World Housing Encyclopedia

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

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

HOUSING REPORT
Multistory reinforced concrete frame building

Report #	15
Report Date	05-06-2002
Country	GREECE
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Dual System - Frame with Shear Wall
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Summary

These buildings represent a typical multi-family residential construction, mainly found in the Greek suburbs. This housing type is very common and constitutes approximately 30% of 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-sized reinforced concrete core is usually

present and serves 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. General Information

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. This construction type has been in practice for less than 25 years.

Currently, this type of construction is being built. .

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. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

Typical shape of a building plan is rectangular. 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.

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

2.4 Modification to Building

Usually demolition of interior infill walls.

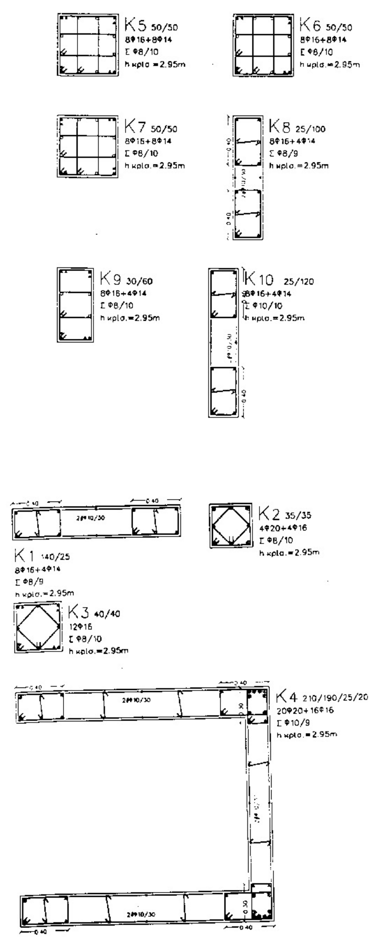

Figure 2: Plan of a Typical Building

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	☐
		11	Clay brick/tile masonry, with wooden posts and beams	☐

	Confined masonry	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete moment resisting frame. The gravity load-bearing structure consists of RC solid slabs, transferring the gravity loads to the beams and columns and finally to the footings.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). 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.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 15 and 15 meters. The building has 4 to 6 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical Span: Span variation is 3.5-4.5 m. The typical storey height in such buildings is 3.0 meters. The typical structural wall density is up to 5 %. Total wall area/plan area (for each floor) 3-4%.

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	☐

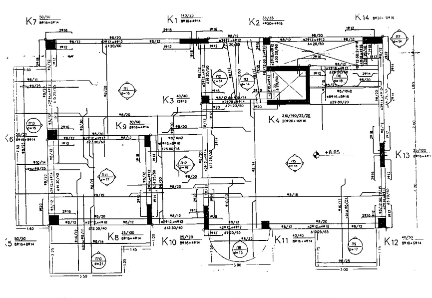

Figure 3: Key Load-bearing Elements

Figure 4: Critical Structural Details

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 16 units in each building. The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is more than 20.

4.2 Patterns of Occupancy

1 family per housing unit.

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 'House Price/Annual Income' is usually more than 4.

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 2 bathroom(s) without toilet(s), no toilet(s) only and 2 bathroom(s) including toilet(s).

In some housing units there is only 1 bathroom. .

4.4 Ownership

The type of ownership or occupancy is renting and individual 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	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 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *E: LOW VULNERABILITY (i.e., very good seismic performance)*, the lower bound (i.e., the worst possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance), and the upper bound (i.e., the best possible) is *F: VERY LOW VULNERABILITY (i.e., excellent 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	Athens		

1996	Aegion	6.1	MSK
1999	Athens	5.9	IX (MSK)

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.

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

Figure 5B: Building Collapse in the 1999 Athens earthquake

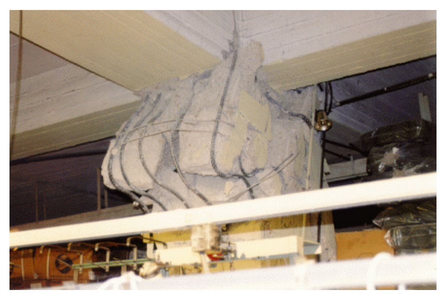

Figure 5C: Earthquake Damage - Dislodged Column due to Soft Ground Floor Effect (1999 Athens earthquake)

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

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

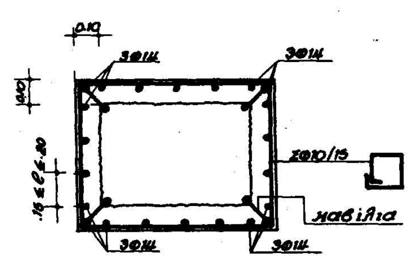

Figure 5F: Typical damage to the shear wall surrounding the stairwell in an apartment block i the 1999 Athens earthquake (Source: EQE)

6. Construction

6.1 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)		
Foundation	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		
Frames (beams & columns)	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		
Roof and floor(s)	Reinforced Concrete	Concrete strength: 16/25 MPa Steel: S500 (fy=500 MPa)		

6.2 Builder

These buildings are usually built by developers.

6.3 Construction Process, Problems 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.

6.4 Design and Construction Expertise

Structural Engineer (five years University studies and minimum 5 years experience) Experienced professionals for the construction. Occasional low quality construction is observed. Architects are responsible for architectural drawings and civil engineers for the structural design.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Greek Code for Earthquake Resistant Design (NEAK). The year the first code/standard addressing this type of construction issued was 1955. Greek Code for Earthquake Resistant Design (NEAK), Athens 1995. Greek Code for Reinforced Concrete Design (NKOS), Athens 1995. The most recent code/standard addressing this construction type issued was 1995. Structural Engineer (five years University studies and minimum 5 years experiTitle 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 ence) Experienced professionals for the construction. Occasional low quality construction is observed.

Building design must follow the National Building Code and EuroCodes.

6.6 Building Permits and Development Control Rules

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

6.8 Construction Economics

250,000 GRD/m² (600 US$/m²). 1 month per floor 50 man-months per floor.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Earthquake insurance for this construction type was only recently imposed. Repair works.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
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 /m²). Seismic strengthening using the concrete jackets is illustrated in Figure 6 (Source: UNIDO).

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).

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, to a great extent.

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

Repair following the earthquake damage.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

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, with the involvement - supervision of an architect and a civil engineer.

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

The performance was satisfactory.

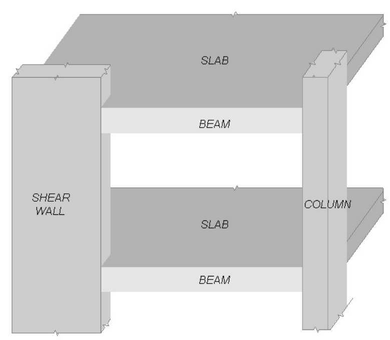

Figure 6: Illustration of Seismic Strengthening Techniques

Reference(s)

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   Institute of Engineering Seismology and Earthquake Engineering, Thessaloniki, Greece (www.itsak.gr)

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

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   Building Construction Under Seismic Conditions in the Balkan Region, Volume 5, UNDP/UNIDO Project RER/79/015, United Nations Industrial Development Organization, Vienna, Austria 1983

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