

Classic and New Materials Used for Structural Rehabilitation. Case Study

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Abstract. New materials development with different combination of properties were always a challenge in terms of their adequate use in civil engineering. Introduction of carbon fibres as strength material for structures was a beginning of a new approach in structural rehabilitation, and sometimes meant the end of classic rehabilitation solution use. The present paper gives an example of a building rehabilitation that use a melt of both new and old solutions in order to achieve the optimum result for building itself. The problem was even more challenging, because the structure considered is only 22 years old, but having some design faults in terms of seismic behaviour and, in addition, one floor was added to existing structure. The chosen solution was a compromise between the use of old and new materials in places where their qualities were best suitable and their minuses could be compensated by the other material.

1. Introduction

Buildings rehabilitation is a challenge in terms of calculus, solution choice and technological possibility to apply the designed solutions. In addition, use of new materials become a “fashionable design way”, used everywhere needed or not, and the old ones use was diminished even when they were the best choice for a certain purpose.

In this line, the rehabilitation solutions for concrete structures shown in the last years by the scientific literature, were divided between new materials use [1-6] and new innovative technological solutions [4-7], the use of classic rehabilitation solutions being avoided. The only thing in common of these trends was the preservation of the materials of the original structure [1-4].

The building rehabilitation solution presented here combines this new trend with the old school solutions, in order to achieve the best possible result.

2. Existing situation

The considered building was designed in 1994 and built in the next year, as orthopedic clinic of a regional hospital (figure 1). The construction as a whole, is a building consisting of two independent L-shape sections forming an interior light yard. The original blue print for the ground floor is shown in figure 2. Resistance structure for both sections is a spatial frame – diaphragm structure of reinforced concrete, monolithic solution. Currently it was considered the necessity of increasing the operational space by adding an additional floor to the existing building.





Figure 1. Existing building.

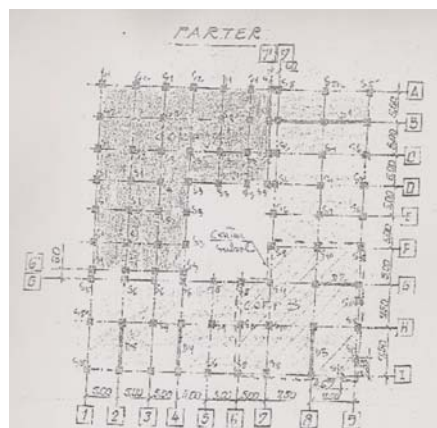


Figure 2. Original design – ground floor.

2.1. Strength structure

The two sections named A and B, have the following characteristics. The A section, an L-shaped building with dimensions of 30.32 x 30.32 m x 16.30m is 2 floors high, ground floor and 1 withdrawn floor. The structure is made of spatial frames reinforced concrete monolith with spans of 5.0x5.0 m except in areas of operating rooms where the spans are 10.0x 10.0 m. The B section, also an L-shaped building, is the largest building, having the dimensions 48.00 x 48.00 m x 15.98m. Its height is also larger, being a 4 floor building with one basement. The structure is made of monolithic reinforced concrete frame – diaphragm solution. Frames are developed after two perpendicular directions with 5.0 x 7.5 m spans respectively 7.5 x 7.5 m on margins. The diaphragms are placed inside the structure in axes 2, 4 and 8 between I and H axes, and in axis G between 8 and 9 and B between 7 and 9. The frames and diaphragms are connected and work as a continuous structure. The slabs for both sections are monolithic reinforced concrete slabs with constant thickness of 15cm supported on frame beams, secondary beams and transverse diaphragms for intermediate floors. In the basement slab is monolithic reinforced concrete slab with constant thickness of 30 cm frame that stands on beams and reinforced concrete diaphragms.

Due to the difference in level of buildings infrastructure, the foundation system is slightly different for the two wings. The foundation system of B wing consists of rigid isolated foundations under the columns and continuous foundations under diaphragms masonry walls that makes the building envelope. The basement has perimeter concrete diaphragms with role of forming a rigid box. The wing A foundation system consists of rigid bearing isolated foundations under reinforced concrete columns and continuous foundations under masonry perimeter closing walls.

2.2. Architectural and structural interventions considered

After the owner requirements, at Building A, it is required a secondary floor over the existing terrace considered in a solution of light steel structure, and increase the technical areas for HVAC equipment. In this way the hospitalization capacity is increased by a third, and the new HVAC equipment could fulfill the requirements for health operating rooms. To achieve vertical access in these conditions is necessary to create a new lift access in the interior yard with the structure of reinforced concrete diaphragms designed independently of the existing structure. Given the nature of the interventions described above, it follows that only the section A is affected by structural interventions, section B not being affected in structural terms.

At Building A, the changes in functionality led to drastic changes compared to the original solution, as follows:

- Arrangement of an operating room and its annexes, in place of former lobbies and terrace. Creating the necessary space for the operating room required the demolition of columns and changing the mode of transmission of the loads.

- Replacing protocol space with the technical area for installations with high increase in value of live loads, namely from 2.10 kN/m^2 to 11.25 kN/m^2 (78% increase)
- Increasing the area for equipment installation space from 100 m^2 to 168 m^2
- Change of circulation areas with room for residents and safety airlocks.
- Increase width all lobbies from 2.20 m to 2.40 m , taking over space from areas with destination hospital room.
- Moreover, the architectural rearrangement from existing floors is doubled by addition of an entire new floor.

3. Technical factors to be considered for structural assessment

Due to the conditions presented, the assessment of the structure needed to consider four factors, besides the assessment of real condition of the structure, namely: change of norms provisions [9-11] for seismic loads, change in loads value due to norms and change in loads position due to functional change, in addition to new supplementary loads that could not be considered by the original design and geometrical alteration due to functional change.

3.1. Geometrical alteration of the structure

The last two factors led to the following changes in general geometry of the structure:

Demolition of a column at the first floor leads to a modified static scheme for the entire structural strength with the consequent redistribution of efforts in structure and increase of efforts and strains in the elements that take on the role of the demolished column.

The new floor is proposed as metal structure with transversal and longitudinal bracing frames. The elements are designed to be made of laminated profiles. The columns are considered with hinged supports, the connection with the existing reinforced concrete structure being achieved with two chemical anchors. The beam - columns joint was considered in embedded solution. All these modifications altered the height of the building differently, as shown in table 1.

Table 1. Changes in height due to functional change.

Built area [m ²]	Levels	
	Designed	Proposed
391.15	1	2
67.14	1	3
280.98	2	2

3.2. Change in loads intensity and position

The geometrical modifications changed both the total of dead and live loads. Besides that, the intensity of live loads were changed for certain areas of the building [11], as shown in table 2.

Table 2. Changes in live load intensity due to functional change.

Design loads	Loads after functional change	Change type
Areas designed as hospital rooms turn into lobbies $200 \times 1.5 = 300 \text{ daN/m}^2$	$500 \times 1.5 = 750 \text{ daN/m}^2$	Increase with 150%
Areas designed as offices turn into technical areas $200 \times 1.5 = 300 \text{ daN/m}^2$	$750 \times 1.5 = 1125 \text{ daN/m}^2$	Increase with 275%
Areas designed as lobbies turn into hospital rooms $500 \times 1.5 = 750 \text{ daN/m}^2$	$200 \times 1.5 = 300 \text{ daN/m}^2$	Decrease with 60%

In the same time, the change of loads intensity and safety coefficients values were also altered, as shown in table 3.

Table 3. Changes in live load intensity and safety factors due to norms change.

Design values	Assessment values
SAFETY PARTIAL COEFFICIENTS	
- for dead loads – structural elements	
1.1	1.35
- for dead loads – finishing	
1.3	1.35
- for wall loads	
1.2	1.35
LOADS INTENSITY	
-live loads – hospital rooms	
$150 \times 1.4 = 210 \text{ daN/m}^2$	$200 \times 1.5 = 300 \text{ daN/m}^2$
- live loads - lobbies	
$300 \times 1.4 = 420 \text{ daN/m}^2$	$500 \times 1.5 = 750 \text{ daN/m}^2$
- live loads - terrace	
$75 \times 1.4 = 105 \text{ daN/m}^2$	Turn into functional space with different live loads
MINIMUM REQUIREMENTS FOR MATERIALS	
- concrete C12/15	- concrete C25/30 (H ductility class)
LIVE LOADS FOR INSTALLATIONS	
1. Heating system:	1. Heating system:
$300 \text{ daN/m}^2 \times 1.4 = 420 \text{ daN/m}^2$	$750 \text{ daN/m}^2 \times 1.5 = 1125 \text{ daN/m}^2$
Not provided by design	2. Ventilation and cooling system
	$750 \text{ daN/m}^2 \times 1.5 = 1125 \text{ daN/m}^2$

In conclusion, the modifications changed the live load as follows: in about 10% of the structure, the live loads increased by 78%, in 26% the live loads has increased by 62.66%, and for 64% of the area the live loads remain unchanged. Considering that in addition, the structure has the shape of L, it follows that increasing load by about 70% on 36% of the area leads to change in the position of gravity center away from rigidity center, and affecting the efforts path and leading to their concentration on the sides of the building.

4. Structural assessment

Because the placement of the structure is in a seismic area of 7.5 degrees on Richter scale, the seismic response of the structure is the first thing to be considered. The local normative [10] for seismic design impose certain regulations that are partially fulfilled by the considered structure:

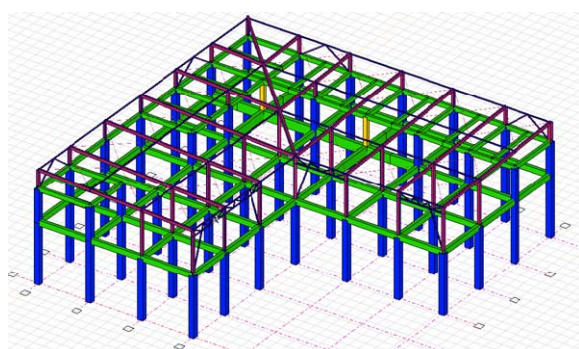
Structural simplicity is a requirement that is not totally respected because a building is divided into two L-shaped wings is not the most rational decision for a building placed in a seismic area. The stiffness center differs from center of gravity so that the first vibration mode will be a torsional mode – a real disadvantage for a seismic response.

The structural system is mostly continuous and provide a clear, direct and uninterrupted path for seismic forces transmission, regardless of the force direction, directly to the foundation, except columns SB2 and SB4 which stand directly on a beam – situation that is to be avoided as seismic design – but can be accepted for the last two levels of a building as it is the present situation.

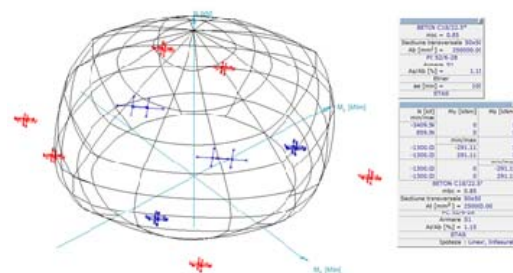
All the seismic forces that can appear in the structure will be supported in all the floors of the building that can work as horizontal diaphragms due to their thickness – 15 cm.

Structural redundancy: from the geometric viewpoint one can consider that a plastic mechanism with sufficient plastic hinges is provided, allowing the use of structure strength reserves and a good seismic energy dissipation. At the same time, reinforcement of beams and columns (figure 3) compromise this system, by not taking into account the provisions of [10].

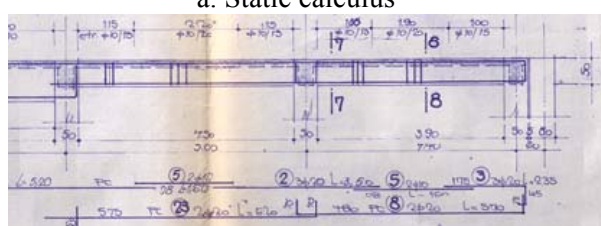
Structure configuration: structural regularity in plan and elevation sections is not satisfied.



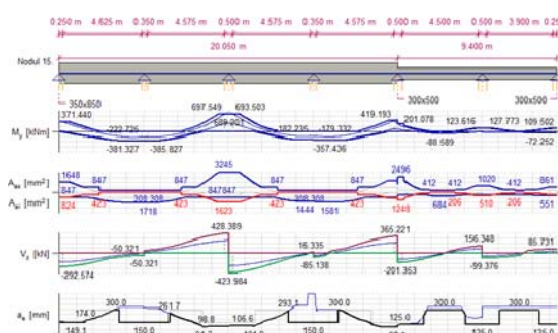
a. Static calculus



b. Column results for ground floor



c. Beam reinforcement – original design



d. Beam results

Figure 3. Static calculus.

Cross sections selected for strength elements satisfy the condition of rigidity required by [10], except beams section 35x80cm and 35x85 cm, where the beams rigidity is higher than the columns', the structure nodes being then compromised.

The materials used do not meet the minimum requirement for ductility class H (C25 / 30) being used concrete C18 / 22.5.

5. Rehabilitation solutions

Choosing rehabilitation solutions [2] was imposed by two things: combining the results obtained with the possibility of applying the chosen solutions in a space that could not be partially dismantled.

The solutions had to meet the following technical findings.

Increasing the lateral stiffness of the structure for seismic reasons: vertical elements must have increased cross sections. By adopting this solution the main scope is reached and, besides this, a correct stiffness ratio between beams and columns in junction will be achieved, and the stiffness of the column to exceed the sum of beams rigidities for each node. At the same time, supplemented longitudinal reinforcement leads to the increase of columns bearing capacity of columns up to the level required for supporting the efforts of structure. The increase of cross section was made symmetrically for intermediate columns and only on the interior sides for envelope columns (figure 4). For all cases, the longitudinal reinforcement was supplemented. A particular case appeared for the envelope columns, because the thickness of the new concrete layer. In this particular case, a strengthened corner was created by adding a supplementary stirrup in double L shape together with double longitudinal reinforcement (figure 4).

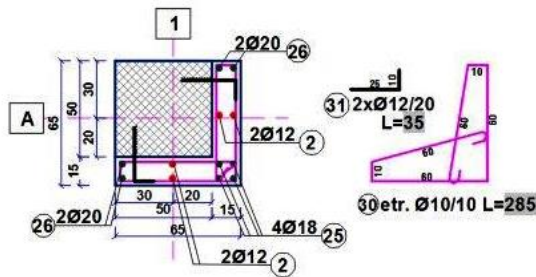


Figure 4. Column rehabilitation.

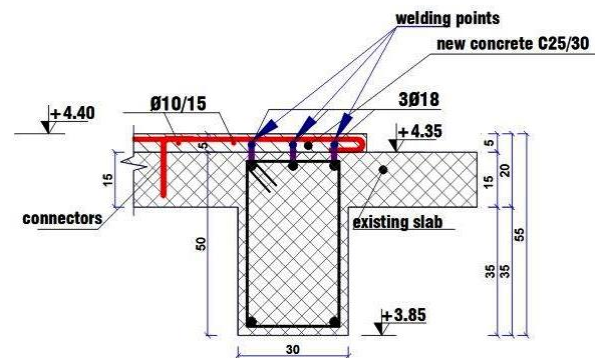


Figure 5. Slab rehabilitation.

Increasing the bearing capacity of the horizontal resistance strength elements: the structural calculus revealed that structural elements are not adequately reinforced for the loads required by current standards and architectural changes. The problem appeared on beams and slab over the ground floor.

The slab rehabilitation (figure 5) was done by adding supplementary reinforcement on the top side. The connection was made by welding between old and new rebars, through connection Z shape reinforcement. The floor top side being mainly free (terrace and technical areas), the solution was easy to apply. In addition, it increased the slab thickness, contributing also to the limitation of lateral displacements.

The same idea (figure 6) was applied to the upper side of beams consolidation. The result was not enough for the efforts supported by beams, but an increase of section on the lower side of the beam was not possible for two reasons: the ground floor was fully working during rehabilitation process the walls below beams could not be demolished, and another increase of beam stiffness could not be supported by the stiffness balance in the structure nodes, even with the designed change in section for the columns.

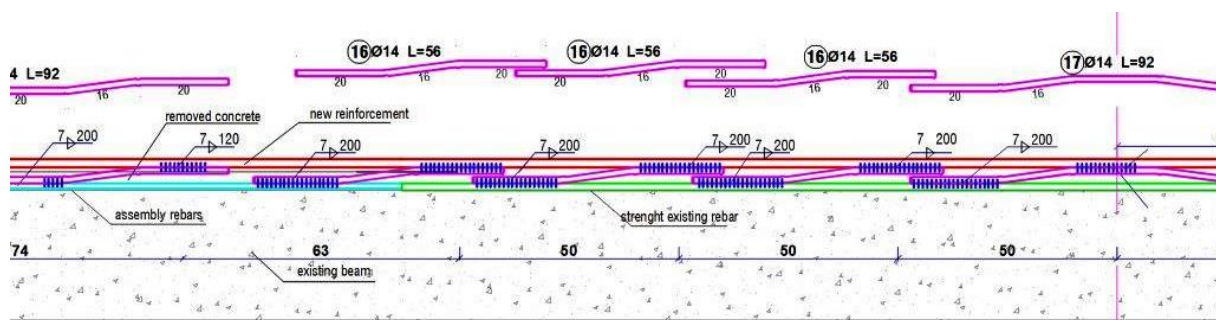


Figure 6. Beam rehabilitation on upper side using classic solution.

The carbon fiber solution appeared to be the most suitable for that purpose. A mix of fiber strips and fiber net applied on the lateral sides (figure 7) and bottom of the beams created the perfect solution for this particular case: increase of bearing capacity and keeping the same stiffness [3].

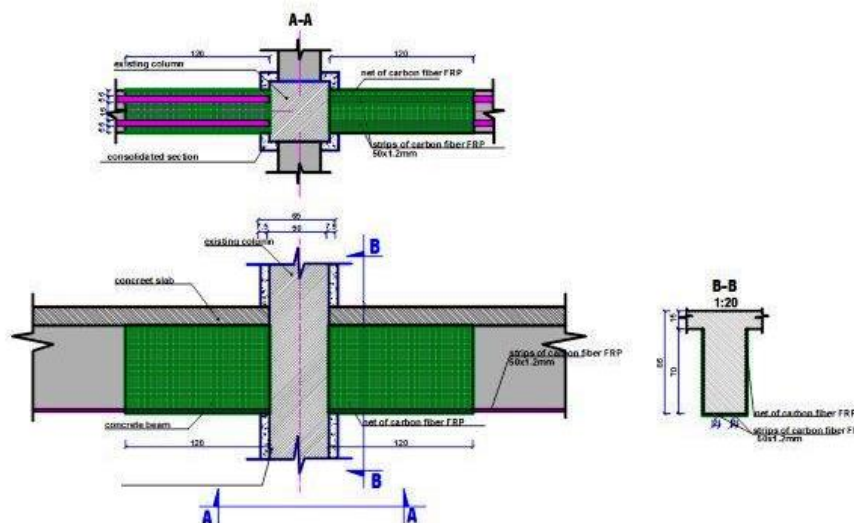


Figure 7. Beam rehabilitation using carbon fiber.

6. Conclusions

Structural rehabilitation became a normal fact for fair new building that did not finished their designed life span. This appeared due to a quick advance in technical development followed by change in norms.

The adopted solution implied using of a melt of new and classic rehabilitation solutions, each of them contributing to achievement of a certain task: the classic increase of concrete cross section improved the seismic behavior of the structure from the point of lateral displacements together with an increase of bearing capacity for columns. The use of FRP increased the bearing capacity of beams without affecting their stiffness. In this way, the two solutions together rebalanced the stiffness balance in nodes and insured the correct strength level for all structural elements.

In this way it was once more demonstrated that all technical solutions – new or old – have certain advantages that cannot be undermined by a subjective preference for one of them. One must keep an open mind to both directions and use each solution wherever is best suited, and a calculated blend between them may sometimes lead to the optimum result.

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