STRUCTURAL REHABILITATION OF HISTORICAL MASONRY BUILDINGS IN ROMANIA

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Summary: *The paper is focused on the analysis, redesign and rehabilitation solutions applied for old existing structures in seismic zones. The old malting building, erected between 1857-1876 at the "Timisoreana" Brewery, is a five storeys masonry structure and a tower composed of: walls of (140-50) cm thickness; inter-storey floors - brick masonry vaults supported by steel profiles; a tower, of about 14 m height and 2.80 m diameter, supported by an interior dome. The main structural damages were: vertical cracks in the tower masonry structure; corrosion of steel members – horizontal circular rings for confining the tower; steel profiles for supporting the floor masonry vaults. The static and dynamic analysis at different actions showed up major structural vulnerability, mainly due to the period of design and erection (19th century). In order to preserve the old building as architectural monument and to reduce the seismic failure risk, some strengthening solutions were designed and applied. The strengthening solutions were selected in order to obtain technical and economical advantages: safe behaviour at seismic actions; slight change of overall structural stiffness; easy strengthening technology and short refurbishment period; low rehabilitation cost.*

Keywords: *masonry structures; old buildings; seismic zones; stability; strengthening solutions; carbon fibre reinforced polymers (CFRP)*

1. INTRODUCTION

The main target of the paper represents the rehabilitation of an old masonry buildings located in seismic zones. Masonry structures present some important vulnerability in seismic zones: the overall lateral stiffness values along the two main axes are different; lack of seismic joints to divide building parts having different dynamic characteristics; lack of reinforced concrete straps at each level; defects of wall connections at corners, crossings and ramifications as well as the presence of cracks; inadequate bearing capacity at normal forces on the walls.

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On the other hand, structural weakness is characterised by various irregularities and discontinuities or by general structural vulnerabilities: irregular distribution of stiffness at lateral displacements; strength discontinuities; mass irregularities; vertical load discontinuities.
Existing masonry structures without reinforcement may be strengthened by different classic and/or modern technologies: erection of RC cores at appropriate distance combined with straps at each level; masonry jacketing with reinforced concrete; masonry confinement with steel profiles; masonry coating with CFRP systems; interlocking of masonry walls at corners, crossing and ramifications with RC elements and/or some steel profiles; adding new inner walls and/or some outside abutments.

2. REHABILITATION OF A TOWER STRUCTURE

The old malting building, erected between 1857-1876 at the "Timisoreana" Brewery, is a five storeys masonry structure and a tower (*Figure 1*) composed of:

- walls of (140-50) cm thickness;
- inter-storey floors - brick masonry vaults supported by steel profiles;
- a tower, of about 14.00 m height and 2.80 m diameter, supported by an interior dome.

Figure 1. Old malting building

2.1 Structural assessment

The assessment of the structure was performed in 2007 according to the present-day Romanian codes for existing structures and codes for design loads magnitude.
The main structural damages are:

- vertical cracks in the tower masonry structure (*Figure 2*);
- corrosion of steel members: horizontal circular rings for confining the tower; profiles for supporting the floor masonry vaults.

Figure 2. Vertical cracks of masonry tower

The static and dynamic analysis at different actions showed up major structural vulnerability, mainly due to the period of design and erection (19^{th} century):

- the tower, about 14 m high, presents general instability at seismic actions: the total bending moment at tower base leads to an eccentricity $e_0 = 1.78\ m > D_{ext} / 2 = 1.50\ m$ where D_{ext} is the tower exterior diameter;
- in some zones of the tower masonry structure actual stresses, due to various loads, are greater than the tensile strength R_{ti} of masonry:
  - σ_{ef} = 0.93 daN/cm^2 > R_{ti} = 0.8 daN/cm^2 at the tower – dome crossing (50 cm width masonry);
  - σ_{ef} = 3.10 daN/cm^2 > R_{ti} = 0.8 daN/cm^2 at the tower base (20 cm width masonry);
- in the masonry dome, which supports the tower, the actual stresses by parallel direction are:
  - σ_θ = 0.85 daN/cm^2 > R_{ti} = 0.8 daN/cm^2 at the lower part of the dome;
  - σ_θ = 2.19 daN/cm^2 > R_{ti} = 0.8 daN/cm^2 at the upper part of the dome;
- temperature variations inside-outside the tower produce actual stresses σ_t = 1.0 daN/cm^2 > R_{ti} which causes the vertical cracking.

The structure, also, presents general and specific detailing lacks: no rigid floors at two storeys; no straps at all levels; the ratio between span and width of masonry shear wall is too large. These major vulnerability classify the structure as having high risk of failure at present seismic code design magnitude.

2.2 Strengthening solutions

In order to preserve the old building as architectural monument and to reduce the seismic failure risk, the following strengthening solutions were designed:

- for general stability of masonry tower: vertical reinforcement (*Figure 3*) bars (4 x 2ϕ28) embedded at the upper side of the tower in a RC beam (*Figure 4*) and welded on steel profiles (*Figure 7*) I 30 placed in the dome, at the tower base (*Figure 5*); vertical CFRP wrap (4 x 2 strips of 20 cm width) on the entire tower height (*Figure 3*);

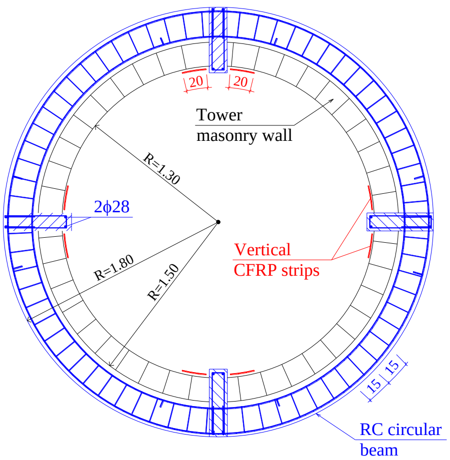

Figure 3. Tower strengthening at base section

- in masonry structure, at zones with stresses greater that masonry tensile strength, were placed horizontal RC straps: at the tower – dome crossing (*Figure 3*); at the base of dome; at the level of steel profiles I 30 network (*Figure 5*) for its embedding into vertical masonry structure;
- on the vertical cracked tower: corroded circular steel rings for confining the tower

on outside face were replaced by horizontal CFRP strips (*Figure 6*).

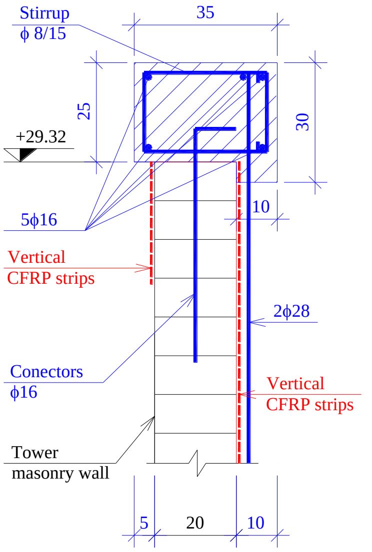

Figure 4. Tower strengthening at top section

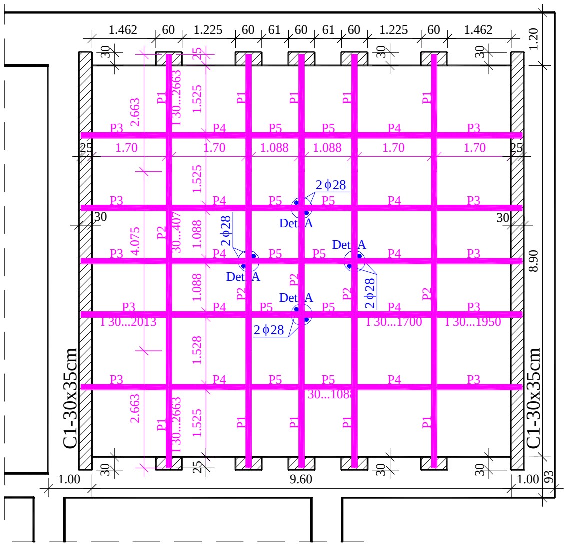

Figure 5: Steel beams network for tower stability

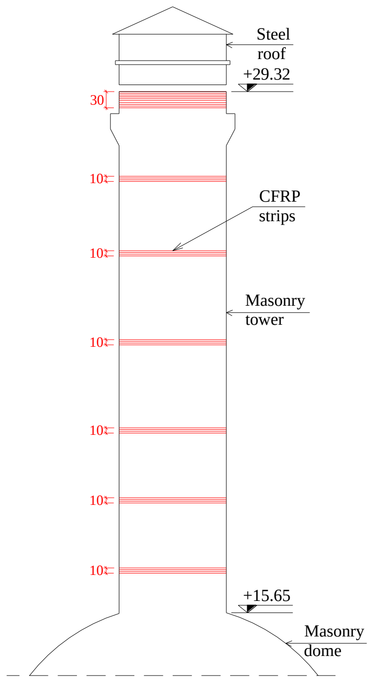

Figure 6. CFRP strips for tower confinement

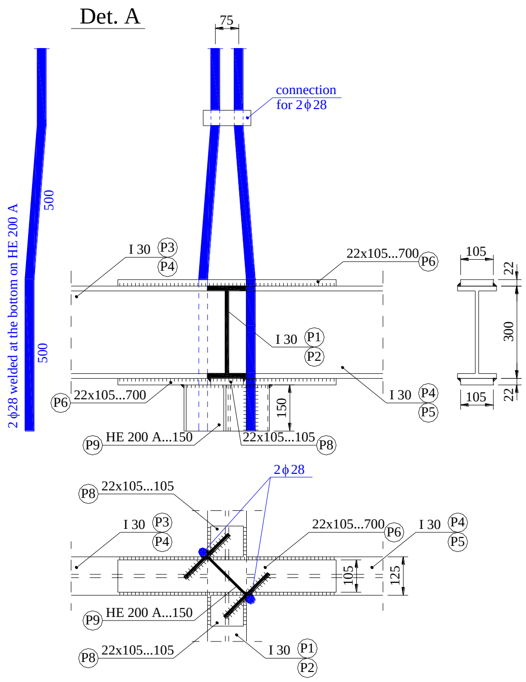

Figure 7. Detail of connection between vertical bars and base steel profiles

2.3 Construction procedures

The old malting building at the “Timisoreana” Brewery was firstly repaired and rehabilitated.
Than, in 2008, the masonry tower structure was strengthened (*Figure 8*).

Figure 8. Strengthening of tower structure

In the dome, at the tower base was placed the steel beams network (*Figure 9*) and embedded in the masonry walls by means of reinforced concrete straps (*Figure 10*).

Figure 9. Steel beams network

Figure 10. RC straps for steel beams embedding

The general stability of masonry tower was ensured by vertical reinforcement bars and vertical CFRP wrap on the entire tower height (*Figure 11*).

Figure 11. Vertical rebars and CFRP strips

Vertical reinforcement bars were embedded at the upper side of the tower in a reinforced concrete beam (*Figure 12* and *Figure 13*) and welded at the bottom side on steel profiles from the tower base.

Figure 12. Reinforcing of the tower top beam

Figure 13. Reinforced concrete top beam

3. CONCLUSIONS

The assessment of the old malting building, erected between 1857-1876 at the "Timisoreana" Brewery, emphasized some structural damages and the static and dynamic analysis at different actions showed up major structural vulnerability, mainly due to the period of design and erection.
In order to preserve the old building as architectural monument and to reduce the seismic failure risk, the following strengthening solutions were designed and applied:

- for general stability of masonry tower: vertical reinforcement bars embedded at the upper side of the tower in a RC beam and welded on steel profiles placed in the dome, at the tower base; vertical CFRP wrap on the entire tower height;
- in masonry structure, at zones with stresses greater that masonry tensile strength, were placed horizontal RC straps: at the tower – dome crossing; at the base of dome that supports the tower; at the level of steel profiles for its embedding into vertical masonry structure;
- on the vertical cracked tower due to temperature variations: corroded circular steel rings for confining the tower on outside face were replaced by horizontal CFRP strips.

The strengthening solutions for rehabilitation of historic structure were selected in order to obtain technical and economical advantages: safe behaviour at seismic actions; slight change of overall structural stiffness; easy strengthening technology and short refurbishment period; low rehabilitation cost.

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