Energy Saving with Rehabilitation Solutions for Existing Structures

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Abstract: - The paper deals with aspects regarding energy saving of reinforced concrete existing structures strengthened in seismic zones. Some case study and the rehabilitation of characteristic structures are analysed. The rehabilitation solutions were chosen in accordance with the actual stage of building deterioration as well as function of the actions characteristics. Classic (reinforced concrete and/or steel) and modern (Carbon Fibre Reinforced Polymers) materials and technologies for strengthening have been used. Finally, the total cost of strengthening solution and the energy used with raw materials are presented.

Key-Words: - Existing reinforced concrete structures; Seismic action; Strengthening; Classic rehabilitation solutions; Modern rehabilitation techniques; Carbon fibre reinforced polymers (CFRP); Raw material; Embodied energy.

1 Introduction
Sustainable construction has recently been identified as one of lead markets for the near future of Europe because of its high innovation potential, its ability to respond to market needs, the strength of European industry and the necessity to support it through the implementation of public policy measures.

The main concept of sustainability regards buildings with a long service life, low operating and maintenance costs and high energy efficiency.

In addition the sustainability is based on the environmental, economic and social components and includes criteria such as technical process and site quality. A global quantitative model for evaluating the sustainability is difficult to be produced but for each structural element or building it may be established. In this paper the calculated components of sustainability are: total cost of strengthening solution; the energy used with raw materials.

The sustainability and the energy saving of the strengthening solutions were slightly discussed in comparison to the new buildings.

Three strengthening solutions will be analyzed in the paper. The strengthened elements are existing reinforced concrete columns as vertical structure of different constructions.

The rehabilitation solutions are:
- steel bracing with four angle steel shapes connected by flange plates;
- carbon fibre polymer composites (CFRP): longitudinal strips and transversal wraps;
- jacketing by reinforced concrete using longitudinal reinforcement bars and transversal stirrups.

2 Rehabilitation Solutions

2.1 Structural rehabilitation using steel profiles vs. carbon fibre reinforced polymers

2.1.1 Reinforced concrete silos
The assessment and rehabilitation solutions for a group of silos owned by the SAB Miller Brewery Company “Timisoreana” are presented. The silos (Fig.1) were built 40 years ago and stand 28 m high and 7.30 m in diameter.


Fig.1. RC silos.
The silos infrastructure consists of foundation raft, discharge funnel and its supporting columns and beams. The main damages are due to water infiltration and high humidity inside of each cell bottom part, which caused important dislocated concrete cover and corrosion of the columns steel reinforcement (Fig.2).

The strengthening of supporting columns for the discharge funnel consists of steel profiles (Fig.3). This solution has a smaller cost than CFRP materials. On the other hand, steel profiles have a better buckling behaviour than CFRP strips.

In order to have the comparison of sustainability and energy saving criteria of the rehabilitation solutions, the column strengthening was re-designed using CFRP as follows (Fig.4):

- longitudinal strips S1012, on four sides, having a width of 100 mm, a thickness of 1.2 mm and the length of the column. The strips were anchored in foundations and at the top joints;
- transversal confinement with a single layer of wrap closed jacket at both ends of the columns. The jackets had a width of 900 mm and a thickness of 0.12 mm.

2.1.2 Reinforced concrete framed building
The Western University of Timisoara has many buildings, among them the Main Building (Fig.5 and 6) that is used as administrative part as well as classrooms for students, was built in 1962-1963.

The RC structure consists of:
- transversal and longitudinal frames with eight storeys and two spans of 5.6 m and eleven bays of 3.8 m;
- floors with girder mesh in two directions and a slab of 10 cm;
- foundation with a thick slab and deep beams in two directions.
On examination of the building and from non-destructive measurements no important damages of the RC structure were noticed. Some local damage due to incipient reinforcement corrosion was detected at the columns of the ground storey.

The analysis of the structure has been performed at both combinations of actions: fundamental combinations and special combinations including seismic action at present-day level. From the analysis it was noticed:

- weakness of reinforcement and insufficient anchorage of beam-positive reinforcement at the beam-column joint, especially in the longitudinal direction;
- the drift limitation conditions are not within the admissible limits at the ground storey.

Rehabilitation solution consists in strengthening of the columns located at the ground storey (Fig.7 and 8); some columns were strengthened in 1999 to prevent the local damages due to reinforcement corrosion; the other columns were rehabilitated in 2004 for decreasing the lateral displacements (drift limitation conditions) and for a homogeneous columns stiffness at the ground storey.
In order to have the comparison of sustainability and energy saving criteria of the rehabilitation solutions, the column strengthening was re-designed using CFRP as follows (Fig.9):

- two longitudinal strips S1014, on each of the four sides, having a width of 100 mm, a thickness of 1.4 mm and the length of the column. The strips were anchored in foundations and at the top joints;
- transversal confinement with a single layer of wrap closed jacket at both ends of the columns. The jackets had a width of 1200 mm and a thickness of 0.12 mm.

Fig.9. Strengthening solution with CFRP.

2.2 Structural rehabilitation using reinforced concrete
The "Palace" structure (Fig.10) is a huge building (underground floor, ground floor - restaurant, 3 storeys - apartments, timber roof), built before 1900's with a composite structure: masonry and reinforced concrete framed structure (Fig.11).

Initially it was an entire masonry structure, but later the ground floor was changed: some resistance brick walls were cut and two longitudinal RC frames were erected to sustain all the vertical loads. Due to this architectural operation the structure became more vulnerable at seismic actions: by the transversal direction main part of the ground floor became unstable at horizontal actions because of some erected columns with hinge connection at both ends (masonry wall supports from the underground floor and ground storey). Other vulnerabilities of the building consist of: 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 straps at each floor.

The building assessment emphasized some aspects: concrete quality is very variable in structural elements, having different classes (C8/10 - C16/20); some cracks in longitudinal beams; corrosion of the slab reinforcement; etc.

From the static and dynamic analysis a very important conclusion could be drawn: the earthquake capacity ratios R between the actual values of ultimate bending moment (M_{cap}) and the necessary bending moment (M_{nec}), given by the present-day seismic action level, were very low for columns. That meant that the building was characterized by a high risk of collapse at seismic actions. Resulted the necessity of structural rehabilitation.

In accordance to the structural analysis, the strengthening of the ground floor was chosen in order to obtain technical and economical advantages: safe behaviour at seismic actions; slight change of the overall structural stiffness; easy strengthening technology and short period of refurbishment (December 2004 - June 2006).

The strengthening have been made on the following structural elements:
strengthening by RC coating (7 cm on each side) of masonry walls from the underground floor of the building;

new reinforced concrete floor with embedded steel profiles (HEB 220) in two directions, which stands as beams for the new structure;

strengthening of half from the existing columns (60x60m coated by RC to become 90x90cm – Fig.12) and erecting of new transversal RC beams in order to create new transversal frames (Fig.13);

strengthening by RC coating of existing longitudinal beams;

rehabilitation of some structural elements having corroded reinforcement.

Fig.12. Strengthening of columns.

Fig.13. Ground floor rehabilitation.

3 Embodied Energy of Rehabilitation Solutions

The calculated characteristics of the five strengthening solutions were: the total cost of strengthening solution; the total energy for each solution, based on embodied energy of raw materials. The results of the analysis are presented in Table 1.

<table>
<thead>
<tr>
<th>Strengthening solution for columns</th>
<th>Cost</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total [€]</td>
<td>Per m² [€/m²]</td>
</tr>
<tr>
<td>RC silos</td>
<td>33200</td>
<td>49</td>
</tr>
<tr>
<td>steel bracing *</td>
<td>71800</td>
<td>105</td>
</tr>
<tr>
<td>CFRP ▲</td>
<td>48200</td>
<td>102</td>
</tr>
<tr>
<td>RC frame</td>
<td>76000</td>
<td>161</td>
</tr>
<tr>
<td>steel bracing *</td>
<td>21800</td>
<td>53</td>
</tr>
<tr>
<td>CFRP ▲</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: * applied solutions; ▲ CFRP solutions designed for comparison;
- for the cost per m² the total construction rehabilitated area was taken into account.

Table 1. Main characteristics of strengthening solutions.
The main conclusions from this data are:

- The energy saving regarding structural strengthening is possible by using CFRP – strips and wraps.
- The strengthening by steel bracing and RC jacketing are energy consuming solutions in comparison to the CFRP solutions.

4 Final Conclusion

The main ideas which may emerge from these studies are:

a) As structural rehabilitation for existing reinforced concrete structures several strengthening solutions may be used: steel bracing; carbon fibre polymer composites (CFRP); jacketing by reinforced concrete.

b) For energy saving is important to use building materials with minimum embodied energy during manufacturing process.

c) For strengthening of the existing structures the energy saving is possible by using modern CFRP materials (strips and wraps).

d) The manufacture time is also shorter in case of using CFRP in comparison to classic strengthening solutions (steel bracing or reinforced concrete jacketing).

e) The cost of CFRP solutions for strengthening is higher than other solutions.

f) Using of CFRP solution for strengthening of columns may be inadequate in case of structural stiffness increase demands.

References:


