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# The analysis of the behaviour of some historical consolidated buildings made of brick masonry to repeated earthquakes

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ABSTRACT: The paper approaches an important domain of the constructors activity: the rehabilitation of historical buildings, at that must participate equally the structural engineer and the architect. After an qualitative analyse and the evaluation of the risk level, the consolidation solutions follow the whole continuity restoring and the supplementary connection of the masonry structural walls for three buildings existing in Moldova and degradated by repeated earthquakes.

## 1 THE REHABILITATION PROBLEM OF HISTORICAL BUILDINGS

The historical monuments are for the world a message of the past; they illustrate technique and specific materials of the respective period.

Today, in our country, a great number of historical buildings, schools, houses of old noble families, are in different stages of degradation, due to the climaterical agents, repeated earthquakes, ground factors, fires and also because of the absence of their maintenance, conservation and protection works.

The inventory of this veritable national thesaurus, the estimation of the degradations and their causes, the present level of security of the building is a preocupation of all Romanian specialists, being coordinated by the National Committee for Monuments, Ensembles and Historical Sits, which is dependent on the Ministry of Culture.

The maintenance in exploatation of a historical building means, firstly, the assurance of the resistance and stability of the structure, realized often by brick masonry or stone. The rehabilitation operations are difficult because of the architectural details of the place, which must be kept, by the necessity of conservation of distinguished finishings: fresco, interior decorations etc.

We think that the consolidation of historical monuments is an engineering activity of great refinement, capable to restore the security and stability of the structure, without changing the essential message for posterity of the building, creating conditions for restoration and conservation.

There are reported brutal interventions by including the old masonry in concrete diaphragms, which causes the problem concerning the masonry breathing, ventured underbuildings which modify the ground stability, intervations occasioned by the privating in the ground floor of buildings, from historical sits which brings about serious damages to the exterior aspect, going to the complete alteration of the monument.

For these considerations reported and from the multitude of observations made in a zone with a great density of historical buildings (Moldova), the authors propose to comment on a series of aspects concerning the behaviour at repeated earthquakes of three historical buildings subjected to expertize after the seism on March, 4, 1977, for each building being elaborated the consolidation solution, also being given technical assistance in execution.

The authors analyse also the present stage (1992) of the consolidated buildings, making evident the role of masonry reinforcement, the efficiency of the binding (connection) which trusses and other compounds of the consolidation concerning the long - term behaviour.

## 2 CASE STUDIES

### 2.1 A military old building from Iaşi

This building, with a historical value, was begun in 1850, during the ruling of the Prince Grigore Alex. Ghica, when there were made the foundations, the basement and partially the ground floor. The works stopped after the abdication of the ruler, being resumed in 1875, when the Government sanctioned the completion of the works.

The building develops an H form with a length of 80,86 m and width of 31,80 m and 17,56 m; height over 19m. is divided into basement, ground floor, two stories and garret (unused), fig.1

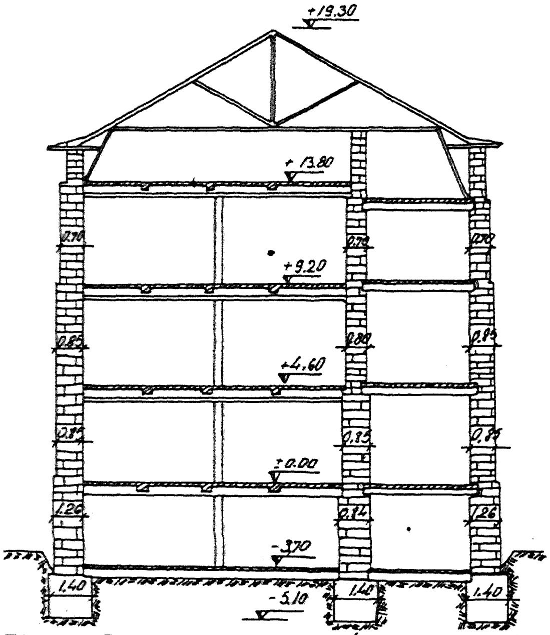



Figure 1. Cross-section (structure 2.1.)

The resistant structure of the building is realized by diaphragms of brick masonry, disposed longitudinally and transversally. The floors are made in two variants: over the basement ground floor and first storey they are of metallic beams, I section, with brick arches, the other floors are of reinforced concrete (slab and beams which are supported on diaphragms); the reinforced concrete slabs may have been realized at the reconstruction of the building, in 1935.

The infrastructure in the form of continuous stone footing under the masonry has a width of 1,40 m and continues to - 2,40 m.

The building roof is realised by a wooden framework, central props, braced in tongs with metallic bolts, over which the purling ridge is situated the roof timbers; they are supported on the purling ridge and on wall plates by braces. The openings for doors and windows in walls have at their upper part brick arches; at the exterior part, on the openings there were realized different frames with architectural role. To the same purpose the building has 12 towers of brick masonry, filled with stone.

### 2.2 The girls High school building from Bîrlad

This building was built in 1920-1921. The construction, in U form, develops on two levels, ground floor and 1 storey and has 920 m² areas. The general aspect of the building is pleasant. Externally the walls are adorned with relief profiles, coloured flanges; the architecture is specifical for the beginning of the 20 th century for teaching buildings and represents a historical building, the first construction from Bîrlad in which the concrete was used to a great extent.

The foundation is of stone and concrete, good quality, brick walls 62 cm. thick on the exterior and 46 cm. on the interior. The floors are of reinforced concrete. The walls are bound by flanges on the slabs bord, whose width is smaller than that of the wall. In two end walls there were used steel tension rods anchored with x profile for the binding of masonry, solution found in the important buildings realized in that time. The roof

Figure 2. Building 2.2 façade.

has wood framework; the roof covering was initially of tiles, and then, after the 1977 seism was replaced with galvanized steel sheet roof (fig.2).

2.3 The Sturdza House

Placed in Sterian Dumbravă Street in Bîrlad, the Sturdza House was built at the end of the 20 th century, his old age and the architectonical expression allow us to consider it a hystorical building, which must be preserved in the town patrimony.

The structure develops on one level, having a height of 5 m, the plane form being square (21,3 x 22,7 = 700 $m^2$). The building is made of one body with brick masonry walls and stone foundations; one stone block layer, included in clayey-sand-ground, binded with lime stone:, the floors are of wood; the roof is a wood framework, and the covering roof is of metal sheet. After the 2nd World War, till 1977, when it was evacuated, in this building there was the Bîrlad Court of . Justice. The plane of the house enables it to become a museum without any other modifications (fig.3).

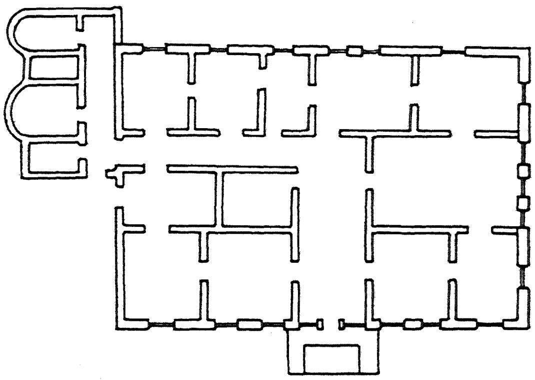


Figure 3. Plan structure 2.3.

## 3 DAMAGES

The longterm behaviour analysed of historical buildings at repeated earth quakes, described above, developed by one or more levels, with structural brick walls having big thichnesses, revealed a common spectrum of damages. It's possible to appreciate that, as a whole these buildings were made judiciously enough for the respective period, with a good quality material and careful execution.

The expertise of these buildings (1,2,3) was conditioned by the structural system damages (buildings of A1 category = built up to 1940, with ground floor and 4 floors, group a = with brick structural walls) /4/ .

The investigation method was the qualitative evaluation (E 1 - /4/)on basis of buildings examination, of all structure elements and of the important details, to appreciate the protection level, because there were no projects of the buildings; there were made damages surveys for each element.

The damages refer to:

. important cracking of walls placed about the principal wave direction of the seisms and even dislocations of diaphragm portions;

. cracks and dislocations at corners, crossings and allways in lengthways of areas where were made repairs, changes, openings fillings, without taking measures for binding the new masonry with the old one;

. important damages over the openings (doors, winddows), equipped with wood lintels or brick arches, in the form of vertical or inclined cracks, developed near the slabs.

The seismic risk level evaluation (R) using the simplified method of calculation for determining the resistance capacity (recommended by /4/ under the code E 3)was made using the relation :

$$R = S_{cap} / S_{nec} \qquad (1)$$

where:

$S_{cap}$ represents the seismic conventional capable load of the building - the base shearing force;

$S_{nec}$ being the conventional seismic load - the base shearing seismic force.

The seismic conventional capable load of the building was evaluated taking into account the natural seismicity of the place (Iaşi, Bîrlad)-zone C with $k_s = 0,02$ and $T_c = 1$; $k_s$ being the ratio between the maximum acceleration of the seismic movement of the ground, considered with an average period of return of about 50 years, corresponding to the seimic zone under calculation and the gravitation acceleration.

For the building 1 : $R_1 = 0,40 < R_{min} = 0,60$ (class II);

For the buildings 2 and 3 : $R_2 = 0,28$ and $R_3 = 0,20 < R_{min} = 0,50$ (class III)/4/, which proves quantitatively the intervention necessity.

## 4 CONSOLIDATION SOLUTIONS

To consolidation there were proposed some measures for maintaining of the existing configuration and fonction of the buildings, which refer to the repairing-remedy of the structural elements so that they be brought as closely as possible to their initial state, and even the increasing of the structural resistance and ductility by introducing suplimentary binding

elements. So:
. the structural walls, entirelly degraded, out by the construction plan (rarely cases) were pulled down and rebuilt;
. in highly cracked zones, the masonry was replaced on the degraded portion with new masonry, by weaving, using the same kind of brick and assuring the continuity of the structural wall (fig.4);

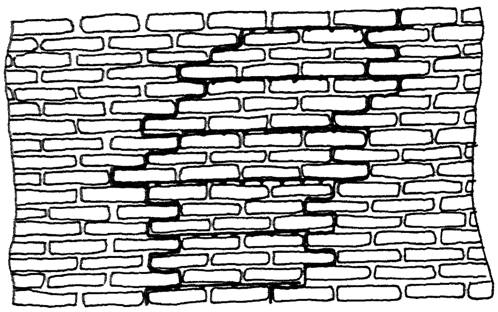


Figure 4. Masonry weaving

. with good results concerning the longterm behaviour there were applied reinforcing solutions of the vertical and horizontal joints of the new masonry embedding the nets in the old masonry opened by denticulations and by using a quality cement grount;
. the cracks partially penetrated in the walls were injected with epoxide resins or cement grount with polyvinylacetate by a technology elaborated by our group; for layer openings of the cracks there was used the unification of the two portions of masonry by metalic cramps;
. in the corner areas and masonry crossings there were introduced, along all the height of the wall, reinforced concrete corner blocks (inside and outside), connected among themselves (see figure 5);

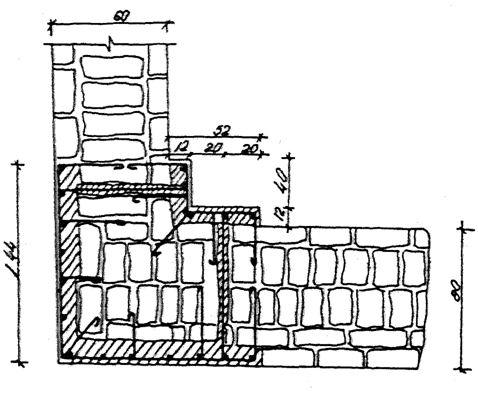



Figure 5. Waals connection

. at the upper side of the masonries there were disposed, on one side and the other of this, reinforced concrete girdles binded by flanges in the place where they were not provided (fig6)

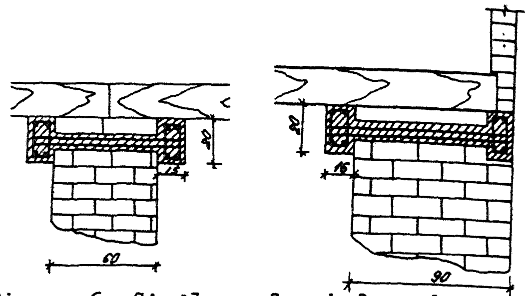
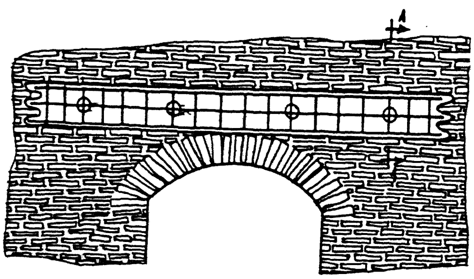



Figure 6. Girdles of reinforced concrete

. the chimneys of these old buildings abandoned by introducing central heating were transformed in reinforced concrete cores.
The damages appeared near the openings were resolved by:
. reduction the inside openings, so what they didn't affect the architecture of the assembly, by framing them with closed reinforced concrete frames,
. another solution was applied for consolidating the brick arches lintels by disposing twin lintels at the upper zone of the key (fig.7) for arch decharging, disposed inside and out-



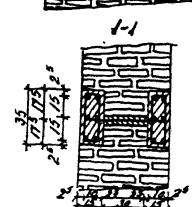



Figure 7. Arch consolidating

side of the wall (thick diaphragm) and binded with steel flanges, they were disposed in openings made in walls, from place to place, along the lintel, the cracks from arches being injected afterwards.
All this measures had in view to preserve the architectonical expression of the monument, the local introducing of same bindings being made

after considerable thought without apparent and brutish interventions.

The security level of the consolidated structure is superior to the minimum one provided by the Romanian Code /4/. The validy of the solutions which were applied for reabilitation was demonstrated by the adequate behaviour of the buildings during the next seisms.

## 5 CONCLUSIONS

We have stated in introduction that the reconstruction of historical buildings is a refined problem,which must be solved by an expert. To design a new building - resistant and stable - to built it now, at the end of 2 nd millenium, these are two actions in which we rediscover two proffessions: the structural engineer and the architect.

To rehabilitate a historical building, which belongs to the national patrimony is a more difficult problem. This intervention, from the analysis of the damages, the finding of the causes, the elaborating of the solution which ensures the resistance and stability of the building, the execution of the consolidating solutions, the restoration and the conservation of the monuments, supposes, in our opinion a "contiuous,persevering,fruitful dialogue between the architect and engineer, at the same level, with the same responsability, in equal hierarchy. This dialogue is that of CONSTRUCTORS" (cited from Le Corbusier).

It is necessary to remind that the great creator E.Torroja, in his treatise "The Philosophy of Structures" invite us to understand the structures, to feel them; this is also valid in the rehabilitation works of the historical buildings and this is what we tried to do: to fortify the crossings, to discharge the cracking arches, to weave the new masonry, to reinforce it in vertical and horizontal joints, to bind it with twin flanges, with undisturbing changes for the assemble architecture.

In the end I will cite the words of E.Torroja, for their beauty and message: "A structure is not a cold assemble of bricks, mortar, wood and iron. The structure is like a being which thinks, which wants or not, which suffers and which revolts itself, if is too much ill-treated".

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