World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Reinforced concrete frame structure with diagonal bracings and brick infill walls

Report#	71
Last Updated	
Country	Romania
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Important

General Information

Building Type:	Reinforced concrete frame structure with diagonal bracings and brick infill walls
Country:	Romania
Author(s):	Maria Bostenaru Dan Ilie Sandu
Last Updated:	
Regions Where Found:	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 housingconstruction is commonly found in urban areas.
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 the World War II until the nationalisation in 1947. Buildings of this type are still in use, mainly as apartment buildings. Buildings 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); the guidelines were based on the German recommendations. This region is well known as a seismically prone area, with the epicentre of damaging earthquakes close to Vrancea. Earthquakes with the Richter magnitude of over 7.0 occur once in 30 years. Bucharest, the capital, is located around 150 km south of the epicentre and lies in the main direction of the propagation of seismic waves. The Bucharest area is located on the banks of the Dmbovita and Colentina river, on nonhomogenous 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

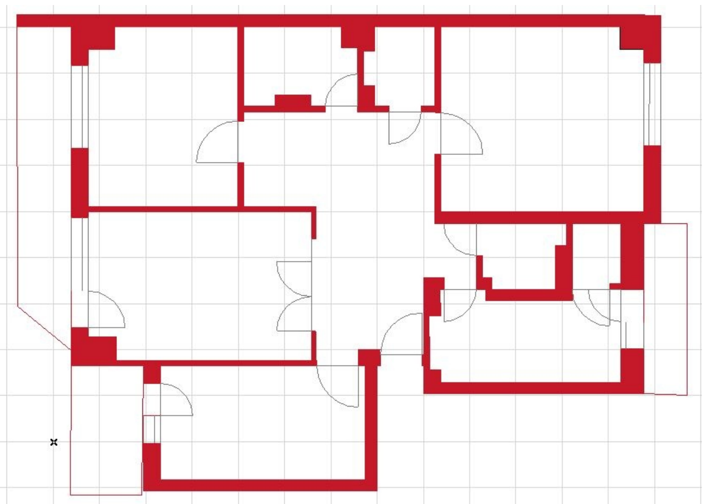
	that buildings of this construction type had experienced severe damage, mainly cracking in the columns and the brick masonry infill walls, however collapse was not reported. After the 1977 Vrancea earthquake, the damaged buildings were repaired and strengthened. One of the example buildings described in this contribution was retrofitted by strengthening the existing columns with new reinforced concrete jackets and replacing the existing brick masonry infill walls with new lightweight concrete block walls. It should be noted that the diagonal bracings were removed as a part of the retrofit. Another example shows a t
Length of time practiced:	51-75 years
Still Practiced:	No
In practice as of:	1947
Building Occupancy:	Residential, 10-19 units
Typical number of stories:	5-8
Terrain-Flat:	Typically
Terrain-Sloped:	3
Comments:	Blocks of apartments of this type were built after the World War II until the nationalisation in 1947. Period of practice was le

Features

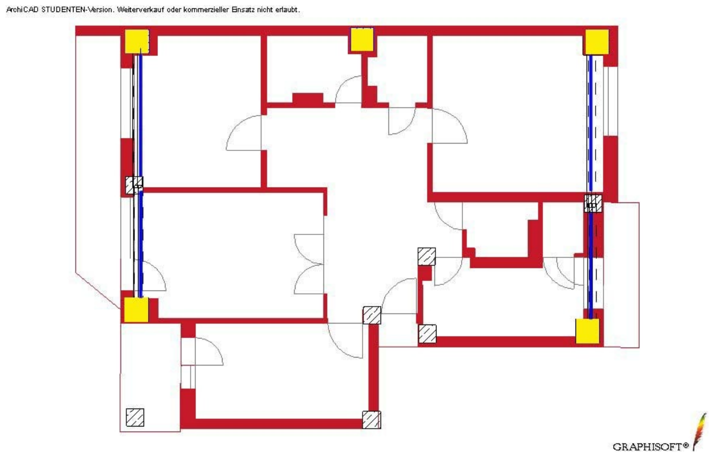
Plan Shape	Rectangular, solid
Additional comments on plan shape	Mostly rectangular, with notable exceptions; for example, a building with triangular-shaped plan is shown in this contribution.
Typical plan length (meters)	15-20
Typical plan width (meters)	15
Typical story height (meters)	2.75
Type of Structural System	Structural Concrete: Moment Resisting Frame: Designed with seismic effects, with URM infill walls
	Reinforced concrete ftrame supported by two-way slabs on beams. Although the brick infill walls are

Additional comments on structural system	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.The main load-bearing structure consists of a reinforcedconcrete space frame with reinforced concrete diagonal bracings and masonry infill walls. The floor structure consists oftwo-way RC solid slabs supported by beams cast in place. The masonry infill walls are 140 mm or 280 mm thick andthey are considered as nonstructural walls. In some buildings of this type the braces were removed as a part of theretrofit. Figures 10 and 13 illustrate possible bracing layout.
Gravity load-bearing & lateral load-resisting systems	These buildings, along with having RC frames, also have RC diagonal braces.
Typical wall densities in direction 1	>20%
Typical wall densities in direction 2	>20%
Additional comments on typical wall densities	The main loadbearing system is concrete frame, and the information regarding wall density is not relevant.
Wall Openings	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.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	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 plan 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.
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footing
Additional comments on foundation	The columns are supported by the individual (isolated) footings tied with the beams.
Type of Floor System	Other floor system
Additional comments on floor system	Floor and roof structures are two-way solid slabs with beams; cast-in-place and precast solid slabs
Type of Roof System	Roof system, other
Additional comments on roof system	Floor and roof structures are two-way solid slabs with beams; cast-in-place and precast solid slabs
Additional comments section 2	Whenseparated from adjacent buildings, the typical distance from a neighboring building is several meters.



Plan of a Typical Building



Plan of a Typcial Building (after the retrofit)- the jacketedcolumns are yellow - colored

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	brick masonry infill walls	brick dimensions 280 x 140 x 70 mm 28-day cube

		compressive strength Quality A= 21.0 MPaCommercial steel yield strength = 240 MPa
Foundations	reinforced concrete	
Floors	reinforced concrete	
Roof	reinforced concrete	
Other		

Design Process

Who is involved with the design process?	Other
Roles of those involved in the design process	Information not available.
Expertise of those involved in the design process	Information not available.

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in the building process	Information not available.
Expertise of those involved in building process	Information not available.
Construction process and phasing	There were no data available about the original construction which took place in 1946. The retrofit was completed byspecialized teams, with adequate background and technical skills. The construction of this type of housing takes placein 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	"Provisions for the Design andConstruction of Reinforced Concrete Buildings" (contained seismic provisions based on the Germanrecommendations).The recommendations included the seismic zonation of the country into 2 zones and had dividedthe buildings into 3 categories according to the number of floors. The recommendations also address the type offoundations, the presence of underground water, masonry construction materials, wall thickness, and the provision ofmetal anchors or tie beams. For buildings higher than 2 floors, seismic provisions were required to resist seismic forceslarger than 5% of the supported weight. Also included were prescriptions related to the quality of mortar, constructionrules for clay brick masonry, distribution of reinforcement bars and stirrup spacing in columns and joints, based oncommon deficiencies observed in earthquake-damaged buildings. These recommendations were only partially followedduring the World War II, however some designers had introduced reinforced concrete diagonal bracings in the endpanels of taller buildings. Later on, P.13-70 and STAT 9684-74 were developed as mandatory provisions. (Prager,1979). The year the first code/standard addressing this type of construction issued was 1942. P100-78 (containsseismic provisions)-used for the evaluation of buildings damaged in the 1977 earthquake P100-92 "Standard forseismic design of residential, public, agricultural and industrial buildings". The most recent code/standard addressingthis construction type issued was 1992.
Process for building code enforcement	Information not available.

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	This construction practice is no longer followed.

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	

Construction Economics

Unit construction cost	Information not available.
Labor requirements	Information not available.
Additional comments section 3	

Critical Structural Details - Frame withDiagonal Braces and Masonry Infill

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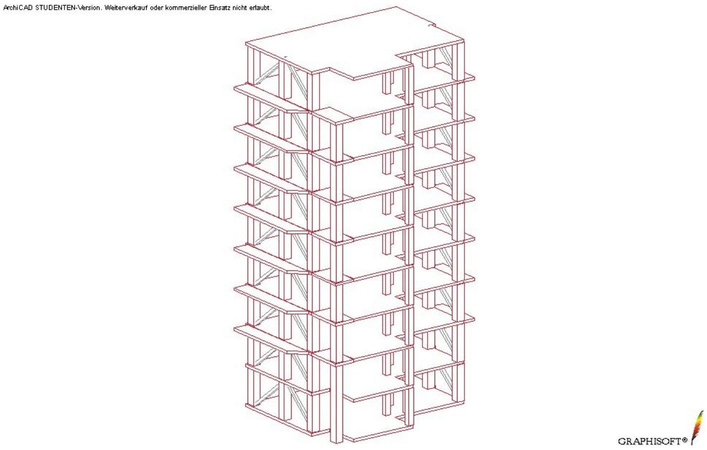
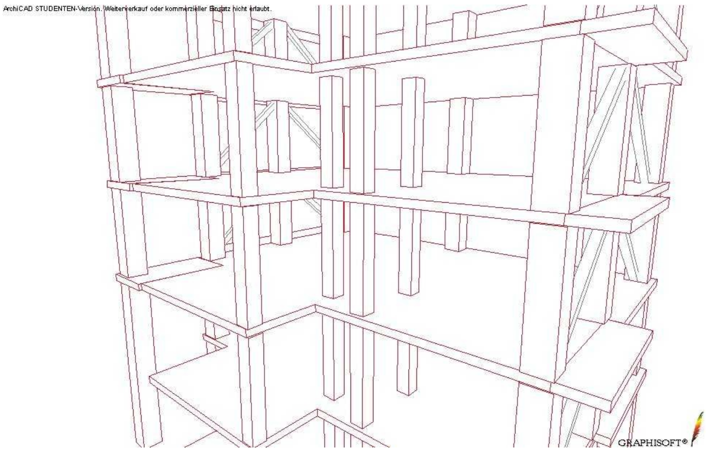
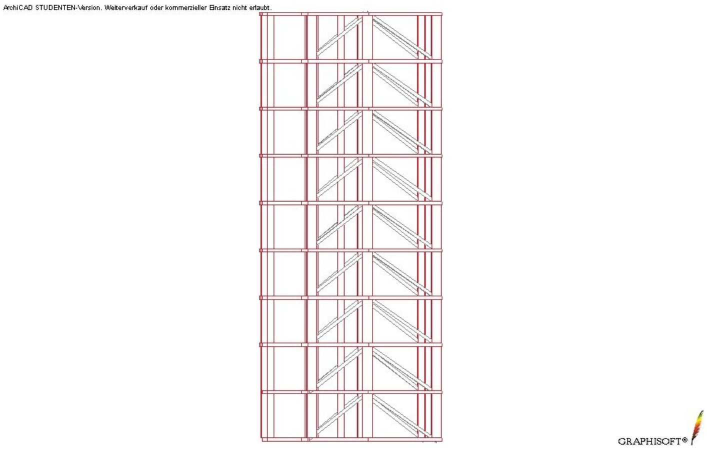


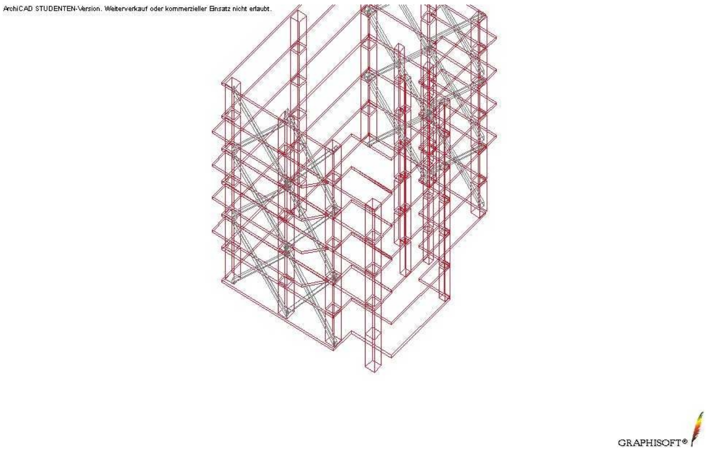
An Illustration of Key Seismic Features



Key Seismic Features - RC frame withBracings



Key Seismic Features-Vertical Section



Perspective Drawing Showing KeySeismic Features

Socio-Economic Issues

Patterns of occupancy	One family per housing unit, and two housing units per floor.Each building typically has 10-20 housing unit(s).
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	About 4inhabitants per housing unit so more than 80 inhabitants occupy the building.
Economic level of inhabitants	High-income class (rich)
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 1:1 or better
Typical Source of Financing	Owner financed
Additional comments on financing	
Type of Ownership	Own outright
Additional comments on ownership	

Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	ADAS insurance available.
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1977	Vrancea
1986	Vrancea
1990	Vrancea

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	No damages to the buildings of this type were observed in the 1986 and 1990 earthquakes. In the 1977 earthquake (M7.2), no significant damages were observed on other buildings of similar construction.
Additional comments on earthquake damage	-The brick masonry infill walls were damaged in the 1977 earthquake (crack width over 0.3 mm).-The example building was affected by the 1977

earthquake damage patterns	earthquake. Over 30% of the columns were cracked. - The bracings were severely damaged in the 1977 earthquake. T

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)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
Roof Construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	TRUE
Floor Construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	TRUE

Foundation Performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	N/A
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);	N/A
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.	N/A
Wall Openings		FALSE
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	TRUE

	standards).	
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

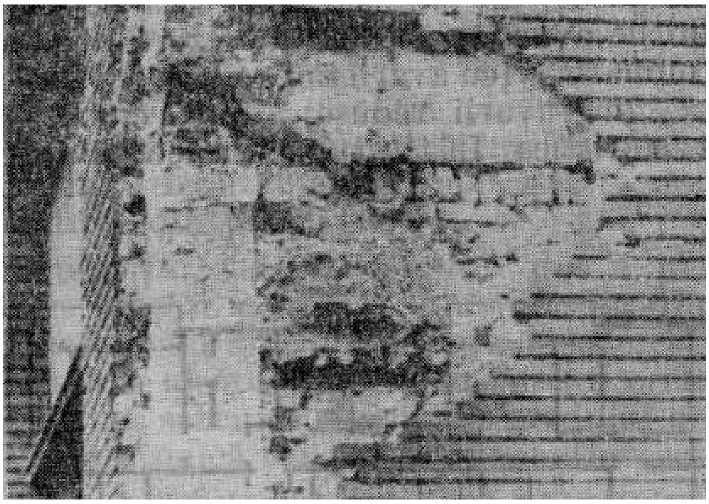
Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	- Irregular wall layout; - Too heavy walls; - Walls not a part of the loadbearing structure; - Wide openings
Earthquake-resilient features in walls	- Very rigid; might be of assistance to the frame structure to behave as a dual (frame-wall) system
Seismic deficiency in frames	#NAME?
Earthquake-resilient features in frame	#NAME?
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	Behave as rigid diaphragm
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	-|	



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

Retrofit Information

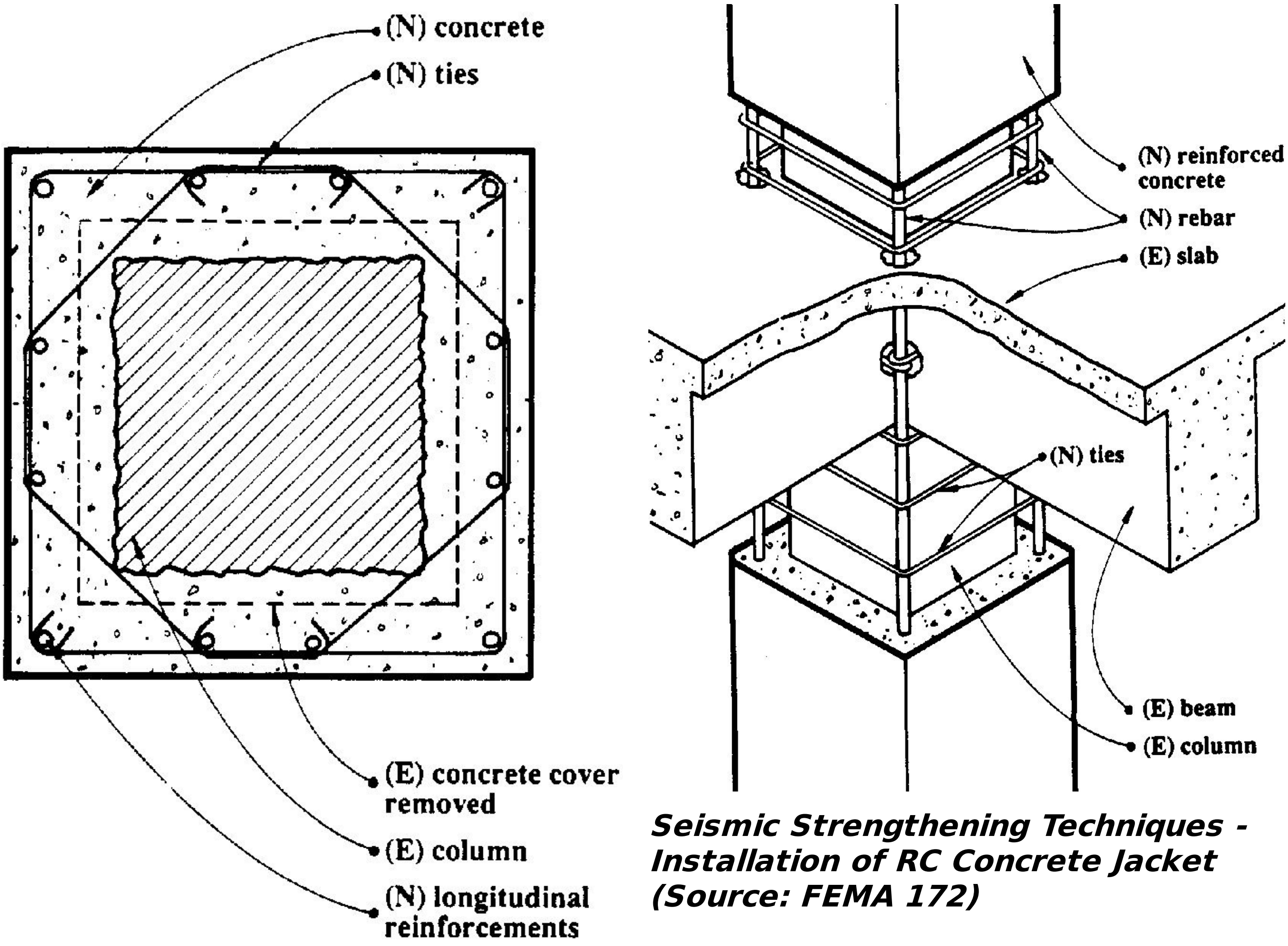
Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Almost 30% of the total number of columns were cracked	Jacketing of columns with reinforced concrete (see Additional Comments and Figures 15-17); As a result of the jacketing, the original column size (450 x 450 mm) was increased to600mm x 600mm. The jacketed columns are shown in yellow color in Figure 7
Cracking of brick masonry infill walls (crack width over 0.3 mm)	#NAME?
Severely damaged RC bracing	The damaged bracings were removed. The original position of bracings is shown in Figure 7 (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.

Additional comments on seismic strengthening provisions	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 necesssary, 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) prvides 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 16 and 17.
Has seismic strengthening described in the above table been performed?	Yes
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	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 (nationalisation) 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

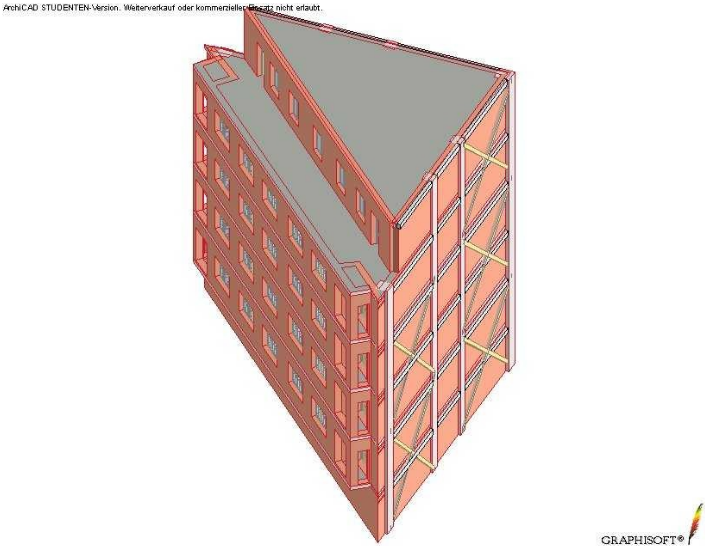
	available.
Was the construction inspected in the same manner as new construction?	The construction was inspected according to the current codes (P100-78).
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	After the 1977 earthquake the retrofit design was 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 has been 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.
Additional comments section 6	



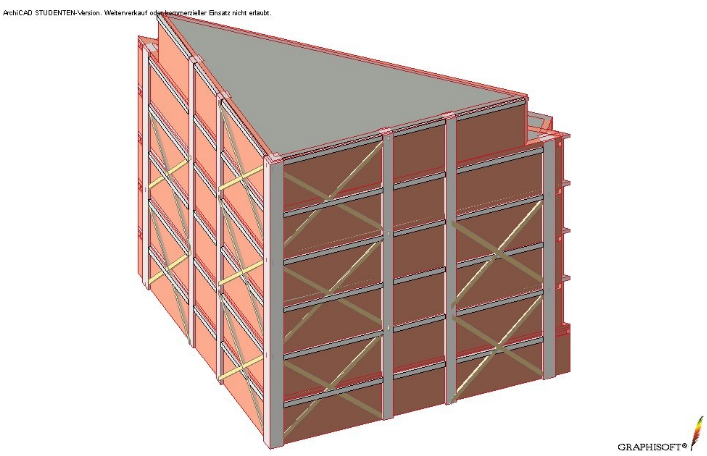
Seismic Strengthening Techniques - Installation of RC Concrete Jacket (Source: FEMA 172)

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

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



A Building with a Triangular Plan - aPerspective Drawing Showing Key Load-BearingElements



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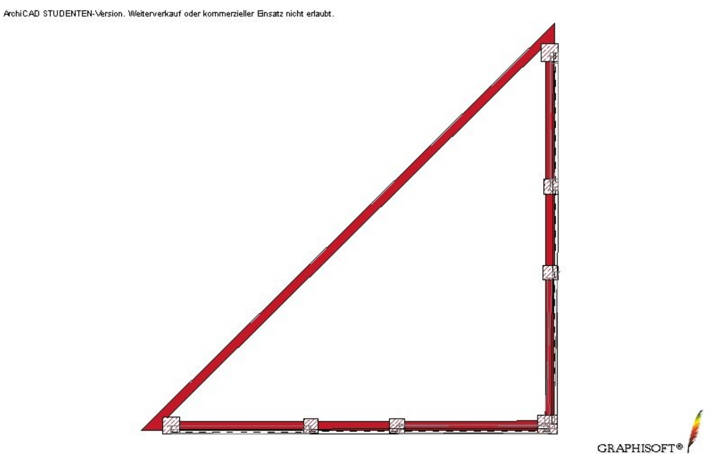
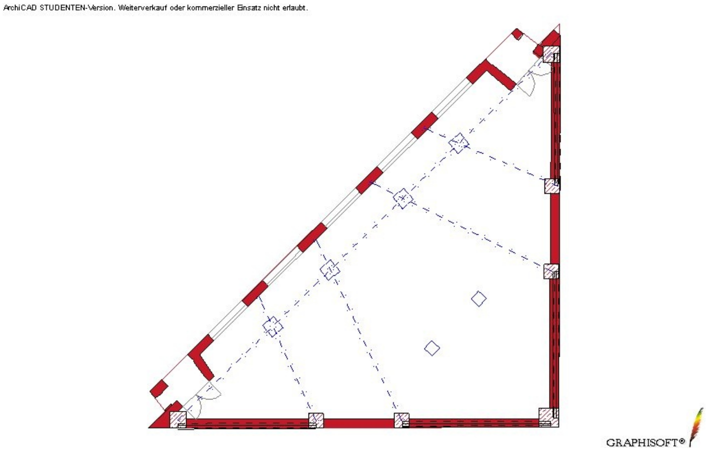


Typical Triangular Floor Plan



Typical Triangular Floor Plan withBalconies

References

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FEMA 172 (1992). NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings, Building Seismic Safety Council, Washington, D.C., figures 3.1.2.2b

Dritsos, Stefanos (2000). "Ep.s.e... .a. e..s..se.. .atas.e... ap. .p..s... s....dea" (Retrofit of Reinforced Concrete Buildings) (in Greek), The University of Patras, Greece, p. 212.

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