Penthouse Steel Structure for a Five Story Building – Extension of the “Sigma” Office Building, Cluj-Napoca, Romania

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Abstract

The article describes the designed structural solutions to extend an existing five storey office building with an additional level in the city of Cluj, Romania. The existing building has a concrete framed structure and was in use during the intervention time. Using a light steel structural solution, the structure will overcome the in situ technological constraints due to the position of the existing building and the internal activity of the fifth floor. There is limited access due to the fact that the building is located close to a main road in the city with frequent traffic jam and the existing neighbor buildings are connected to the extended one along two sides. Also, the existing weak roof structure makes more complicated the connection of the new structure. Taking into account the above mentioned restrictions, the article describes the applied structural solutions which will make the structural steelwork erection possible. The designed structural solution using steel ensured the extension without refurbishment of the existing building structure and without to suspend the activity of those companies, which was located in the extended building. The paper emphasizes the particular aspects of the design process of an extension work, and summarizes technical and economical performances of the intervention.

Rezumat

Articolul descrie soluţiile tehnice adoptate în vederea realizării extinderii unei clădiri de birouri cu cinci etaje cu un nivel suplimentar, localizat în oraşul Cluj. Clădirea existentă având structură în cadre din beton armat, a fost în plin proces de exploatare pe toată durata intervenţiei. Utilizând soluţii structurale uşore din oţel, a făcut posibil depăşirea constrîngerilor tehnologice şi neîntreruperea activităţii la etajul cinci al clădirii pe durata intervenţiei. Clădirea existentă ce face subiectul intervenţiei este lipit pe două laturi de clădiri existente şi se situează în apropierea unei artere rutiere cu trafiic intens. Deasemenea, structura acoperişului existent realizată din chesoane subţiri a făcut mai dificilă ancorarea structurii noi de cea existentă. Cu toate acestea, extinderea clădirii cu încă un nivel adiţional s-a realizat cu succes, fără întreruperea activităţii din clădire şi fără consolidarea structurii existente. Articolul prezintă aspectele particulare ale procesului de proiectare şi evidenţiază performanţele tehnice şi economice ale soluţiilor proiectate.

Keywords: penthouse steel structures, refurbishment, technical and economical performances

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1. Introduction

The article describes the designed structural solution in order to transform an existing five storey building into a six storey building in the city of Cluj, without any intervention on the existing structure. The existing building has a framed structure with in situ poured concrete columns and transverse beams and precast concrete longitudinal beams. Due to the previous function of the building (industrial building, built in 1977-1978), the intermediate floors are realized locally with on site poured concrete solution (heavy loading) and precast concrete bottom ribbed elements. The extension imposed to use light solution, for this purpose steel structure have found suitable. Respecting the 6,00x6.00 m concrete column raster, the geometrical dimensions of the proposed over roofing resulted 18,00x78,00 m (width x length). The existing roof level was at +23.25 m from ground floor level. The extension on the sixth floor consists of the office area - 1404 m² (18 x 78 m) and the necessary annexes (stairs, elevators, access etc.). The scope of works included the following main requirements:

- To extend the existing building in order to maximize the rentable office area;
- To disturb as less as possible the existing activity;
- To avoid roof leakage during the intervention;
- To extend the structure without any refurbishment of the existing concrete structure.

In that condition, the design team needed to fulfill a list of constrains like:

- The given size of the roof, maximization of rentable area were possible only with local increase of plane dimensions of the extension;
- Limited access to the fifth floor offices, this imposed a quick and easy to apply fixing solution for the extension structure;
- All time waterproof, which imposed water tightness of the structural connection to the existing roof;
- Limited capacity reserve of the existing concrete structure and foundations, the extension was possible only keeping the supplementary loads below the capacity reserve limit;
- One side access to the roof imposed to fit the structural design to the site conditions with a corresponding erection technology

Figure 1. The site conditions (arrow indicates the access side)
2. Detailed description of the penthouse structure

2.1 The steel structure

The primary load-bearing structure of the extension was aligned to the existing concrete column raster positions. Due to architectural reason, the roof was designed with a special shape (see Figure 2.) in order to improve the “industrial“ look (see Figure 3.). The transverse steel frames are based on a 6.0 m grid. The roof girders covers the width of the building with additional 2,50 m extension on both sides (fig. 2.a). Fixed base connections for the frames have been chosen. To avoid excessive loading of the existing weak roof floor structure (built with precast reinforced concrete bottom ribbed elements) and to avoid bending moments from the penthouse column bases, imposed a totally new supporting structure for the extension, serving as an interface between existing and new structure. Having a special shape of the existing roof, all the assemblies decided to made from welded steel sections. A structural steel with S355 steel grade ($f_y=355$ N/mm$^2$) have been used. In order to create a stiff structural element between existing and new structure, for the sixth floor slab in situ reinforced concrete solution was applied. For the composite action of steel and concrete, welded shear studs have been used on floor beams. To maximize the extension area, a dry intermediate floor has been added around the elevator and access area (fig. 2b).

2.2 The building envelope

The standing seam roofing solution makes it possible to ensure the water tightness of the special shaped roof. Adequate thermal insulation of the envelope was necessary to optimize the heating cost of the extension. On the roof 150 mm thick rock wool insulation is laid down on the supporting deep trapezoidal steel profiles, waterproofing is assured by standing seam steel roofing. Large glazing of the facade combined with the additional extension of the roof protects the occupants in summertime from the overheating. The supporting structure of the facade is a steel framework of rectangular hollow sections. Local centrally placed skylights cut out of the roof to bring daylight down to the office area.
3. Structural design aspects in case of intervention works

In case of building extensions, designers must handle the following problems:
- Evaluation of capacity reserves for the existing structure and foundations
- Appraisal of on site conditions
- Site access
- Collect the list of constrains and take care of it in the design process
- Manage the implications due to intervention (proactive instead of reactive approach)

Following chapters will show the application of this list of concept in this particular case.

3.1 Evaluation of existing capacity reserves for the structure and foundations

One of the most important aspects in case of intervention over an existing building structure is to have a proper evaluation of the capacity reserves. This activity involves a data collection about the existing structure (existing documentation study, on site measurements, tests and structural appraisal). To have a reasonable response to the mentioned aspects, a global structural analysis has been performed, taking into account the collected data about the existing structure and considering the future extension.

In order to evaluate the global structural response, in the design process the following loads have been considered (characteristic values):
- Live loads on floors $u_{k} = 3 \, \text{kN} / \text{m}^2$
- Snow loads on the roof according to CR 1-1-3-2005 , $s_{o,k}=1.5 \, \text{kN/m}^2$
- Wind loads on building envelope according to NP-082-04, $q_{ref}=0.4 \, \text{kN/m}^2$
- Seismic action according to P100-2006, with peak ground acceleration $a_{g}=0.08g$ and control period of seismic motion $T_c=0.7$ sec
- Load combination for ultimate limit state (ULS) and serviceability limit state (SLS) according to CR-0-2005.

The design of the steel structure has been performed following the Romanian code STAS 10108/0-78. For strength, stability and stiffness requirements of the structural elements the prescription of SR-EN1993-1-1, SR-EN1993-1-8 and P100/2006 were used also. Fortunately, Cluj-Napoca being located on a low seismic zone (lowest on the Romanian territory), the influence of the extension on the existing structure was quite low consequently no supplementary interventions being necessary. In this particular case, the capacity reserves of the existing structure represents one of the major...
constraints in the design process. Because the load bearing capacity of the existing roof was fairly low a steel-concrete deck was proposed as a base for the extension. In order to keep under control the reaction loads over the existing frames, pinned connections for the new floor structure were chosen. The structural configuration of the extension was based on a main frame made on vertical columns supporting an elliptical truss. Although 2 lateral columns would have been enough for the roof support, four columns on a raw were provided, in order to counterbalance the efforts on the existing concrete frame. The transverse girders have been extended on both sides outside of the building, both from architectural and structural considerations. It has been obtained in that way a uniform distribution of the loads in the existing columns. A suitable horizontal and vertical bracing was provided in order to control structural flexibility, eigen values and deflections of the extension structure. Longitudinal girders, along the column line, were disposed in order to improve the lateral buckling resistance of the transverse girders.

![Figure 4. Façade of the building from access side.](image)

To express the penthouse building structural performances, the following results are relevant:

- Eigen period on transversal direction (building A) = 1.35 sec
- Eigen period on transversal direction (building B) = 1, 35 sec
- Eigen period on longitudinal direction (building A) = 1,30 sec
- Eigen period on longitudinal direction (building B) = 1,25 sec
- Steel consumption index for the interface structure = 32 kg /m².
- Steel consumption index for penthouse structure (building A) = 32 kg /m².
- Steel consumption index for penthouse structure (building B) = 38 kg /m².

### 3.2 Appraisal of on site conditions

The design of the final solution needs to consider the on site conditions. The decided intervention will generate different solutions in case of a totally evacuated building and for a building in use during the intervention. For a totally evacuated building, there is reasonable constrains in terms of intervention mode, time, location, infiltration etc. In case of a building in use during the intervention, the structural solution needs to consider the activity, which should be disturbed in the intervention area. For this particular case, due to the continuous activity in the existing building, the designed solutions imposed quick and easy to apply fixing solution for the structure of the over roofing, because the intervention on inside was possible only out of the office hours (night and weekend) and with respect of very strict security conditions. Also the intervention was accepted
only with minor damages and clean technologies, in order to be possible to maintain a quick cleaning process after the applied solutions.

3.3 Site access

In the design process of the final solution needs to take important decisions concerning to execution technology. This will be strong connected to the site access, which needs a carefully study of the site plan, where the building is located. In this particular case, due to the access from only one side (see figure 1) it was necessary to place the crane in a position to use as less space as possible along the free side and in the same time to cover as much as possible from the intervention area. In this way the free side was possible to use also for site organization, being impossible to create other options for crane placement and site organization in this particular case.

3.4 Managing the constrains

For such type of design works, it is very important a proper management of the collected constrains. Usually the involved actors have different expectations, placing the designer in a very difficult position: even the resistance and safety are the main goal; each involved actor will evaluate his own position according to the circumstances: “designer want safe connections, but user don’t want dust, dirt, noise and suspended activity”. It is important to notes that in such kind of projects also the actual user of the building is “part of the project” and needs to be included in the whole communication process. With proper communication, it was possible to maintain divergences and to obtain acceptance of the implicated actors.

3.5 Proactive approach

Depending by the site conditions is recommended to evaluate the impact over the direct exposed and neighbor area: the occupants of the building are directly exposed to have negative experiences due to the intervention. But dust, noise pollution could have negative impact over the direct exposed neighborhood. Traffic necking in case of important road routes should disturb the traffic on the whole city level, due to that site is located close to a place with frequent traffic jams. For those sites is good to have prepared strategy: what and how to proceed in case of foreseen problems?

4. Erection process and follow up

One of the most challenging activity was the erection of the main structure. Due to permanent activity inside of the building, water tightness requirement of the roof it was the major concern. That imposed clear detailing work of the structural connections to the existing structure, not only in terms of resistance. The joints to the existing structure have been designed in a way to facilitate the required structural safety, water tightness and a proper erection (figure 5). The new interface between existing and extension structure served as support for the extension works. For this operation the site placed 10 tones capacity crane was used. This was followed by the erection of the sixth floor structure (see Figure 6). Once the structure was erected, all other specialty work was possible to perform. A very important component of the whole process was the site follow up: during the execution process, each connection detail was carefully checked, in order to ensure the way of load transmission to the existing structure similarly as it was considered in the structural analysis.
5. Conclusions

The paper illustrates the successful application of the steel structure for the extension of a multi storey building without any refurbishment work. A wide range of design parameters are briefly summarized. The paper emphasizes the particular aspects of the design process of an extension work, and why such projects differ in many ways from Greenfield investments. The paper shows the importance of some particular aspects of the design process like: evaluation of existing capacity reserves for the structure and foundations (1), appraisal of on site conditions (2), importance of site access (3), proper management of constrains (4) and proactive approach during intervention works (5). The authors applied successfully a set of particular structural solutions and handled unusual design situations which cannot meet in current practice. The evidence is the final building (see figure 7) and was demonstrated by the obtained technical and economical performance, described in this paper. This case study is a good example of holistic role of structural engineering in the design process in a changing world; confirming a step forward in merging of architecture, structural engineering and other specialties (not exclusively engineering).
Figure 7. Intermediate and actual stage of the building.

6. References