World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Precast, prestressed concrete frame structure with concrete shear walls

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Last Updated	
Country	Serbia
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General Information

Building Type:	Precast, prestressed concrete frame structure with concrete shear walls
Country:	Serbia
Author(s):	Radovan Dimitrijevic
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in The technology has been used throughout the former Yugoslavia for building the Post-World War II urban settlements. Over 50% of the apartments in New Belgrade (a part of the country's capital built after the World War II) were built using the IMS technology. It can be also found in the cities of Novi Sad, Nis, Banja Luka, Sarajevo, Tuzla etc. (currently a part of Bosnia and Herzegovina) and in other countries e.g. Cuba, Russia, Georgia, China (where this technology was used for building the sustainable housing). Recent design applications were reported in the Philippines and Egypt. This type of housing construction is commonly found in urban areas. This technology has been mainly used for medium to high-rise buildings; however, some design applications include single-family row housing units (such as townhouses), as well as schools, hospitals, offices, shopping malls, multi-story garages, etc.
Summary:	This housing type is a prefabricated frame structure, consisting of precast concrete columns and other structural elements, e.g., waffle floor slabs, edge girders, stairs, and wall panels. The frame structure carries the gravity load, while shear walls are the main lateral load-resisting elements. The main feature of this technology is that the key structural elements are joined together by prestressing in two orthogonal horizontal directions. The technology has been used in Yugoslavia during the last 40 years under the proprietary name, IMS Building System, and it can be found in all major Yugoslav cities, including Belgrade, Novi Sad, Nis, etc., and also in other countries, such as Cuba, the Philippines, and Egypt. To date, around 400,000 housing units (approximately 2.5 million/m# of the

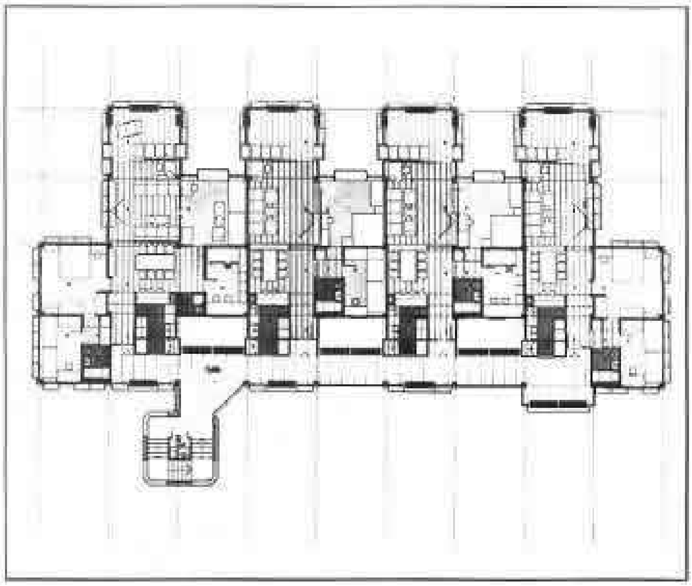
	built area) have been constructed using this technology. Design applications include both residential housing and public buildings (e.g., hospitals). Seismic performance of the main IMS structural elements has undergone extensive experimental laboratory tests, and has also been tested in a few major earthquakes. Several buildings of this type sustained the effects of the 1968 Banja Luka earthquake without any damage.
Length of time practiced:	25-60 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 50+ units
Typical number of stories:	5-10
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	

Features

Plan Shape	Other
Additional comments on plan shape	In general, a regular shape. In some cases shear walls are perforated with door or window openings.
Typical plan length (meters)	40-60
Typical plan width (meters)	10-15
Typical story height (meters)	2.8 residential, 3.2 public
Type of Structural System	Structural Concrete: Structural Wall: Moment frame with precast shear walls
	The structure consists of the following gravity load-bearing elements: - Columns, continuous for up to three stories; - Floor slabs, supported on 4 columns, and cantilever (balcony) slabs, supported on 2-3 columns; both floor slabs and balcony slabs are waffle slabs; - Edge girders to carry facade loads and different types of stairs. Main structural elements are shown in FIGURE 4. The gravity load transfer from the floor slabs to the columns is

Additional comments on structural system	achieved by friction in the joints induced by axial forces developed in the prestressing cables; the joint shear capacity is proportional to the force developed in the cable and to the friction coefficient value. The prestressed cables play a very important role in this type of construction, and therefore it is very important to protect the cables from the corrosion by grouting the cement emulsion into the holes provided in the columns. The elements of the gravity load-bearing structure, i.e., columns, floor slabs, cantilevers and edge girders are joined together by prestressing in two orthogonal directions. Shear walls are the main structural elements providing lateral resistance in this system. The walls consist of reinforced concrete panels (typically 15 cm thick) enclosed with the two adjacent columns. The columns are provided throughout the building height. As elements of the shear wall, columns carry additional axial load (tension/compression) due to the bending moment. The concrete wall panels are subjected to shear effects. It is very important to ensure the continuity of shear walls in both directions throughout the height of the building. The concrete wall panels are usually cast in-situ. However, in some cases precast panels have been used. Generally, the concrete frame itself is able to sustain the lateral force effects. However, because the structure is too flexible, excessive lateral movements would have detrimental effects on the performance of nonstructural elements, e.g., the facade, partitions, installations. The shear walls therefore have a role in increasing the lateral stiffness of the structure and in limiting lateral deflections to the acceptable level. The main feature of this building type of space frame is the high load-bearing capacity of the prestressed floor-column joints. This capacity is based on the friction developed between these two concrete elements after the prestressing is completed. A number of tests were performed, in which column-slab joint models were subjected to static or quasi-dynamic loading. The tests have revealed that failure occurs in the connected elements (i.e., in the slab) and not in the joint itself. Typical floor-column joints are illustrated in FIGURE 4A.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	0-1%

Typical wall densities in direction 2	0-1%
Additional comments on typical wall densities	The typical structural wall density is none. Information on a typical wall density is not available.
Wall Openings	In some cases shear walls are perforated with door or window openings.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	It is easy to perform modifications on buildings of this type, considering that the main gravity load bearing system is a concrete frame and majority of the walls are non-load bearing structures (except for the shear walls).
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footingShallow Foundation: Reinforced concrete strip footing
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	Precast columns and waffle slabs joined by prestressing cables The floor slabs are considered to be rigid diaphragms and are able to transfer lateral loads to the shear walls.
Type of Roof System	Roof system, other
Additional comments on roof system	Precast columns and waffle slabs joint by prestressing cables.
Additional comments section 2	Typical separation distance between buildings: 0.5 meters



Plan of a typical building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Concrete, Reinforcing stee	Characteristic Strength- Concrete- minimum C 40 (40 MPa cube compressive strength) Steel- minimum A 40 (400 MPa yield strength) C 40 (concrete) and A 40 (steel) is based on the Eurocode. Quality control is mandatory. Mix Proportion/Dimensions- Minimum 3 fractions of gravel and 400 kg/sq. m of cement
Foundations	Concrete and reinforcing steel	Characteristic Strength: Minimum C 40 Minimum A 40 Quality control is mandatory. Mix Proportion/Dimensions: Minimum 3 fractions of gravel and 400 kg/sq. m of cement
Floors	Concrete and reinforcing steel	Characteristic Strength: Minimum C 40 Minimum A 40 Quality control is mandatory. Mix

		Proportion/Dimensions: Minimum 3 fractions of gravel and 400 kg/sq. m of cement
Roof	Concrete and reinforcing steel	Characteristic Strength: Minimum C 40 Minimum A 40 Quality control is mandatory. Mix Proportion/Dimensions: Minimum 3 fractions of gravel and 400 kg/sq. m of cement
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	Architects and engineers have a role in preparing a design for each building of this construction type. There is no typical (generic) building design, and therefore it is necessary to prepare a separate design for each new building. Cooperation between the architects and engineers is very important and leads to more cost-effective design.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	Builder
Roles of those involved in the building process	In a typical situation, developers build this type of construction. In some cases, developers also live in the buildings of this construction type. Note that, until few years ago, developers were generally government-owned construction companies.
Expertise of those involved in building process	
	All structural elements are prefabricated in the plant using steel templates. For smaller size projects, the prefabrication can be carried out at the construction site. The erection is simple and fast, and it is carried out using erection equipment

Construction process and phasing	(cranes, etc.). Temporary support to the structural elements needs to be provided before permanent connection by prestressing is achieved. Before the prestressing is carried out, the space between the columns and horizontal elements (floor slabs, cantilever and edge girders) is filled with cement mortar (in order to enable transfer of axial forces). After the prestressing is completed, the holes in the columns are grouted with cement grout and the space between the adjacent floor slabs, cantilevers, or edge girders, is filled with concrete. In this way, the cables are protected from corrosion. Erection of concrete columns is shown in FIGURE 13.Examples of buildings of this type under construction are shown in FIGURE 5 , FIGURE 10, FIGURE 11 and FIGURE 12. 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 standards	The buildings of this construction type are designed in compliance with the Yugoslav National Building Code and related standards. The year the first code/standard addressing this type of construction issued was 1964. Yugoslav National Building Code1987 (based mainly on the Euro Code). The most recent code/standard addressing this construction type issued was 1987. Yugoslavia is located in the Balkan Peninsula, an area considered among the most seismically prone regions in 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. Since then, several editions of the building code have been issued and the code is generally being enforced. National building code, material codes and seismic codes/standards: Yugoslav National Building Code1987 (based mainly on the Euro Code)
Process for building code enforcement	All new buildings need to get a building permit, which is issued if the design has been done properly and is based on the National Building Code. Building permits are required to build this housing type.

Building Permits and Development Control Rules

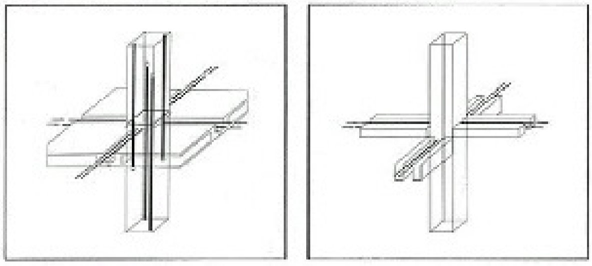
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	Typically, the building of this housing type is maintained by Owner(s). In the cities, government companies are in charge of the maintenance for the buildings of this type.

Construction Economics

Unit construction cost	The unit cost depends on the building function. In general, for the apartment buildings of this type the unit cost of structure only is on the order of US$ 50-60 per m#. However, as this is a prefabricated construction, there needs to be a certain level of annual production (around 20,000-30,000 m#) is needed in order to achieve cost-effective construction.
Labor requirements	A table summarizing material and labor requirements per hour is shown on FIGURE 15. Note that the requirements are a function of floor-slab dimensions (first column to the left). A small number of trained staff is required for the fabrication and assembly of this construction type. The majority of labor can be local, without any special training.
Additional comments	



Details of a typical post-tensional slab-column connection

Details of a typical post-tensional slab-column connection

Details of an IMS building under construction showing cantilevered balcony slabs

IMS building under construction showing columns under construction

A medium-rise residential building under construction

A building under construction, showing columns at the top floor erected in the vertical position

An Illustration of column erection

Socio-Economic Issues

Patterns of occupancy	Typically, a single family occupies one housing unit. Each building typically has 51-100 housing unit(s). Up to 100 units in each building. It varies from one housing unit per building (case of a family house) to 40 or even 200 units in the condominium buildings.
Number of inhabitants in a typical building of this construction type during the day	>20
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	The average number of inhabitants depends on the building function (i.e. is it a single- or multi-family housing).
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	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. However in spite of the extremely poor economic situation new construction is carried out per the latest Euro Code requirements. Economic Level: For Middle Class the ratio of Housing Price Unit to their Annual Income is 30:1 For Poor Class the ratio of Housing Price Unit to their Annual Income is 50:1.

Typical Source of Financing	Personal savingsCommercial banks/mortgagesInvestment poolsGovernment-owned housing
Additional comments on financing	At the present time, it is not possible to obtain a mortgage due to the current socio-political-economic situation in Yugoslavia.
Type of Ownership	Units owned individually (condominium)Owned by group or pool
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is available. The annual insurance rate is 0.45% of the building's value, increased by 15% for earthquake risk.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	Yes
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1969	Banja Luka, Bosnia
1977	Vrancea, Romania
1979	Montenegro
1980	Kopaonik

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	There was no reported damage to the buildings in the past earthquakes in Yugoslavia. In other countries, where this technology has been used, e.g. Cuba, Georgia and the Philippines, buildings of this type were subjected to strong earthquakes also without any reported damage.
Additional comments on earthquake damage patterns	

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 forces from the building to the foundation.	TRUE
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	TRUE

	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.	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.	TRUE

Wall Openings		TRUE
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	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Shear walls may be under-reinforced and might suffer damage in a major earthquake; however, the damage can be repaired by injecting the cracks with cement or with an epoxy emulsion.
Earthquake-resilient features in walls	Shear walls do not have any function in the gravity load-carrying system and therefore any damage to these elements would not affect the gravity load-bearing capacity of the structure in an earthquake.
Seismic deficiency in frames	
	During an earthquake, columns adjacent to the

Earthquake-resilient features in frame	shear walls are subjected to axial tension and to compression forces induced by the bending effects in the shear walls.
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	Roof and floor elements are reinforced concrete waffle slab designed to carry gravity loads. However, these elements also act as rigid diaphragms in the seismic load transfer.
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	-|

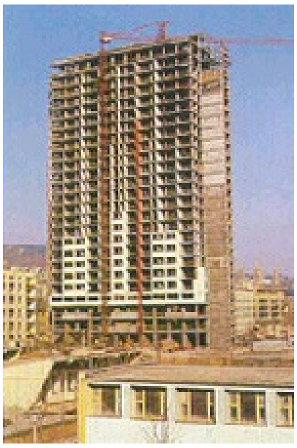
Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	**Seismic Strengthening**

Additional comments on seismic strengthening provisions	The prestressed prefabricated concrete frame structure is an inherently earthquake-resistant system and hence seismic strengthening is not required.
Has seismic strengthening described in the above table been performed?	There are no reports of seismic strengthening performed on buildings of this construction type
Was the work done as a	

mitigation effort on an undamaged building or as a repair following earthquake damages?	Not applicable.
Was the construction inspected in the same manner as new construction?	Not applicable.
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Not applicable.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Not applicable.
Additional comments section 6	



A high-rise building under construction

Spans	Material			Labour		
	concrete m3	reinf. steel 10 kg	strand kg	production h	assembly h	total h
7.2x7.2	0.16	1.72	3.03	1.72	2.14	3.85
6.6x7.2	0.17	1.84	3.09	1.88	2.32	4
6.0x7.2	0.18	1.95	3.03	1.82	2.37	4.19
6.6x6.6	0.17	1.97	2.65	1.69	2.18	3.87
6.0x6.6	0.17	1.96	2.08	1.77	2.26	3.91
6.0x6.0	0.18	2	2.09	1.83	2.3	4.11
5.4x5.4	0.19	2.2	2.16	1.73	2.4	4.13
4.8x4.8	0.22	2.41	1.78	1.84	2.76	4.6
4.2x4.8	0.133	1	1.19	0.85	1.9	2.75
4.2x4.2	0.137	1.03	1.26	0.96	1.97	2.92
3.6x4.8	0.139	1.04	1.29	0.97	1.99	2.96
3.6x4.2	0.145	1.17	1.37	1.05	2.1	3.15
3.6x3.6	0.152	1.22	1.47	1.18	2.2	3.38

Material and labor consumption per hour as a function of floor slab dimensions

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