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

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HOUSING REPORT
Confined masonry building with concrete floor slabs

Report #	69
Report Date	05-06-2002
Country	SERBIA
Housing Type	Confined Masonry Building
Housing Sub-Type	Confined Masonry Building : Clay brick masonry, with concrete tie-columns and beams
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Summary

This type of construction has been used for single-family and medium-rise residential buildings throughout urban and rural Yugoslavia during the past 30 years. The structure consists of

load-bearing masonry (brick, stone, concrete block) walls confined with reinforced-concrete posts and tie-beams. The walls are typically made of hollow clay tiles. Floor slabs are composed of prefabricated joists infilled with brick elements and topped with a reinforced-concrete slab in-situ.

1. General Information

Buildings of this construction type can be found in urban and rural areas of Yugoslavia. 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. .

Figure 1A: Typical Building

Figure 1B: Typical building

Figure 1C: Typical building

Figure 1D: Typical building

Figure 1E: Typical building

Figure 1F: Typical building

Figure 2: Key Load-Bearing Elements

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 5 meters.

2.2 Building Configuration

Usually regular shape. According to the Yugoslav National Building Code, size of the openings should not exceed 2.5 to 3.5 meters (depending on the seismic zone). The size can be increased up to 30% if the openings are confined with reinforced concrete posts and tie beams.

2.3 Functional Planning

The main function of this building typology is single-family house. Buildings of this type are single family houses frequent, but there are a lot of multiple housing units and mixed too. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There is no additional door besides the main entry in residential buildings of this type. However, standards for commercial buildings define number and type of exit stairs.

2.4 Modification to Building

The most common pattern of modification in residential houses is complete removal or displacement of interior walls and columns. House owners usually perform modifications without seeking an advice of a competent technician (engineer/architect).

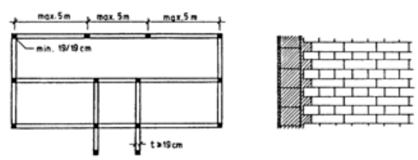

Figure 3: Plan of a Typical Building

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	☐
	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Masonry walls transfer all gravity loads from the roof and floor slabs to the foundations. Minimum thickness for bearing masonry walls is 190 mm (as prescribed by the code). The Yugoslav National Building Code classifies masonry buildings into three categories, depending on the wall layout: - buildings with walls in transverse direction; - buildings with walls in longitudinal direction, and - buildings with walls in both directions.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The main lateral load-resisting system for this housing type is a wall structure in with brick walls laid in both directions (transverse and longitudinal) carry lateral seismic forces and transfer them to the foundations. Reinforced concrete posts and tie-beams are effective in increasing the stiffness and ductility in this construction type and providing an improved level of seismic safety for this type of construction. Details of concrete posts and tie-beams are shown in Figure 4A. A possible failure mechanism for confined masonry walls is illustrated in Figure 5.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 10 and 10 meters. The building has 2 to 4 storey(s). The typical span of the roofing/flooring system is 5 meters. Typical Plan Dimensions: Plan dimensions (i.e. length and width) of this building type should not exceed 40 to 50 meters. Length to width ratio is usually on the order of 3-4. In case the plan dimensions exceed these values, the walls need to be divided into sections by means of control joints. Typical Story Height: Typical floor height for residential buildings is 2.8 m, and 3.0 m for public buildings. Total height for buildings of this type should not exceed 20 meters (according to the code). Typical Span: Typical span (between the adjacent concrete posts) ranges from 3 to 6 m. The National Building Code prescribes the maximum span of 5 meters. The typical storey height in such buildings is 2.8 meters. The typical structural wall density is none. Varies from 6% to 12%.

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)	☐	☐
	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	☐	☐

Timber	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	☑	☑

According to the National Building code, floor/roof must act as rigid diaphragm.

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	☐

Foundation details are illustrated in Figure 4B.

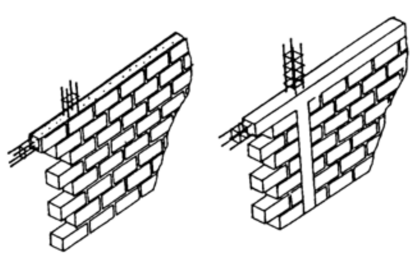

Figure 4A: Details of concrete posts and tie beams

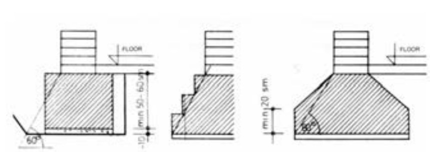

Figure 4B: Foundation Details

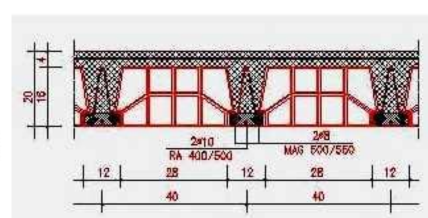

Figure 4C: Floor slab details (an example of a precast floor slab type LMT)

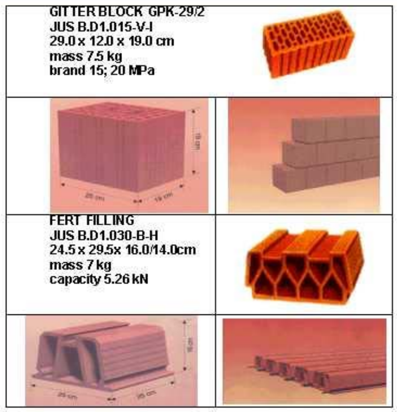

Figure 4D: Typical masonry units used in wall and floor-slab constructions

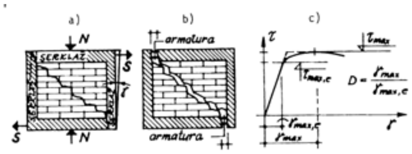

Figure 5: A possible failure mechanism for confined masonry walls

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). It varies from one unit per building (single-family house) to 50 units in condominiums. 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 11-20.

4.2 Patterns of Occupancy

Usually one family occupies one 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)	☐

In the last 10 years, the economic situation in Yugoslavia has been very bad. The average net salary is less than 50 $ US per month. Economic Level: For Poor Class the ratio of the Housing Price Unit to their Annual Income is 50:1. For Middle Class the ratio of the Housing Price Unit to their Annual Income is 30:1.

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 no bathroom(s) including toilet(s).

In case of units with over two bedrooms there is one bathroom and a separate WC. The majority of units are two- or three- bedroom units; mostly there is one bathroom, or one bathroom with separate WC. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership , ownership with debt (mortgage or other) 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		
		Yes	No	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
Wall	Low shear strength and diagonal tension cracking as a result of brittle seismic response of unreinforced masonry walls subjected to seismic shear forces and gravity loads; brittle behavior	Typical brick strength is more than 20 MPa.	Diagonal tension cracks
Roof and floors	In some cases inadequate rigidity of roof and floor slabs		
Concrete post-to-tie beam joints	Special construction requirements for the joints are not followed in some instances.	Reinforced concrete posts and beams increase stiffness and ductility in this construction type	

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 C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate 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
1969	Banja Luka	6.4	
1980	Kopaonik	5.7	
1980	Banja Luka	6.2	
1987	Kraljevo	4.9	

Other earthquakes: 1998 Mionica (magnitude 5.7); 1999 Trstenik (magnitude 5.1). Damage to confined masonry buildings in these earthquakes was not extensive. Figure 6 shows damage to masonry buildings in the 1998 Mionica earthquake (magnitude 5.7). A number of older unreinforced masonry buildings were damaged in the earthquake however confined masonry buildings performed well and did not suffer any significant damage, as illustrated in the figure.

Figure 6: Damage to masonry buildings in the 1998 Mionica earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments

Walls	Bricks/hollow clay tiles mortar	Characteristic compressive strength Bricks : from 7.5-20 MPa Hollow clay tiles: from 5.0 to 20.0 MPa Mortar: from 5-15 MPa)		According to the Yugoslav standards concrete compressive strength is determined using 200 mm cube specimens. Typical masonry units are shown in Figure 4D.
Foundation	Concrete and steel reinforcement	Concrete: minimum compressive strength 15 MPa Steel: minimum yield stress 240 MPa	Minimum 3 fractions of gravel and 200 kg/m^3 of cement	Foundation details are illustrated in Figure 4B.
Frames (beams & columns)	Concrete posts and tie-beams: - Concrete -Steel reinforcement	Concrete posts and tie-beams: Concrete minimum strength 20 MPa Steel: minimum yield stress 240 MPa	Concrete posts and tie-beams: Minimum 3 fractions of gravel and 250 kg/m^3 of cement	
Roof and floor(s)	-Concrete -Steel reinforcement	Concrete strength 15-30 MPa steel yield stress min. 240 MPa	Minimum 3 fractions of gravel and 300 kg/m^3 of cement	Details of prefabricated floor-slab construction are shown in Figure 4C.

6.2 Builder

Typically, builders (developers) build the housing of this type. In some cases, builders live in the houses of this type, too.

6.3 Construction Process, Problems and Phasing

In this construction system, brick elements must be built and tied together in a specific way. Thickness of reinforced concrete vertical posts must be equal to the wall thickness. Minimum reinforcement to be provided in vertical posts consists of 4 -14 mm diameter steel bars tied with 6 mm diameter stirrups spaced at 250 mm on centre. Tie beams are constructed after the bricklaying is completed. Minimum reinforcement required in the tie beams consists of 4 - 12 mm diameter bars tied with 6 mm stirrups at 250 mm on centre spacing. In seismic areas lime/cement mortar has to be used. The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size. In some cases there are changes and differences between the designed and the constructed building. In such case, National Building Code prescribes the development of technical documentation describing the "as constructed" condition. Modifications (especially vertical expansion) for the buildings of this type are common, especially in case of single-family houses.

6.4 Design and Construction Expertise

Architects and engineers design buildings of this type. If certified engineers are not involved in the building design (i.e. non-engineered construction), National Building Code allows the construction of a building up to max. two-storey high. Engineers and architects work jointly on developing project for buildings of this construction type.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Technical regulations for masonry construction. The year the first code/standard addressing this type of construction issued was 1987. Technical regulations for construction in seismically prone areas. Title of the code or standard: Technical regulations for masonry construction. Year the first code/standard addressing this type of construction issued: 1987 National building code, material codes and seismic codes/standards: Technical regulations for construction in seismically prone areas.

For all newly constructed buildings, building permits confirming that the construction has been done in conformance with the National Building Code must be issued; the code also prescribes the seismic zone the buildings are located in. Yugoslavia (and Serbia) are the part of the Balkan Peninsula, which is known to be one of the most seismically prone regions of Europe. However, until the catastrophic 1963 Skopje (Macedonia) earthquake, there were no seismic codes or regulations in the country. In 1964, the Preliminary National Building Code (including the seismic provisions) was issued. The latest edition of the National Building Code was issued in 1987. In addition to the National Code, Euro Codes have been used in the country as well.

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). In the urban areas, public companies take care of maintenance for the housing stock.

6.8 Construction Economics

Construction cost is about 100 to 150 $US/m² of built-up area (structure only), whereas the price of the finished building is on the order of 200 to 300 $US/m² of built-up area. Construction of a typical building of this type (built-up area of 120-200 m²) takes approximately 6 months, depending on the finances. It should be also noted that this type of construction requires a limited number of trained labor and technical personnel. Majority of the other construction labor involved in this type of construction are generally unskilled.

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. The annual insurance rate is 0.45% of the building value increased by 15% to account for earthquake risk.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Low shear strength and diagonal tension cracking as a result of brittle seismic response of unreinforced masonry walls subjected to shear forces and gravity loads; brittle behavior	Reconstruction of damaged walls; New reinforced concrete wall overlay; Injection grouting of cracks; Application of carbon fiber laminates bonded diagonally to the walls

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, all strengthening methods were used in design practice. Structural engineers provide design specifications for the seismic strengthening design.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
In most of the cases, seismic strengthening has been performed as a part of post-earthquake rehabilitation (e.g. after the 1979 Montenegro earthquake or 1998 Mionica earthquake).

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?
Usually it was owner/user who performed the construction, with competent participation of an architect and engineer.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The buildings that were seismically upgraded were generally not subjected to another major earthquake. However, it is expected that the strengthened buildings would show improved seismic performance if subjected to an earthquake.

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