Mixed Consolidation Solution for a Reinforced Concrete Structure

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Abstract. During the last years, reinforced concrete structures become subject for rehabilitation due to two factors: their long life span and large change in norms that leaded to a large increase of seismic loads in Eastern Europe. These lead to a necessity for rehabilitation of existing building stock in order to use them during their entire life span at the maximum potential. The present paper proposes a solution for rehabilitation for three reinforced concrete building of a hospital, that consumed a half of their life span and do not correspond anymore to present norms. The chosen solution is a combination between CFRP rehabilitation and increase of structural elements cross section in order to achieve the stiffness balance in the structure nodes that is required by present norms. As a further matter, correction in stiffness of local elements diminished the lateral drifts of the structure and improved the global seismic response of the building.

1. Introduction
Structural rehabilitation of reinforced concrete structures become a matter of sustainable development of modern cities [1,2] because of both economic and technical reasons. The technical side of the problem lies in the fact that the design norms [2-13] for seismic structural response suffered a large increase of design values, making that a large part of building stock designed before 1990 to became unsafe for leaving from seismic point of view, especially for Romania. From the economical side, demolishing all these buildings is not an option, so reliable and easy to use rehabilitation solution should be provided by Engineers.

The buildings that are subject to this debate, have structural flows only because the change in design values, their behaviour at vertical loads still being accepted by actual requirements. Moreover, the development of non-destructive testing methods [5-8] shown that the materials integrity was preserved during the years. Also, tests regarding the materials behaviour at polluted environments were conducted [6] for areas where acids were used for laboratory testing. These considerations contributed to the rehabilitation decision concerning the existing modern buildings.

The three buildings described in the present paper are part of a large hospital complex that fulfil all the above hypothesis.

2. Historical overview. Existing situation
The considered buildings are part of the Timis County Hospital, the largest hospital in the Western Romania. The hospital was created as a mixture of fourteen different buildings, containing all medical specialties and provide education act at the same time for medicine students. Eight buildings are arranged to form an interior courtyard, four lateral buildings and one building for heating plant.
The buildings are different both in terms of architecture, with different height levels, ranging between one and ten levels, different functionalities, and different strength structures adapted to support each of these requirements. The assembly and was designed in 1970 and built in 1974.

From the total assembly, the buildings subject of this paper are marked in figure 1. The buildings F and G are four levels high and building H is 3 levels high, one level being basement for all buildings.

The surgical department for the entire hospital is placed at the second floor of all these three buildings, and has the functional arrangement given in figure 2. Given its importance, the general rehabilitation of the hospital complex started with this department.

Figure 1. Timis County Hospital – aerial view

Made in 1974, the surgery department functioned without interruption, a situation that led to justified degradation both of interior finishing, construction of specific facilities, medical facilities and medical devices supplied. Above these considerations, the current situation was also characterized by the fact that the operating procedures worked without the specific standards and regulations occurred mainly after 2000 when Romania joined the EU. Moreover, no integrated modernization or upgrading works were carried out during this time. A general upgrade of the functional spaces, finishes and instrumentations was then required.

Structural description
All the three buildings are spatial frames reinforced concrete structures, and the structure integrity is almost perfectly preserved. Only interior and exterior finishing were damaged, as seen in figure 2.

Figure 2. State of finishing degradations.
The only problem appeared concerning structure integrity is the change in norms, so that the location that has been an area free of earthquakes [1,3] after the norms valid in 1970 [10], changed in 2006 into an area strongly affected by seismic loads [11].

3. Improvement measures proposed at structure

Architectural interventions considered

In order to implement the measures for good function of surgical block, the existing space was proposed to change its functions both as dimensions and interior traffic management. With the reconfiguration, resizing and redistribution of surgical area, it requires rethinking traffic of clean / dirty items both on horizontal and vertical directions. In the current situation the traffic flow for clean / dirty items is overlapping horizontally and intersected in vertical transport, thing not accepted by European regulations.

The measures proposed can be summarized as follows:

- Overall increase of total area designed for surgical department by adding cantilever slab around the floor perimeter. The space is added both at operational floor as seen in figures 2 and 3, and at terrace (figure 4 and 5).
- Creating a technical space on terrace, by placing there all the necessary technological equipment.
- Create auxiliary closed space on extended terrace with role for technical staff and equipment.
- Add supplementary elevators in order to increase the vertical flux for patients.
- Add two new staircases for vertical access
- Increase all the existing stair with one additional floor

![Figure 2. Surgery floor: existing situation.](image1)

![Figure 3. Surgery floor: proposed solution.](image2)

![Figure 4. Terrace existing situation.](image3)

![Figure 5. Terrace proposed solution.](image4)

The proposed modifications increased the existing surface of surgery from 3276 m² to 4854 m². The supplementary added space was used in order to obtain:

- Increase in dimension of all surgical rooms, and arrange them upon medical specialties;
- Separate wards for sick – before and after surgery – could be arranged;
- Auxiliary spaces for medical personnel could be added;
- Continuity in flows of "clean" aseptic with the "dirty" septic routs and total separation of them, so no accidental overlapping of the two routes could be possible. This was possible by
reserving the mid lobbies to septic routes and perimeter lobbies to aseptic routes. In this way, the central core of the floor is kept completely aseptic;
− The new configuration insures more transversal connection between longitudinal lobbies;
− The vertical transport could be divided between sterile and non-sterile routes;
− All supporting technical and technological equipment could be moved on the extended terrace (figure 5).

Structural interventions considered
The structural interventions were generated by architectural requirements and can be summarized as follows:
− Slab floors enlarged with cantilevers in composite metallic-reinforced concrete structure (metallic cantilever beams with connector at top side that support a concrete slab)
− Close the slab openings (where needed) using metallic solutions (as network of metallic girders)
− Heightening existing stairwells with metal spiral staircase
− Create new opening in floor slabs for new elevator emplacement
− Create new storey for technical purpose using spatial metallic frame solution.
− New independent structures for staircases and elevator shaft in reinforced concrete solution: shear walls and spatial frames

As it can be seen the solutions for spatial interventions were chosen to add the minimum additional load possible, taking into account the fact that the seismic behaviour will be further diminished by any additional load. The heavy elements that had to be added – new staircases and elevator shaft – were created as new independent structures that do not interfere with the existing one. Great care was considered at placement of the new foundations between the existing ones to that the foundation system not to be disturbed.

4. Structural assessment
The structural assessment for these buildings had to take into account several distinct aspects as loads change due to norms and new added structural and technological loads together with the characteristic seismic behaviour of the existing structure due to their design particularities.

Changes in load levels
The buildings’ design was made in 1971, when Timisoara city was included by seismic zoning map in the area that did not require structural calculation of seismic loads, dimensioning being made for gravitational loads only. The seismic norms weren’t the only more permissive norms. The levels of design loads were also lower than that provided by current regulations, and partial safety coefficients considered in evaluating the loads were much lower than that required by Eurocodes.

Table 1 bellow shows the comparison of these modifications. It also shows some spotlights regarding the existing reinforcements toward the new technological requirements and change in seismic design requirements.

| 1971 – year of building design | 2012 |
|-------------------------------|------|
| SEISMIC ZONING               |      |
| - according P13-70 was not necessary to calculate the seismic loads | - P100/1-2006 Normative : ground acceleration for seismic design 0.16g |
| PARTIAL SAFETY COEFFICIENTS  |      |
| - dead load of structural elements |      |
| 1.1                          | 1.35 |
### Table 1. Changes in load, intensity safety factors and technological requirements.

| 1971 – year of building design | 2012 |
|-------------------------------|------|
| - dead load of finishing elements | 1.3 | 1.35 |
| - live load offices | 200 x 1.3 = 260 daN/m² | 300 x 1.5 = 450 daN/m² |

**EXISTING SITUATION**

**ACCORDING TO DESIGN**

**MINIMAL CONDITIONS IMPOSED**

**BY NORMATIVE P100/1-2006**

* **Columns reinforcement**
  - Total amount of longitudinal reinforcement:
    - \( A_s = 11.12 \text{ cm}^2 \)
  - Minimum acceptable level:
    - for the minimum percentage of reinforcement \( p_{\text{min}} = 1\% \Rightarrow A_s = 15.75 \text{ cm}^2 \)

* **Transversal reinforcement:**
  - stirrups \( \phi \geq 6/12.5 \text{ cm} \Rightarrow p = 0.11\% \)
  - Minimum acceptable level:
    - stirrups \( \phi \geq 8/10 \text{ cm} \)
    - \( p_{\text{min}} = 0.5\% \)

* **Concrete quality:**
  - class C16/20
  - Minimum acceptable level:
    - minimum admitted class C25/30 (H ductility class)

* **Strength rebars placed in cross section corners only, no matter the distance between them**
  - Distance required between strength rebars: maximum 25 cm

From table 1 it can easily be seen that, besides the loads change, the structures do not respect a large part of constructive conditions imposed by seismic norms for concrete quality, quantity and position of reinforcement, things that must be corrected by the rehabilitation solution.

**Seismic behaviour of existing structure**

Even in the conditions shown above, the buildings’ conception meet some of the issues specified in P100/1-2006. The particularities of structure behaviour relative to seismic standards consist in:

- Structural simplicity: the structure has been divided into 3 separate structure with expansion joints in-between to provide better structural regularity of the structural assembly. The structural system is mostly a continuous one, and provides a clear path, a direct and uninterrupted transmission of seismic forces, regardless of their direction towards the foundation soil.

- Seismic forces that arise in all building elements are sent to the 20 cm thick floor slabs that works as horizontal diaphragms. For thin slabs with 8-10 cm height, the horizontal forces are transmitted through the longitudinal and frame beams and sent further to vertical columns.

- There are no important discontinuities in the path of seismic loads transmission: the slabs are continuous, without notable openings, the beams have horizontal, continuous paths after two perpendicular directions, and the columns show a vertical continuity.

- Structural redundancy: from the geometric viewpoint, one can consider that a plastic mechanism was achieved and have enough potential plastic hinges, enabling the exploitation of strength reserves of the structure and have to show an advantageous seismic energy dissipation pattern.

- Structure configuration: structural regularity in plan and elevation of all three buildings is partially achieved; thus, all the buildings show some geometrical discontinuities in limited areas and present short columns.

- The cross section sizes for structural columns and beams do not meet the condition of rigidity required by P100-2006. The beams’ stiffness is in many cases greater than the columns’, so the structure nodes are compromised from the point of seismic behaviour.
The concrete used for structure do not meet the basic requirement for structures in ductility class H (C25/30), or even for M class (C20/25).

5. Rehabilitation solutions

The MEP seismic spatial design was conducted first for the existing buildings without structural changes, these being added at a later stage. At all stages, the loads were considered with their real value and amended with partial factor of safety according to the regulations currently in force. The levels of lateral stiffness of the structure are non-compliant, none of lateral drifts meet the accepted level of P100. Moreover, all three buildings are subject of second order effect of torsion. The bearing capacity of structural elements – beams, columns and part of slabs – does not cover the efforts that has to be supported by the building, and the ratio between the stiffness of beams and columns do not meet P100 regulations for directing the plastic hinges in beams.

Consequently, the superstructure must be strengthened so that can meet the current requirements of strength and stability. On the other hand, the infrastructure does not require structural interventions because the foundation blocks have the appropriate dimensions so the pressure transmitted to the foundation soil not to exceed the permitted values. In addition, the geotechnical study shows that the admitted soil pressures can be 10% increased, value that covers the supplementary loads brought by the new metallic light storey.

The solution choice was made by combining the qualities of traditional strengthening solutions with modern solution of bearing capacity increase in order to match the goals of the entire building. Thus the advantages of beams and columns strengthening by reinforced concrete cross section increase:
- increase of structure lateral stiffness and limitation of lateral drift
- gives the possibility to add additional reinforcement to reach the minimum required quantity
- reliable technological solutions for node anchorage of longitudinal rebars from beams
- eliminate the second order effects that introduced additional efforts in structure
- solution economically advantageous

With the advantages of carbon fiber use [4] for bearing capacity increase:
- short execution time;
- execution can be done on limited areas one by one, so that the medical activity can be stopped on small areas;
- increase both flexural ad shear force bearing capacity of structural elements;
- economic disadvantage – 75% more expensive than the classic rehabilitation solution

The strengthening measurers agreed to cover all these aspects were the following:

a. Increase the lateral stiffness of the structure through the increase of reinforced concrete cross sections and add new reinforcement for vertical structural elements. This measure insure also the correction of the ratio between stiffens of beams and columns in node. In this way, the bearing capacity of the column is corrected and brought to the required bearing capacity to support all the structural loads. The transversal reinforcement could also be corrected with this solution.

b. Increase the bearing capacity of horizontal strength elements that do not have enough bearing capacity in regard with norms and actual load level. There has been adopted several measures, taking into account the actual behaviour for each structural element:
- Ground level: carbon fiber strengthening at top and bottom side of the slab
- First and second level: consolidation of all beams with 6 cm reinforced concrete at top side, with additional reinforcement connected to the old one, together the bottom side consolidation of beams using carbon fibers.
- Second level: additional consolidation for cantilever beams using fiber carbon on top side
- Third level: general rehabilitation for beams and slab with 5 cm thick reinforced concrete at top side, together with new cuts for openings required by the new technological circuits.
6. Conclusions
By strengthening the structure in the presented manner, the following results were achieved:
- The lateral drifts are within the permissible limits, both at the ultimate limit state and service limit state;
- Bearing capacity of beams and columns matches the efforts level in the structure
- The effects of torsion do not affect the structure, the second order effect being cancelled
- The reinforcement layout both for longitudinal and transversal rebars, complies with the normative requests for all structural elements
- No unnecessary interventions were made. The blocks of foundation that have appropriate dimensions did not suffer any structural interventions.
- The overall structure will work as new structure, designed according to P100/1-2006.
These goals were achieved only by a smart combination of strengthening solutions with carbon fibers and reinforced concrete and by considering all supplementary elements added to the structure in light metallic solutions.

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