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SEISMIC PROTECTION OF INDIVIDUAL BUILDINGS LOCATED IN RURAL AREAS

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Abstract

According to the new seismic design code of buildings, Campina - Doftanei Valley area /Prahova County has a ground acceleration of 0.28 g. This value places it as the second seismic area after Vrancea epicentral area. In these conditions, the article presents some seismic protection measures considered by the owners in the execution of own buildings. Some structural shortcomings of buildings with one or two storey, which were observed at the incidence of intermediate Vrancea earthquake of March 4, 1977, will be emphasized. Also, strengthening solutions are presented as a result of lessons learned from this seismic event. Some structural types like timber structure with bracing and walls with OSB paneling, timber-frame structure filled with masonry brick and mixed structure, with rigid base from masonry and floors with timber frame structure. It is interesting how the transition is made from the rigid structure to the flexible one, knowing that the amplification of efforts appears at the top of them. It is studied how it is treated "the design" of these buildings which is the evidence of local seismic culture, where the flexible system is stiffened by bracing and the beams are arranged by the two orthogonal directions in the plane. The general idea is that in rural areas, even in those affected by earthquakes, an acceptable vulnerability of buildings with a minimum transfer of knowledge in the local community can be maintained.

Key words: *masonry, timber, bracing, belt beams.*

INTRODUCTION

Seismicity of Doftana Valley-Campina area

The Vrancea seismogenic zone is the most important seismic zone, taking into account the energy, the extent of the macroseismic effects and the persistent and confined character of the earthquakes that occur in this narrow area.

A very small mantle volume of about 30×70×160 km hosts earthquakes that occur repeatedly with magnitudes in excess of 7.5. All intermediate-depth earthquakes are contained in the high-velocity volume beneath Vrancea which is bigger than the seismogenic volume [Wenzel et al, 2002].

After Vrancea, as the second seismic area Doftana Valley-Campina region is considered. The Prahova County is situated on the moesic subplate, including the contact zone with the inter-alpine subplate. Thus, according to the new seismic design code of buildings, all seismic areas were assigned higher pga, and in this context, Campina - Doftanei Valley area/Prahova County has the peak ground acceleration of 0.36g, for earthquakes with the mean recurrence interval IMR = 475 yr., and of 0.28g, for earthquakes with the mean recurrence interval IMR = 100 yr. The value for control period is T_c = 1.0s, and the seismic intensity is VIII (on MSK scale) according to SR 11000/1-93.

Some existing categories of dwellings in Doftana Valley-Campina area/Prahova County

The rural residential buildings (non-engineered buildings) can be divided into two main categories. The first category of non-engineered buildings is those built according to tradition, their types suiting the culture and materials available in that area- the traditional rural dwellings. The second category of non-engineered buildings is the rural city type dwellings or a combination of traditional look only, but not adopting the traditional skills and crafts in detailing, material use etc.

Their structural systems can include timber, load-bearing masonry (stone, adobe, kiln brick), wooden-clay mixed structures, clay or compacted clay structures and with some reinforced concrete elements of buildings.

Most of the rural dwellings are of traditional shape, with a regular building plan, and, in both cases of non-engineered buildings, the local culture imposed some resistance elements in order to provide gravity and lateral load-resisting systems.

Due to the "honeycomb" building configuration, the load-bearing walls are well connected and carry the loads uniformly. The use of the mortar brick walls, belts and tie rods, wall-ties and floor-joists anchors, wooden columns, arches of light materials, the presence of interior walls etc. are considered as providing sufficient lateral bracing. On the other hand, using concrete hollow blocks, reinforced concrete columns, slabs and collar beams, reinforced concrete frames or reinforced concrete skeleton (masonry bordered by reinforced concrete columns and collar beams), a more lateral load resisting is obtained.

Further some of the structural systems of traditional and city type rural dwellings are described in the following tables, Table 1…5 [Georgescu and Crainicescu, 1979; Georgescu, 1986].

Table 1. Timber structures

Structural system	Non-engineered buildings- traditional rustic dwellings	Non-engineered buildings- city type rural dwellings
Foundation	thick wooden beams under external and main transversal walls and stone boulders below	ground floor is often in stone and brick; foundation in stone or plain concrete or hollow blocks
Walls	horizontal wooden beams or planks; keys at half section, nut and father or dowel joints; walls are sometimes plastered for protection	similar
Floors	collar, main and secondary beams, ceiling	sometimes reinforced concrete slab over basement or gound floor
Roof	wooden structure with round wood, in 2-4 slopes, rafters and purlins joined with superior collar beams; cantilever eaves; roofing with wooden tiles, straws or reed	galvanized sheets and asbestocement plates
Layout	rectangle, symmetrical for single story houses; asymmetrical for two storied houses when first floor is usually with stone walls	urban influence in room distribution

Table 2. Masonry structures - Stone masonry

Structural system	Non-engineered buildings- traditional rustic dwellings	Non-engineered buildings- city type rural dwellings
Foundation	stone plates walled with clay or lime mortar or in dry masonry	similar
Walls	walled stone plates (40-50 cm wall thickness) wooden lintels; lime or mud mortar	similar
Floors	vaults in old buildings basement; wooden floor over first story	reinforced concrete collar beams and floors
Roof	in 2-4 slopes, wooden structure with round wood rafters and purlins; cantilevers; roofing with woden tiles, straw, reed, tiles; local roofing with stone plates (5cm) cut in tuffa, limestone	similar
Layout	rectangle, symmetrical for single story houses	similar

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Table 3. Masonry structures - Kiln brick masonry

Structural system	**Non-engineered buildings- traditional rustic dwellings**	**Non-engineered buildings- city type rural dwellings**
Masonry structures- Kiln brick masonry		
Foundation	brick or stone with lime mortar; basement on masonry vaults in old buildings	plain concrete or concrete hollow blocks
Walls	masonry in kiln brick and lime mortar (clay-sand mortar in por houses); wooden lintels or arches for openings	masonry made of pressed brick, hollow brick, concrete hollow blocks, ytong blocks, reinforced concrete columns and collar beams
Floors	wooden beams and timber ceilings; masonry vaults in old monumental buildings	reinforced concrete slabs
Roof	in 2-4 slopes with wooden structure, with round wood rafters and purlins; cantilever eaves; roofing tiles, lead or copper sheets	wooden structures, new forms with reinforced concrete slab roof
Layout	rectangle, T or L; 1-3 stories with towers, external stairs, balconies	similar

Table 4. Framed wall structures - Timber frame structure with infilling materials

Structural system	**Non-engineered buildings- traditional rustic dwellings**	**Non-engineered buildings- city type rural dwellings**
Framed wall structures- Timber frame structure with infilling materials (padlle or trellis work)		
Foundation	sometimes river stone boulders below the wooden beams at the wall base in the foundation trench	ground floor is erected in stone or masonry with plain concrete foundation
Walls	timber frames with corners columns and opening bordering posts as well as horizontal beams, sometimes horizontal wattled tree branches; inclined bracings; infilling in the timber frame with: mud, clay brick and clay, stones and clay; plastering with clay or lime sand mortar	finishing works in stucco
Floors	wooden collar beams and main beams connected plastered timber or tree branches ceiling	similar
Roof	in 2-4 slopes; structures connected with frames and collar beams; roofing with wooden tiles, tiles, galvanized sheets	similar
Layout	rectangular, symmetrical	similar

Table 5. Framed wall structures - Plated timber frame structures

Structural system	**Non-engineered buildings- traditional rustic dwellings**	**Non-engineered buildings- city type rural dwellings**
Foundation	river stones; wooden beams at wall base	plain concrete with rc perimetral beam
Walls	timber frames with corner columns and opening bordering posts as well as horizontal beams	rc frames or rc scheleton; masonry bordered by rc columns and collar beams
Floors	main and secondary beams, timber ceiling	reinforced concrete precast hollow strips or monolithical slabs
Roof	in 2-4 slopes using wooden structure joined with frames and superior collar beams; roofing with wooden tiles, tiles, galvanized sheets	in 2-4 slopes or flat terrace, tiles or galvanized sheets
Layout	rectangular, T or L	villa type

MATERIALS AND METHODS

The behaviour of residential buildings with non-engineered construction systems at the Vrancea earthquakes

Some architectural and constructive elements that impose a good behaviour to the Vrancea earthquakes are as follows:

- reduced dimensions of Romanian rural buildings and a relatively simple layout;
- a relatively light roof, in 2-4 slopes having a structure well tight with the masonry and the walls;
- the room floors are built with dense beams tightly connected with the masonry walls;
- the height of only 1-2 levels, the floor being made of lighter materials (wood, trellis work);
- the existence of a sufficient number of elements that take over the horizontal loads (columns, masonry walls, wooden walls with corner joints, bracings);
- a relative symmetry of the building layout and a symmetrical distribution of the doors and windows openings;
- the pressure of certain elements that provide the spatial interaction: wooden contour beams at the foundation and roof levels, working as belts, wooden horizontal elements at corners in the earthen walls.

Some typical damages to non-engineered buildings (the structural systems of traditional and city type rural dwellings) which equates to a poor behaviour to the Vrancea earthquakes are as follows:

- roof covering tends to be dislodged or separate from its supports;
- walls tend to tear apart, to shear off diagonally in direction or to collapse;
- additional shear due to twisting or warping for unsymmetrical building;
- concentration of stresses in openings and failure at corners of openings; failure at corners of walls;
- failure due to sudden change in mass or stiffness;
- weak connection between wall and wall, wall and roof, wall and foundation;
- failure of rigid and insufficient strength of structural elements and connections;
- poor quality of construction (poor material and poor workmanship) etc.

Behaviour of rural structures during 1977 Vrancea earthquake and others (1986, 1990)

Generally, at the earthquakes from 1977, 1986 and 1990, the damages of dwellings from some villages ranged from apparently no damage, or a slight one, to heavy damage and even collapse. Many roofs, chimneys and walls of the buildings were damaged. Apparently few roofs collapsed, but many were displaced laterally. Vertical and horizontal cracks and evidence of torsion were observed in chimneys. More chimney damage was observed in buildings with high-pitched roofs. This may have been due to the fact that chimneys on buildings of this type were higher, and consequently more flexible. Gable walls supported on columns were displaced up to some cm. There was also some damage to buildings as a result of foundation settlement [Georgescu, 1979, 1986; Vlad, 2008].

From the point of view of structural system, the timber structures withstand earthquakes without collapse or major damage [Georgescu, 1979, 1986]. Several nonstructural damage have occurred (plaster and chimneys failure). The stone structures have presented cracks and partial failure due to bad mortar quality or poor workmanship. The masonry structures have presented damage by wall corners and crossings cracking, diagonal cracking, local failure of untied walls. The quality of mortar and brick, the overall layout and conception of the building played an important role. The timber frame structures with infilling or timber plated behaved better than masonry. Nonstructural damage by plaster falling and lintels cracking were often observed. The spatial braced wooden frame makes this type of structure proper for seismic zones.

Types of failure mechanisms and damage to residential buildings with traditional construction systems. Some seismic protection measures considered in the rural area.

During an severe earthquake, certain effects are seen to occur, the roof tends to separate from the supports, the roof covering tends to be dislodged; the walls tend to tear apart and if unable to do so they tend to shear off diagonally in the direction of motion; infill walls within reinforced concrete or timber framing tend to fall out bodily unless properly tied to the framing members. From those facts, an analysis of the mechanism of damage is performed.

Timber floor construction may be in the form of wooden beams covered with wooden planks, ballast fill, and tile flooring. In most cases, timber joists are placed on top of walls without any positive connection; this has a negative effect on seismic performance.

After the strong earthquakes, in the absence of belt in the floor the propagation/expansion of inclined cracks can be observed on the masonry walls.

Some seismic protection measures considered in the rural area

Reinforced Concrete coating to masonry with independent bars and concrete, pillars in the corners of building are layout, Fig. 1.

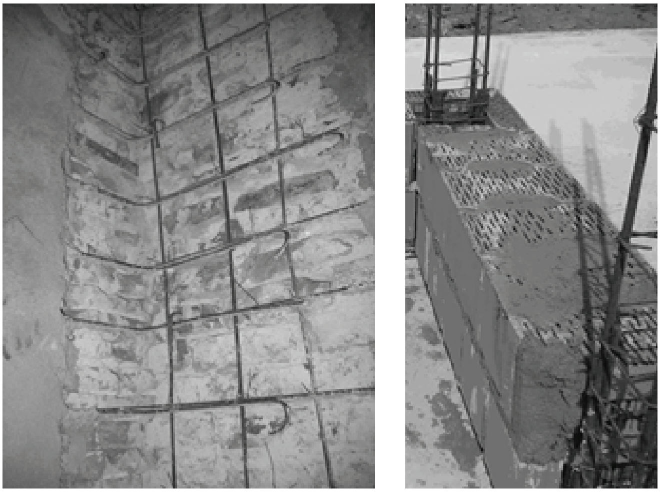

Figure 1. RC coating to masonry wall with independent bars and concrete; layout pillars in the corners

Reinforced Concrete Floors/Roofs. It is a common structural/seismic rehabilitation practice to replace the original floor structures in old buildings with either a precast concrete joist system or solid Reinforced Concrete slabs.

Seismic Bands (Ring Beams). Usually provided at lintel, floor, and/or roof level in a building, the band acts like a ring or belt, as shown in Fig. 3-8. Seismic bands are constructed using either reinforced concrete or timber. Seismic bands hold the walls together and ensure integral box action of an entire building. Also, a lintel band reduces the effective wall height. As a result, bending stresses in the walls due to out-of-plane earthquake effects are reduced and the chances of wall delamination are reduced. In some cases, a lintel band is combined with a floor or roof band.

The system of seismic bands participates in ensuring the spatial character of the structure through: the connecting of walls on the two directions; the formation of a spatial skeleton with reinforced elements, capable of taking up the tensile stresses, by the binding of all pillars in each floor; increasing the rigidity in the horizontal plane of floors; the transfer of seismic forces from the floors to the walls of the structure. The seismic bands/belts contribute to limiting crack propagation from one level to another. This type of damage can lead to wall collapse under the combined effect of seismic action in the plane and perpendicular to the wall.

Some illustrative examples of rural residential buildings are shown in Fig. 2-12.

Figure 2. Strengthening of the external walls with some buttress to a traditional dwelling

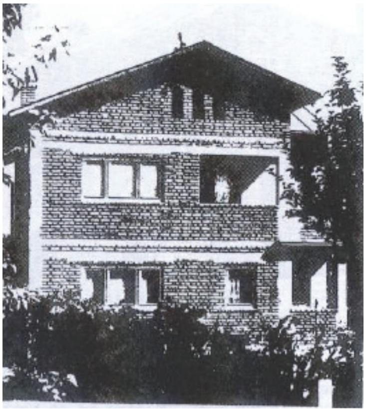

Figure 3. City type rural two storied brick masonry dwelling with embedded RC columns and RC slabs (the collar beam as a frame beam)

Figure 4. City type rural two storied ytong blocks dwelling with RC members (RC window beam lintel parallel to the collar beam and floor slab acting as a frame with columns; foundation is made of concrete)

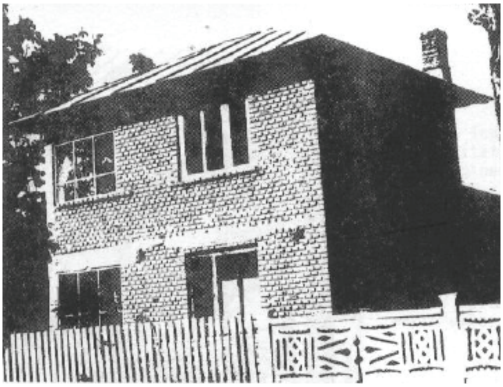

Figure 5. City type rural two storied brick masonry dwelling with RC floor slabs (lintels are embedded in RC floor slab)

Figure 6. City type rural two storied brick masonry dwelling with embedded RC columns and RC slabs (the collar beam as a frame beam)

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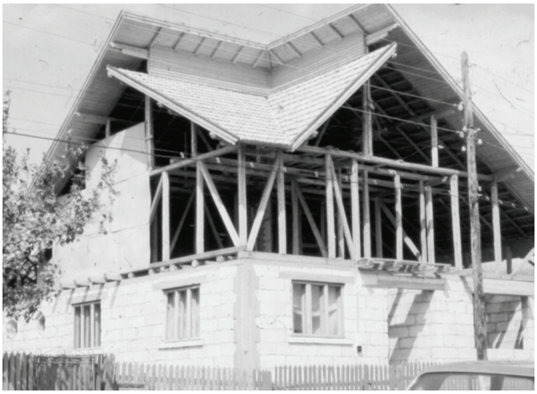

Figure 7. A traditional dwelling with roof band and RC lintels, pillars at corners, a light roof, in 2-4 slopes having a structure well tight with the masonry

Figure 8. A traditional dwelling with roof band and rc lintels, without pillars at corners, a light roof, in 2-4 slopes having a structure well tight with the masonry

Figure 9. A traditional dwelling with RC floor and without RC belts

Figure 10. A traditional dwelling with RC floor slabs (lintels are embedded in RC floor slab)

Figure 11. City type rural three storied brick masonry dwelling RC skeleton mixed with timber beams

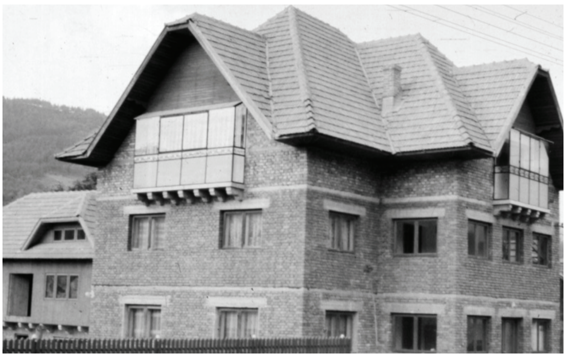

Figure 12. City type rural three storied brick masonry dwelling with RC floor slabs and without RC belts

Vulnerability characterization of non-engineered construction systems using quantitative indicators.

In order to characterize the vulnerability of non-engineered construction systems, the following simple indicators may be considered [Sandi et al, 1985]:

- the area indicator, $I_{ar} = \frac{A_{active}}{m}$, where

A_{active} = the total area of horizontal sections of shear resisting members, oriented along a direction considered (m^2)
m = the mass generating seismic forces to be transmitted through A_{active} (t)

- the acceleration indicator, $I_{ac} = I_{ar} R_s$, where

R_s = the ultimate shear strength of the material
I_{ac} = the ultimate static acceleration corresponding to the shear strength of the structure considered (critical acceleration).

As a general observation, regarding non-engineered buildings-traditional rustic dwellings, the area indicator has high values, I_{ar} = 0.02…0.05 m^2/t, and this leads to high values of the acceleration indicator too, I_{ac} > 5m/s2. By comparison, for non-engineered buildings-city type rural dwellings, with ground floor and stories, but with lack of internal walls (replaced by reinforced concrete pillars or columns not designed to resist to earthquakes), the area indicator has low values, I_{ar} = 0.005…0.01 m^2/t, leading to values of the acceleration indicator of around I_{ac} = 1m/s^2.
For dwellings with masonry bearings walls and flexible floors and buildings with masonry bearing walls and rigid floors the vulnerability characteristics are analysed and the damage degree corresponding to the VIII intensity on MSK scale may be 2…3, which would mean moderate or heavy damage according to EMS-98; the structural damage cost can be 20%...50% of total repair cost.

CONCLUSIONS

From the above, it is shown that, in rural areas, according to a local seismic culture, the non-engineered dwellings may contain some elements which give them a good behaviour to Vrancea earthquakes. Breakdowns occur when parts of these houses are not connected properly, and work independently, or they are insufficient and have few ductility sources. Thus, the total area of horizontal sections of shear resisting parts of structural systems, oriented along the earthquake direction and, also, the mass generating seismic forces to be transmitted through this area are very important for all residential buildings with non-engineered construction systems. The damage degree corresponding to the VIII intensity on MSK scale may be 2…3, which would mean moderate or heavy damage according to EMS-98; the structural damage cost can be 20%...50% of total repair cost.

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REFERENCES

Wenzel, F., Sperner, B, Lorenz, F., Mocanu, V., 2002, Geodynamics, tomographic images and seismicity of the Vrancea region (SE-Carpathians, Romania), EGU Stephan Mueller Special Publication Series, 3, 95–104.
Georgescu, E.S., Crainicescu, M.M., 1979, Traditional residential buildings in Romania rural, the behavior of the earthquake of 4 March 1977 INCERC Studies and Research, no. 4/1979 (in Romanian).

Georgescu, E.S., 1986, The earthquake behaviour of earthen and low-strength masonry rural buildings in Romania, Middle East and Mediterranean Regional Conference, On earthen and low-strength masonry buildings in seismic area, Ankara, Turkey.

Vlad, I., Vlad, M., 2008, Behavior of dwellings during strong earthquakes in Romania, The 14th World Conference on Earthquake Engineering, Beijing, China.

Sandi, H., Cazacu, D., Constantinescu, C., Stancu, M., 1985, A summary of studies on the seismic vulnerability of buildings, carried out in Bucharest subsequent to the March 4, 1977 Earthquake, Joint US-Romanian Seminar on Earthquake and energy, Volume 2: Earthquakes.