Integrated Design and Construction Planning of a High Rise Residential Building

Camille A. Issa, PhD, PE, F. ASCE and Anthony El-Hachem, BE

Department of Civil Engineering, Lebanese American University Byblos, Lebanon; email: cissa@lau.edu.lb

ABSTRACT

The main issues that significantly contribute to problems and delays on construction sites are changing client's view, incomplete design information, and poor site monitoring and control. Although experienced designers and construction managers control or minimize such problems during the design stage, the complexity and amount of the information in pre-construction project make such a task very difficult to accomplish effectively. This paper presents an actual case study model for an integrated system which aims at presenting construction activities in 3D using virtual reality. Firstly, the technology enables construction managers to walk-through the proposed building perhaps at different construction time intervals-giving a vivid appreciation of the whole situation. Secondly, its enables the users to interrogate the building structural elements to present its details progress thus giving total virtual structural view of the project. Thirdly, the design effect of any changes in the building configuration can be modeled, visualized, and cost effect be calculated. Finally the system enables virtual models to be shared and thus facilitates collaborative global design and construction.

INTRODUCTION

This paper presents a case study of a high rise building on top of an underground metro station, and consisting of two basement floors and 10 floors above ground level. The structural engineer is required to design all the structural components of the building and the metro station. The building is composed of 10 stories with two basements, and the metro station is formed of three levels, under platform, platform, and over platform level. The ground level is at +12.4 m from MSL, the top of the metro station is at 3.2m, and the metro station floor is at -11.8 m. The building is placed directly on top of the metro station roof; therefore, a transfer system must be designed in order to hold the building columns as they cannot be extended all the way to the main foundation due to the conflicting architecture between the two structures. Consequently, this transfer system constitutes the main structural challenge for this project. This paper discusses the non-gravity building loads used, as well as it summarizes the sizing and reinforcement of some of the structural components. Moreover, it includes the analysis of shear, axial force, and bending moment diagrams for a typical frame in addition to the building deformed shapes under dead and earthquake loads. Finally, it presents the suggested solution for the structural challenge that would be practically is solved in order to facilitate the construction process.

Non gravity building loads.

Wind load Simulation. The wind load is calculated according to Chapter 6 of ASCE 7-05. The resultant wind load is $0.48KN/m^2$ applied on the mostly exposed face of the building where the resultant of the wind loading is maximum at the top and zero at the ground level as shown in Figure 1.

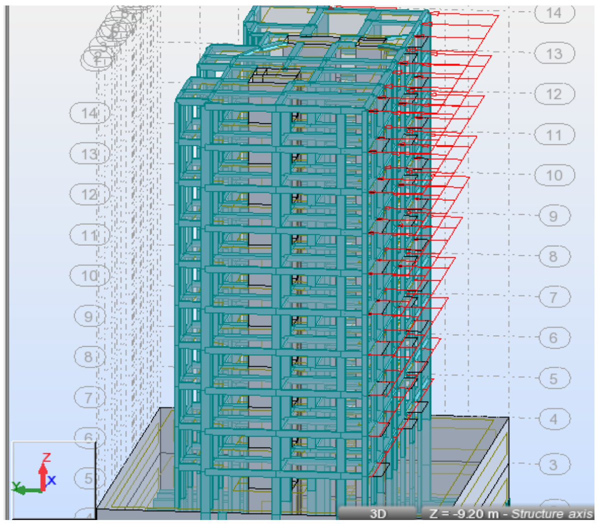

Figure 1. Wind loading.

Seismic load. A seismic design was performed on ROBOT according to IBC 2006 where the design parameters are as shown in Figure 2.and they are:

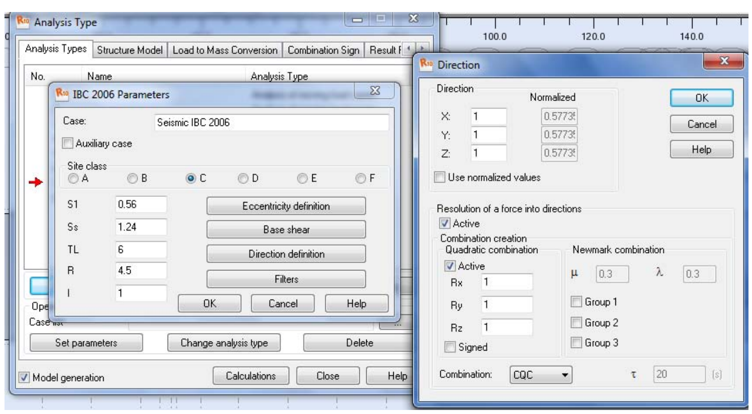

Figure 2. Seismic design parameters.

The site class is determined according to the table 1615.1.1 included in the code (Site Class Classification). The site class depends on the soil properties where A is for hard rock and F for very week soils that require special site response analysis. S1 is the Spectral accelerations for second period, Ss is the Spectral accelerations for short periods, TL is the long period transition period in seconds, R is the Response modification factor , I is the Importance factor based on occupancy category.

Metro station loads.

Dead Load. In addition to the self weight a superimposed dead load of 3 KN/m^2 is applied as by the Design Criteria Manual for Metro Light Rail Transit Projects.

Live load. The bottom level of the metro (under-platform level) consists of the mechanical, pump, sanitary, signaling, UPS & Battery rooms. Therefore, it is considered a heavy storage area with a live load of 12 KN/m^2. The other metro station levels are regarded as public spaces with 7.2 KN/m^2 live loads.

Moving load. The vehicle loading is generated as a moving load on ROBOT by creating a vehicle as shown in Figure 3.

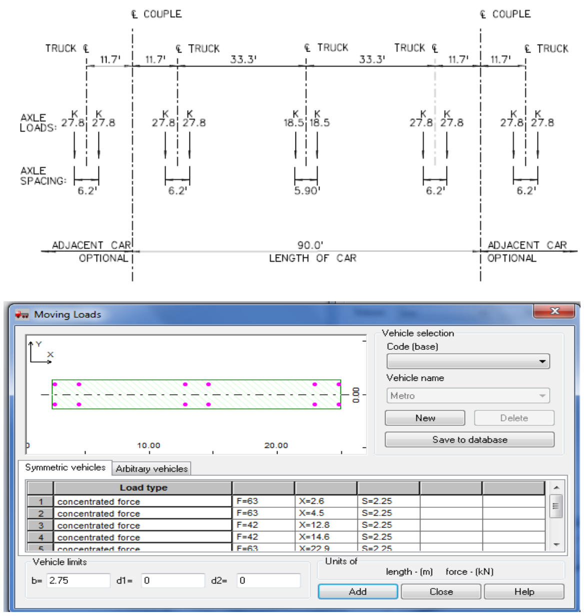

Figure 3. Vehicle load representation.

Load combinations. The load combinations are according to Load and Resistance Factor Design (LRFD) which generates seven typical combinations from which the one resulting the most critical value is adopted for the design.

Structural components. The structural components present in the building are the beams, columns, slabs, walls, stairs, and foundation.

Beams. The beams are sized depending on their position relative to the slab orthotropy direction where the critical beams lie perpendicular to the slab ribs. The beams are intended to be impeded within the 25cm slab; however, 4 beams with large spans were designed as drop beams. This has a minimum effect on the architecture of the building due to the presence of partition beneath those beams

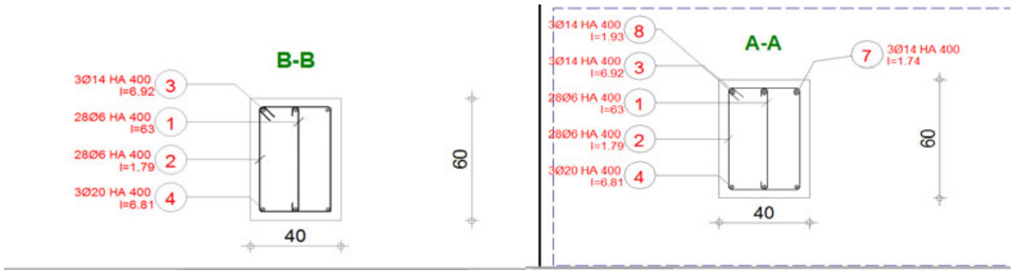

Figure 4. Typical dimensions and reinforcement.

Columns. The columns in the building are sized according to the tributary area according to which the loads are divided. As a typical example, the analysis of column 36 on robot resulted in steel ratio of 2.51% which is considered close to the one obtained by hand calculation (2.3%). The provided steel by ROBOT is 12Ø20mm as shown in Figure 5.

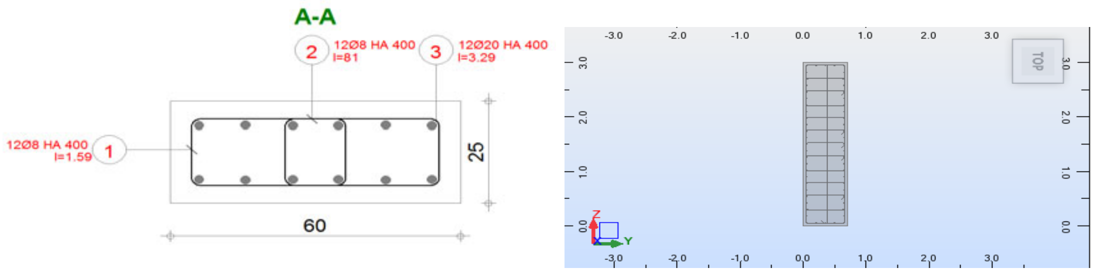

Figure 5. Reinforcement details for column 36.

Metro station Columns. In order to be able to sustain the large loads, the metro station columns are sized 70*300cm as per the architectural drawings. The main reinforcement for the metro station columns is 56ϕ22mm, and ϕ10mm@35cm ties.

Solid slabs. As the basements extend beyond the metro boundary walls, their area (882 m^2) is larger than that of the typical floor (435 m^2). Therefore, they have larger spans that required a solid slab system. The basement slabs are designed as two way reinforced 20cm solid slab, and the metro slabs are designed as two way reinforced 30cm solid slabs .Figure 6 summarizes the sizing of the building beams in addition to the slab orthotropy direction.

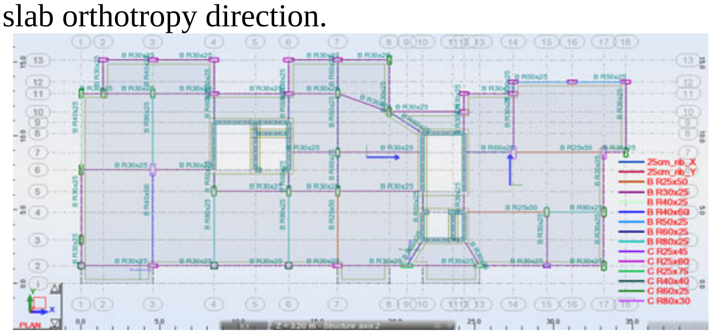

Figure 6. Floor plan with beam sizing.

Walls.

Shear walls. Shear walls are designed carry the later loads of the structure. They are mainly constructed as stairs and elevator casings. Shear walls also acts as earthquake resisting elements. Figure 7 is an example of the design of a shear wall. The shear walls were designed as an earthquake resistant element per chapter 21 of ACI318-08.

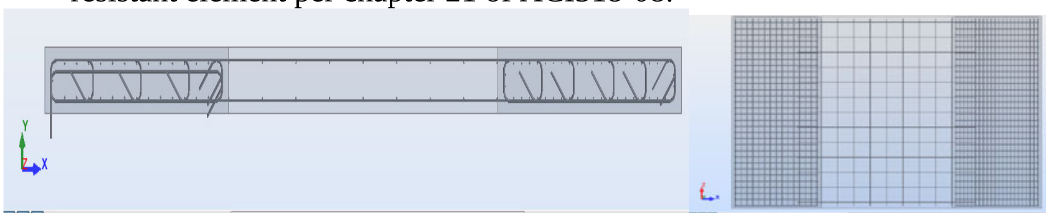

Figure 7. Shear wall reiforment: top and side view.

Basement walls. The basement walls constitute the boundary elements of the substructure, and they are subject to the soil pressure. A typical basement wall design is shown below.

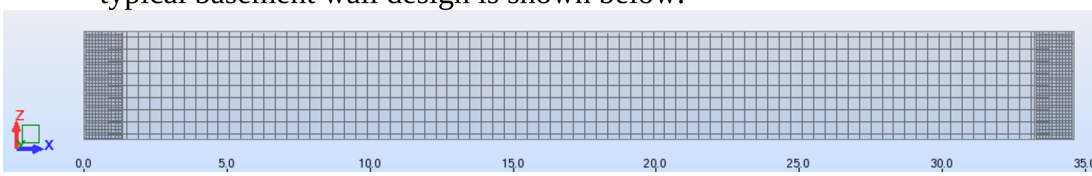

Figure 8 . Basement wall reinforcement.

Axial, shear, and bending moment diagrams for a typical frame

Figure 8 is a typical frame chosen for analysis.

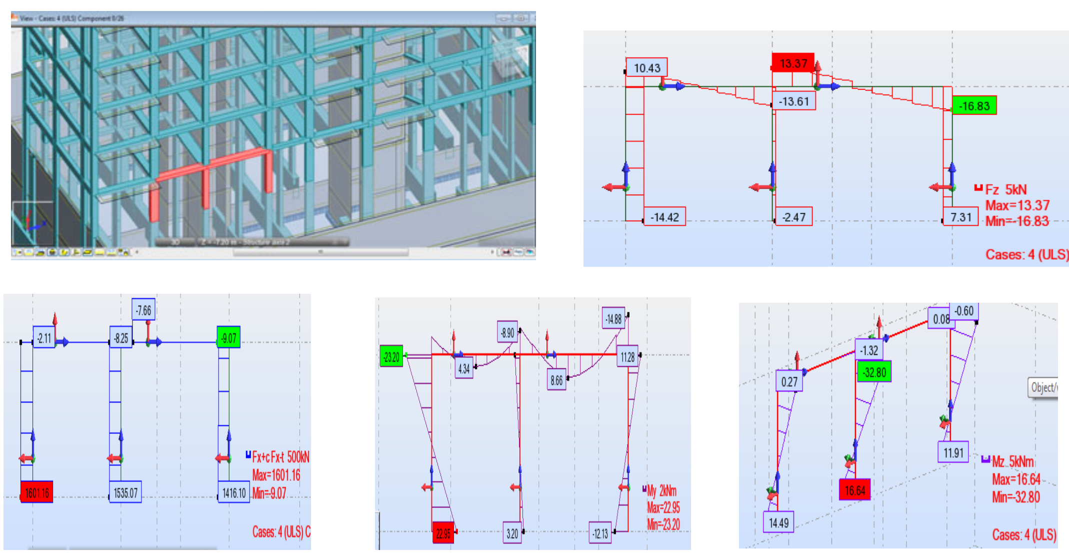

Figure 9. Column moment diagram about z-axis for a typical frame.

Foundation. The foundation is designed as a raft foundation (Figure 10) due to the present soil conditions and the high water table in addition to the large building loads. Therefore, a 1m mat foundation would handle the 300Kpa stresses with a uniform 3.9 cm settlement. As provided by robot, **Ø10mm@20cm** steel bars are required in both directions.

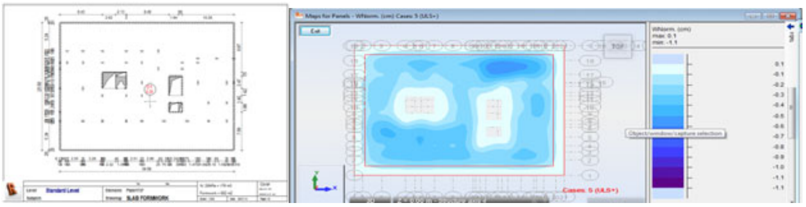

Figure 10. Foundation analysis results.

BUILDING DEFORMED SHAPES

Due to dead load. The building has a minimal deflection due to the dead load where the maximum value is 1:

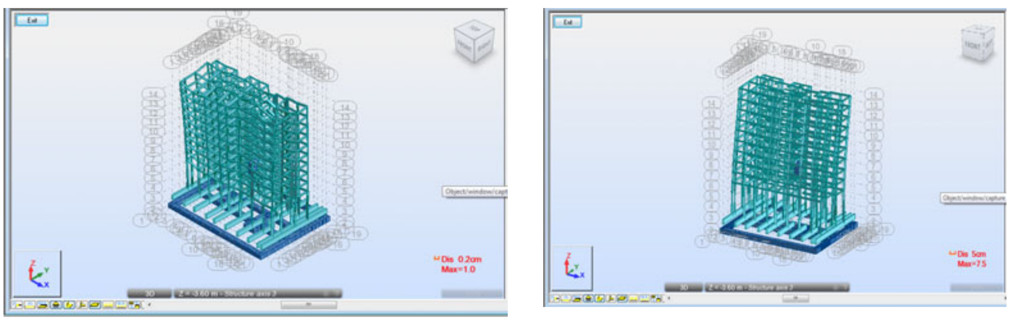

Figure 11. Building deformed shape due to dead load.

Due to earthquake load. The seismic design of the building is conducted according to IBC2006 which states that structures should be designed in a way that prevents catastrophic collapse in case of an earthquake. Several parameters must be determined in order to perform a seismic analysis of the structure. The spectral accelerations must be determined. For our geographic location, the spectral response acceleration for short periods (0.2s) is 1.24g and the spectral acceleration for one second is 0.56g. The long term period transition period is TL=6seconds. Moreover, the response modification factor is 4.5 for shear wall frame interactive system with ordinary reinforced concrete moment frames and ordinary reinforced concrete shear walls. Finally, an importance factor based on the occupation category is determined. Our occupancy category is II, thus the importance factor is 1. The maximum story drift is 7.5 cm. The allowable story drift is 0.02h where h is the story height level below the point under consideration. The allowable story drift for the 10^{th} floor is 0.02*(3.2*10) = 0.64m = 64 cm. Thus, the building is safe according to IBC.

STRUCTURAL CHALLENGE

Building column foundation. The main challenge in this project was to found the building columns on a sort of a transfer system due to the conflicting architecture between the building and the metro station. As the metro station requires large spans in order to be able to serve its purpose, the building columns could not be extended all the way to the foundation. As a first alternative, a transfer slab was suggested in order to hold the building columns. Several iterations were made in order to try to carry the large point loads on the slab. However, this solution was aborted when a 2 meters thick slab was still witnessing a non-allowable deflection. The second alternative was to place the columns on deep beams as shown in Figure 12.

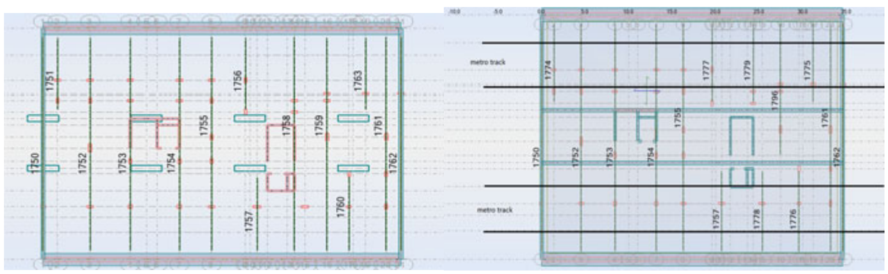

Figure 12. Deep beams.

In this solution, some of the beams were spanning over 25.5 meters. Therefore, this combination of long span with large point loads resulted in a punishing moment that a 100*200 cm beams were not able to safely handle the loads. Therefore, the following improvisation was suggested in order to carry the column loads. The idea was to reduce the moments carried by the beams since the applied loads cannot be reduced. Thus, if the beam spans are reduced by replacing the metro columns beneath the building by a 40 cm thick wall.

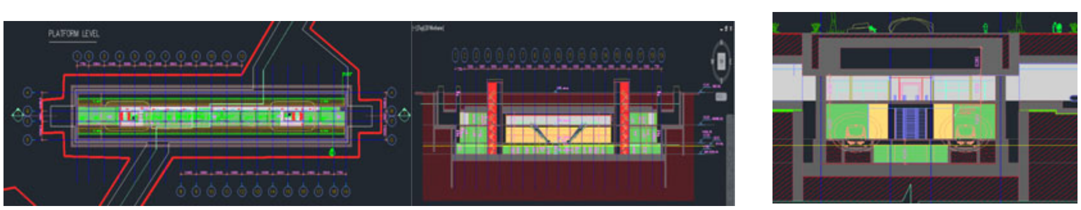

Figure 13 Metro layout.

In order to be able to do so without severely affecting the metro station layout, the position of the building has to be shifted from the center of the metro station (Figure 14). In this way, the space provided by the two added walls could be used as service rooms and metro access points. Moreover, the building

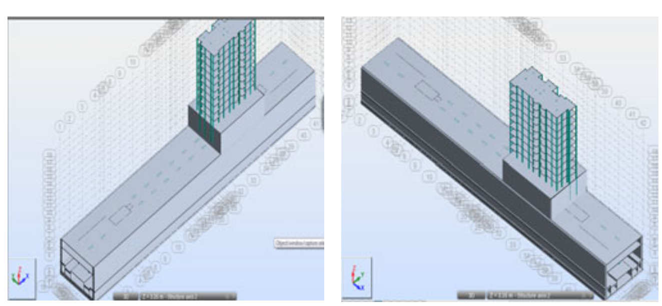

Figure 14. AutoCAD Architectural

shear walls will be extended all the way to the foundation. This would provide a direct access from the building to the metro station and would thus raise its value. Therefore, this system of deep beams is located within a 2 meters space above the metro station roof which provides insulation for the building from the metro station effects.

Metro station roof slab. In this project, we were faced with another structural challenge caused by the heavy soil load on top of the metro station. This load is formed of a 9.2 meters fill above the metro station roof slab in order to reach the ground level. As a first trial, a 50 cm thick slab witnessed a 21.3 cm deflection. Therefore, we started increasing the slab thickness and recording the deflection as shown in Table 1.

LESSONS LEARNED

Table 1. Metro Roof Slab Thickness vs. Deflection

Thickness	Deflection
50 cm	21.3 cm
75 cm	9.2 cm
100 cm	5.1 cm
110 cm	4.1 cm
125 cm	1.5 cm

As everything in life, it is difficult to accomplish the best intended result from the first time. Therefore, the assigned task undergoes several trials and iterations before reaching its final state. This issue is typical for any design project in which it requires several futile attempts before reaching the final design. Consequently, several time-consuming efforts could be rendered useless, and the exercise had to be restarted from scratch. The initial planning and sizing of components could have reduced the fruitless efforts in trial designs. Thus pre-planning at the beginning, would prove to be very beneficial at the latter stages of the project in saving time and effort. An excellent example of how virtual reality lead to a piratical solution was the system of deep beams is located within a 2 meters space above the metro station roof which provides insulation for the building from the metro station effects. This idea forced itself on the design process and ended up in benefiting the ergonomics of the design.

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