World Housing Encyclopedia

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

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International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Reinforced concrete frame structure with diagonal bracing and brick infill walls

Report #	71
Report Date	05-06-2002
Country	ROMANIA
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for seismic effects, with URM infills
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Summary

This is a post-World War II variant of the well-known Romanian 'inter-bellum' building. This urban housing construction was practiced in Romania over a rather short period of time after World War II until nationalization in 1947. Buildings of this type are still in use, mainly as apartment buildings. They are typically 7 to 11 stories high and the main load-bearing structure consists of a reinforced concrete space frame with reinforced concrete diagonal bracings. The floor structure consists of RC

solid slabs and beams cast-in-place. The frames are infilled with brick masonry walls (typical wall thickness 140 mm or 280 mm). These buildings were designed according to the temporary guidelines issued in 1941 by the Ministry of Public Works (MLP) and based on German recommendations. This region is well known as a seismically prone area, with the epicenter of damaging earthquakes close to Vrancea. Earthquakes of Richter magnitude over 7.0 occur once in 30 years. Bucharest, the capital, is located around 150 km south of the epicenter and lies in the main direction of the propagation of seismic waves. The Bucharest area is located on the banks of the Dâmbovita and Colentina rivers, on non-homogeneous alluvial soil deposits. During the earthquake of 4 March 1977 (Richter magnitude 7.2), over 30 buildings collapsed in Bucharest, killing 1,424 people. It should be noted that although buildings of this construction type experienced severe damage (mainly cracking in the columns and the brick masonry infill walls) collapse was not reported. After the 1977 Vrancea earthquake, the damaged buildings were repaired and strengthened. One of the buildings described in this contribution was retrofitted by strengthening the existing columns with new reinforced concrete jackets and by replacing the existing brick masonry infill walls with new lightweight concrete block walls. The diagonal bracings were removed as a part of the retrofit. Another example shows a triangular-shaped building with the original bracing preserved during the retrofit.

1. General Information

Buildings of this construction type can be found in Bucharest. There are a few existing buildings of this type in Bucharest. These buildings were retrofitted after the 1977 earthquake and they are still in use. This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 75 years.

Currently, this type of construction is not being built. Blocks of apartments of this type were built after the World War II until the nationalization in 1947. Period of practice was less than 5 years.

Figure 1A: Typical Building

Figure 1B: Typical Building

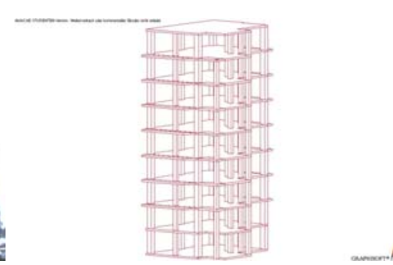

Figure 2A: Key Load-Bearing Elements

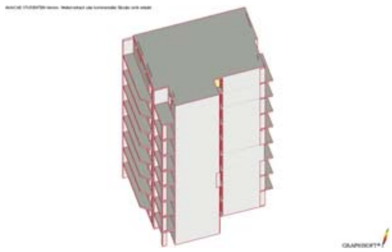

Figure 2B: Perspective Drawing Showing Exterior of the Building

Figure 2C: Perspective Drawing Showing Exterior of the Building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is several meters.

2.2 Building Configuration

Mostly rectangular, with notable exceptions; for example, a building with triangular-shaped plan is shown in this contribution. There is one window in each room. The windows in these buildings are much wider than in their predecessors, the inter-bellum buildings. The width of a window is equal to 60% of the wall length, and the total area of windows constitutes up to 24% of the wall surface area. Each room has a door; however in this building type doors constitute less than 30% of the wall surface area.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. One elevator for 4 persons, and the 1.30 m wide stairs. There are 2 dwellings per floor and the building is typically 5-story high.

2.4 Modification to Building

The dwellings have been modified after the 1978 retrofit, however the modifications vary from building to building and it is hard to generalize. The building plan presented in this contribution was recorded based on the actual condition in November 2001. Neither the original (as constructed) building plan nor the plans existing at the time of the 1977 earthquake are available. It is known that, in general, the new inhabitants after 1948 made their own modifications, and did not follow the regulations concerning the building space. Modifications of the building interior arrangement and in the structural elements were made as a part of the retrofit following the 1977 earthquake. Details of the modifications are not available.

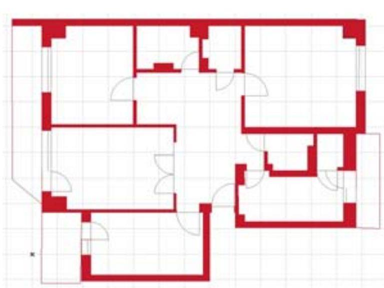

Figure 3A: Plan of a Typical Building

Figure 3B: Plan of a Typcial Building (after the retrofit)- the jacketed columns are yellow- colored

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	
		36	Thatch	

Timber	Load-bearing timber frame	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)	

These buildings, as well has having RC frames, also had RC diagonal braces.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Reinforced concrete frame supported by two-way slabs on beams. Although the brick infill walls are not considered a part of the load-bearing structure, these walls carry an increased gravity load in the course of time, due to the reduced load-bearing capacity of reinforced concrete structure caused by the corrosion.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). The main load-bearing structure consists of a reinforced concrete space frame with reinforced concrete diagonal bracings and masonry infill walls. The floor structure consists of two-way RC solid slabs supported by beams cast in place. The masonry infill walls are 140 mm or 280 mm thick and they are considered as nonstructural walls. In some buildings of this type the braces were removed as a part of the retrofit. Figures 5A and 5D illustrate possible bracing layout.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 0 and 0 meters, and widths between 0 and 0 meters. The building has 5 to 8 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: Width varies from 15 to 20 m. Typical Span: The wall span is rather non-uniform. The typical storey height in such buildings is 2.75 meters. The typical structural wall density is none. The main load-bearing system is concrete frame, and the information regarding wall density is not relevant.

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		

Floor and roof structures are two-way solid slabs with beams.

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	

The columns are supported by the individual (isolated) footings tied with the beams.

Figure 4A: Critical Structural Details - Frame with Diagonal Braces and Masonry Infill

Figure 4B: Critical Structural Details - Frame with Diagonal Bracings and Masonry Infill

Figure 5A: An Illustration of Key Seismic Features

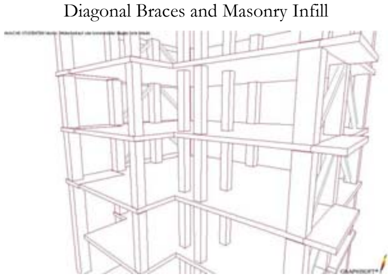

Figure 5B: Key Seismic Features - RC frame with Bracings

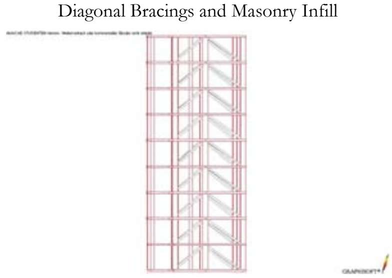

Figure 5C: Key Seismic Features-Vertical Section

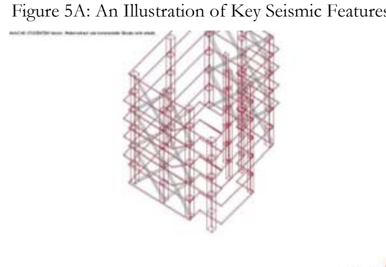

Figure 5D: Perspective Drawing Showing Key Seismic Features

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 20 units in each building. The number varies from 10-20; there are two units per floor. The number of inhabitants in a building during the day or business hours is others (as described below). The number of inhabitants during the evening and night is others (as described below). About 4 inhabitants per housing unit so more than 80 inhabitants occupy the building.

4.2 Patterns of Occupancy

One family per housing unit, and two housing units per floor.

4.3 Economic Level of Inhabitants

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

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

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

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

4.4 Ownership

The type of ownership or occupancy is outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	
outright ownership	
Ownership with debt (mortgage or other)	
Individual ownership	
Ownership by a group or pool of persons	
Long-term lease	
other (explain below)	

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.			

Building Configuration	The building is regular with regards to both the plan and the elevation.			
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.			
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.			
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.			
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.			
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);			
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.			
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps			
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.			
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).			
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).			
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)			
Other				

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Infill walls	- Irregular wall layout; - Walls too heavy; - Walls not a part of the load-bearing structure; - Wide openings	- Very rigid; might be of assistance to the frame structure to behave as a dual (frame-wall) system.	-The brick masonry infill walls were damaged in the 1977 earthquake (crack width over 0.3 mm).
Frame (columns, beams)	- Irregular layout	- Designed according to the German regulations which provided only basic seismic design provisions	-The example building was affected by the 1977 earthquake. Over 30% of the columns were cracked.
Roof and floors	- No significant deficiency	-Behave as rigid diaphragm	- No significant damage observed

Bracings	- A lateral load bearing capacity comparable to the capacity of infill masonry wall wasn't reached.	- The diagonal bracing played a key role in protecting the buildings from collapse in the 1977 earthquake.	- The bracing elements were severely damaged in the 1977 earthquake. They were effective in resisting seismic effects, and as a result concrete cover spalled off. It was considered that the braces were damaged beyond repair and that the retrofitting would prove inefficient. Therefore, the bracing elements were removed as a part of the retrofit.

The structural role of the infill walls was neglected in the original design performed according to the 1941 temporary guidelines for seismic design.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *D: MEDIUM-LOW VULNERABILITY (i.e., good 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 *E: LOW VULNERABILITY (i.e., very good seismic performance)*.

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

5.4 History of Past Earthquakes

Date	**Epicenter, region**	**Magnitude**	**Max. Intensity**
1977	Vrancea	7.2	
1986	Vrancea	7	8 (MMI)
1990	Vrancea	6.7	7 (MMI)

No damages to the buildings of this type were observed in the 1986 and 1990 earthquakes. In the 1977 earthquake (M 7.2), no significant damages were observed on other buildings of similar construction (as discussed in Section 5.2).

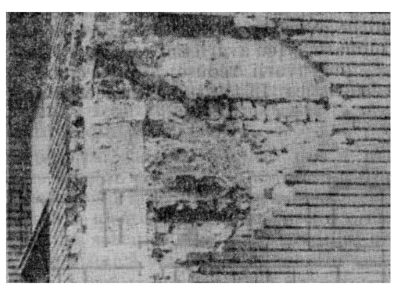

Figure 6: A photo showing a damaged brace panel in the 1977 earthquake (Balan et al. 1982)

6. Construction

6.1 Building Materials

Structural element	**Building material**	**Characteristic strength**	**Mix proportions/dimensions**	**Comments**
Walls	brick masonry infill walls			brick dimensions 280 X 140 X 70 mm
Foundation	reinforced concrete			N/A
Frames (beams &	reinforced	28-day cube compressive strength Quality A= 21.0 MPa		

columns)	concrete	Commercial steel yield strength = 240 MPa		N/A
Roof and floor(s)	reinforced concrete			N/A

6.2 Builder

Information not available.

6.3 Construction Process, Problems and Phasing

There were no data available about the original construction which took place in 1946. The retrofit was completed by specialized teams, with adequate background and technical skills. 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

Information not available. Information not available.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Title of the code or standard: "Provisions for the Design and Construction of Reinforced Concrete Buildings" (contained seismic provisions based on the German recommendations).The recommendations included the seismic zonation of the country into 2 zones and had divided the buildings into 3 categories according to the number of floors. The recommendations also address the type of foundations, the presence of underground water, masonry construction materials, wall thickness, and the provision of metal anchors or tie beams. For buildings higher than 2 floors, seismic provisions were required to resist seismic forces larger than 5% of the supported weight. Also included were prescriptions related to the quality of mortar, construction rules for clay brick masonry, distribution of reinforcement bars and stirrup spacing in columns and joints, based on common deficiencies observed in earthquake-damaged buildings. These recommendations were only partially followed during the World War II, however some designers had introduced reinforced concrete diagonal bracings in the end panels of taller buildings. Later on, P.13-70 and STAT 9684-74 were developed as mandatory provisions. (Prager, 1979) Year the first code/standard addressing this type of construction issued: 1942 National building code, material codes and seismic codes/standards: P100-78 (contains seismic provisions)-used for the evaluation of buildings damaged in the 1977 earthquake P100-92 "Standard for seismic design of residential, public, agricultural and industrial buildings" When was the most recent code/standard addressing this construction type issued? 1992.

Information not available.

6.6 Building Permits and Development Control Rules

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

This construction practice is no longer followed. 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).

6.8 Construction Economics

Information not available. Information not available.

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. ADAS insurance available.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Almost 30% of the total number of columns were cracked	Jacketing of columns with reinforced concrete (see Additional Comments and Figures 7A, 7B and 7C); As a result of the jacketing, the original column size (450 X 450 mm) was increased to 600 mm X 600 mm. The jacketed columns are shown in yellow color in Figure 3B.
Cracking of brick masonry infill walls (crack width over 0.3 mm)	-Replacing the damaged brick masonry infill walls with the lightweight concrete block infill walls.
Severely damaged RC bracing	The damaged bracings were removed. The original position of bracings is shown in Figure 3B (blue lines). It should be noted that the bracings were not removed in all buildings of this type. The bracings were not removed in the buildings that suffered less damage in the 1977 earthquake.

Seismic strengthening of deficient concrete columns was accomplished using a jacketing technique. It is very important to achieve an adequate connection between the existing and new concrete. The following solutions can be applied: (a) Anchorage by means of new ties connecting new and existing reinforcement. Welding is not necessary, however chipping off the concrete cover in the existing column is required (in order to enable passing of hooks of the new ties). (b) Connection by means of bent bars welded to the vertical reinforcement. The concrete must be chipped off locally, in order to expose the vertical reinforcement bars in the areas where bent bars are going to be provided. In this way, concrete keys capable of transmitting shear forces are formed and the force transfer between the existing and the new concrete is achieved. (c) Welding of additional ties to the existing column. The concrete cover in the tie region must be removed and each new tie must be welded to the existing one. The above described solutions are also presented in the UNIDO (1983) publication. Dritsos (2000) provides details about steps followed in applying one-sided RC jacketing. RC jacketing solution likely to have been adopted in this case is shown in the FEMA 172 publication, as illustrated in Figures 7B and 7C.

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.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The work was done as post-earthquake rehabilitation following the March 1977 Vrancea earthquake. Due to the severe damage the building was evacuated and supported on temporary shoring immediately after the earthquake and was retrofitted in 1978. The buildings were built in 1946/47 and became state property (nationalization) in 1948. The owners were evacuated; the institutions were changed frequently, while the buildings were also modified. The documents in the archives were lost or are not accessible. The data and drawings required to understand the original design would have to be obtained from technicians practicing at the time. Neither the construction drawings for the original design, nor the retrofit project drawings were available.

8.3 Construction and Performance of Seismic Strengthening

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

The construction was inspected according to the current codes (P100-78).

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
After the 1977 earthquake the retrofit design was developed by the "Institute for Building Design (IPC)". The design has referred to the 1941 Temporary Instructions of the MLP used in the original design and the then current standard P100-78, which contained seismic design criteria. Specialist architects and civil engineers were involved in the retrofit design.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The earthquakes in 1986 and 1990 did not cause any damage to the retrofitted buildings.

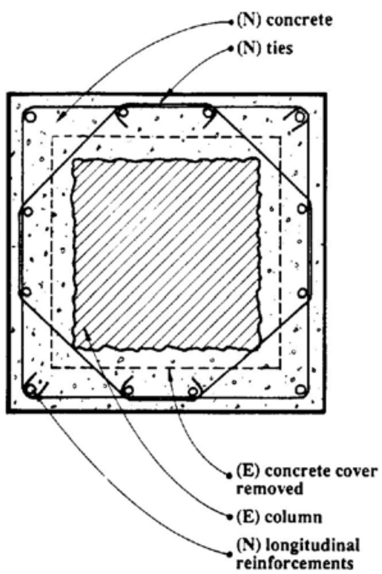

Figure 7A: Illustration of Seismic Strengthening Techniques

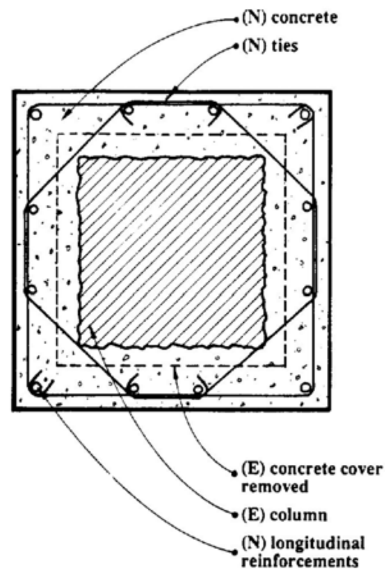

Figure 7B: Seismic Strengthening Techniques: Cross-Section of a Jacketed Column (Source: FEMA 172)

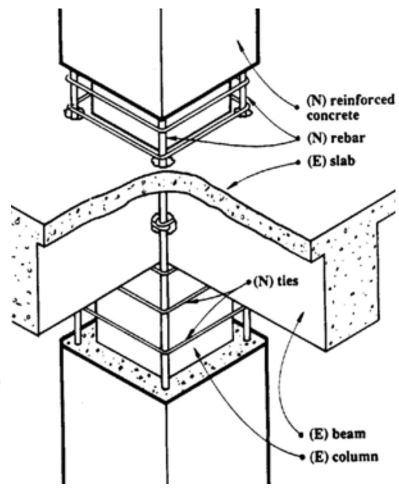

Figure 7C: Seismic Strengthening Techniques - Installation of RC Concrete Jacket (Source: FEMA 172)

Figure 8A: Another example of a Typical Building (triangular plan, suffered minor damage in the 1977 earthquake)

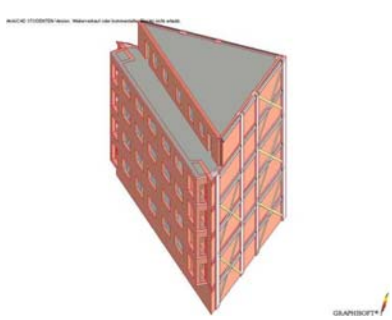

Figure 8B: A Building with a Triangular Plan - a Perspective Drawing Showing Key Load-Bearing Elements

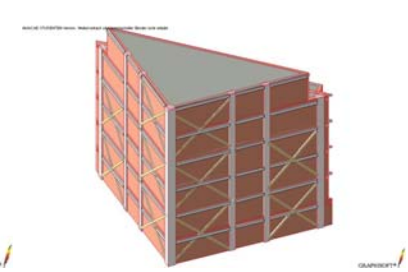

Figure 8C: A Building With a Triangular Plan - Perspective Drawing Showing Key Load-Bearing Elements

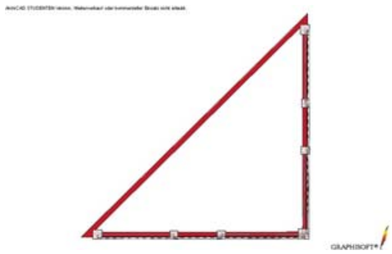

Figure 8D: Typical Tirangular Floor Plan

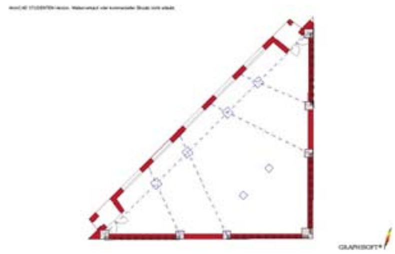

Figure 8E: Typical Triangular Floor Plan with Balconies

Reference(s)

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