MIXED STEEL-BRICK STRENGTHENING SYSTEM FOR DAMAGED MASONRY STRUCTURES

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SUMMARY

The “non”-seismic masonry buildings were built in the most countries, even their site is characterised by high seismicity. Such regions exist in Romania, also, in its Eastern and Southern territories, especially. The city of Galati is placed near the Romanian hipocenter from Vrancea region (about 150 km). The soil of Galati is macroporous and sensitive to the increase of the humidity. Of course, the last major earthquakes (1940, 1977, 1980, 1986, and 1990 years) were affected many masonry buildings from Galati. Generally, the reprofitting of these structures consists in the introducing of the reinforced concrete (as jackets or as infilled frames – belts and small columns). But, an important steel laminate factory exists in Galati and the use of the RC becoming uneconomic, in these special conditions.

The authors of this paper solved the fast strengthening of a very damaged masonry industrial hall using a new method: by the transforming the actual masonry structure into a mixed steel-brick one. The cost of the manufacturing and the strengthening materials were smaller than other usual solutions; the new safety factor increased about four times in these conditions, also.

The philosophy design, practical solutions and used verification analyses will be presented in this work. The good performance of the “new” composite material “steel-brick” is given by the high-tension capacity of the metal and the ability to takes over the compression stresses of the masonry part. Maybe, this solution will be extended in other similar cases, because of its advantages.

INTRODUCTION

The laminate steel strengthening of damaged civil or special structures (build from reinforced concrete frames) is one of the usual methods, if the architectural restrictions do not are imposed. For this reason, the effective works consists in the same jacketing, covering with the cement mortar. This “rigid” steel – “soft” RC core co-operation means:

- A great quantity of the works and additional steel with some difficulty details
- Long duration of the execution
- Interrupting of the activities in the building during its reprofitting
- High final costs.

In the case of the masonry structures, the main strengthening methods is the reinforced mortar (or concrete) jacketing or introducing of a secondary subsystem, consisting in the “weak” infilled RC frames (horizontal belts with thick columns). These solutions have similar deficiencies with the first presented ones.

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The both variants lead to the increase of the total weight of the strengthened building, (first being the jacketing method). Consequently, the interventions over infrastructures (foundation system) can't be omitted, so the final costs being too great.

The "full" activities in an old damaged masonry industrial hall from Galati imposed the finding of another strengthening solution. We named this variant as "mixed steel-brick strengthening system". One found a similarity with the composite materials and structures. The philosophy of this solution, the practical application and the computing informations are given in this paper.

A SHORT DESCRIPTION OF THE DAMAGED INDUSTRIAL MASONRY BUILDING

A single story industrial construction (from Galati, build in 1910 year) was composed by the following structural members:

- perimetral perforated (or not) masonry walls, with contraforts (and one transversal in its interior)
- interior RC columns
- RC floor with longitudinal and transversal beams
- "Weak" stone masonry continuous foundations.

The successive major quakes (the last four mentioned ones) leaded to the major fragmentation of their masonry walls, as in the Fig. 1. The RC members (columns, girders and floor) and masonry interior contraforts rested undamaged, now these space frame being the last survival line (without the earthquake actions).

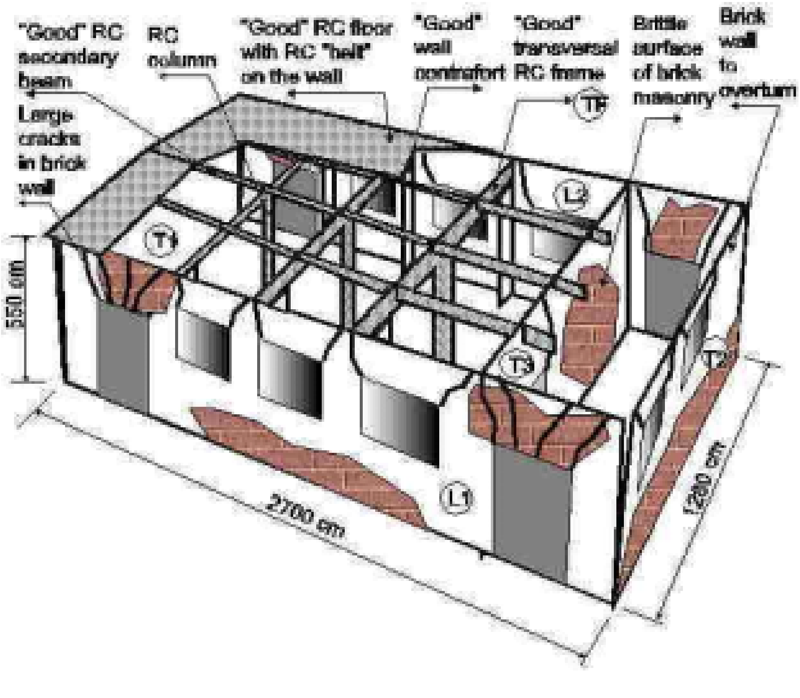

Fig.1. A very damaged masonry building, in the pre-collapse phase.

PHILOSOPHY DESIGN OF THE DAMAGED STRUCTURE STRENGTHENING

The main condition to the re-establish a reasonable earthquake assurance level (safety factor) for shown single storied masonry structure was its maintenance as working industrial space, during strengthening activities. The second condition was the elimination of the intervention of the subsystem footings. And the third one resided in the absence of the workers specialised in RC strengthening, but in the excess of the locksmith and welder workers. The steel laminate profiles are fairer than RC components in the Galati region, also.

The FEM analyses of some “classical” solutions (RC jacketing, RC infilling “easy” frames, steel frames adding, introducing of the horizontal steel tirrants only, rebuilding of the destroyed walls panels – almost all works with the necessary extension of the base of the continuous footings) shown the impossibility of to respect the mentioned restrictions.

Tacking into account these findings and primary restrictions, the authors of this paper decided the following measures:

- To keep the all-existent members in the reabilited structure, (“good” – RC members and masonry contraforts; “bad” – masonry walls), but to reduce the asymmetry in transversal direction and to eliminate the “gaps” by cement mortar injections.

- To introduce the laminate steel profiles in two ways: a. to create the mixed steel-brick columns from actual interior contraforts, with a insignificant increase of their weight; b. to offer a high ability at tension stresses for actually damaged masonry panels by inclined tyrants.

- To keep actual dimensions of the footings, because the increase of the total weight is insignificant (about 1.5%) and the new structural conformation may take over the possible small local depressions of some footings, (soil being sensitive to the increase of the humidity).

PRACTICAL MIXED STEEL-BRICK STRENGHTENING SOLUTIONS

The general schematic view of the “new” type of the strengthening – with “steel-brick” transformations – is given in the Fig. 2.

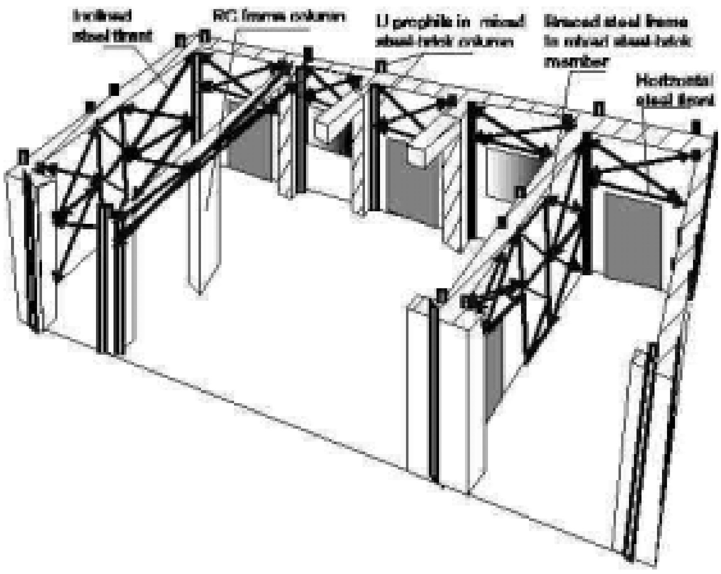

Fig. 2. Scheme of the general mixed steel-brick strenghtening

Some “mixed steel-brick columns” details are given in Fig. 3, while the vertical projections are shown in Fig. 4 and 5. The photo images are given: a. in Fig. 6 – for interior, (with the first author’s paper showing details); b. in Fig. 7 – for exterior, (left – without concrete protection, right – after execution of the protection).

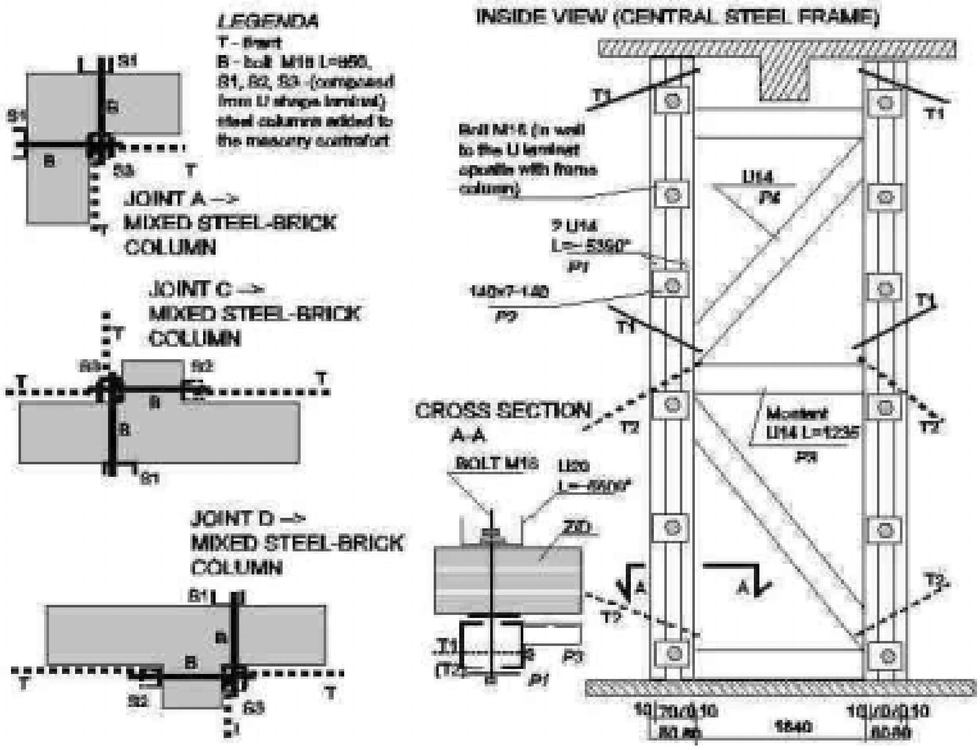

Fig. 3. Details of mixed "steel-brick" columns

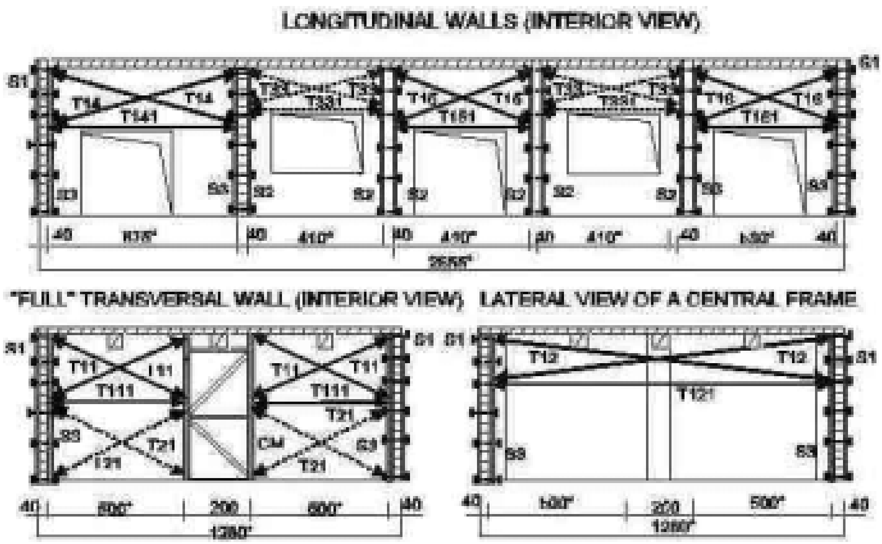

Fig. 4. Interior views of the strengthening (I)

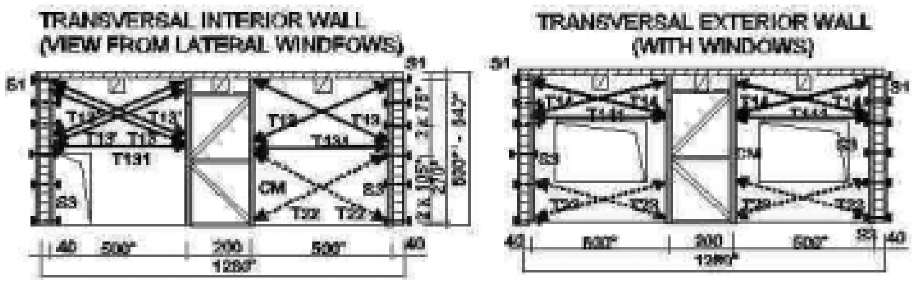

Fig. 5. Interior views of the strengthening (II)

Fig. 6. Interior images after strengthening

Fig. 7. Exterior images after strengthening

The connections of the steel “columns” with the masonry zones by steel bolts can assure a good avoiding of the slippings; the entire steel-brick core becoming a mixed column, with the extremes parts (U steel profiles) placed in the maximal stresses zones.

The tyrants systems and superior connections through RC floor plan offer a space behaviour of the entire structural system; even the footing subsystem remains the same.

On the other hand, the inclined tyrants introduce a superior capacity for diagonal tension for wall panels (between mixed steel-brick columns). This effect means the avoing the dangerous diagonal tension in the wall panels, which produced the “old” inclined, cracks and fractures, (now eliminated by the cement mortar injections).

The transversal tyrant system near the “lateral” RC frame was placed for to increase the stiffness of this substructure (weaker than the equivalent interior transversal opposite masonry wall).

ANALYTICAL COMPARATIVE STUDIES

The efficiency of the various strengthening methods were verified by the use of the FEM analyses, with computer program SAP90. Two kind of the elements were considered:

- SHELL for panels (from old masonry only, for composed "old masonry + reinforced cement mortar jackets < M100T class >", for RC floor plates)

- BEAMS for "bars" (from "mixed steel-brick" columns or steel columns and girders, for RC columns and girders, for steel tyrants).

The Young's modulus, E was correlated with the selected strengthening solution:

- For "simple" damaged brick masonry: 10000, 15000, 20000 daN/cm.p. – after damage degree of each panel

- For mortar cement jacketed masonry:

$$E_{ech} = \left\{\sum_i \left[\left[B_i E_i\right]\right]\right\} / \left\{\sum_i \left[B_i\right]\right\} \tag{1}$$

Where: Bi- thickness of the "i" part ; Ei – Young's modulus of the "i" part → ≈ 100000 daN/cm.p. for reinforced cement mortar

- For RC members: 200000 daN/cm.p.

- For steel members only – cases: a. space steel moment frames; b. tyrants < as single strengthening measure or as a part from "mixed" solution >; c. each laminate U bar in a first analyses idealisation: 2100000 daN/cm.p.

- For "mixed steel-brick" columns:

$$E_{ech} = \left\{\sum_i \left[I_i E_i\right]\right\} / \left\{\sum_i \left[I_i\right]\right\} \tag{2}$$

Where: Ii- inertia moment of the "i" part ; Ei – Young's modulus of the "i" part .

The spectral analyses for three directions were used: a. transversal; b. longitudinal; c. "diagonal" (at 45 degree). The calibration of the shear base coefficient was conditioned by the solution type; the "wrong" behaviour being accepted for "single masonry" and better for "mixed" one, (the value of factor $\psi \approx 1/R$ varying between 0.6 and 0.3). These values were been deduced from a special comparative study of other known strengthening structure cases.

Some results are relevant for this application:

- Necessity of the footing base "enlarging": a. the "tyrants only" and "mixed steel-brick" do not need same work; b. the "RC supplementary infield frames" and "steel supplementary frames" need minor enlargings of the base footing system (with 15 % for RC and 17.5% for steel); c. the "reinforced mortar jacketing" need a "major enlarging of the base footing system (with 22%). So, the selected solution a very good.

- The decrease of the diagonal tension in actual wall panels: a. the "tyrants only" system has an insignificant effect (the stress reduction being about 1-2 % only); b. the "RC supplementary infield frames" has a similar reduced effect (the stress reduction being about 1.5-2.7 % only); c. the "steel supplementary frames" leaded to the appropriate results with the RC frame solution (the stress reduction being about 1.3-2.4 % only); d. the "reinforced mortar jacketing" means a good solution (the stress reduction being about 35-42 %); e. the "mixed steel-brick" solution was comparable with the reinforced mortar jacketing" (the stress reduction being about 31-39

%). Remark: the "mixed steel-brick" solution can be a very good alternative for reinforced mortar jacketing solution.

- The steel consume in the strengthening works: a. the "tyrants only" need about 1.2-1.4 tones; b. the "RC supplementary infield frames" means 2.5-3.0 tones; c. the "reinforced mortar jacketing" need about 8-10 tones; d. "mixed steel-brick" solution means 10-12 tones; e. "supplementary steel frames" lead to the maximum consume → 22 tones.

- If one will take into account and the non-necessity of the interventions over continuous footing subsystem and the other advantages, one can conclude the priority of the new solution – the "mixed steel-brick strengthening".

- Two variants of the idealisation for the "mixed steel-brick" model are tested:

  a. With "weak parallel steel columns (BEAMS finite elements) coupled by hinges (at the bolts)" and the "initial" masonry panels (SHELL finite elements);

  b. With "effective mixed steel-brick continuous" columns (BEAMS), each segment being delimited by the bolts" and the "new masonry panels" (zones delimited by the mixed columns, foundations and superior floor).

  The differences between the two variants were under 0.7%. Consequently, one can consider a valid the first idealisation the "composed steel-brick column".

A suggestive graphic representation of the anterior data is given in Fig. 8.

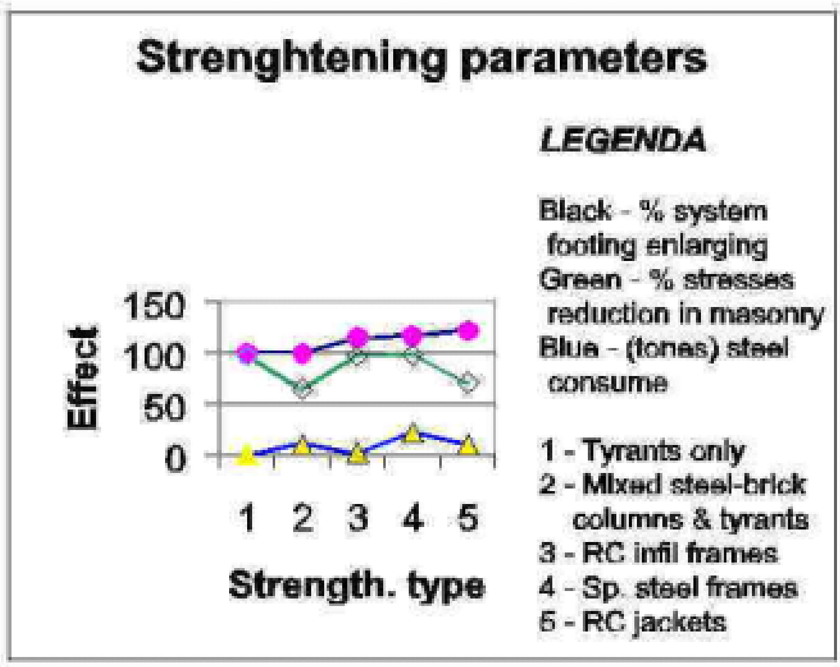

Fig. 8. Comparison among the analysed strengthening solutions.

One can see the beneficial effect of the damaged masonry structure changing into a "composed" one, with:

- Strong mixed steel-brick columns in co-operation with interior RC frames and floor

- "Interior" masonry panels which can take over more diagonal tension stresses that the usual masonry walls

- A lateral supplementary "braced" tyrant system to compensate the initial transversal eccentricity, the cause of the torsional earthquake response oscillations.

This solution will lead to a major increase of the safety factor at the severe earthquakes, even without the interventions over the infrastructure placed on the soft and "bad" soil, (macroporous and sensitive to the increase of the humidity).

CONCLUSIONS

Many masonry buildings were built in high seismicity areas, having and other unfavourable conditions, as foundations over a macroporous soil who is sensitive to the increase of the humidity, also. Generally, the reprofitting of these structures consists in the introducing of the reinforced concrete (as jackets or as infield frames – belts and small columns / in the suprastructures; as "boxes walls" / in infrastructures). Unfortunately, these methods mean a consistent quantity of the manual labour, with a long duration of the execution.

The authors of this paper solved the fast strengthening of a very damaged masonry industrial hall using a new method: by the transforming the actual masonry structure into a mixed steel-brick one. The cost of the manufacturing and the strengthening materials were smaller than other usual solutions; the new safety factor increased about four times in these conditions, also. And the duration of the execution results very shortened, in the special condition to keep the building in use (as factory).

The proposed philosophy design is in accord with the actual international provisions. The practical solutions are enough simple. At the same time, the needed verification analyses can be done using the well-known FEM programs, by the introducing of some equivalent formulas for mechanical properties of the "composed" materials.

The good performance of the "new" composite material "steel-brick" is given by the high-tension capacity of the metal and the ability to takes over the compression stresses of the masonry part. On the other hand, the inclined steel tyrants reduce the sensibility of the wall panels at diagonal tension. The all results shown an important increase of the safety factor for the next design earthquake.

The authors think that this new solution can be extended in other many similar cases, because of its advantages.

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