Floors	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)
Roof	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	Architects are responsible for architectural drawings and civil engineers for the structural design.
Expertise of those involved in the design process	Structural Engineer (five years University studies and minimum 5 years experience).

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in the building process	These buildings are usually built by developers.
Expertise of those involved in building process	Experienced professionals for the construction. Occasional low quality construction is observed.
Construction process and phasing	Developers are usually builders of this type of construction. Ready-mixed concrete is usually used. Concrete pumps and concrete vibrators are used in situ. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or	Greek Code for Earthquake Resistant Design (NEAK) Greek Code for Earthquake Resistant Design (NEAK),

standards	Athens 1995. Greek Code for Reinforced Concrete Design (NKOS), Athens 1995.
Process for building code enforcement	Building design must follow the National Building Code and EuroCodes.

Building Permits and Development Control Rules

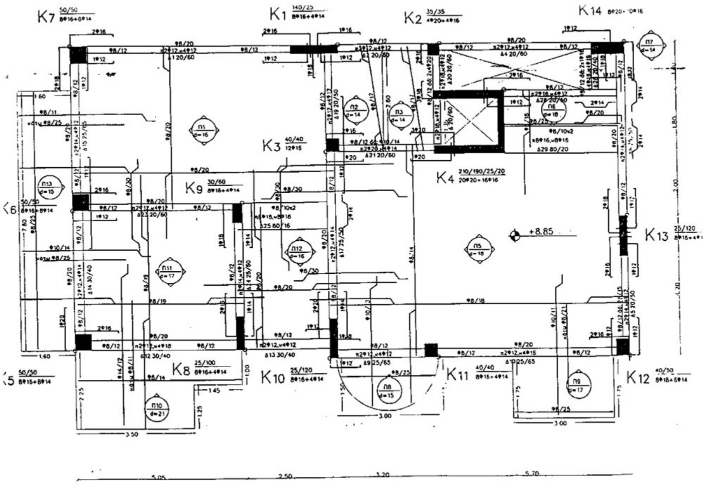
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

Building Maintenance and Condition

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.
Who typically maintains buildings of this type?	Owner(s)Renter(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	250000 DRA/m.sq. (600 US$/m.sq.)
Labor requirements	1 month per floor 50 man-months per floor
Additional comments section 3	



Key Load-bearing Elements

Critical Structural Details

Socio-Economic Issues

Patterns of occupancy	One family per housing unit. Each building typically has 16 units in each building.
Number of inhabitants in a typical building of this construction type during the day	5-10
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income class
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 4:1
Typical Source of Financing	Personal savingsCommercial banks/mortgages
Additional comments on financing	
Type of Ownership	RentUnits owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake	Repair works; earthquake insurance for this construction

insurance typically cover/cost	type was only recently imposed.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1996	Aegion
1999	Athens
1981	Athens

Past Earthquakes

Damage patterns observed in	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 epicentre 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 accelerations were between 0.04 to 0.36g. The most heavily damaged areas lie within a 15 km radius from the epicentre. 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

Damage patterns observed in past earthquakes for this construction type	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.
Additional comments on earthquake damage patterns	Cracking in shear walls of the elevator shaft (1999 Athens earthquake), see Figure 9. 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 7 and 8). 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)

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial	TRUE

	forces from the building to the foundation.	
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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.	TRUE
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.	TRUE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE

Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		N/A
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	TRUE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	Building configuration - buildings of this type are considered to be regular in elevation due to the uniform column and wall sections thoughout the building height. According to the Code, it is not acceptable to have stiffeness variation of over 30%.
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Clay brick infill with low tensile strength. Nonuniform wall distribution (in elevation or in plan) may create problems related to seismic performance.
Earthquake-resilient features in walls	The presence of minimum RC shear walls (a Code requirement) led to an improved structural performance
Seismic deficiency in frames	#NAME?
Earthquake-resilient features	-Capacity design of beam-column joints ensures ductile behavior of the structure -Good seismic performance on

in frame	condition of careful detailing during design and construction after the application of the 1985 Code.
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	Rigid diaphragms (insignificant relative in-plane displacements).
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the [Seismic Vulnerability Guidelines]

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class				|-	o	-|

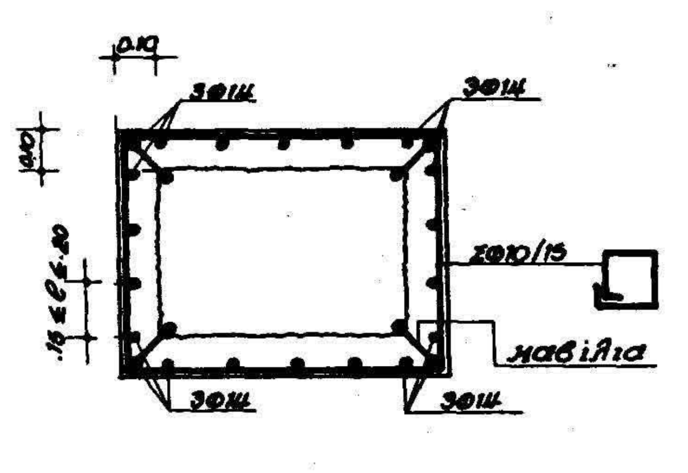
Typical Earthquake Damage (1999 Athens earthquake)

Building Collapse in the 1999 Athens earthquake

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

Typical Earthquake Damage-Column Failure (1999 Athens Earthquake)

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



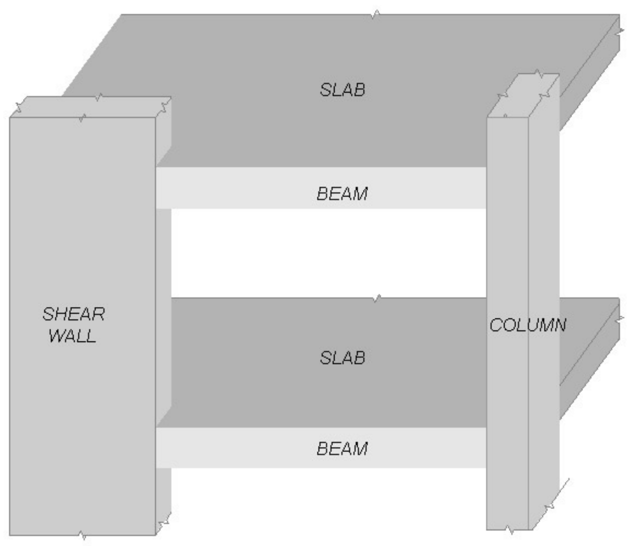
Typical damage to the shear wall surrounding the stairwell in an apartment block in the 1999 Athens earthquake (Source: EQE)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic 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.sq). (Source: UNIDO).

Additional comments on seismic strengthening provisions	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).
Has seismic strengthening described in the above table been performed?	Yes, to a great extent.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	Repair following the earthquake damage.
Was the construction inspected in the same manner as new construction?	Yes
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	The construction was peformed by a contractor, with the involvement - supervision of an architect and a civil engineer.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	The performance was satisfactory.
Additional comments section 6	



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