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THE RETROFITTING OF REINFORCED CONCRETE COLUMNS

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Abstract: *The retrofitting of a building requires an appreciation for the technical, economic and social aspects of the issue. Choosing the optimal solution depends on a large variety of criteria, the most important being the total cost, the construction time length (eventually with the possibility of continuous usage of the building), the ease of technologies application etc. The first part of this paper briefly presents classic and modern retrofitting technologies for industrial buildings. The second part represents a study case of a single storey industrial building retrofitting, using four different intervention options.*

Keywords: reinforced concrete column, concrete jacketing, steel jacketing, stirrup

1. Introduction

Nowadays tendency of urban reconfiguration according to actual inhabitants necessities lead to relocation, conversion or even vanishing of many industrial areas. Whether the industrial buildings left in place keep the initial destinations or receive new ones, rehabilitation measures are imposed in order to guarantee their functionality in safety conditions and, on the other hand, to offer better comfort.

Seismic evaluations show that the old structures not correspond to the new seismic code, more restrictive on design requirements. Additionally, a long service period (more than 35 years), the major earthquake actions in Romania (1977, 1986, 1990), permanent external factors exposure and eventually an improper maintenance of the buildings (without current or capital repair operations) could easily cause serious damage to structural elements.

The best solution for building consolidation must simultaneously meet the following features: to be cheap, fast and easy to implement, environmentally friendly and without personal evacuation or significant implications for technology and business process inside the building or in the immediate vicinity. The particularities of any given case made that process of optimal solution choosing to be often difficult, requiring comparative analysis, careful calculations and of course a rich experience in building design.

Presented below, there is a comparative analysis of variants of building seismic retrofitting for an industrial building that was technical recently evaluated. In order to find the best retrofitting solution, several variants were proposed for a comparative analysis:

- reinforced concrete jacketing method;
- steel jacketing method (with angles and welded bands);
- European wide flange steel profile, placed on one side of the RC column.

2. Case study

The analyzed single storey industrial hall was designed and built in 1970 near Pitesti City, having a simple plan configuration (8 spans x18 m / 5 bays x12 m).

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Precast concrete columns with a constant cross section 60x60 cm2 are fixed on pad (bucket) foundations. The roof structure is a bidirectional net, consists of 18 m and 12 m trusses that support precast caissons. Vertical clearance under the trusses is 6,00 m and the total height of the building is 8,50 m. The building has no cranes.

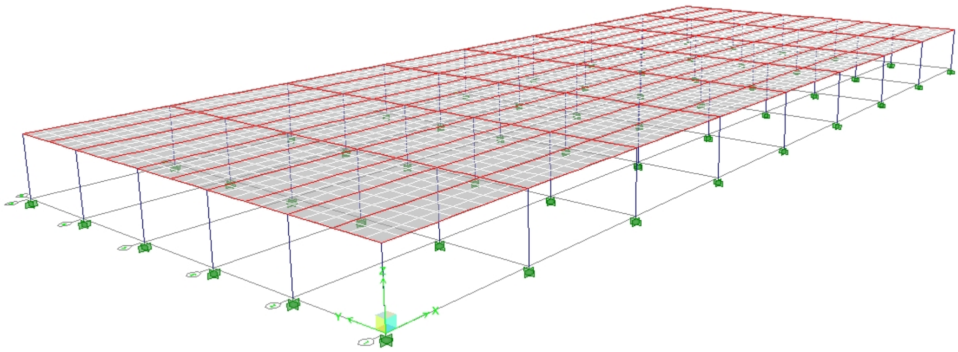


Figure 1: The industrial building 3D model

In term of seismology, the building location is characterized by a peak ground acceleration ag = 0,25g and a corner period Tc = 0,70s, according to Romanian seismic code, [1].

Although the building was scheduled to keep the original destination, the owner requested the technical evaluation in order to establish the level of current damage, the correct assurance degree to seismic actions and whether the structures should be consolidated.

Information resulting from a non-destructive testing program, with direct influence on the technical condition of structural components:

- concrete strength: C16/20;
- longitudinal reinforcement: 4Ø20 PC52 (S355) / on every side;
- transversal reinforcement: Ø8 OB37 (S235) stirrups at 14 – 17 cm;
- concrete cover varies from 2 to 5 cm.

According to the Technical Evaluation Report, the general state of the structure after 40 years of operation was considered to be satisfactory. Earthquakes of 1977, 1986 and 1990 did not produce noticeable damage, although the degree of seismic assurance set by initial design project was obviously less than that provided by current prescriptions. During the building life cycle there were no structural interventions on the elements.

The automatic calculations performed using the response spectra, revealed the following data:

a) vibration periods of the structure:

- the first mode of vibration (translation on longitudinal direction): T1 = 0.87 s;
- the second mode of vibration (translation on transversal direction): T2 = 0.85 s;
- the third mode of vibration (general torsion): T3 = 0.77 s.

b) maximum lateral displacement under seismic action associated with the ultimate limit state exceeded the allowable displacement ($d_{adm} = 193mm$):

- longitudinal direction (x-x): $d_x = 225mm$
- transversal direction (y-y): $d_y = 205mm$.

The flexibility of the building determines the development of lateral displacement associated with extreme seismic, site-specific, beyond the limits imposed by the rules in force at the date of analysis.

Conclusions of the technical expertise proved that analyzed structure had not the strength and deformation capacity required to support, without adverse consequences, major specific earthquakes. Longitudinal and transversal reinforcement of columns was insufficient for heavy stress induced by a site-specific major earthquake, according to calculations based on current regulations.

Also, the maximum lateral displacement exceeded the allowable limits. Regarding the metal roof structure, it was established that it met the acceptable limits required by the new codes.
According to P100-3/2008, structure was framed RsII seismic risk class, corresponding to a building that, under the site-specific seismic loads, could suffer major structural damage, but the loss of stability is unlikely. Therefore, certain retrofitting measures have to be taken, in order to reintroduce the building into the safety domain.

2.1. Analysed retrofitting methods

The report of technical expertise proposed two types of intervention: the first one, keeping the existent structural system, using a metal jacketing with steel angles and welded bands, and the second one, changing the structural system by introducing a vertical bracing system.
Once with the retrofit design project starting, another two variants of intervention was added, both keeping the existent structural system: reinforced concrete jacketing for all the columns and steel European profiles placed on one column side, in order to increase the section strength capacity.
These four variants were analyzed using a response spectrum method and the effect combination of horizontal seismic components, according to seismic code [1], was taken into consideration as follows:

$$E_{PX} + 0.3 \cdot E_{PY} \quad (1)$$

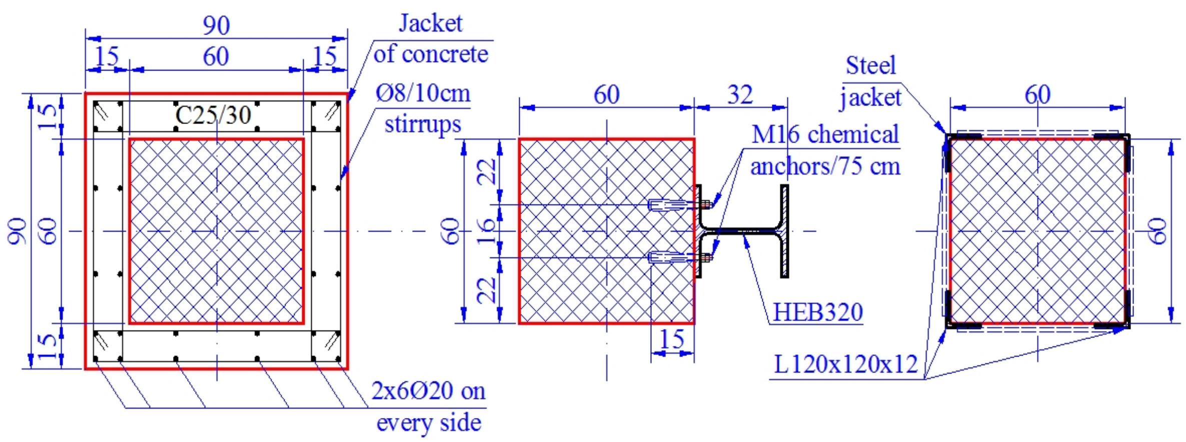
$$0.3 \cdot E_{PX} + E_{PY} \quad (2)$$

where E_{PX} represents the action effects due to the application of seismic motion in X-X direction; E_{PY} - represents the action effects due to the application of seismic motion in the Y-Y direction, perpendicular to X-X direction.

Retrofit method V1 (reinforced concrete jacketing on all four sides of column cross section)

This variant represents the classical solution of increasing column strength and deformation capacity by using longitudinal and transverse reinforcement and a concrete jacket on every side of the column. It aims to achieve the following objectives:
- regarding the element: to increase flexural and shear force capacity;
- regarding the structure: to reduce lateral displacement under seismic loads.

Thereby, existent columns, with a 60 x 60 cm^2 cross section, were designed to be retrofitted using a 15 cm thickness jacket of C20/25 concrete. The added longitudinal reinforcement is 12Φ16 PC52 placed on two rows (interior / exterior) on every side; the added transversal reinforcement consists of Φ8 PC52 stirrups, placed on every side at 10 cm plus another perimetral one (*Figure 2a*).
In order to achieve a proper bond between the existent concrete and the new jacket, the longitudinal rebars should be fixed in foundation using chemical anchors and on the existent corner rebars using metal connectors. During and immediately after the concrete casting, the vibrating operation is important to achieve a good quality of the jacket.
Advantages of this retrofitting method:
- an efficient bond between the new and the existent concrete that leads to uniformly distributed increase in strength and stiffness of columns;
- improved durability (in contrast to the corrosion and fire protection needs of other techniques where steel or epoxy resins are used);



a) *b)* *c)*

Figure 2: Cross-section of RC column for analyzed retrofitting methods

- does not require specialized workmanship.

Disadvantages of this retrofitting method:

- personnel have to be relocated during the execution of construction work;
- long duration of the rehabilitation;
- relatively high total cost.

Retrofit method V2 (reinforced concrete jacketing on all four sides of column cross section)

This retrofit technique is widely used in two variants: full jacket steel and steel cage system. Experimental tests had let to the conclusion that both variants have as results the increasing of axial load capacity but also of ductility, as effect of a better concrete confinement [2], [3]. The metal addition also increases the bending capacity and the shear force capacity. On the other hand, the rehabilitated structure becomes more rigid, having as direct result an important reducing of lateral displacement.

For the analyzed industrial building, a steel cage system was chosen, with continuous angles L120x120x12 on every corner of the column and transverse plates 150x12, placed at every 75 cm (*Figure 2c*). Experimental tests demonstrated that the number of horizontal straps did not have a noticeable effect on the ultimate capacity of the columns. Due to the wide spacing between the horizontal straps, the confinement did not affect the entire column, and failure occurs in the space between the horizontal straps [4].

Regarding the bond between steel angles and column discussions the experimental test have demonstrated that the performance of deficient RC columns under combined axial and cyclic lateral loading can be greatly improved by steel caging technique without using any binder material in the gap between concrete column and steel angles [5]. Nevertheless, the solution applied for steel jacketing proposed M12 expansion bolts, placed on every leg of the angles at 30 cm.

Advantages of this retrofitting method:

- structural response after rehabilitation easily to determine;
- short duration of the rehabilitation, only with local personnel relocations and brief interruption of technological process;

Disadvantages of this retrofitting method:

- relatively high total cost.

Retrofit method V3 (European wide flange steel profile fixed on one column side)

This innovative retrofit technique is not largely used, so that there is no science paper regarding this rehabilitation method. A HEB320 wide flange steel profile is placed in contact to one column side, with the position alternating from column to column (on longitudinal and transversal directions) (*Figure 2b*). The steel profiles are not taking axial loads, but they have the main goal to increase the bending moment and shear force capacities of existent RC column. The global structure rigidity also is influenced by this rehabilitation method, lateral displacement being considerably reduced.

The wide flange steel profiles are fixed on the existent foundations using four M20 resin anchors and on the column height using two M16 resin anchors at every 75 cm.

Advantages of this retrofitting method:

- very short duration of the rehabilitation, with only local personnel relocations and brief interruption of technological process;

Disadvantages of the method:

- lack of experimental tests to adequately calibrate the method, so the structure response after rehabilitation is characterized by a limited degree of trust;
- relatively high total cost.

2.2. Results of comparative analysis

The structure response to seismic loads for all the presented rehabilitation techniques are automatically obtained performing static linear analyzes, using modal response spectra.

In order to efficiently determine the structures dynamic characteristics and for comparative eloquent results, safety factors have been set as the ratio between the maximum possible capacity and maximum probable requirement in terms of lateral displacement generated by the seismic action, capable bending moment, capable shear force. In addition, the execution period and total costs are compared for every analyzed retrofitting method.

Initial amount of longitudinal reinforcement is insufficient in the ultimate limit state and the values of the bending moments are consequently situated far beyond the capacity limit curve of unconsolidated column section.

The bending moment capacity significantly increases for all the rehabilitation technique cases (Table I); the value of the safety factor was obtained for a combined bending and axial loads. Once again, the RC jacketing solution offers the highest value for the safety factor.

The capacity limit curves have two axes of symmetry (square sections symmetrical reinforced and retrofitted), with the exception of the third variant (V3), where the consolidation proposed the asymmetrical steel profile position (*Figure 3*). The fact that the steel profile is alternatively positioned left-up-right-down for columns in a row makes the structural response being globally uniform.

The initial transversal reinforcement is obviously insufficient to offer enough shear force capacity for the unconsolidated column under site-specific major seismic loads.

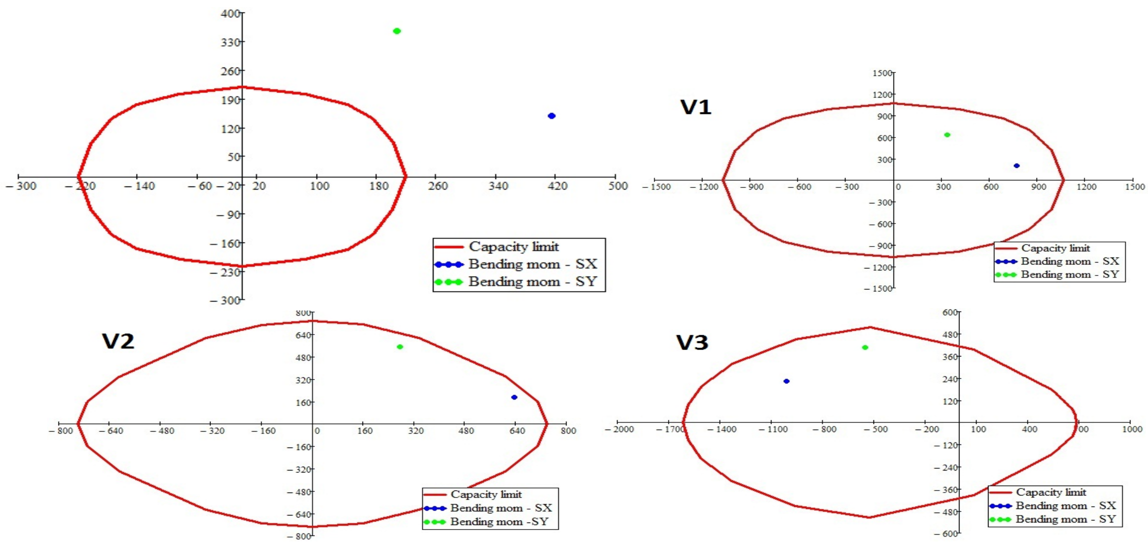


Figure 3: Bending capacity curves for initial unconsolidated column and for all three analyzed retrofitting methods

Table 1 - Safety factor values for every evaluation criteria

Retrofitting method	*Natural vibration period (s)*	*Lateral displacement*	*Capable bending moment*	*Capable shear force*
Unconsolidated structure	0.85	0.858	0.379	0.624
V1 - RC jacketing	0.42	2.075	2.033	2.516
V2 - steel jacketing	0.61	1.485	1.297	3.607
V3 - steel profile fixed on one column side	0.57	1.678	1.753	1.373

3. Conclusions

The present paper presents a thorough analysis of four rehabilitation techniques for a one-story industrial building, with their advantages and disadvantages, considering all the important aspects in order to help the designer to choose the best retrofitting solution. For the analyzed building, few conclusions could be drawn:

a) All the retrofitting methods presented in the paper lead to a more resistant structure, reducing the seismic risks: lateral displacements decrease, while ductility, bending moment and shear force capacities significantly increase.

b) The classical RC jacketing retrofitting method offers the highest values for safety factor, but imposes a long period of work interruptions, with considerable costs.

c) Steel jacketing rehabilitation technique is easy to apply, with a short period of personnel relocation but with a larger amount of steel.

d) The third presented method, using a steel profile alternatively placed on one side on columns, represents an innovative approach, being the quickest method. Lack of experimental test results, nonsymmetrical behavior of consolidated column section and alleged local effort concentration in the chemical anchors raises questions marks.

In conclusion, the multiple-criteria decision analysis offered in this paper helps the designer to find a rational and economical retrofit solution, drawing attention on the pluses and the minuses of presented rehabilitation method. A perfect solution for one case could be easily the worst for another building.

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