Untypical Solution for a Prestressed Concrete Structures Inside The Hotel Building

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***Abstract*— In currently designed buildings, it is often necessary to locate large space, free of support, in the lower floors with a completely different structural system of higher floors. In a currently implemented design for the hotel building, the authors of the design have proposed a prestressed concrete structural system consisting of two slabs and reinforced concrete walls as webs. As a result, they have obtained the system similar to the one used in bridge buildings. The study presents design plans, discusses the problems encountered, presents the design parameters adopted and the results of static and strength analysis of selected elements of the load-bearing system. Based on the results and experiences drawn from the design, appropriate conclusions have been drawn.**

***Index Terms*—post-tensioning, prestressed concrete, building structure**

I. THE ORIGINS OF THE PROBLEM

It is required from now designed hotel, public and sometimes residential buildings to be multifunctional. This requirement creates the need for different structural systems on different floors. For example, a typical functional solution is the location of large open space in the lower floors, forced by the location of conference rooms, restaurants, exhibition halls or reception-representational areas of the hotel. However, in the upper floors, their living function, and thus a dense system of internal walls, does not require using costly slabs with large spans.

The easiest and cheapest way to get large spans, and thus spaces of the lower floors, free of support, would be to use reinforced or prestressed concrete beams carrying the upper floors. With the spans of such beams measuring over a dozen meters and loaded by several floors, the required height of the beam made of prestressed concrete far exceeds the acceptable sizes limited by the permissible height of the slab. Sometimes, a good way to reduce the height of beams is step by step introduction of prestressing [1]. On the other hand, it is a time and cost consuming process.

A common solution is to use prestressed slabs with large spans on all floors as a pre-tensioned (usually made of hollow concrete slabs [2]) or post-tensioned concrete versions. Therefore, each slab carries a load of its floor independently. Such a solution, though simple and effective, increases the costs of building execution and is not favoured by investors.

II. DESCRIPTION OF THE SOLUTION APPLIED

While searching for an effective solution to the presented problem in a designed 7-storey hotel building, the authors of this paper applied a non-standard solution for the structure of the building inspired by a bridge box cross-section. A plan of the first, 2nd, 3rd and 4th floor of one of the two segments of the designed building is shown in Fig. 1. The space of the first floor includes a restaurant room while the upper floors are designed for hotel purposes. The original design plan assumed the use in the first floor two rows of columns carrying higher floors (Fig. 1a - axes C and D). It was attempted to increase its attractiveness by eliminating internal columns due to the representative character of the space of the first floor. The limited structural height of the slab to 0.70m and the maximum distance of external supports measuring 14.5m did not allow for making the beams capable of transferring the load of four floors of the hotel, even when using prestressed concrete. The post-tensioned load-bearing system, consisting of two slabs connected every 4.2m by reinforced concrete walls (webs) was designed. In this way, the I-section with a height of full floor was made. Figure 2 shows a structural plan of the slab above

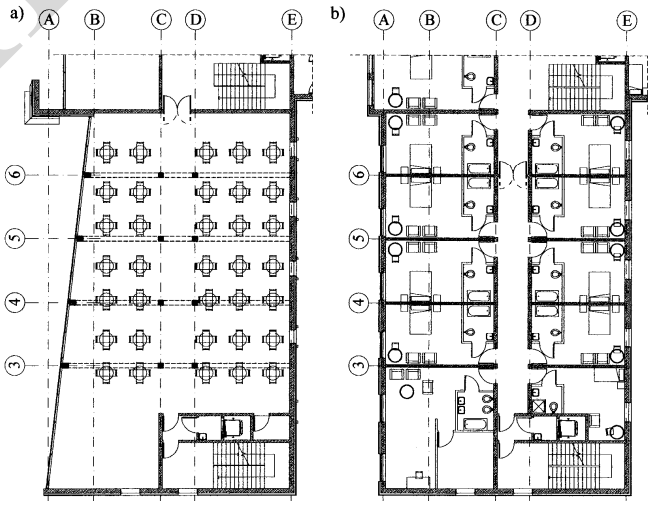


Fig. 1. Plan of the first floor with the prior designed interior column set (a), plan of the upper recurrent floors (b).

the first floor and the cross-section of created supporting beam.

Vertical reinforced concrete walls of the first floor acting as a web of I-beams are further interrupted by a hole resulting from the location of the corridor in the building. Its location in

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the middle of the span of the beam (outside the cumulative shear forces) is not an obstacle. At the slab level of +8.10m, constituting a tension zone of the formed beam, the post-tensioning in the form of four 7L15.5 cables, located in each of the four beams under the walls, was used. The spacing of prestressed supporting elements of the building is 4.20m. Three masonry structures storeys of the third, fourth and fifth floor with reinforcements in the form of reinforced concrete small columns were designed on the created post-tensioned concrete structure. The span of created load-bearing concrete structure is from 13.0 to 14.45m. Vertical cross-section of the building constructed in axis 5 (Fig. 2a) is shown in Figure 3 and the scheme of separated support element is shown in Figure 4. The C35/45 concrete (according to Eurocode 2) was to be used to complete the slabs with prestressed elements.

III. MODEL CALCULATIONS AND CALCULATION RESULTS

A. Model Structure In The FEM System

For the purposes of the project, a complete model of the building structure was made in the FEM (finite elements method) system. Slabs, walls and foundation slab were modelled with surface elements, and columns and beams with rod elements. The four nodal elements with the largest length of the side not exceeding 0.50m were used as the surface finite elements. In total, 2327 finite rod elements and 74300 surface elements were used for the construction of the calculation model. The materials with physical properties corresponding to

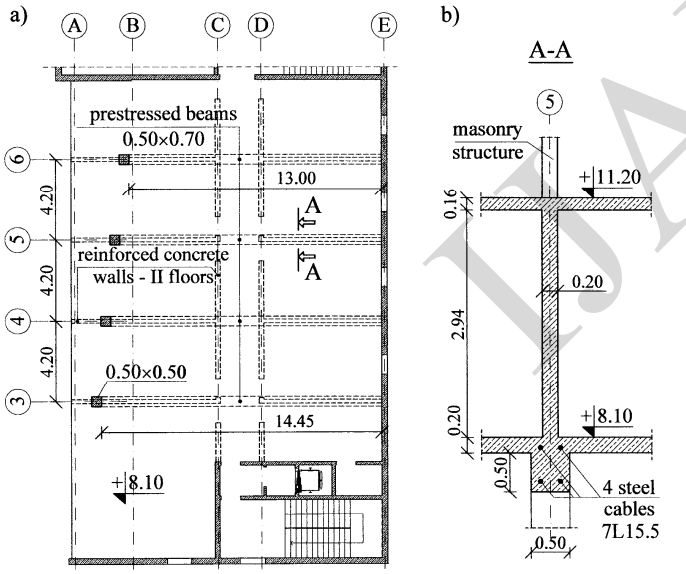


Fig. 2. Structural plan the prestressed slab above the first floor (a), A-A (5 axis) cross-section (b).

the design of the building were used. The loads were summarized and applied in accordance with applicable Eurocode standards for building loads. The general view of the calculation model is shown in Figure 5.

B. Estimation and Program of Prestressing

After the performance of static analysis of the structure and analysis of internal forces, the required amount of prestressing was calculated. It was assumed that the prestressing will constitute the 7L15.5 steel cables (7 strands 7ø5 of f_{pk}=1860 MPa). Due to the high responsibility of prestresssed elements, the prevention of occurrence of tensile stresses for all loads (including the service load) was adopted as a prestress estimation criterion in the construction work. The above assumption required to use 4 cables in each beam (a total of 28 strands with the surface of 39.6cm^2). The tension of each cable with the force of 1,400kN was applied. The adopted system of prestressing with construction details are shown in Fig. 9.

The project assumes that the structures will be post-tensioned after the making of the upper slab, i.e. item +11.20m. The structure will have full load-bearing capacity only after implementation of the prestressing and can then be entirely free of temporary supports.

C. The Results of the Calculations and the Effort of Selected Elements of Structure

Due to the effort of prestressed element, two design situations have been considered:

- Initial design situation: the force increased by 10% (1386kN per cable) after immediate prestressed losses was applied to the structure made up to the slab in item +11.20m, loaded only with its own weight.
- Permanent situation (operational): the force reduced by

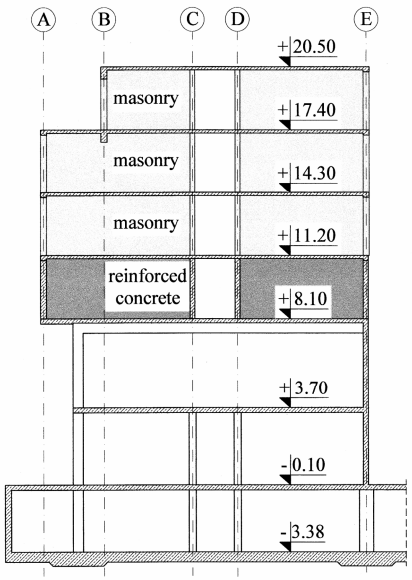


Fig. 3. Building cross-section (a), structural draft of prestressed concrete frame in 5 axis (b).

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Fig. 4. The scheme of separated support post-tensioned element.

10% (1010kN per cable) after time-dependent prestress losses was applied to the full structure model, loaded with a set of loads (including the service load).

Figure 6 shows the stresses in the initial design situation caused by prestressing and self-weight of the structure in the beam in the positions of + 8.10m. The stresses in web-wall are presented in Figure 7. In the middle span cross-section of the beam, the stresses oscillate in area of 5.5÷6.0MPa. Their dramatic increase can be noticed while approaching the support reaching the value of 19.0MPa at the wall. This value is caused by a large bending moment at the beam ends caused by applying the eccentric forces, and far exceeds the initial value of stress, considered to be safer for its linear creep, as compared to the stress of $0{,}45f_{ck}$ (for the C35/45 concrete equal to 16.2MPa). However, it should be noted that this value is the result of a point (theoretical) application of the full force (increased by 10%) in the node. In fact, prestress force is transmitted gradually by the ribs of anchorage cup (Fig. 8). Additionally, stresses have been significantly reduced. This effect disappears as the distance from the support grows

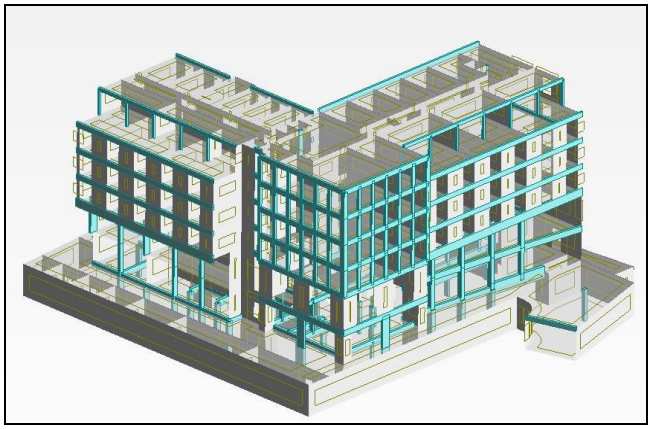


Fig. 5. The building structure model in FEM system.

because of interaction of beams and wall.

Figure 9 shows the effect of prestressing on the column. The prestress force in the beam causes the bending moment (induced) in the column of the value of 312kN. This moment is reduced by the value of 40kNm, resulting from its own weight. The value of the moment induced in the initial design situation, with a slight longitudinal force at this stage of construction (540kN), causes strong bending of the column at the inner side of the upper node. It is referred in the designing of the reinforcement. Along with the increase in loads resulting from the implementation of subsequent floors, the impact of the moment induced in the column disappears. It is caused by increase of opposite moment due to the weight of the structure and increase of the longitudinal force in the column.

Figure 10 shows the minimum stress in the prestressed element for the operational situation calculated for the full program of service loads. It can be seen that the local reduction of stresses is caused by the bending moment pick under the interrupted wall. Based on the obtained results, it can be stated that the presence of the hole is of paramount importance, its lack or reduction would certainly allow to avoid the use of prestressing. The obtained results allow to consider a variant

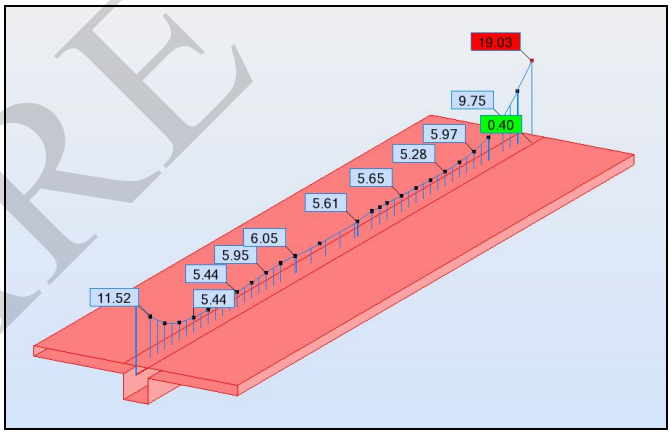


Fig. 6. Maximal compressive stresses after prestressing in the beam of the bottom slab.

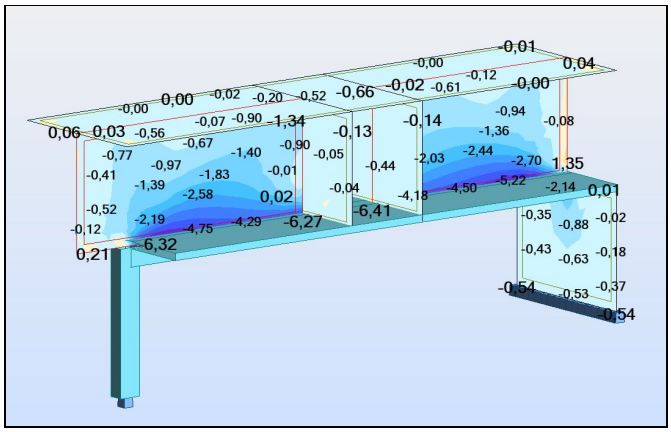


Fig. 7. Maximal compressive stresses after prestressing in the web-wall.

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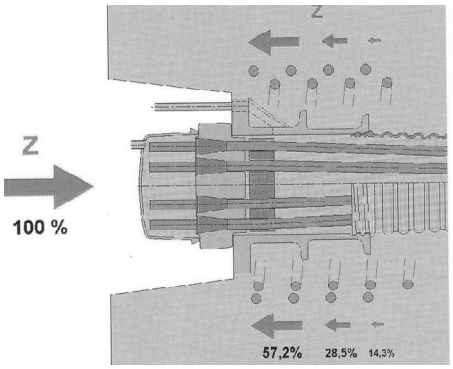


Fig. 8. Scheme of prestress transfer from anchorage to concrete [3].

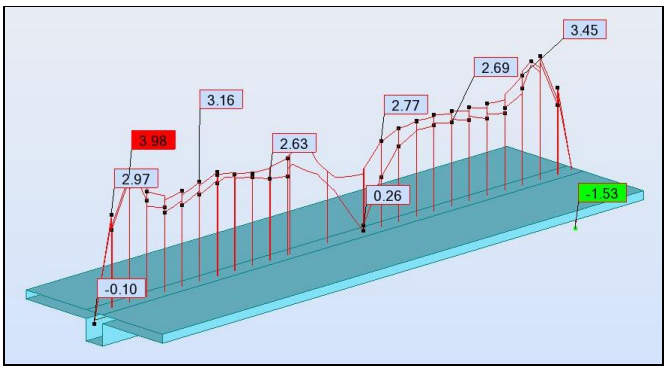


Fig. 11. Minimal stresses in the prestressed beem in the service design situation [MPa].

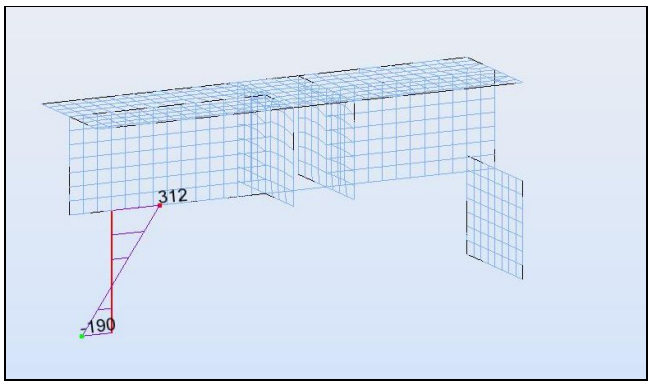


Fig. 9. Prestress effect in the column – bending moment [kNm].

of moving down the cables in the middle span cross-section of the beam (the use of curved prestressing).

IV. STRUCTURAL DETAILS

One of the problems to be solved was to locate air-conditioning ducts with large cross-sections. Due to the fact that the length of the beams covers the entire width of the building segment, and their height uses the full available height of the slab, it was impossible to avoid passing of the ducts through the beams. It was decided to limit the height of the duct up to 250mm, leaving 250mm of the lower zone of the beams for cable location (Fig. 11). The ducts took substantial width because of the reduced height of cross-section. Finally, 2 ducts with a width of 600mm were accepted.

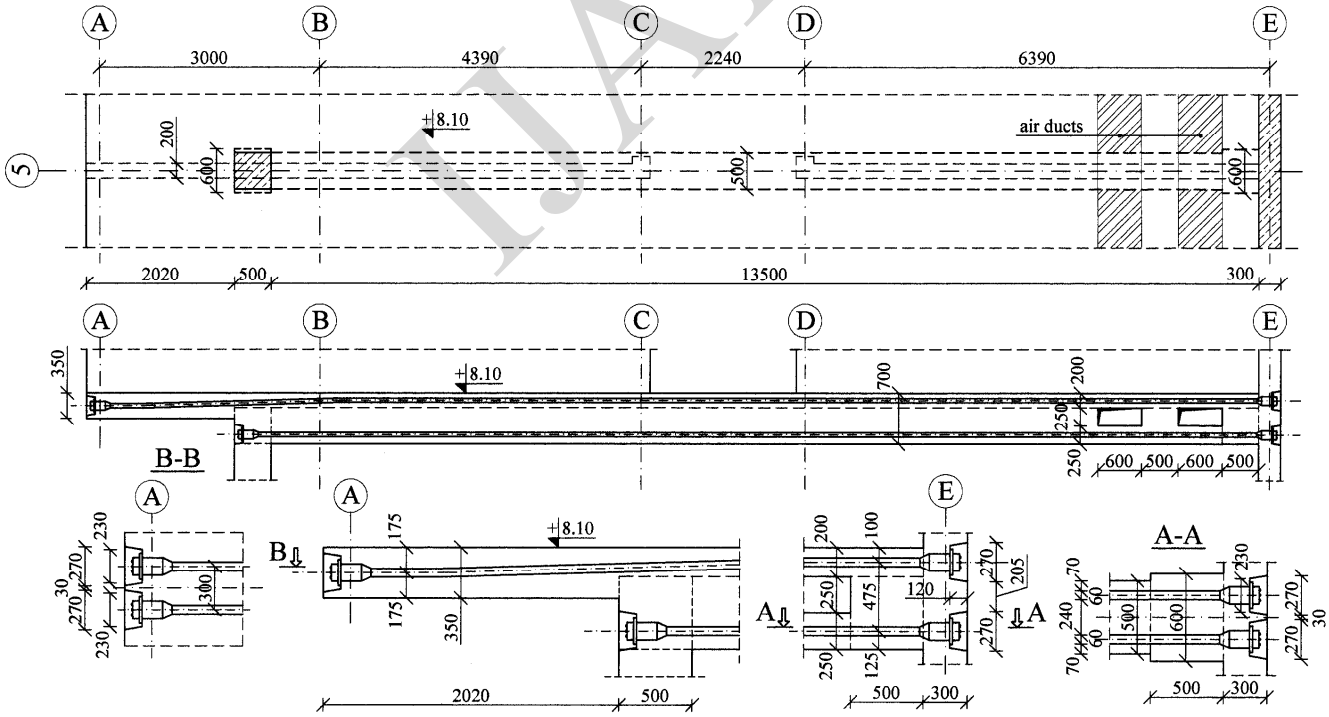


Fig. 10. Structural details of prestressed beam.

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The holes with dimensions of 600×250mm were to be located near the wall due to the presence of the reinforced wall above, transferring the shear forces. The holes were spaced only about 600mm from the edge of the wall beyond the zone of greatest stress caused by prestressing. Additionally, the beam width was increased from 500 to 600mm in the section measuring 600mm from the edge of the wall and on the width of the column. It was decided to safely anchor the ordinary reinforcement of the beam and the column. This procedure is also very important from the point of view of the effort of the element caused by prestressing at the supports. It causes a reduction of the stress at the supports, caused by the eccentric application of force. The geometry of prestressed element along with the course of cables and location of anchors is shown in Fig. 11.

V. CONCLUSIONS

On the basis of calculations and analysis carried out, it was found that:

- The abandonment of the approach commonly used in the design of reinforced concrete buildings and the use of reinforced concrete structure within the one floor (two slabs and connecting reinforced concrete walls) as cooperating load-bearing structures allowed to achieve the span of the slab measuring 14.5m without changing the structural system of higher floors,
- Such a solution allows to design a large, free of support spaces, and selected floors in multi-storey buildings without using costly slabs with large spans in higher floors.

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