World Housing Encyclopedia Report

Country: Romania

Housing Type: Reinforced concrete cast-in situ shear wall buildings ("OD"-type, with "fagure" plan)

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1 General Information

1.1 Country

Romania

1.3 Housing Type

Reinforced concrete cast-in situ shear wall buildings ("OD"-type, with "fagure" plan)

FIGURE 1A: Typical Building

1.4 Summary

This is a typical urban multi-family housing practiced throughout Romania in the period from 1965 to 1989. There are many existing buildings of this type at the present time, with about 8,000 apartments only in Bucharest. Concrete shear wall construction is commonly used for the residential construction and it accounts for over 60% of new housing. Buildings of this type are typically 10 or 11 stories high. The main load-bearing structure is a cast in-situ concrete shear wall structure supported by RC solid slabs. Each building block consists of several (5-6) identical building units ("tronsons" in Romanian) separated by means of seismic joints. The walls are continuous throughout the building height and laid in two directions, with only one centrally located wall in the longitudinal direction and eight walls in the transverse direction. In addition, there are some lighweight concrete partition walls. This building plan is known as honeycomb ("fagure") plan. The buildings are often supported by mat foundations due to soft (aluvial) soil conditions. Many buildings of this type were designed according to the 1963 Romanian Building Code (P13-1963) which was updated in 1970 (P13-1970). The 1963 Code considered a magnitude 7 design earthquake for the Bucharest area.

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 Dâmbovita 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. The buildings of "OD" type suffered damages of various extent in the 1977 earthquake, and one building unit ("tronson") totally collapsed (that was the only shear wall building that collapsed in the

earthquake). Buildings with their longitudinal direction aligned parallel with the direction of seismic waves were most affected. The earthquake action in 1977 was mainly in NNE-SSV direction. Out of 167 building units ("tronson"s) of the "OD" type existing in Bucharest at the time of the 1977 earthquake, only 7 were lightly damaged; the remaining building units suffered a partial collapse (7 units) or damages (19 were significantly damaged, 72 were moderately damaged, and 61 were lightly damaged). According to the reports, damages to this construction type were due to inadequate wall density in the longitudinal direction, inadequate amount and detailing of wall reinforcement, lack of lateral confinement in the walls and in the boundary elements ("bulbs") causing brittle concrete failure and buckling of reinforcement. In addition, the quality of concrete construction was found to be rather poor.

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	
< 50 years	X
< 75 years	
< 100 years	
< 200 years	
> 200 years	

Is this construction still being practiced?	Yes	No
		X

Additional Comments: This construction was practiced in the period from 1965 to 1989.

1.6 Region(s) Where Used

This construction had been practiced throughout the country, and is particularly common in the capital Bucharest. This construction can be found in six quarters (districts) of Bucharest: Militari, Colentina, Drumul Taberii, Pantelimon, Berceni, Iancului, with the total of 8,000 apartment units. Except Iancului, other quarters are located in the suburban area of the city and consist mainly of newer settlements (built after the World War II). Concrete shear wall construction is commonly used for the urban residential construction and it accounts for over 60% of the new buildings. There are four different types of shear wall construction which were affected by the 1977 earthquake - type "OD" described in this contibution is one of them.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	X
In rural areas	
In suburban areas	
Both in rural and urban areas	

2 Architectural Features

2.1 Openings
One window and door opening per room, in some cases with a door leading to balcony/loggia. The total window area is about 25% of the overall wall area, and the total door area is even smaller. The walls with windows are generally not load-bearing structures.

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?	X	
Is this type of construction typically found on sloped terrain? (hilly areas)		X
Is it typical for buildings of this type to have common walls with adjacent buildings?		X

The typical separation distance between buildings is 0.07 meters

2.3 Building Configuration
Buildings of this type are of rectangular shape, with a very large length/width aspect ratio (of over 10). Each building consists of several (5-6) identical building units (tronsons in Romanian) of rectangular shape separated by means of seismic joints. "OD" in Romanian stands for Double Orientation ("Orientare Dubla") - meaning that the larger apartments have light from two sides (i.e. in the morning and in the afternoon) in different rooms. This building type is characterized with a so-called "honeycomb" ("fagure" in Romanian) building plan typical for the Romanian housing design. It consists of smaller box-type units creating rooms. In this system, there are no corridors, and the rooms are connected only by means of openings (doors and windows). This construction is characterized with large cantilevered balconies.

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	
Multiple housing units	X
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

2.5 Means of Escape
Each building unit (tronson) contains four apartments per floor, with a 1.2 m wide staircase, a 4-person elevator, the main entrance with a double door, and the secondary entrance with single door. For a typical 10-11 storey building, 44 flats or about 110 persons use the above described means of escape for evacuation (note that each building typically consists of 5 to 6 building units).

2.6 Modification of Buildings
No modifications were observed.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

One family per housing unit (apartment).

3.2 Number of Housing Units in a Building

units in each building.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5		
5 to 10		
10-20		
> 20		
Other	X	X

Additional Comments: >600 About 120 inhabitants per each building unit ("tronson"); there are typically 5 tronsons per building.

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 1
Number of Latrines: 1

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor		/
Middle Class	X	/
Rich		/

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	X
Personal Savings	
Informal Network: friends and relatives	
Small lending institutions/microfinance institutions	
Commercial banks / mortages	
Investment pools	
Combination (explain)	
Government-owned housing	X
Other	

3.7 Ownership

Type of Ownership/Occupancy	
Rent	
Own outright	X
Own with Debt (mortgage or other)	
Units owned individually (condominium)	
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

The main lateral load-resisting structure consists of reinforced concrete shear walls supported by RC slabs. The walls are continuous throughout the building height and laid in two directions, with only one centrally located wall in the longitudinal direction and eight walls in the transverse direction (four are continuous over the building width, and other four are of smaller length). The transverse shear walls end on facade with "bulbs"- boundary elements. Wall thickness is on the order of 140 mm. Walls are rather lightly reinforced, with one layer of 12 mm diameter vertical bars and 8 mm horizontal bars. The reinforcement spacing varies from 150 mm (longitudinal direction) to 250 mm (transverse direction) on centre. There are light concrete partition walls.

4.2 Gravity Load-Bearing Structure

This building type is characterized with a so-called "honeycomb" ("fagure" in Romanian) building plan characteristic for the Romanian housing design. It consists of box-type units creating rooms. Due to such building configuration, the walls are well connected and are able to carry the loads in a uniform manner. The walls are supported by 120 mm reinforced concrete solid slabs clamped in the walls and elastically supported by the facade beams. These buildings are typically supported by mat foundations.

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Massive stone masonry (in lime or cement mortar)	
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	
		20	Precast prestressed frame with shear walls	
	Shear wall structure	21	Walls cast in-situ	X
		22	Precast wall panel structure	
Steel	Moment resisting frame	23	With brick masonry partitions	
		24	With cast in-situ concrete walls	
		25	With lightweight partitions	
	Braced frame	26	Concentric	
		27	Eccentric	
Timber	Load-bearing timber frame	28	Thatch	
		29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers	
	Other	35		

4.4 Type of Foundation

Type	Description	
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	X
	No foundation	
Deep Foundation	Reinforced concrete bearing piles	
	Reinforced concrete skin friction piles	
	Steel bearing piles	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

Additional Comments: The Bucharest area is located on non-homogenous alluvial soil deposits. The buildings usually rest on mat foundations.

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)	X	X
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
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 single roof		
	Wood planks or beams that support clay tiles		
	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			

4.6 Typical Plan Dimensions

Length: 137.5 - 137.5 meters
Width: 137.5 - 137.5 meters
Additional Comments: Length of a building unit (tronson) = 27.5 m; length of entire building (with 5 tronsons) = 137.5 m

4.7 Typical Number of Stories

10 - 11

4.8 Typical Story Height

2.60 meters

4.9 Typical Span

4.5 meters

Additional Comments: Spans are variable in the range from 2.2 m to 4.6 m (based on the available information)

4.10 Typical Wall Density

1.4% - 4.8%
1.4% in the longitudinal direction and 4.8% in the transverse direction

4.11 General Applicability of Answers to Questions in Section 4

This contribution describes a typical building of this construction type. The retrofit solution presented is based on a block in Militari, Bucharest, and the photos of a typical building are taken in the Drumul Taberii area (also in Bucharest). The drawings show the variant of this construction with very large balconies, like the one which partially colapsed in the 1977 earthquake (located in Boulevard Pacii in Bucharest).

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	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 form the building to the foundation.	X		
Building configuration	The building is regular with regards to both the plan and the elevation.	X		
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.	X		
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.	X		
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.	X		
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.		X	
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2)Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).	X		
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	X		
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.			X
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	X		
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).		X	
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).		X	
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).			X
Other				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake-Resilient Features	Earthquake Damage Patterns
Shear Walls	- Inadequate (too small) wall thickness of 140 mm; - Inadequate wall density in the longitudinal direction (one shear wall only); - Significantly different wall density in the two principal directions (i.e. larger wall density in the transverse direction); - Lack of ductility and inadequate amount of reinforcement (especially in the transverse direction);	- Large stiffness, resulting in small displacements and minimized damage to nonstructural elements;	- Damage was more pronounced in the longitudinal wall (vertical and inclined cracks); - Cracking in the transverse walls was more pronounced at the lower levels (extensive "X" cracks developed in the piers between the door openings); - Brittle failure of wall end zones with spalling and crushing of concrete at the base and buckling of reinforcement bars; - see Figures 5C and 5D
'"Bulbs"-Boundary Elements'-boundary elements	- Inadequate cross-sectional dimensions (too small); - Inadequate reinforcement (10-12 mm dia longitudinal bars, very scarce ties (300 mm spacing on centre)	- Bulbs can be considered as a provision against the brittle failure; these boundary elements carry large compressive forces induced by overturning moments acting on the walls.	- Brittle failure with concrete spalling and crushing at the base and buckling of the reinforcement (OD16 building) - Crushing of concrete and reinforcement buckling at the first floor level (OD1 example) - see Figure 5E
Lintels	- Too small depth (around 500 mm) due to the reduced floor height (2.60 - 2.70 m)	- Energy dissipation	- Extensive cracking
Other	- Actual gravity loads were larger as compared to the design loads due to finishing works and some flower pots at the balconies. - construction deficiencies: variation in concrete strength, honeycombing of concrete (especially in boundary elements); - inadequate construction of seismic joints (Figure 5D)		

5.3 Seismic Vulnerability Rating

Vulnerability						
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performace) F
Seismic Vulnerability Class				<	0	>

0 - probable value

< - lower bound

> - upper bound

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
1977	Vrancea	7.2	VIII (MMI)
1986	Vrancea	7	VIII (MMI)
1990	Vrancea	6.7	VII (MMI)

Additional Comments: This region is well known as a seismically prone area, with the epicenter 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 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 river, on non-homogenous 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 the buildings of "OD" type suffered damages of various extent in the 1977 earthquake, and one building unit ("tronson") totally collapsed (that was the only shear wall building that collapsed in the earthquake). Buildings with their longitudinal direction aligned parallel with the direction of seismic waves (mainly in Berceni and Drumul Taberii areas of Bucharest) were most affected. The damage patterns were the strongest on the OD16 site. The earthquake action in 1977 was mainly in NNE-SSV direction. Out of 167 building units ("tronsons") of the "OD" type existing in Bucharest at the time of the 1977 earthquake, only 7 were lightly damaged; the remaining building units suffered a partial collapse (7 units) or were damaged (19 significantly damaged, 72 moderately damaged, 61 lightly damaged) Balan (1982), Argent (1998). According to the reports, damages to this construction type were due to inadequate wall density in the longitudinal direction, inadequate amount and detailing of wall reinforcement, lack of lateral confinement in the walls and in the boundary elements ("bulbs") causing brittle concrete failure and buckling of reinforcement. In addition, quality of concrete construction was found to be rather poor.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Shear walls	Reinforced Concrete	Concrete:cube compressive strength 25 MPa Reinforcement: tensile strength 370 or 520 MPa		
Foundations	Reinforced Concrete	Concrete:cube compressive strength 25 MPa Reinforcement: tensile strength 370 or 520 MPa		
Roof and floors	Reinforced Concrete	Concrete:cube compressive strength 25MPa Reinforcement: tensile strength 370 or 520 MPa		
Partitions	Lightweight concrete			Non-load bearing

Notes:
1. Steel 52 is usually used for slabs and longitudinal reinforcement, while steel 37 is used for transversal reinforcement.
2.

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

These buildings were built as residential construction by the government-owned companies.

7.3 Construction Process

Between 1960-1990 all construction was performed by government-owned companies. Technical professionals were involved in the construction.

7.4 Design/Construction Expertise

The quality of design and construction was ensured by "The State Inspection for Construction".

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

Title of the code or standard: P13-1970, STAS 8000-67
Year the first code/standard addressing this type of construction issued: 1963
National building code, material codes and seismic codes/standards: The code reffers explicitly to seismic design of buildings (issued in 1963 and revised in 1970) P13-1963, P13-1970; the latest Code is P100-1992
When was the most recent code/standard addressing this construction type issued? 1996

7.6 Role of Engineers and Architects

Design professionals (engineers and architects) were involved in the design and construction of this type.

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required	X	
Informal construction		X
Construction authorized per development control rules	X	

Additional Comments: This construction practice is no longer followed.

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)		X
Building originally designed for its final constructed size	X	

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
Owner(s)	X
Renter(s)	X
No one	
Other	

7.10 Process for Building Code Enforcement

Many buildings of this type were designed according to the P.13-1963 Romanian Code, although the Code was changed in 1970 (P13-1970). The P13-1963 Code considered a magnitude 7 earthquake for the Bucharest area.

7.11 Typical Problems Associated with this Type of Construction

Please explain

8 Construction Economics

8.1 Unit Construction Cost (estimate)

At the time of the original construction (1974) the unit cost was 1170 lei/m².

8.2 Labor Requirements (estimate)

The information is not available as the construction company ceased to exist in 1990.

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available	X	
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		X

Additional Comments: There is "The Voluntary Complex Insurance of the Households and Physical Persons" through ASIROM

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	Shear walls: inadequate wall thickness and reinforcement	- Cast in-situ RC jacketing of the boundary elements-bulbs (see Figure 6). A special care is taken to ensure the adequate bond between the new and existing concrete. - Jacketing with glass fibre woven fabric and epoxy resins in the severely damaged areas.
	Cracks in shear walls and lintels	Small cracks - injecting the cracks with epoxy grout; Large cracks - filling the cracks with epoxy mortar (paste);
	Small cracks in shear walls and lintels	Crack injections with epoxy resins. This was the most widely used method to repair the damages after the 1977 earthquake. The domestic resin DINOX 10L was used per the INCERC technology (C. 183-77). The injection is applied by cleaning the surface, making the injection holes and applying the resin.

Additional Comments: The above described methods are used for seismic retrofit of RC structures in Romania. These methods were used for retrofitting the buildings OD16 and OD1 damaged in the 1977 earthquake.

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?

Seismic strengthening was performed in the design practice after the 1977 earthquake. Many buildings in Bucharest were damaged in the 1977 earthquake, however the strengthening was not performed in most cases. For that reason, in 1999-2000 the Ministry for Public Works (MLPA) established a special committee to evaluate seismic resistance and possible retrofit requirements for this construction type according to the P100-1992 Code (latest edition issued in 1996). The scale of work and financial ressources required for the retrofit are quite significant. As a result, the progress is rather slow and in case of an earthquake a significant life and property loss could be expected.

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

The work was done as a repair following earthquake damage.

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

Yes, the construction was inspected through "The State Inspection for Construction Works".

10.5 Who performed the construction: a contractor, or owner/user? Was an architect or engineer involved?

The construction was performed by a specialized state agency.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

The strengthening was performed after the 1977 earthquake. The 1986 and 1990 earthquakes were not very strong and did not cause damages to the strengthened buildings.

11 References

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12 Contributors

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13 Figures

FIGURE 1A: Typical Building

FIGURE 1B: Typical Building

FIGURE 1C: Typical Building

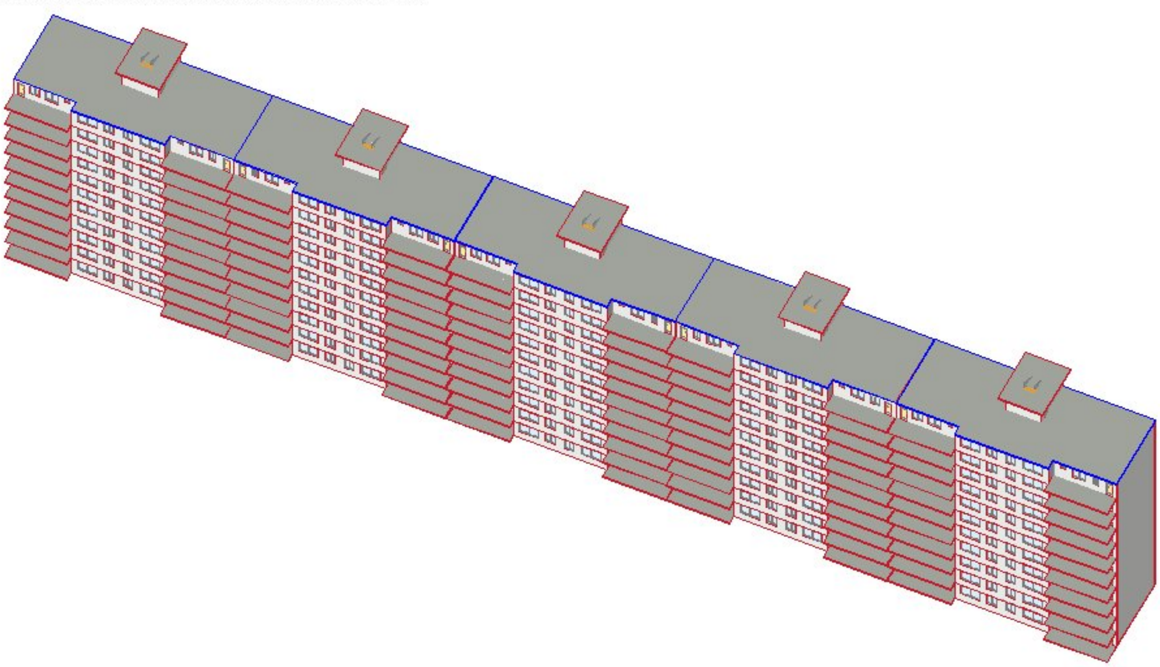

FIGURE 1D: Typical Building

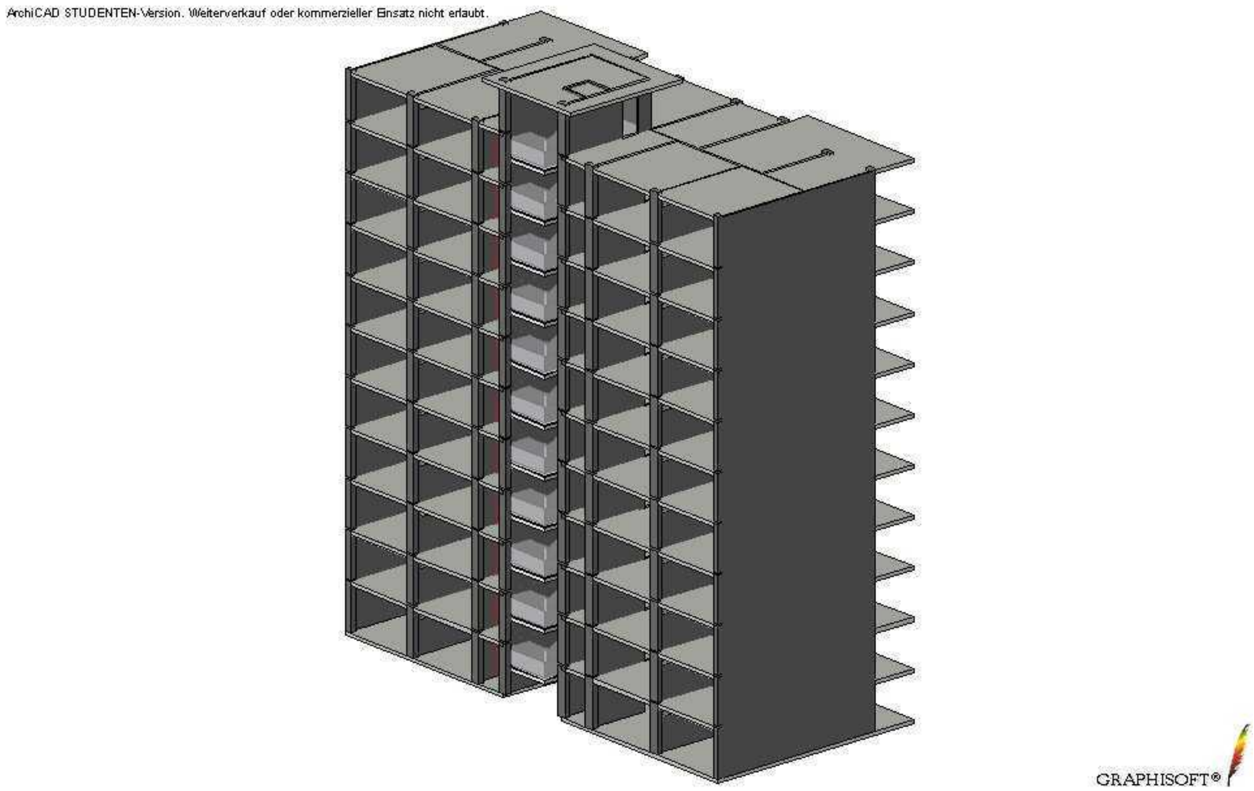

FIGURE 2A: Key Load-Bearing Elements

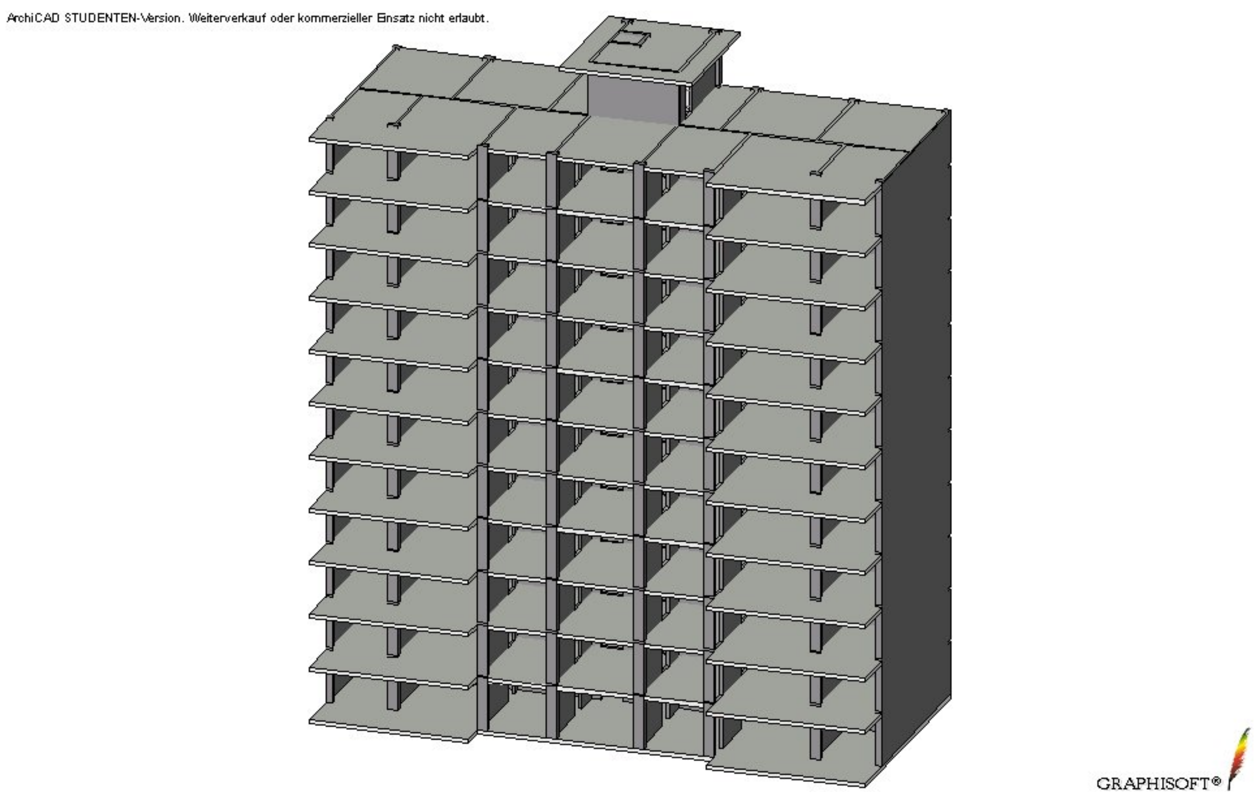

FIGURE 2B: Key Load-Bearing Elements

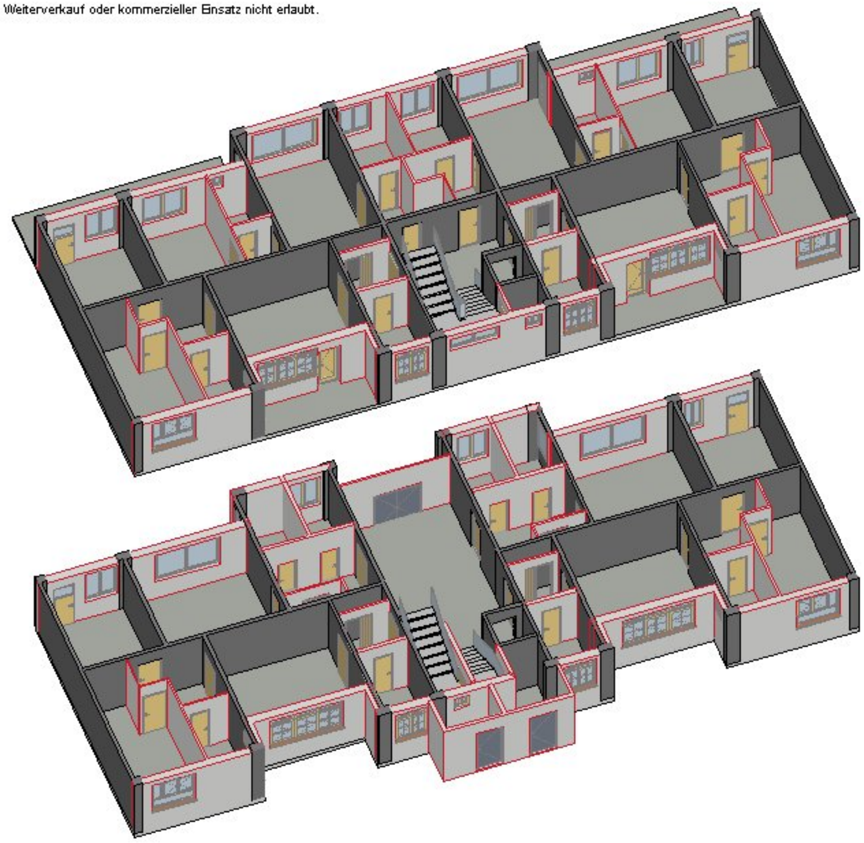

FIGURE 2C: Key Load-Bearing Elements- a typical building unit (tronson)

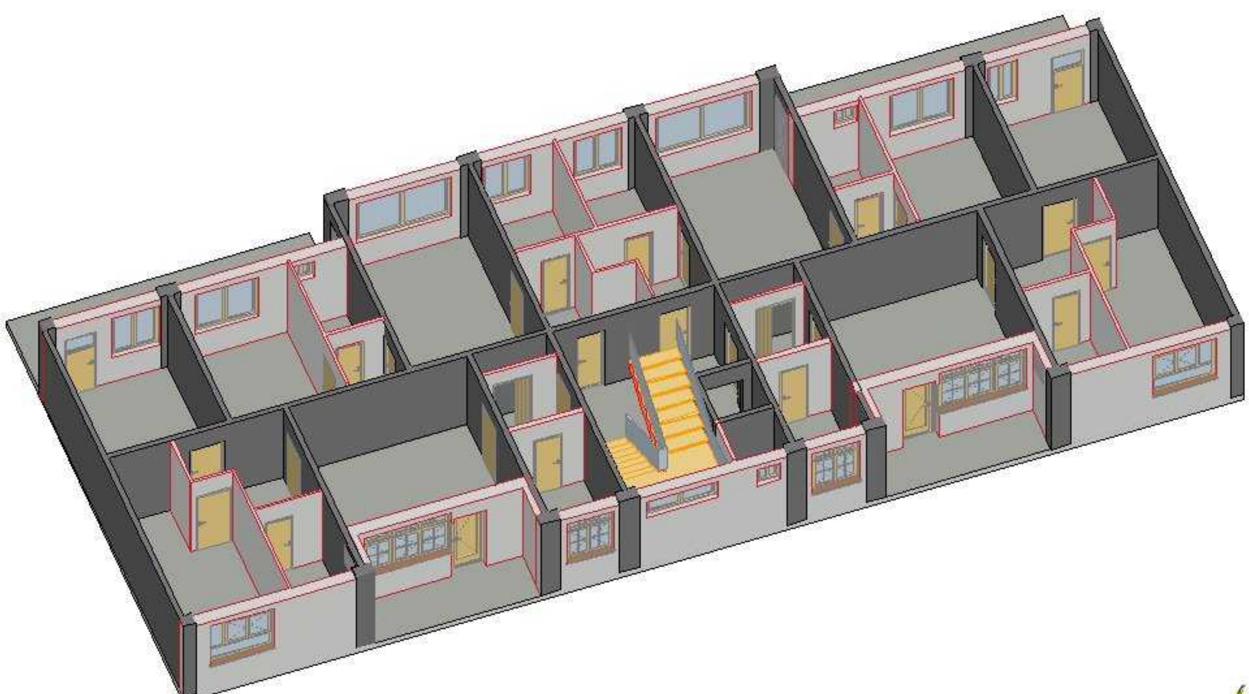

FIGURE 2D: Key Load-Bearing Elements - a typical building unit (tronson)

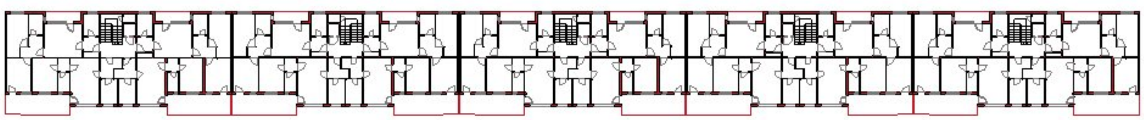

FIGURE 3: Plan of a Typical Building

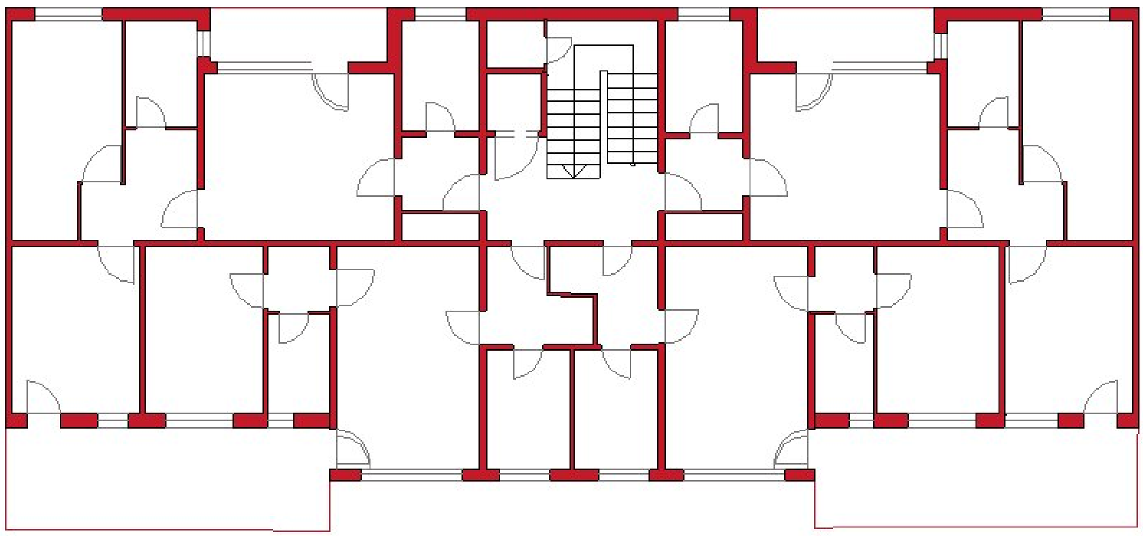

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FIGURE 3B: Plan of a Typical Building Unit (tronson)

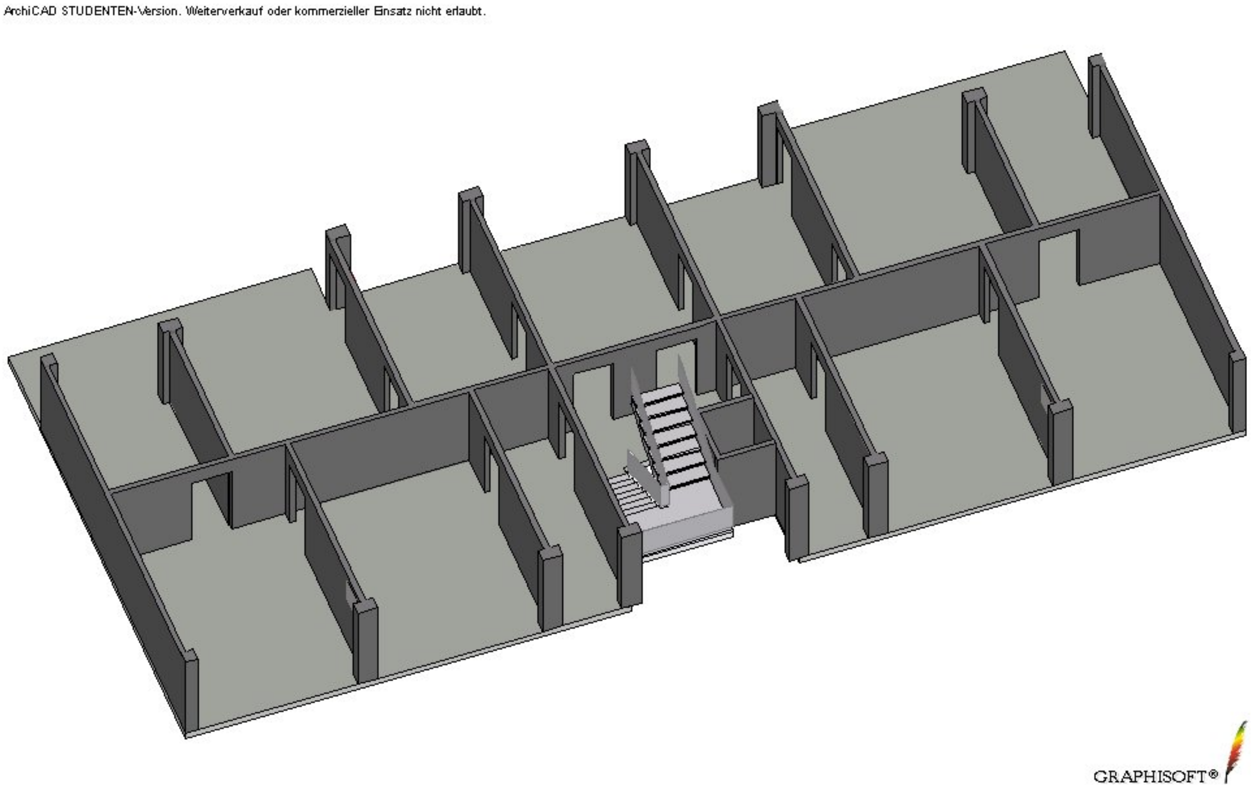

FIGURE 4A: Key Seismic Features - Shear Wall Layout (note only one shear wall in the longitudinal direction)

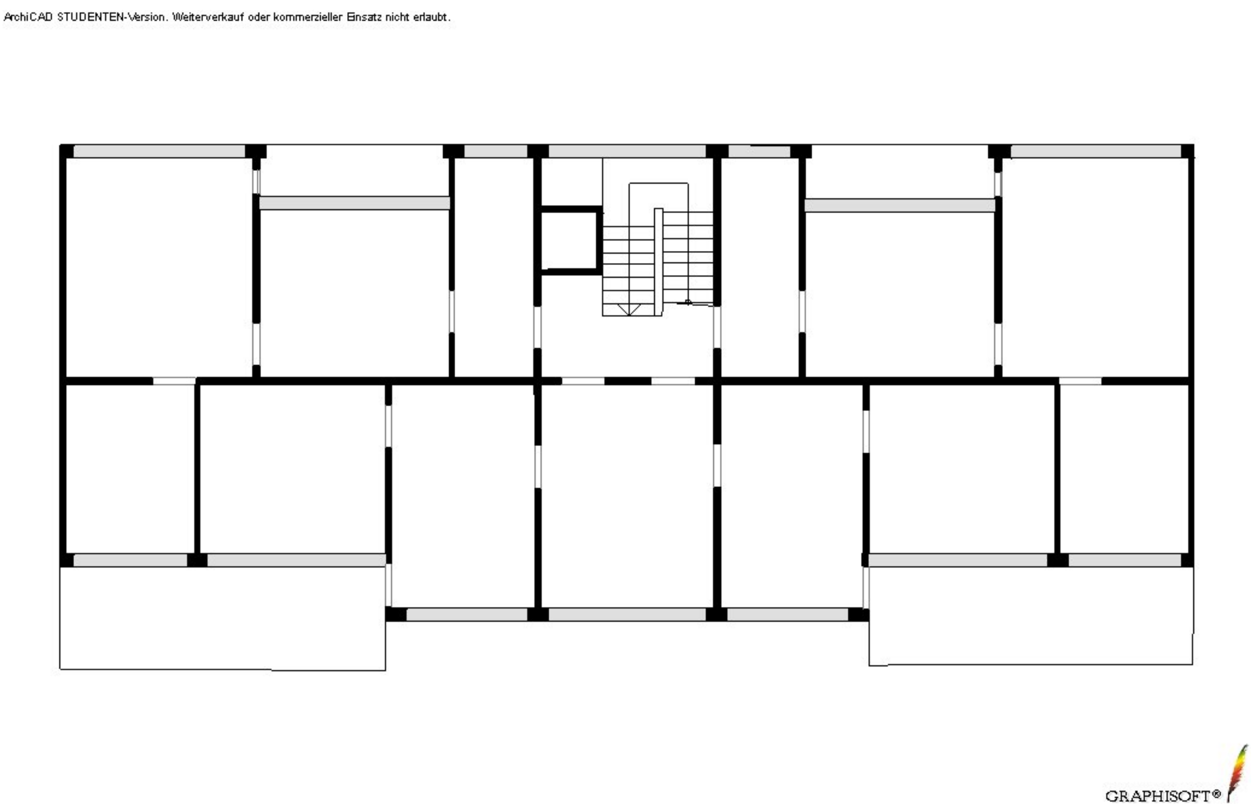

FIGURE 4B: Key Seismic Deficiencies - Significantly Smaller Wall Density in the Longitudinal Direction

FIGURE 5A: Collapse of OD16 Building in the 1977 Vrancea Earthquake

FIGURE 5B: Building Collapse in the 1977 Vrancea Earthquake (OD16 Building)

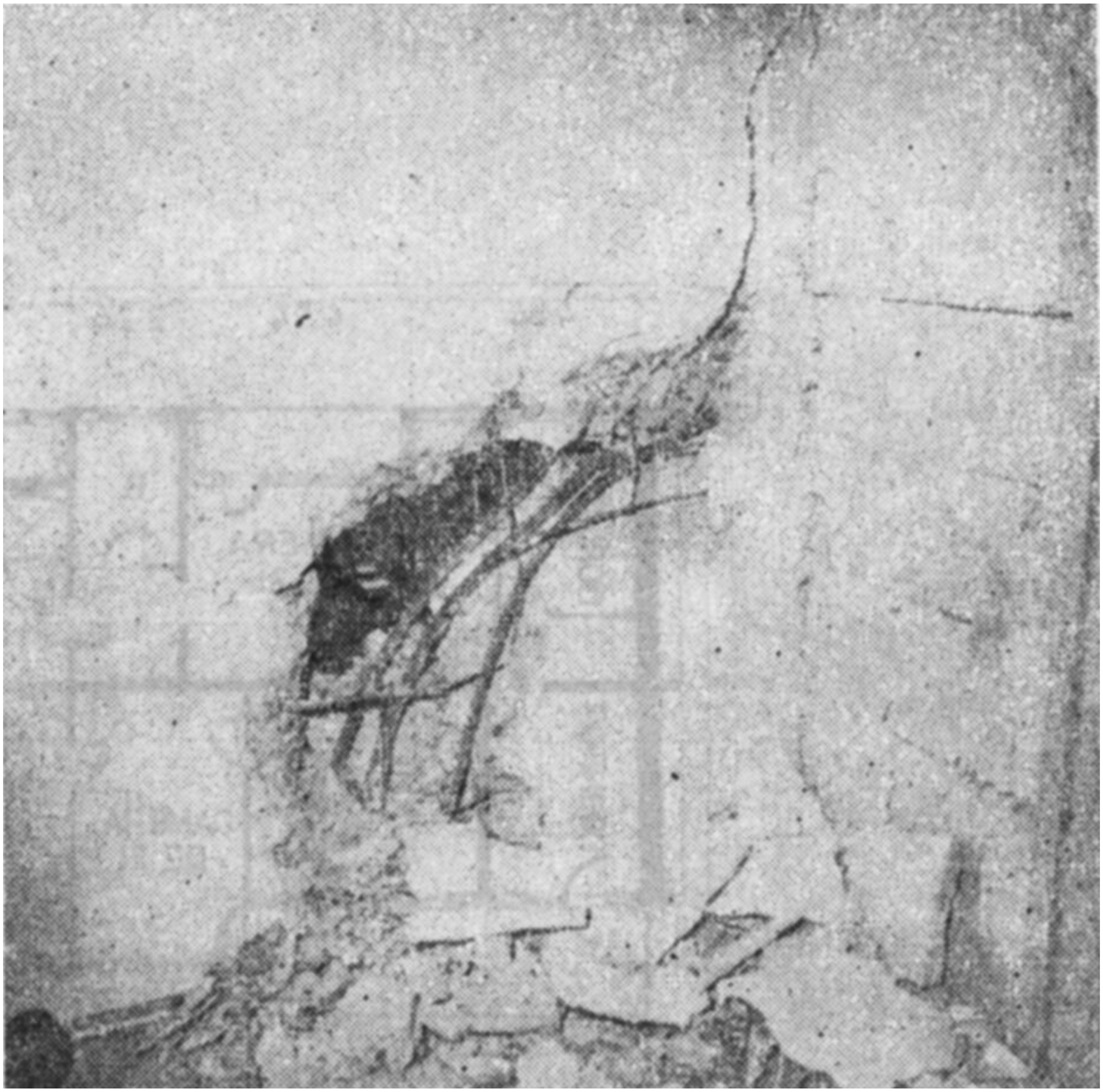

FIGURE 5C: Typical Earthquake Damage in RC Shear Walls (1977 Vrancea Earthquake)

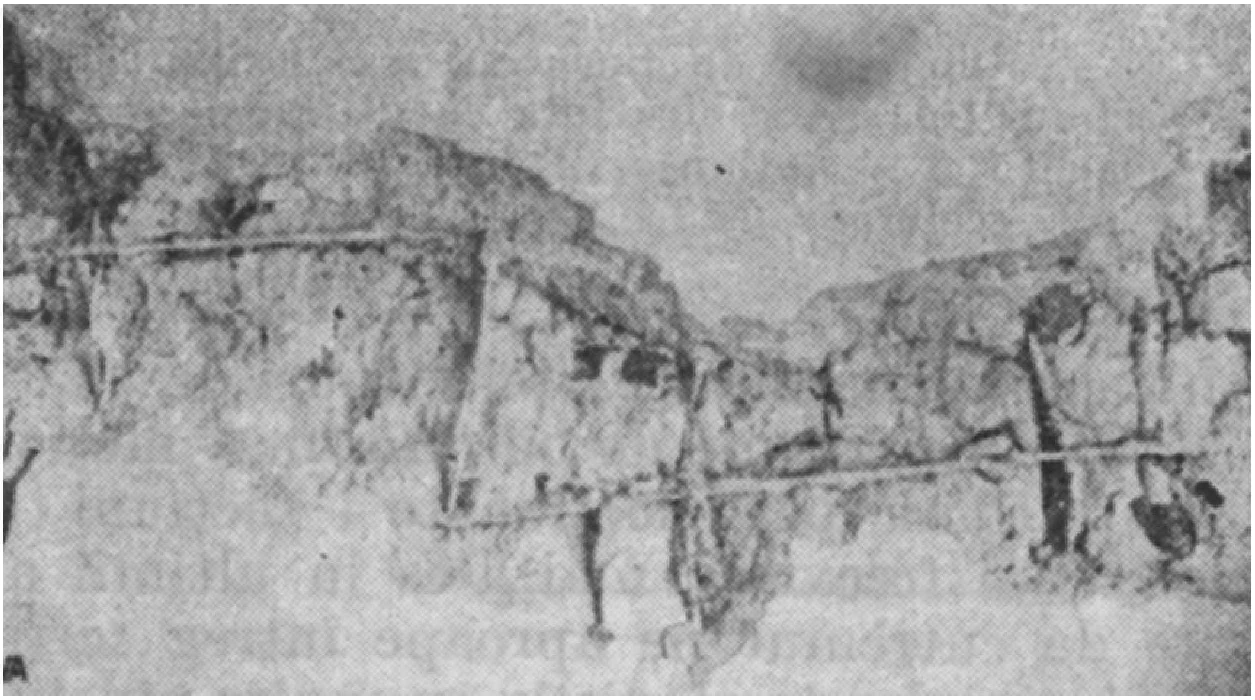

FIGURE 5D: Typical Earthquake Damage in RC Shear walls; note cracking in the construction joint (1977 Vrancea Earthquake)

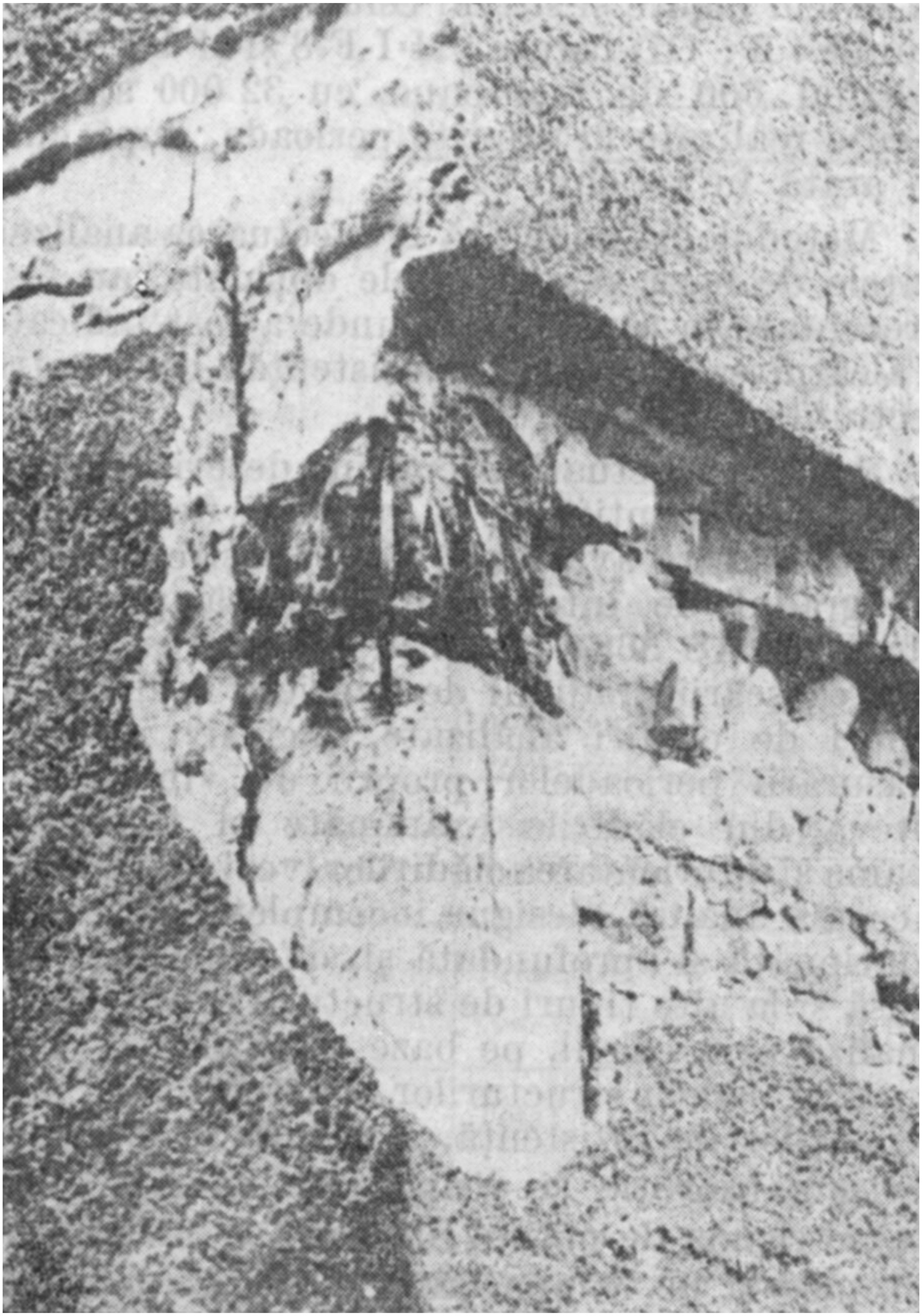

FIGURE 5E: Typical Earthquake Damage to a Boundary Element (bulb) (1977 Vrancea Earthquake)

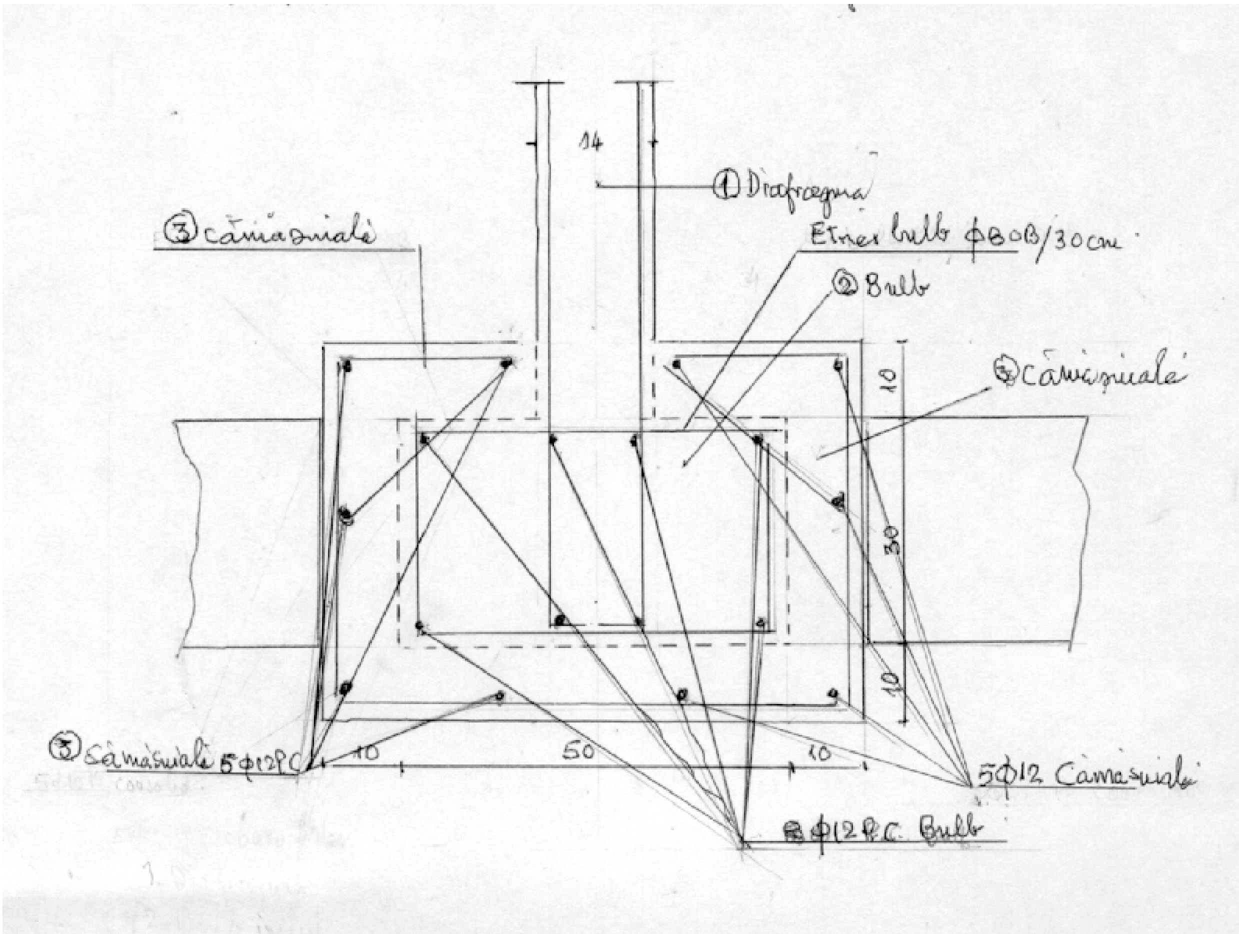

FIGURE 6: Illustration of Seismic Strengthening Techniques-Retrofit of Boundary Elements (bulbs)