World Housing Encyclopedia

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

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
One family one storey house, also called "wagon house"

Report #	85
Report Date	13-11-2002
Country	ROMANIA
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in lime/cement mortar
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Summary

This is one of the oldest housing types in Romania with a statistically significant number of buildings in existence. The overwhelming majority of residential buildings in Romania have been built after 1850. Today. only churches remain from the previous "post-Byzantine"

period. Issues relating to the age of historical buildings of cultural value are also discussed within the report. This urban housing type is particularly common in Romanian towns, especially in the southern part of the country, such as in the former Wallachia. It is a middle-class family house constructed from the end of the 19th century until the Second World War. The houses were designed to be semidetached, but have been constructed individually. Thus, in most of cases, the adjacent building, separated structurally, is a totally different construction type, The design of this housing is astonishingly homogeneous, especially considering the relatively lengthy time span the construction has been practiced. The single-unit housing is generally characterized by a rectangular, elongated-shape plan, with an entrance on the long side. The load-bearing system consists of two longitudinal unconfined brick masonry walls and several transversal unconfined brick walls, usually 28 cm thick, which form a wagon-like arrangement -- hence the name of this building type. The horizontal structural system is made out of wood plates and joists separated by a distance of 0.70 m. Buildings of this type have been affected by damaging earthquakes in November 1940 and in March 1977, and by two earthquakes of lower magnitudes in 1986 and 1990. They performed well except for the occurrence of some minor cracking in the plaster.

1. General Information

Buildings of this construction type can be found in small towns, near centre districts. This type of housing construction is commonly found in both sub-urban and urban areas.

The areas have been suburban at the time when these buildings have been constructed.

This construction type has been in practice for less than 200 years.

Currently, this type of construction is not being built. Practiced until 1947. Many of them have been demolished in the Ceausescu era. However, there are still enough existing to provide specific character to the district of Bucharest in which they are most common, just outside the city centre.

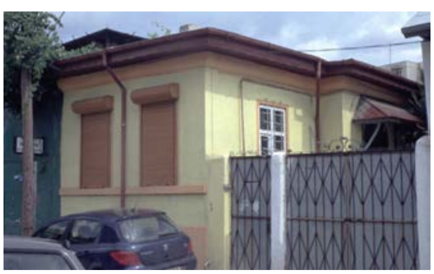

Figure 1: Typical building (from Bostenaru, 2004, TAFEL VII)

Figure 2: Variant of the building with high basement.

Figure 3: Coupled buildings

Figure 4: Buildings of this type not coupled, but in vis-a-vis.

Figure 5: Building from the courtyard side, with added unit over the time (from Bostenaru, 2004, Abb. 2-19 on P. 40)

Figure 6: Structural modifications: partial upper floor and closed windows to the street.

Figure 7: Structural modification: Facade with walled-up windows.

Figure 8: Whole view of the building with closed windows to the street (from Bostenaru, 2004, Abb. 2-4 on P. 24)

Figure 9: Structural modification: one closed facade window and one changed to door opening.

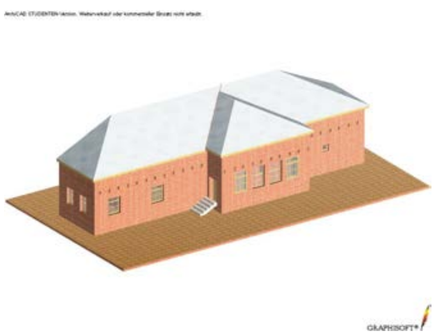

Figure 10: Axonometric view

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. This is the separation between the long wall (the one perpendicular to the street) and the cadastral unit boundary. Depending on the position of the building on the adjacent cadastral unit, the distance to this one may be up to 3.8m (see Figures 3 and 4). There is no typical separation at the back of the house - it may be again 1.9m with the same observation, when windows provided, or no distance at all, when no windows provided When separated from adjacent buildings, the typical distance from a neighboring building is 1.9 meters.

2.2 Building Configuration

rectangular (see fig. 11 and 26 for possible recesses). Figure 10 shows a typical building in axonometric view. 5-10 openings, depending on the number of rooms (see fig. 23 and 24 for their layout). ~20% For the building taken as model for this report (late building of this type): A typical window in the longitudinal wall to the courtyard is 1.44sqm in size. There are smaller ones for secondary rooms, of 0.36sqm or 0.9sqm. Bigger windows are 1.2mx1.9m (2.28sqm), to the vestibule. To be noted is that all windows to main rooms are 1.2m wide. A typical door is 0.8mx2.1m (1,68sqm). Smaller doors to the secondary rooms are 0.7mx2.1m (1.47sqm), and also door openings for double doors of 1.4mx2.1m (2.94sqm). The entrance door is wider (0.9m), but same height. In older buildings the windows were all like those to the vestibule (fig. 20) in this one. The back longitudinal wall is usually solid without openings, as it is situated on the cadastral unit boundary, where it is expected that the adjacent semidetached twin unit will be built.

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Escape through the vestibule directly into the yard.

2.4 Modification to Building

Typical changes in time are additional floors over the existing ones (especially taking in consideration the thickness of the walls, considered to be able to carry one floor more, see fig. 6) or additions of "wings", typically one room more with vestibule (fig. 5). Some of these can be used as office, study room, artists workshop and similar. A typical modification includes filling the windows to the street with masonry infill (fig. 7-9). This has been also performed at the model building considered for this report.

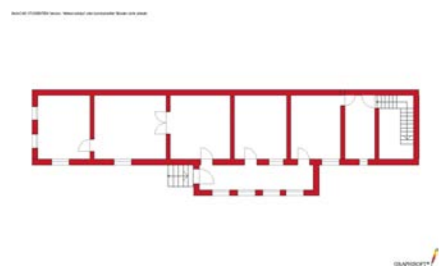

Figure 11: Ground floor plan

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	☐
	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	☐
			Moment frame with in-situ	

Structural concrete	Structural wall	22	shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

In the constructions of the type analysed in this report hydraulic lime based mortar, considered to be the highest possible quality mortar of that time, have been used. For common buildings (ie not in very wet environments) hydraulic lime mortar has been used. This was prepared solely out of "fat lime" ("var gras" in Romanian), sand and water. The lime is obtained through burning of calcar stones (Cao+CO2) in either field or vertical ovens.The obtained CaO was then treated with water in boxes called "varnite" in Romanian. As a result the lime paste or lime putty is obtained: Ca(OH)2 with relatively high water content. The paste is then left at least one year in a dug hole to "mature" ("decantare" in Romanian). Characteristic for this kind of mortar is that it does not present hardening, as this depends on the permeability of bricks. Hardening takes place when the CO2 in the air reacts with the Ca(OH)2 in the lime to give CaCO3. See figure 12 for the way how masonry bricks are crossed woven ("tesatura incrucisata" in Romanian).

3.2 Gravity Load-Resisting System

The vertical load-resisting system is others (described below). Timber slabs with joists every 0.70m (interaxes) and a suspended ceiling out of lime mortar on slat and cane form the upper floor structure. The roof itself consists of wood framework ("acoperis pe scaune" in Romanian, fig. 12). The girders are perpendicular and sustained by the longitudinal walls (fig. 25). The roof is simply supported by the walls. In some cases the load floor structure below the ground floor consists of jack arches on metal joists. In other cases the difference between the ground floor and the upper floor will consist on the timber type, as shown in the Simetria (2000) publication: fir tree for the upper floor and oak tree for the ground floor. The load bearing elements (timber or metal joists) are linear and transmit the loads into one direction only. Floor joists are simply supported by the walls, not anchored. There are no tie beams. The materials of the foundations varied significantly across time. Thus the oldest buildings of this type have clay brick foundations (some of them being built on the remained basement of previous constructions). An example building from the second half of the 19th century had already strip foundations out of unreinforced concrete, under all load bearing walls. In the (c) Simetria(2000) publication more details are available: around 1900 such a foundation consisted of hydraulic lime mortar concrete in 20cm layers. The depth of the foundations is known to be 1.10m, as required by the Romanian freezing limit. The ground floor lays about 0.5m above the ground level. As drawings in the Simetria (2000) publication show, half of the space between the ground level and the floor under the ground floor were filled with a different material than earth, but the nature of this is unknown. The size of foundations for this building was 0.50mx0.42m (depth x width) for exterior walls and respectively the wall separating the part with basement from that without (see the device catalog in Simetria, 2000). For interior walls the size of the foundations for the same building is shown to be 0.28mx0.50m (width x depth) in plan. The length is the same as that of the wall. Totally 13.18m³ of foundation material were needed for such a typical building. A partial basement of 3m depth was also found in some cases. The structural system is characterised by the "honeycomb" (in Romanian "fagure") plan layout. In a "fagure" layout masonry structure all rooms are prescribed as box type units with less than 30-35 sqm surface (for this building type 9-16m²) (fig. 13).

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). There are two longitudinal and several transversal 28 cm thick unreinforced brick in hydraulic lime mortar masonry bearing walls (see a sketch of main load bearing elements in fig. 15). This dimension is usual for interior walls of all building of this type. Older buildings might have thicker exterior walls (42cm, up to 50cm). The transversal walls separating room units are not load-bearing (they are only loaded with their own weight). The Romanian terminology identifies them as stiffening walls (Romanian "contravantuire", meaning contribution to lateral load bearing system only). Typically, there are no further, structural or non-structural separation walls in longitudinal direction. The only exception where three parallel walls in longitudinal direction may appear is at the entrance, enlarged by an increased building width (fig. 18 and 19). The distance between the two longitudinal walls varies between 3.0 and 4.0m depending on the presence or absence of a special vestibule room. The distances between the transversal walls is fairly typical, and starting from the street wall the span sequences are 4.25m, 2.25m, 4.25m, 3.25m, 3.25m and 1.75m for 19th century buildings and 3.0m, 4.0m, 3.5m, 3.0m, 2.75m, 1.75m, 2.0m for 20th century buildings respectively. Therefore it can be stated that typical spans are 3.0-4.0m in both directions, except for the last rooms where these can be smaller. All walls have sufficient stiffness to contribute to resisting lateral loads, both in terms of load capacity and deformation. Although stiffness isn't evenly distributed between the walls no damage due to torsional effects has been observed, despite rigid back longitudinal wall with no openings. This is supposed to be owed to the floors, which do not assure a spatial collaboration of the structure and thus the existing stiffness asymmetries loose weight. The back longitudinal wall is not common for two neighbouring buildings, which completely separate structural units. Currently in Romania there are 4 kinds of mortar used in masonry construction: "fat lime mortar" ("mortar de var gras" in Romanian), "lime mortar with added cement", "cement mortar with added lime" and "cement mortar". Today under "lime" is meant the non hydraulic lime, and contemporary mortar only behaves well in humidity conditions if cement is added. In some cases brick dust might been added (after Bratu, 1992), to increase the hydraulic quality. While so-called "weak lime" ("var slab" in Romanian; 6-12% clay and CaCO3) had never been produced in Romania, "middle lime" and "strong lime" (12-24% clay) had been used formerly to obtain mortar, but not for this type.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 25 meters, and widths between 3.5 and 5 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 4 meters. Typical Story Height: Up to 4.5 when monumental. Houses are at least 30cm over street level and the roof floor is at least 1.2m high. Typical Span: between 3 and 5m. The typical storey height in such buildings is 3.5 meters. The typical structural wall density is none. 7.5% - 12.5% ~ 10% in both directions.

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	☐	☐
	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐

Structural concrete	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	☑	☑

see 4.2. See for: timber floor structure in plan and respectively in axonometric view figures 16 and 17, for roof structure in plan and respectively in axonometry figures 21 and 22 and for typical sections through timber floor and roof systems figure 29 (legend in Romanian). Some buildings of this kind may have composite masonry and metal joist structure, not practiced today any more (fig. 28).

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	☐

Some buildings (like those from the first half of the 19th century) of this kind might have clay brick foundation. Later (begin of 20th century) this changed to unreinforced concrete: hydraulic lime mortar concrete, as stated in a document in (c) Simetria (2000). The above classification refers to a newer building of the same type, constructed in 1929 (see fig. 14 for the plan of foundations).

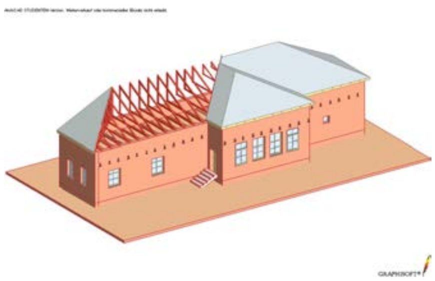
Figure 12: Axonometrie with view to the roof

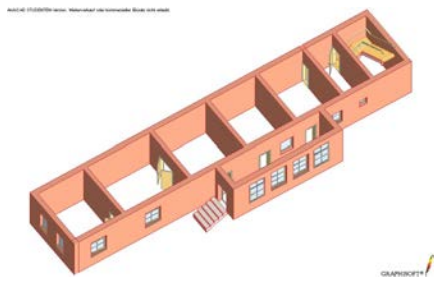
Figure 13: Axonometric view with load bearing walls and openings

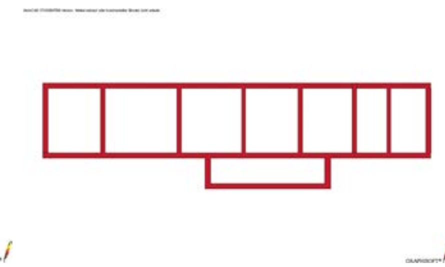
Figure 14: Plan of foundations

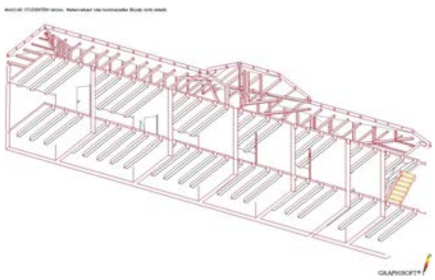
Figure 15: 3D section


Figure 16: Ground floor plan with timber joists

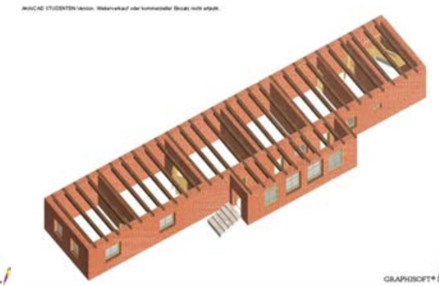
Figure 17: Axonometric view showing timber joists (from Bostenaru, 2004, TAFEL VII)


Figure 18: Transversal section

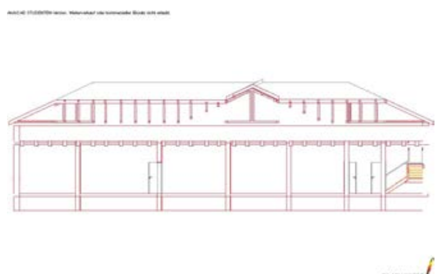
Figure 19: Longitudinal section

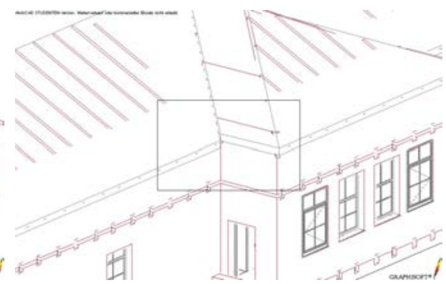
Figure 20: 3D view - detail


Figure 21: Roof plan


Figure 22: Axonometric view showing the roof

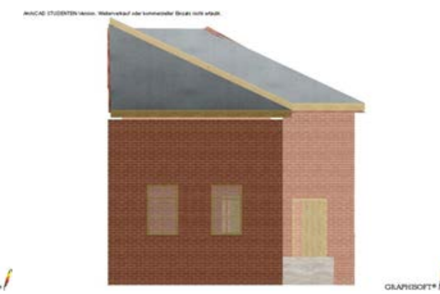
Figure 23: View to street

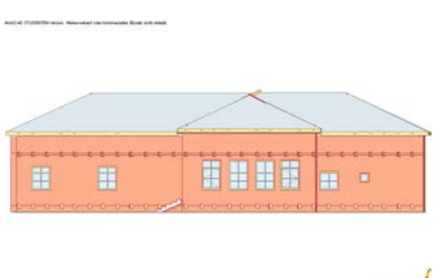
Figure 24: View to courtyard


Figure 25: 3D section with rendering (from Bostenaru, 2004, TAFEL VII)

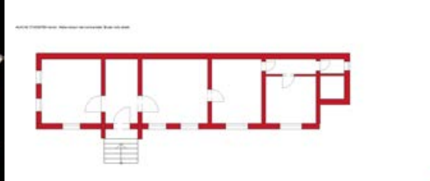
Figure 26: Ground floor type when the vestibule is not specially marked; in this case the width of the house is about 4.6m; length is about 20m (from Bostenaru, 2004, TAFEL VII)

Figure 27: Masonry detail (from Bostenaru, 2004, TAFEL VII)

Figure 28: Photo of a brick and metal joists floor structure.

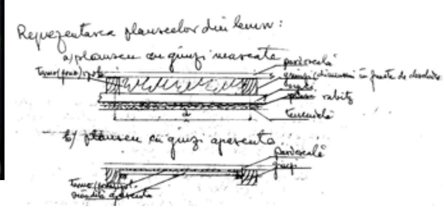

Figure 29: Typical sections through floor and roof

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). one units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is less than 5. During the crisis years in the late 20s rooms might be rented with strongly specified contracts, in the cases when the number of the people in the family decreased (ex. only the old retired persons remaining). During communism times new inhabitants have been "let" to rent rooms in such buildings, leadings to up to 3 families (each 2-4 persons) occupying a building (usually one family in 1-2 rooms).

4.2 Patterns of Occupancy

One family consisting of usually 4 persons. In the XIXth century there might have been 6-7 people in a family living in such a house (ex. parents, 4 children and an older person).

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)	☐

The house price/annual income ratio refers to that when this kind of buildings were constructed. Today this kind of construction is not practiced anymore and the price raised. At the time this kind of buildings were constructed (not built today anymore), the house price/income ratio ranged between 2.5/1 and 4/1 and the worse value has been chosen. Today the price of the house depends a lot on the place in the town where it is situated and on the facilities available (like gas central heating, for instance), but it is estimated that they are much more expensive to buy than, for example, dwellings in blocks of flats where this ratio ranges between 6/1 and 10/1. What is less expensive in this kind of houses compared to the block of flats are the monthly running costs for water, gas, heating and electricity.

Economic Level: For Middle Class the ratio of Housing Price Unit to their Annual Income is 4:1.

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

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

Credit has been possible to complete the price (1/3 from owner for example, the rest from Credit), as documented in Simetria (2000) p.33. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

This is valid for the example building for this report, which is from the 20s. In the buildings described by Dinescu in Simetria (2000) there were no bathrooms, only latrines (Romanian "closet"), and this is considered to be typical for that time. Many of the housing units from that time have been upgraded, but the authors estimate that not all of them. .

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)	☐

Renting was possible. For such a building the rent in 1928 was about 12,5% of the insured value/year, and this did not vary dramatically. In 1942 the rent has been almost 10% of the insured value/year (for details see Simetria, 2000).

5. Seismic Vulnerability

5.1 Structural and Architectural Features

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

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	The disposition of walls sometimes does not respect rules concerning uniform distribution of mass and stiffness. Brickwork can be extensively worn out (poor maintenance, decay) No reinforced concrete vertical posts. Height differences to adjacent buildings possible. Use of mortars with moderate strength.	Good quality (hydraulic) lime mortar. Because of the wall-roof connection, which do not assure the spatial co-operation of the structures, the appeared asymmetries don't cause significant general torsion effects under the action of seismic forces.	Some cracks in the plaster Vulnerability to pounding In some buildings: diagonal cracks on the facades and on the party wall. Corner damage (see figure 31)
Foundations	Foundations are clay brick masonry as well, and rarely stone masonry or concrete.		no data
Roof and floors	No stiff floors so no co-operation of load bearing walls and floors, so eventual capacity deficiencies of walls cannot be compensated by a uniform distribution of loads through the floors to walls with higher capacity. Linear load bearing elements with one direction load transmission, not anchored to the walls. No tie beams. Buildings are lower height than their neighbours.	Timber floors with joists every 70cm assure an uniform distribution of rigidities in the plane avoiding torsional effects. Timber joists are sustained by the longitudinal walls. Roof support on these girders leads to the fact that horizontal forces from earthquakes are absorbed without causing significant damages.	In some buildings the timber floors were damaged to collapse (INCERC, 2000, page 13). Specifically in a 19th century building described in Simetria (2000) the edge of the floor above the ground floor was separated from the wall, but the building was not damaged significantly (P. 38). Also Balan (1980) mentions that floors at building of this kind, both with timber and metal joists might present numerous rifts, especially on the contour (P. 232). UAIM (2000) classifies small rifts in the ceiling plastering as being characteristic for both not affected and light affected buildings, while in affected buildings the floor joists might move from their supports. The movement and collapse of the roof is also characteristic for affected buildings. For more details including figures see Agent (P. 72-78). Damage can also occur from neighbouring buildings (fig. 34).
Openings	Not always respecting the actual prescriptions regarding the dimensions and the areas of openings in walls. Piers (between windows) of reduced sections compared to the loads to be supported. Lintels are usually brick vaults, timber or metal joists.		In some buildings: X shaped cracks above the openings; Z shaped cracks on the "parapet" (under the window); cracks in the lintels over the entry door (fig. 30); cracks in the piers of the facade.

The data in the table is based on Bostenaru (2004), Table 2-6, P. 41. Roof damage: Due to excessive tensile stresses would fibers can fail (Croci, 2000, P. 59-60). In the opinion of the authors this type of failure is similar to the most common type of damage in RC beams, which is cracks in the tension zone. According to Penelis & Kappos (1997) the vertical component of the seismic action makes visible the microcracks due to bending of the tension zone. Although the vertical component at Vrancea earthquakes (those affecting Romania) is important, as the earthquakes occur deep, this is seems not to be that kind of damage, but rather bending shear effect. Roof systems are considerably more sensible to missing maintenance, as the ruins of buildings of this type show (fig. 32-33).

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance).

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

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1940	Vrancea	7.4	7, MERCALLI
1977	Vrancea	7.2	8, MERCALLI
1986	Vrancea	7	8, MERCALLI
1990	Vrancea	6.7	7, MERCALLI

The occurrence of slight or heavy damages depends mainly on the construction quality of this building type (foundations, masonry, roof, wood works and so on), which ranges from poor to excellent. These buildings may present: slight damages: falling of of finishing and decorations from walls and ceilings; crack nets, isolated rifts in masonry or later introduced concrete elements; large rifts in later introduced non-structural walls; heavy damages: big rifts, dislocations, sliding of construction elements, joint degradation, remaining deformations. The most frequent damage appears in the stiffening walls (these are the transversal walls, which are not designed as gravity load bearing walls, but contribute to the lateral load system), sometimes the timber joists detached from the walls, rifts at 45° at the lintels. There is thus an evident difference between the damage patterns of longitudinal walls (compressed by vertical load) and unloaded transversal walls. Global damage includes leaning from the vertical of the whole building by 4 to 9 cm (INCERC 2000). The most usual ones are the rifts. In Simetria (2000) p.38 detaching of ceiling border after the 1940 earthquake at such a house is documented. Generally this type of buildings is affected at the upper part: cracks, rifts, dislocations under and above the openings, in wall piers and wall fields; wall collapse especially in walls in the roof part (if inhabited), party wall and chimneys.

Figure 30: Damage over opening (from Bostenaru, 2004, TAFEL VII)

Figure 31: Damage at corner

Figure 32: Ruins of such a building

Figure 33: Ruins of walls of a building of this type

Figure 34: Fallen party wall in neighbouring masonry building, damaging the roof of a building of this type (see Balan, 1980: figure VI.6. on page 234)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	clay brick mortar	clay brick: bricks mark C75: compression strength: average (7.5-10.0) N/mm²; minimal 5.0 N/mm²; bending strength: average 1.8 N/mm²; minimal 0.90 N/mm². Further values are available in UAIM(2000). mortar: strength of masonry (in N/mm²): C50+M10: 2.8; C75+M10: 3.4; C100+M10: 4.0. Bending strength of mortar (in N/mm²): in horizontal joint: M10 - 0.2; in zig-zag joint: M10 - 0.4. Longitudinal module of elasticity depending on mortar mark for clay brick masonry (in N/mm²): M10 - 1200. Characteristic curvature(°/oo): M10 - 1.75, ; at ultimate M10 - 2.5. Further values are available in UAIM (2000).	clay brick: 7cm (63mm;+/-3mm)x14cm (115;+/-4mm)x28cm (240;+5/-6mm) The numbers in the parenthesis concern the brick itself, the others include the dimensions in the wall, i.e. with mortar. mortar: Today's cement-clay is cement:clay:sand = 1:2:8 (compared to 0:1:3 for clay and 1:0:4 for cement mortar) see Balan P. 372	clay brick: Values according to UAIM brick of middle class mark are shown. Also C50 and C100 exist. The mark shows 10 times the lowest compression strength. mortar: Values out of experimental works valid for Romanian historical buildings, recommended as input data for analytical methods(see UAIM2000). Values for mortar M10 have been taken (Romanian cement-clay, and EC6 M2), after the experiments of Sofronie.
Foundation	masonry			older buildings have clay brick foundations, newer buildings concrete foundations.
Frames (beams & columns)				
Roof and floor(s)	Roof/Floors: timber Floors: steel (and clay brick)	timber (Roof/Floors) : Fir scantling strength (N/mm²): bending, compression along fiber: 10.0; tension along fiber: 7.0; compression perpendicular on fiber: 1.5; bending shear, along fiber: 2.0; shear perpendicular on fibre: 4.5; "strivire" perpendicular on fibre: 1.5; "strivire" at supporting surfaces: 2.5. Broad-leafed scantling strength (N/mm²): tension, bending, compression and "strivire" along fibers: 1.1-1.3; compression and "strivire" perpendicular on fiber 1.6-2.0; shear 1.3-1.6. Floors (steel (and clay brick): tension, compression and bending strength 120.0 N/mm²; sliding strength 96.0 N/mm² respectively 0.8 in the other direction. For anchors and "tirant"s: 100.0 N/mm². The steel module of elasticity is to be considered: 210.000 N/mm².		timber (Roof): Usually this type of building has ovens, usually out of "terracota" corresponding to each room. The roof is usually also out of fir tree, fixed with metal parts. At the turn-of-the century German iron has been popular as covering. timber (Floors): Usually out of fir tree, both mid XIXth century and begin of XXth century. Basement might be oak. Floors (steel (and clay brick): for metal elements there are no experimental results available. Here what the UAIM (2000) recommendations say has been documented.

6.2 Builder

Typically the builder lives in this construction type. If it is a typical middle class house the owner might be the developer but not the actual builder contractor.

6.3 Construction Process, Problems and Phasing

Construction process adapted for a building from 1904, from a figure by Dinescu in Simetria (2000): Digging the ground and reinforced concrete foundation (reinforced concrete already, like in the model building considered for this form) - 2 positions; Making clay brick masonry wall works - one position; Wood works - two positions; Wood works for the roof - one position; Metal works for the roof (the covering) - three positions; Interior plastering - two positions; Exterior plastering - two positions; Floors - one position; Filling between the joists - three positions; Stone stairs at the vestibule - one position; Wood works for windows and doors - two positions; Fir tree mobile staircase - one position; Toilette with everything - one position; Basalt tubes - one position; "terracota" ovens - one position; Decorative plastering - one position; Iron cover - one position. For retrofit: According to the UAIM methodology cracks under 2mm in masonry walls cannot be injected during retrofit works as this implies availability of materials and equipment hard to be found today in Romania. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. Changes in time may be cause of later damages. Such ones are: geometry changes: widening of openings, removal or addition of walls or floors (fig. 9); stiffness changes through closing up windows (fig. 6-9); material degradation (fig. 28, 32, 33); load changes: addition of floors without approval, use change (fig. 6); missing maintenance: especially related to water damages (ex. from rain, missing facade plaster, as visible in figures 27 and 28 for walls and floors); previous damages from earthquakes or fire (fig. 30-33).

6.4 Design and Construction Expertise

No data. This is rather an informal type of building. However, some of them are designed by architects. An example of a building designed by an architect ("inginer-arhitect" has been the title of the time), G. Brezeanu (not a renowned one), 1904 is given in "Povestea Caselor" p. 53-56, including drawings and some construction management tables.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

It was not built any more when the provisional guidelines, preceding the first seismic code in Romania, appeared.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

It's not built any more. It has been built both in times when building permits were required and not. However, even in the time when no urban development rules were enforced, "act" (i.e. documents) were required to juristically declare the buildings, the begin of the construction process and give some details about, like building materials and succession in the construction process. 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). which are also the inhabitants.

6.8 Construction Economics

No equivalent possible, as they used to be built before WWII. In the mid XIXth century the value of a recently built house of this type was around 200 Austrian "galbeni" or respectively Romanian lei, later on, as documented by Dinescu in Simetria (2000). Turn of the century the builder (Romanian "antreprenor") got 7% benefit of the construction cost. This has been, including that benefit, around 50 months pensions of a retired functionary or 30 months salary of a functionary, who were the typical inhabitants (a bit lower than the value of an existing house). The proportions did not change 10 years later between salary-house price, although the prices absolutely doubled, as it can be understood from the Simetria (2000) publication. Prices for the positions in the construction process of a typical house at the begin of the XXth century (1904) can bee seem in Simetria (2000) page 55, in the reproduction of an original document. Detailed are presented: the digging for the foundations, the foundation works themselves, and the masonry works with dimensions in a typical form of the time ("ante-mesuratorea si pretuirea lucrarilor" in Romanian, which means "pre-measuring and cost estimation for the works"). A house of this type has been built withing two years of work, both in 1865 and 1904, from which one might be spent with planning and only one with the construction itself, as it can be understood from the description given by Dinescu in Simetria (2000).

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Dinescu in Simetria (2000) mentions documents proving the insurance of the house between 1920 and 1950. These were against fire and lightning, no earthquake, and show the change in the value of the building as well as the premiums (see reference, p. 57). No data.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Small cracks in structural walls	Injection with cement milk of small cracks (after Bourlotos, 2001, and (c)INCERC, 2000): 1. removing plaster; 2. widening the rift with hammer and chiesel or mechanical hole making; 3. cleaning the rift; 4. injecting the rift with mortar; 5. transport of break-off plaster to rubbish container; 6. disposal of removed plaster; 7. new plaster. (Fig. 40)
Large diagonal cracks in the walls or wall dislocations	Shotcrete ("torcretare" in Romanian) (after Bourlotos, 2001, compared with (c) INCERC, 2000; see also report #84): 1. Removal of plaster; 2. Removal or mortar in horizontal joints up to 1cm; 3. Cleaning of the wall with water; 4. Shotcrete of 4~8mm. Alternatively cast-in-place concrete, about 10cm thick.
Serious wall damage	Reinforced concrete jacketing (after (c) INCERC, 2000, completed after Bourlotos, 2001): 1. Scaffolding; 2. Screening; 3. Building up an removing drop tub; 4. Removing outside and inside plaster; 5. Knocking off the masonry wall; 6. Breaking through the slab; 7. Cleaning up the masonry; 8. Concrete roughening; 9. Blasting compressed air; 10. Reinforcement works; 11. Formwork; 12. Binding anchors between masonry walls and shear walls; 13. Mounting the binding anchors; 14. Concrete casting; 14. Dismanteling the formwork; 16. Interior and exterior plastering, for interior M100 mortar recommended by INCERC; 17. Masonry repair. (Fig. 39)
out of plane walls after earthquake (reparation work)	Replace collapsed portions of old walls with new masonry walls: 1. loads to be carried usually by the walls are hold off and directed to the sustainable subsoil (with bolts); 2. knock off of the old wall; 3. building of a new wall; 4. reloading of the wall (disassembling the support). (after Bourlotos, 2001)
Low capacity of wall-to-wall and wall-to-floor joints and/or damage along these joints	Anchoring two neighbouring walls or floors to walls by means of metal tension struts (in Romanian "tirant"): 1. dismanteling plastering; 2. breaking holes through the wall; 3. anchor head for the strut; 4. fixing of the solidisation metal plates; 5. making and mounting of the screw dispositiv for screwing in; 6. mounting of the protection tube for guiding the tyrants through the walls; 7. making and mounting the metal strut; 8. filling in the holes; 9. remaking plastering. (see fig. 41 and after INCERC, 2000)
No stiff floors so no co-operation of load bearing walls and floors, so eventual capacity deficiencies of walls cannot be compensated by an uniform distribution of loads through the floors to walls with higher capacity The load bearing elements (timber of metal joists) are linear and transmit the loads into one direction only	Replacement of timber floors or of floors out of brick vaults on metal joists with reinforced concrete slabs (summarised after (c) INCERC, 2000; for both if not specified otherwise): 1. Demolishing of partition walls; 2. Dismanteling of doors; 3. Dismanteling of plaster on the walls; 4. Dismanteling of flooring. 5. (timber) Dismanteling of under-flooring; 5a. (vaults) Dismanteling filling materials over the vaults; 5b. (vaults) Demounting brick-vault-floors; 5c. (vaults) Demounting metal joists over 4m length; 6. Realisation of fingerprints and binding openings in the walls of different thicknesses (but over 14cm); 7. Formwork; 8. (timber) Support out of metal joists for the slab; 9. (vaults, before formwork) Mounting the reinforcement (out of OB37 and PC52 steel); 10. Concrete casting (B250) into the fingerprints; 11. Concrete casting (same quality) into the slabs; 12. Support layer for flooring; 13. Realisation of the floor and its finishing; 14. Floor-wall finishing pieces; 15. Plastering of the interior walls; 16. Plastering of the ceiling; 17. Rebuilding the partition walls; 18. Mounting the doors. (Fig. 36).

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Inadequate capacity of structural walls	Strengthening with polymer grids (TENSAR), see report #84
Lintels are brick vaults, timber or metal joists; Not always respecting the actual prescriptions regarding the dimensions and the areas of openings in walls; Piers of reduced sections compared to the loads to be supported	Reinforcement of door frames: 1. old door and door architrave are knocked off and disposed; 2. eventually available lintel is also knocked off and disposed; 3. masonry around the door opening is also knocked off and disposed; 4. cleaning works; 5. the reinforcement of the reinforced concrete frame is anchored to the floor plate; 6. other reinforcement works are in progress; 7. setting up formwork; 8. casting concrete; 9. dismanteling formwork; 10. the new door is build in. (after Bourlotos, 2001, see fig. 37)
no reinforced concrete vertical posts	Strengthening of corners: 1. Loads from roof or floor are first hold off with a scaffolding construction. Slamming in two directions along the interior side of the wall (distance between the steel columns ~0,60m); 2. Knocking off and cleaning away the broken masonry; 3. Reinforcing the corner post; 4. Setting up the formwork, casting the concrete, dismanteling the formwork of the corner post; 5. building up reinforced masonry in the area of the corner post. (after Bourlotos, 2001; fig. 38)

There is no information available about preparing beddings for new slabs and the way of anchoring them to supporting walls. Figure 35 shows contemporary composite masonry and concrete joist in Romania, an alternative for the replacement of the similar ones with metal joists. For more comments about stengthening with polymer grids see report #84. For more measures see Bostenaru(2004), Tabelle 2-7 on P. 42 and Tabelle 2-8 on P. 43. Strengthening works may be applied independently (on a new building) or together with reparation (UAIM, 2000). Retrofit methods with reinforced plaster (polymer grids and shotcrete) can be also applied as repair measures, not only on undamaged buildings. The same is valid for the replacement of floors, which can follow floor destruction in either earthquakes or missing maintenance. Main reparation works which can be performed on historical masonry buildings are according to UAIM2000: re-weaving with bricks similar to the original ones; injection with lime grout; injection with cement grout; injection with cross-shaped metalic incisions; closing of rifts with cement mortar; threatment of large dislocations with mortar-concrete reinforced with flexible bars; closing of rifts on painted walls with special mortar ("caseinat de calciu"); injecting of cracks with special past ("caseinat de calciu"). Specific for small residential buildings of historical value are: no additional structural walls; old: composite out of masonry within reinforced concrete or reinforced mortar. These should be on bigger surfaces and smaller thickness; posible with polymer grids in one of the following ways: grids between the horizontal brick rows, jacketing of walls, confinement of structural parts, according to th respective technology; reinforced masonry or with included metal elements may be added; timber floors may be replaced with reinforced concrete slabs; metal floors may get an overconcrete layer or metal diagonals connecting the metal joists; In case of a minumum intervention: at least one floor shall be of reinforced concrete or metal with comparable stiffness, usually the roof one, timber joists must be reigidised at 45°; complete change of interior structure is allowed when only the exterior appearance is of historical significance, exterior walls should be strengthened concomitently; in exceptional cases when any structural changes would affect the cultural values base isolation is recommended; beam ties or tension struts ("tirant") shall be realised.

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?
After the earthquakes form 1940, 1977, 1986, 1990 in case of the model building considered for this form only superficial rifts occurred which have been repaired. After the 1977 earthquake following strengthening methods have been used: crack injection with cement paste (most widely used), replacement of collapsed portions of old walls with new masonry walls built in cement mortar, shotcrete, replacement of heavy walls with light walls or connection of those with the walls of the load bearing system. The last one of these has been described in report #84. Added reinforced concrete vertical posts leads to changing the structural type into reinforced masonry and thus might be suitable for historic constructions of this type. Tension struts and floor replacement have been also used for buildings of this type as shown in the figure. Reinforcement of door frames addresses like floor replacement specific seismic deficiencies of this type again. For the other ones this report presents a new view, comparing the Romanian practice after the 1977 earthquake with provisions from today, as it resulted from joint research work of one of the authors with a student from Greece (see Bourlotos, 2001).

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
Strengthening measures like repairing cracks, rifts, out of plane wall collapses are made following an earthquake damage. Strengthening measures like reinforcement of door openings, providing of vertical posts are made on undamaged/previously repaired buildings. Strengthening of walls with reinforced mortar (see report #84), jacketing, as well as strengthening of floors can be made for both cases.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?
"Functional specifications" are required today. For example for the application of TENSAR strengthening a so called "Agrement tehnic" i.e. technical provisions, issued by MLPAT (The Ministry for Public Works and Regional Planning), with no. 008-01/017-1999 is used.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
owner.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The model building wasn't damaged significantly. However, Balan (1980) documents failure of reinforced concrete posts at masonry buildings (P. 376), so this type of damage should be taken into account also for reinforced buildings. Thus also the potential reinforcement elements, like vertical posts, can be damaged in Vrancea earthquakes, as shown in figure 42.

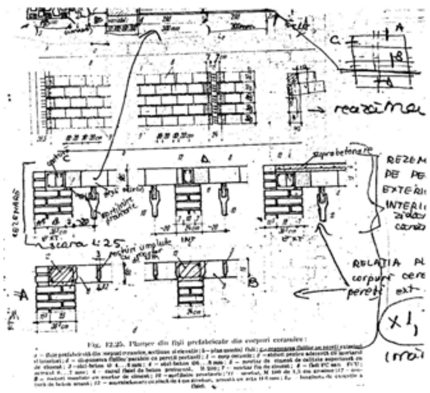

Figure 35: Sections through a brick and metal joists floor structure: a - prefabricated sheet out of bricks, section and elevation; b - mounting plan; c - support of the sheets on exterior and interior walls; d - layout of the sheets parallel to the bea

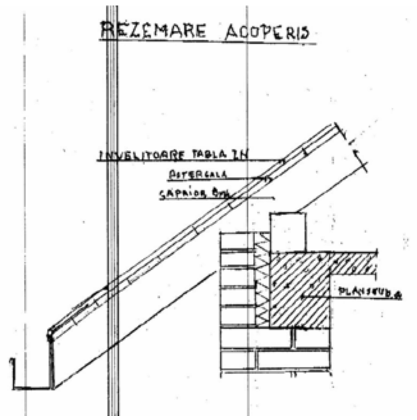

Figure 36: View of roof-wall-floor connection in case of proposed retrofit of rigid slab at roof level.

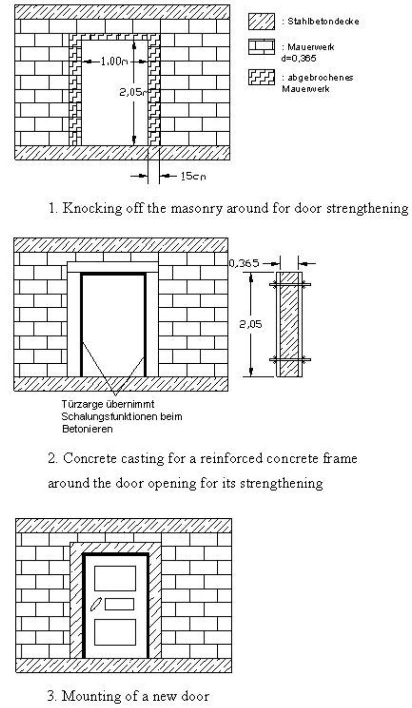

Figure 37: Reinforcement of doorways (after Bourlotos, 2001)

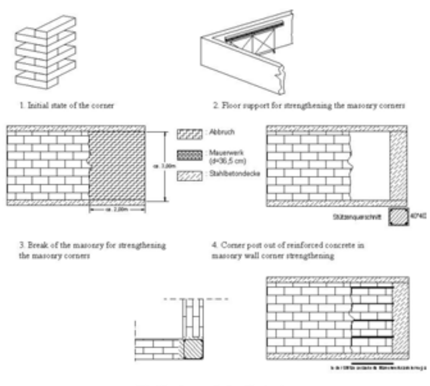

Figure 38: Strengthening of masonry corners (after Bourlotos, 2001)

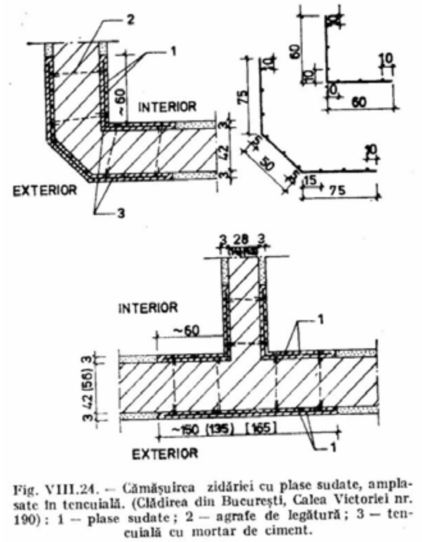

Figure 39: Masonry jacketing with steel nets, in the plaster: 1 - nets; 2 - joining anchors; 3- plaster with cement mortar. (see Balan, 1980: figure VIII.24. on page 428)

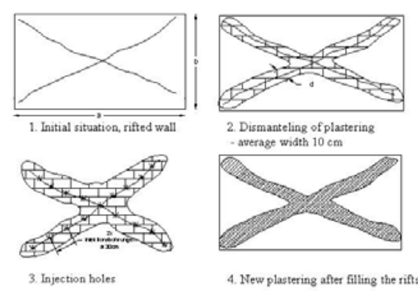

Figure 40: Masonry wall reparation through rifts injection (after Bourlotos, 2001)

Figure 41: Reinforcement with tension strut, in Romanian "tirant" (from Bostenaru, 2004, TAFEL VII)

Figure 42: Damages at a vertical post at the corner of a midrise masonry building in the 1977 earthquake. (from Balan, 1980: figure VI.28.b. on page 253)

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