Rehabilitation and Reinforcement of the Industrial Building Reconverted in University with Elimination of Main Columns

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Abstract: The objective of this work is present a study of the rehabilitation of an industrial building from 1970 to a university building. For this purpose this document can be used afterwards for design and definition of reinforcement solutions for similar situations.

The building, defined on the first floor by a reinforced concrete structure with spans of 8,5 meters and a prestressed slab of 0.39 m thick, is adapted for the introduction of an auditorium. Its location requires the elimination of two central columns. Two reinforcing solutions with prestress are presented, but applied with different techniques, by means of external cables and by the application of displacements of supports with flat jacks. Regarding to the second floor, the roof structure is interrupted with the introduction of a patio. The bases of the columns that compose the interrupted frames need to be clamped. In addition are also introduced horizontal supports which allow the stiffening of the roof frames. The modification of the conditions of support of the slab and its loads, require the verification to punching shear and bending. For this, a comparative analysis of the distribution of vertical reactions by the vertical elements was made for the two loading situations, previous and current.

Keywords: Rehabilitation, reinforcement, prestress, external prestress, support displacement, punching shear capacity.

1 Introduction

Urban rehabilitation is a developing area in the construction industry sector. Repair and reinforcement of structures are required in order to improve their performance. In order to promote the rehabilitation of structures in the construction sector and at the same time present a set of reinforcement techniques for specific practical situations, the main objective of this thesis is document for other rehabilitation exemplify some structural techniques.

In this specific case an industrial building of 1970 is presented, whose alteration of its functionality is the main cause of reinforcement of the structure. The loading conditions are changed to accommodate the Swiss Public Administration University (IDHEAP), as well as the structural arrangements, due to the introduction of an auditorium on the 1st floor and a patio on the 2nd floor (Vaz Rodrigues, Rui; Fellrath, Mario, 2012).

2 Prestress as a Structural Reinforcement

The contrast between the degradation of housing and institutional heritage and the new construction represents an important understanding in the concern growth of the restoration work of the old buildings. In addition, all of the recent infrastructures will need rehabilitation and conservation in a near future (Oliveira, Rui; de Sousa, Hipólito; Lopes, Jorge, 2004). Other factors that also aggravated this concern were still the recent economic crisis and the concentration of the offer of buildings in areas already saturated, forcing a non-investment decrease of the new construction market.

Rehabilitation is an intervention in the structure with the aim of repairing or reinforcing its structural behavior, in order to satisfy all required safety and behavior criteria. This intervention is necessary when a change occur in the functionality for which the structure was preconceived. Other examples would be in case of accidents or damages caused by fires or earthquakes, with the adaptation of the structure to new safety criteria defined for them; And the correction of anomalies that appear during the use of the structure (design, construction of the structure, operation of the structure). The lack of information regarding the reinforcement regulations of structures that defines for each situation the technique and methodology of design and the design of reinforcement makes the repair process harder. In addition, its necessary a prior knowledge of the design of the structure to be rehabilitated, details of ordinary reinforcement and the regulations applied on the project of execution and operation, which are recurrently unavailable (Costa, António; Appleton, Júlio, 2011).

The evaluation of the structure is initially divided into a selection of information of the elements of project design, construction and normal use of the structure. The visual inspection is fundamental in the identification of the anomalies, for the subsequent formulation of the respective diagnosis and consequent resolution of the problem. This solution eliminates the detected cause or adapts the structure or its elements, to the patent load situation (Aguiar, José; Reis Cabrita, A.M.; Appleton, João, 1998).

The visual inspection uses a set of equipment, such as the underbridge truck, the UAV's, the sclerometer, the laser-scanning, the cover meter, among others, essential for the correct characterization of the anomaly, and consequent classification of the structural safety, validated by the their numerical model.

Finally, the design of the reinforcement depends on the selected intervention. The introduction of new elements such as steel bracing and structural walls; the reinforcement of existing resistant elements, through the application of steel profiles, steel or reinforced concrete jacketing, or with FRPs; and the application of prestressing and special devices, such as exterior prestress, shock absorbers, power dissipaters and base insulators, are some of the interventions to consider.

The prestress causes a self-balanced tension state in the structure by imposing a deformation. This deformation is introduced by means of high strength tendons which are initially tensioned and, when released, introduce a state of compression into the element by relieving its tensile stresses and aggravating those of compression. This variation will depend on the position and design of the cable. One of the prestressing objectives is to improve the performance of the concrete in service through the control of the deformation and cracking of the element due to the fact that there is inertia in the non-cracked state. Its application can occur by pre-tensioning or post-tensioning.

In isostatic structures, the imposition of a deformation does not introduce additional efforts, since the structure deforms freely contrary to the hyperstatic structures. In hyperstatic structures, as the deformation is prevented, hyperesthesic stresses appear in the element that has to be accounted for. The prestressing can be carried out by means of high-strength steel cables, as in the external prestress, but can also be achieved by the introduction of bearing displacements.

The main advantages of applying external prestress are to increase its bending strength, facility of monitoring, replacement and tensioning of the exterior cable and its placement is still practical and affordable. This is an active reinforcement because it introduces a set of efforts that reduce those that are transmitted by the load of the structure, reducing its effects (deformation, cracking, internal tensions), both in the loads applied after the reinforcement, as well as in those that come of the loads that were already applied in the structure.

3 Swiss University of Public Administration - IDHEAP: Case study

3.1 Considerations

The Swiss institute, IDHEAP - Swiss Graduate School of Public Administration, emerged as an industrial building in the year 1970. Its rehabilitation occurs in the year 2010, mostly due to the change of functionality. The two-storey industrial building is based on a reinforced concrete structure on the first floor with a 3.65 meters height and a 39 cm thick prestressed slab consisting by panels of 8.5x8.5 meters of span. The roof support on the second floor by a series of continues frames with 4.6 meters height, in both directions. Among the various adaptations made to the building, the introduction of a patio (Figure 1 (a)) and an auditorium (Figure 1 (b)) constitute the significant changes in the load path arrangement of the structure.

(a) **(b)**

Figure 1 – (a) Patio. **(b)** Auditorium (Vaz Rodrigues, Rui; Fellrath, Mario, 2012).

3.2 Auditorium

The installation of an auditorium on the first floor with spans of 17 meters by 15.5 meters prevents the positioning of any vertical elements in this. The load path of the loads is modified, because of the previously loads unloaded by the removed columns will have to be redistributed by the remaining vertical elements, which are not designed for these additional loads. For this purpose, two concrete walls are implemented, with foundations adapted to the existing columns. The solutions of how the vertical loads of cut columns are carried to the new concrete walls are analyzed. Two solutions are studied: the application of the prestressing technique by means of external cables, and by means of steel beams over the slab, capable of suspending the load of removed columns, by imposing displacements of supports with the use of flat jacks.

3.2.1 Exterior Prestress

In the case of prestressing with external cables, the existence of a false ceiling in the auditorium architecture (21 cm), guarantees a protection of the presstressing ducts of the tendons and the deviators to the fire. Considering the load plane of the real structure, a quasi-permanent load with a value equal to 14.83 kN/m^2 and the use of a numerical model (CSI Computers and Structures), the axial load value for the balanced load by the removed columns was obtained (Nqp = 1038.5 kN).

The considered cable profile was optimizing by the new reinforced concrete walls, with the definition of parabolic design and under the columns to demolish (Figure 2). Since these walls are not symmetrical regarding to the central span, it is necessary to reconcile the layout between them and their respective columns, ensuring the minimum radius of curvature of the parabolic design. For all these situations several solutions were adapted: the increase of the thickness of the sections of wall above the slabs so as to achieve, then, to make eccentricities. This design ensures the stability of cut columns, with the direct balance between the axial stress of the removed columns and the equivalent loads resulting from the parabolic design under these columns. Thus, 4 prestress cables with 5 tendons each of 0.6'N are adopted, whose prestressing value, including losses, is 2780 kN.

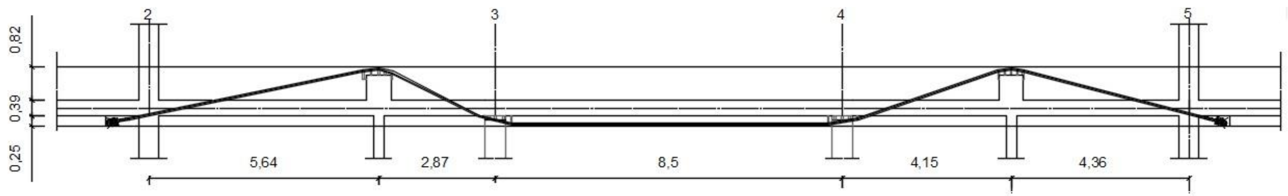

Figure 2 – Prestress cable profile.

The deviator is a set of metal parts that allow the connection of the prestress cable to the main structure, ensuring the transmission of forces from the cable to the element. Taking into account the number of strands required, a non-adherent multi-strand prestressing system was chosen, since it is an external solution. This system is surrounded by a PEAD plastic sheath, injected with non-adherent petroleum waxes. As the anchors are positioned under the slab, the concreting of this one is accomplished by means of two vertical holes executed in the slab. This zone is still fixed to the slab with screws, in order to avoid its slipping, caused by the horizontal component of the prestress. In addition, 10ϕ20 mm are also placed, to absorb the tension region of the anchorages.

3.2.2 Support Displacement

The solution concept emerges as a way to take advantage of the technical void above the slab and that therefore requires an optimal coordination between the arrangement of the HVAC systems and the positioning of the steel profiles. The steel profile is on the slab according to alignment C, supported on the columns of the 2C and 5C alignments and on the new reinforced concrete walls. The imposed deformation consists of the introduction of vertical displacements on the steel profiles above the new reinforced concrete walls with flat jacks, whereas the remaining supports (2C, 3C, 4C and 5C) are fixed by prestressed steel bars (ϕ36mm), which by making the free deformation of the profile impossible, introduce a state of tension capable of balancing the displacements introduced, with reactions in alignments 3C and 4C of equal value to the loading of the columns to be demolished (Figure 3). Thus, considering the final equilibrium situation of the metal profile, for the ultimate limit state, it was dimensioned for an active transverse stress load equal to 1600.9 kN, resisted in safety by two HEM550 profiles. The existence in the alignment C of a stairs prevents the positioning of one of the profiles, which is in that section replaced by a profile HEM400, lower and of equivalent resistance.

The flat jacks responsible for the vertical displacements of the PBA1C and PBA2C alignments are made up of thin welded metal sheet cushions, which have been filled with water under pressure, increasing in volume. The imposed displacements capable of annulling the reactions in the columns to demolish, suspending them and directing them to the remaining vertical elements, have values of 21 mm and 31 mm, respectively.

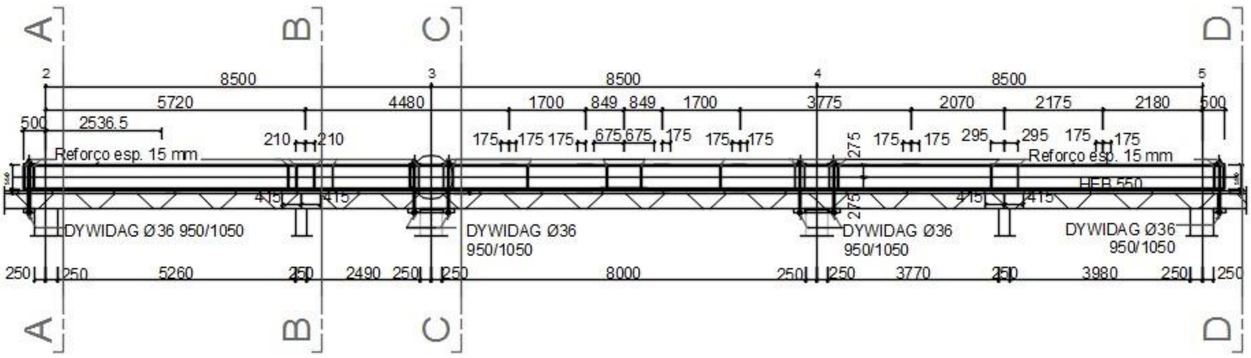

Figure 3 – Solution with vertical displacements on the steel profiles with flat jacks.

After the decompression of the 3C and 4C alignment columns, their demolitions were performed with a saw with disc and a pneumatic hammer.

3.3 Patio

The introduction of a patio on the second floor as the objective of illuminates the interior spaces of the university. The second floor is defined by continuous steel frames supported by interior columns of HEA280 and exterior columns of HEA200, which support the roof of the previous industrial building. The roof is based on IPE 270 profiles, which load to the main structure (HEA500), supported by vertical steel columns HEA280 and HEA200.

The location of the patio interrupts the steel frames of alignments 4 and 5 and therefore the IPE270 profiles are removed and the HEA500 main beams are interrupted from these alignments. Thus, stability problems arise in the supporting steel frames of alignments 4 and 5, since when they are interrupted, reducing the frame lateral resisting load and stiffness. The considered loads, to which the roof is subjected in both loading situations, are permanent loads, the wind and snow actions due to the location of the building, Lausanne, Switzerland.

The lateral pressure of the wind on the facade is the action considered, since it is the major action capable of introducing horizontal displacements in the steel frames, for the rare combination which is the most unfavorable combination.

The horizontal displacement of the frame with the interruption of the structure increases 57% in comparison to the previous situation, in the case of suction in the roof, whose horizontal displacements are superior compared to the case of pressure. One of the solutions considered to guarantee stability of this frame was the clamping of its vertical elements in order to increase stiffness and to reduce its displacements, with the introduction of two lateral steel profiles, HEA600, that prevent the rotation of the base of the profile, connected to the reinforced concrete slab (Figure 4).

(a) (b)

Figure 4 – Change in support conditions: **(a)** Fixed support - previous situation. **(b)** Clamping support - current situation.

3.4 Increase of Punching Shear Capacity

The changes in the support conditions of the slab and the new loads change the loading of the vertical elements which may cause punching shear in the slab. The verification of the punching shear of the slab is thus fundamental, avoiding a localized brittle failure. This verification takes into account a comparative analysis of the efforts that the vertical elements will be subject on the two loading situations, using the SAP2000 finite element software (CSI Computers & Structures). With this it was possible to analyze a reduction of efforts in the vertical elements in the new loading situation. However, the punching shear of the slab has to be checked, since the regulation applied, when designing slab is not the same as that currently in use, according to modern stands.

The punching shear verification is defined in the Swiss standard SIA 262: 2003, "Construction en béton" in subchapter 4.3.6 (SIA262, 2003) and is given by the equation (1). The resistant transverse stress for slabs without punching reinforcement is given in the present standard by the equation (2). This calculation is iterative, since the equation is nonlinear (taking Ved = Vrd in the equation (2), for the calculation of ry). All the unknowns of this equation are defined by this standard.

$$V_{sd} \leq V_{rd} \quad \textbf{(1)}$$

$$V_{rd} = k_r \times \tau_{cd} \times d \times u \quad \textbf{(2)}$$

The fact that the slab is prestressed contributes to the reduction of the transverse acting stress calculated by the finite element software SAP2000 (CSI Computers & Structures) due to the action of the vertical component of the prestressing force.

The comparison of the transverse acting force, with the transverse resistant load of the slab, by the equation (1), validates the safety of the slab to punching shear for most of the vertical elements. In the case of columns B6, D4, E3, E4 and E5, the strength of the slab is insufficient to transfer the forces.

The most common reinforcing techniques for increase punching shear capacity occur in the critical zone near the column conditioned by the shear forces, and they are: the increase of the superior thickness of the slab; the increase of the column section; the introduction of capitals in the head of the column; and the introduction of transverse reinforcement in the slab. All these reinforcement´s techniques are only passive, which means, they are only mobilized when the element deforms.

The introduction of a complementary concrete layer is not current used, since the location of the HEB550 profiles adopted would prevent the concrete from being placed on the slab. The increase of the dimensions of the columns throughout its length where the concreting of the superior section of the column near the slab would have to be realized with vertical holes in the slab, affecting its resistance, because the positioning of the ordinary reinforcement in this one is not totally known. The application of steel capitals in the heads of the columns is the solution used (Figure 5).

(a) **(b)**

Figure 5 - (a) (b) Steel capitals in the heads of columns**.**

4 Conclusion

The industrial building of the year 1970, changed its functionality in 2010, and became the Swiss University of Public Administration. This rehabilitation has adapted the building to new structural arrangements.

The introduction of an auditorium on the first floor led to the demolition of two central columns. In this way, two solutions capable of suspending the loads previously balanced by the columns to removed, directing them to other vertical elements, are proposed. The application of external prestress is a current reinforcement technique in the case of suppression of a column because the force of deflection of the cable equilibrates directly the force transmitted by the column to be demolished. The application of prestressing by means of displacements of support of steel profiles, appears as a solution to take advantage of the technical void between the +0.00 and the +0.955 quote above the slab, and that will be used for the passage of the system and equipment HVAC. The solution of the exterior prestress is under the slab in the zone limited by the false ceiling. However, for the implementation of the cable layout capable of balancing the forces of the columns to demolish, the false ceiling must be lowered and the auditorium height is reduced. In addition, the positioning of the stairs must be displaced to accommodate the profile of the cable. In the case of the solution of the imposition of displacements on supports in the steel profiles, the solution is entirely placed in the technical void and no architectural accommodations are necessary.

The introduction of the patio into the steel structure forced the changing of the support conditions of the interrupted frames, avoiding high horizontal displacements. In order to reduce the flexibility of the frames and increase their rigidity, the bases of the frames were fixed to support the frames and their displacements reduce.

As previously mentioned, changing the load of the building and changing the conditions of support of the slab require checking the safety of the slab by comparing the two loading conditions of the slab which lead to the need of increasing punching shear capacity by means of steel capitals.

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