REPLACEMENT OF A REINFORCED CONCRETE SLAB WITH A LIGHTWEIGHT COBIAX SYSTEM

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Replacement of a Reinforced Concrete Slab with a Lightweight COBIAX System"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

REPLACEMENT OF A REINFORCED CONCRETE SLAB WITH A LIGHTWEIGHT COBIAX SYSTEM

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This study consists of a detailed analysis of the voided slabs, taking into account the impact that these slabs have on the weight of the structure, their impact on the environment where it is built, the cost of construction and the time that these slabs seek to be implemented in our country. The large-span concrete slab system with internal spherical void former Cobiax has been used in Europe for more than ten years. They are biaxial reinforced concrete slab systems with internal spherical void former grids. This article discusses three issues related to Cobiax flat panel systems: their shear strength, total weight of the structure and their economic value in the context of Albania. Since the shear resistance of the COBIAX slab requires the "loss" (or reduction) of the aggregate interlocking, it will affect the design requirements of the reinforced concrete design code. To make it more distinct how the building changes when reinforced concrete slabs are replaced with voided slabs a four-story building with reinforced concrete slabs 18 cm thick will be taken as a case study and a comparison of the load in foundation will be made.

Keywords*: Cobiax, monolithic slab, load, shear, weight.*

ABSTRAKT

ZEVENDESIMI I SOLETAVE TE PERFORCUARA ME SISTEMIN COBIAX

Dulla, Anxhela

Master Shkencor, Departamenti i Inxhinierisë së Ndërtimit

Udhëheqësi: Dr. Enea Mustafaraj

Ky studim konsiston në një analizë të detajuar të soletave me sfera me ajer, duke marrë parasysh ndikimin që këto sfera kanë në peshën e strukturës, ndikimin e tyre në mjedisin ku është ndërtuar, koston e ndërtimit dhe kohën që ky sistem kërkon të zbatohet në vendin tonë. Sistemi i soletave të betonit me sfera te mbushura me ajer Cobiax është përdorur në Evropë për më shumë se dhjetë vjet. Ato janë soleta betoni të përforcuar ne dy drejtime. Ky studim diskuton tre çështje në lidhje me sistemet e panelit të sheshtë Cobiax: forca e tyre e prerjes, pesha e strukture dhe vlera e tyre ekonomike në kontekstin e Shqipërisë. Meqenëse rezistenca ndaj prerjes së pllakës COBIAX kërkon "humbjen" (ose zvogëlimin) e ndërthurjes së agregatit, kjo do të ndikojë në kërkesat e projektimit të betonit të armuar. Për ta bërë më të qartë se si ndryshon ndërtesa kur soletat e betonit të armuar zëvendësohen me soleta me sfera te mmbushura me ajer do të merret si një rast studimi një ndërtesë katër katëshe me soleta betoni të armuar me trashësi 18 cm dhe do të bëhet një krahasim i ngarkesës në themel.

Fjalët kyçe: *Cobiax, solete monolite, ngarkese, force prerëse, pesha.*

Dedikuar familjes sime, e cila ka qenë mbeshtetja ime me e madhe ne cdo hap te jetes ime dhe cdo arritje e imja i takon vetem asaj.

Dedikuar motres sime, Elges si dhe shokut tim me te mire Francit per suportin e tyre te pakushtezuar cdo dite te ketij rrugetimi.

Dedikuar miqeve te mi, kolegeve te mi te cilet me kane ndihmuar dhe me kane shtyre qe te permiresohem cdo dite e me shume.

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I would like to thank Dr. Enea Mustafaraj for his assistance and guidance during this demanding task. His persistence was a key factor in the compilation and completion of this Master Thesis.

Thank you!

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

In recent years in Albania the construction of new buildings has increased significantly, for many different reasons. The construction of these buildings has its impact on the economy, politics, infrastructure, environment and pollution of our country. Therefore, it is the duty of construction engineers to always be looking for new ways of construction to bring in their place the most optimal ways, which means: buildings with maximum safety, lower cost, lower pollution for citizens of this place and time saved. During the period of communism for almost 45 years in Albania were built many factories and masonry residential buildings, mainly 4 to 6 floors. After the 2000s, the construction of reinforced concrete residential buildings over 7 floors up to 12 floors began. And in recent years even taller buildings are being built. Taking into account the recent seismic events in Albania as well as the weights of these buildings, we as engineers must find the most efficient ways to make the buildings lighter. The constituent parts of the building which have the greatest weight are the columns, beams and slabs. One of the methods of lightening the weight of the building is the replacement of reinforced concrete slabs with voided slab.

A lot of attempts have been made in the past to carry out heavy slab activities, without reducing the strength of the court. Reducing the own weight in this way will reduce the deflection and make a greater long span reachable. Not all concrete is internal replaceable though, since concrete aggregate is very important for shear resistance,

Concrete at the top of the slab needed to form compression blocks for bending resistance, and the concrete in the stress zone of the slab needs to be bond with reinforcement to make it effective for bending resistance. Also, above and below the slab it is necessary to ensure pressure transfer.

1.2 Thesis Objective

The idea of removing ineffective concrete in slabs has been always studied by engineers and is still used to reduce the self-weight of long-span structures. Cobiax® are not introduced yet to Albanian market, but are being used for a decade in the European market. This systems purpose is to create a grid of void formers inside the slab by using hollow plastic spheres cast into the concrete. As a result, a flat slab soffit is created which bear the benefit of using flat slab formwork. By reducing the concrete's self-weight, even without the need to use prestressed cables, large spans can be formed, if the loads are low. Cobiax slabs are formed by fixing 6 mm diameter reinforcement cages with high-density Polyethylene or Polypropylene spheres. The reinforcement is put together tightly in order to create a grid with of evenly spaced voids. Using Cobiax slabs is a very easy to implement method of construction since the cage and the spheres are very lightweight. This method, erases the need for concrete chairs and increases the slab's shear strength.

When speaking of this type of slab, its cross section, which has both top and bottom flanges, enables low compressive stresses, wither for sagging or hogging bending. The flexural design of a Cobiax slab, even though it has a more complicated cross section, is not too hard in respect to flat slab designs. Although, when designing for shear, the spherical void formers increase web width of the concrete which change through the depth of the section. They also cause changes in the horizontal direction. This type of slab is relatively new, thus there are no specific recommendations for design. The most effective method so fare, have been using empirical methods in order to consolidate shear resistance. Continuous studies are done to create the most effective method in the complete design of a Cobiax slab, through analyzing 3D finite element software models.

The Cobiax system has had vast implementation in Europe and UK. Design methods in Switzerland are common to the ones used in South Africa whereas German methods are a bit stricter. In Albania, this system is yet to be implemented because of lack of design methods and necessary workmanship training. It is yet to be proved if this design system is safe enough for areas with high seismic activity, such as Albania or the Mediterranean.

1.3 Scope of works

In this thesis, focus on creating shear capacity in Cobiax slabs without having the need for reinforcement in shear by using the comparison of experimental results with theoretical predictions. Current design practices dictate that flexural reinforcement and slab depth are the most important parameters to be reviewed and studied. If we increase slab depth and flexural reinforcement, we automatically increase shear resistance but not linearly. Concrete strength and shear span are also worth mentioning when discussing influence on shear capacity, although they are not as important.

This thesis will also investigate into this slab's peculiar design, more elaborately, the effect of the steel cages on the spheres. The steel reinforcements have a big effect on vertical shear capacity and horizontal shear transfer at the cold joint at the bottom of the slab. The deflection of the slab will also be studied, which will be done by analyzing a 3x3 span Cobiax slab with different span lengths and under different loads. This analysis will dictate short-term deflections in Cobiax slabs, by using simplified stiffness calculations.

A Cobiax slab is cast in two layers – an 80mm thick layer at the bottom and a second layer on the top. In order to allow the setting of the first layer of concrete, there should be a few hours between pouring. This is also done to keep the cages in place and not allow the polypropylene or polyethylene spheres from drifting. Similar slab patterns will also be analyzed to create an estimation of the economical range needed to implement Cobiax slabs. The recent, will take the form of waffle slabs.

Graphs will be used to show the comparison for different spans and loads. Finite element slab analysis will create the comparative graphs, in order to come to the best economical choice.

The study of Cobiax slabs in this thesis will be on their usage on commercial buildings. The analysis will be done only with low live loads and short spans. An assumption is made that the structure will have only a few floors, thus column sizes and foundations will not have a great economical effect on the relative costs of Cobiax slabs.

1.4 Organization of the thesis

This report consists of the following chapters:

- Chapter 1 will be an introduction to the thesis.
- Chapter 2 will study the literature on the shear and deflection in Cobiax slabs, how the design process is done and the comparison of the most economical solution between different types of designs.
- Chapter 3 contains experimental work done when studying the shear capacity of Cobiax slabs.
- Chapter 4 discusses technical issues of Cobiax slabs, and the cost comparison results obtained for long span slab systems.
- Chapter 5 contains the conclusions and recommendations after the whole process of investigation.
- The list of references follows the last chapter.
- The Appendices supporting the cost analysis follow.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter it will be discussed design guidelines for load bearing members such as concrete slabs and beams, with emphasis on the design of ordinary flat slabs, Cobiax flat slabs and post-tensioned flat slabs. The goal is to describe the requirements regarding strength and serviceability of Cobiax slabs.

The shear strength, flexural performance and different analysis methods of these slabs of reinforced concrete slabs without shear reinforcement have been studied in detail to introduce the Cobiax system. The Eurocode 2 design code was consulted to describe the general structural properties of concrete beams and floor slabs, with a focus on shear characteristics.

The behavior of the post-tensioning slab will be discussed for reference, and the Cobiax slab will be compared with the post-tensioning and waffle slab.

Figure 1 Cobiax slab and its components (Stefan Sommer)

2.2 Shear Resistance based on Eurocode 2

Eurocode 2 (EC 2) has detailed design on two shear design methods-standard method and variable strut tilt method. The variable strut inclination method assumes that all shear forces are only reinforced by shear forces, and concrete does not contribute (Mosley et al., 1996). This study mainly takes into consideration the shear strength of beams without using shear reinforcement, so the variable pillar tilt method will not be used.

To calculate the concrete's resistance without shear reinforcement, the standard method considers the following empirical formula:

$V_{Rd1} = \tau_{Rd} * k * (1.2 + 40 * \rho_1) * b_w * d$ *(Equation 1)*

Where

τ_{Rd} *is basic design shear strength =* $0.035\, f_{ck}^{1/3}$ *Mpa with* f_{ck} *limited to 40 Mpa*

f_{ck} *is the characteristic cylinder strength of concrete, (MPa)*

d is the effective depth in mm

k is $1.6 - d \{>1\}$ *or 1 where more than 50% of tension reinforcement is curtailed, unitless*

b_w *is minimum width of section over area considered, mm*

$\rho_{1} = As_1/b_w d$

As_1 *is the area of longitudinal tension reinforcement extending more than a full anchorage length plus one effective depth beyond the section considered,* mm^2

EC 2 has design guidelines in the form of partial material safety factors, and the shear force applicable to fck is ym= 1.5. In order to obtain the characteristic capacity (ym = 1), if written in the following form, the equation must be established

$\tau_{Rd} = 0.035(1/1.5)^{-2/3}(f_{ck}/y_m)^{2/3}$ *(Equation 2)*

Shear capacity provided by shear reinforcement

A simpler truss can be considered where equilibrium determines the resistance provided by the shear reinforcement Vs. The total resistance is the combined effect of Vs and Vc.

$V=Vc+Vs$ *(Equation 3)*

Where:

V = total shear resistance

V = resistance of concrete and tension reinforcement

The following equation for vertical shear links is used to find the shear resistance that the links provide:

$V_s=A_{sv} f_{yv} \cot\beta\,(d/s_v)$ *(Equation 4)*

V_s *is the shear resistance of all links that intersect the crack*

f_{yv} *is the yield strength of steel*

A_{sv} *is the area of each stirrup leg that crosses the shear crack*

s_v *is the center to center spacing of the links*

d *is the depth of tension reinforcement*

β Is the crack angle being 45° according to research, with cot (β) = 1

2.3 Cobiax and Flat Slab Shear Resistance

The way that the Cobiax system Works is that it need to form an internal void in a biaxial flat panel system. Prefabricated spherical hollow balls made of polypropylene or polyethylene are fixed in a 5-h mm thick high yield cage. Depending on the area of the slab, the number of the fixed steel balls. It can wither be from 1 by 4 (four balls in a row) to 8 by 8 (eight balls in eight rows) or more, depending on the size of the balls and the processing power of the user, such as on-site crane capacity. After that, the entire grid is placed on the tensile steel bars and the cage is fixed on it with metal wires. The concrete was poured at two different time stamps, first extending 80 mm thick above the horizontal rods of the cage, and then pouring to the top of the required slab height after a few hours. It is necessary to let the first layer harden so as the balls are not moved from their position and avoid their lifting during the second pouring. The result is a flat slab, which allows the use of flat formwork. The method used to fix the sphere was improved after 1999. These tests were carried out on Technical University Darmstadt (TUD) and the results were compared with Eurocodes and DIN design codes. Methods as below:

- The theoretical research is done on a system called bubble deck, which fixes the sphere by constraining the sphere between the top and bottom rebar's instead of the cage used in practice today and in the research reported in this project Sphere.
- It is assumed that there are no stirrups (no shear reinforcement).
- The loss area of aggregate interlocking is calculated by considering the diagonal plane along the shear crack minus the void area on the plane. The effect of the pin and the resistance of the compression block are not considered, which means that only one shear component is used, the aggregate interlock.
- A 30º or 45°angle of shear crack is taken into consideration.

2.3.1 Shear Resistance of Cobiax Slabs

Due to the presence of the internal spheres, the shear behavior in these slabs will be different from that of solid concrete flat slabs. There are two main factors that need to be considered. The fact that the reinforcement steel cages act as partial shear reinforcement and the loss of aggregate interlock. A diagonal shear crack will encounter voids in the central part of the beam; thus, it is necessary to investigate shear behaviors for conventional concrete and then for Cobiax slabs.

2.3.2 The behavior of the concrete beans without shear reinforcement

Equilibrium in the shear span of a beam is described by Park and Paulay (1975) as follows:

One side of a simply supported beam with a constant shear force over the length of the beam under consideration is shown in Figure 2. The top of the beam is in compression (*C*) and the bottom region in tension (*T*). Internal and external forces maintain the beam's equilibrium, bounded on one side by a diagonal crack. By combining 3 components in a beam without web reinforcement, the transverse external forces are maintained stable.

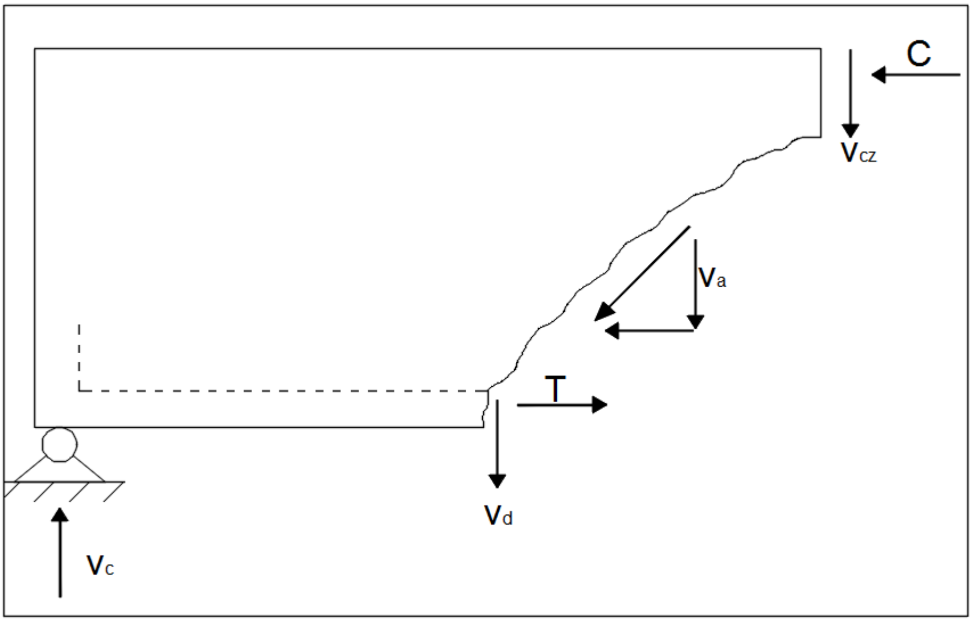

Figure 2 Mechanisms of shear transfer (Roberts and Marshall, 2006)

Shear force across the uncracked compression zone V_{cz} (20 to 40%).

A dowel shear force transmitted across the crack by flexural (tension) reinforcement V_d (15 to 20%).

Aggregate interlocking is V_a which is the sum of the inclined shear stresses, V_a, which move across the inclined crack by means of interlocking, is referred to as aggregate interlocking, and estimated at 35-50%.

Aggregate interlock is the one factor with the largest contribution.

The equilibrium condition is stated by the formula:

$V_{C=}V_{cz}+V_{A+}V_d$ (Equation 5)

The above formula shows the total shear capacity resulting from the three main shear-carrying components V_{cz}, V_a and V_d described above.

In this step there are established 3 different a_v/d mechanism ratio sectors which cause shear failure of simply supported beams where the load is concentrated on point loads, where:

a_v = distance of a single point load to the face of the support

d = effective depth of the tension reinforcement

When Leonhardt and Walther (Leonhardt 1965) tested 10 beams, the abovementioned conditions were discovered. No stirrups were present and the materials were the same on all the beams.

The ten beams were plotted in terms of shear span vs. depth ratio. In Figures 2.c and 2.d we observe the shear forces and the failure moments. Theoretical ultimate shear forces are Vu and Mu are the moments represented by the solid lines without dots.

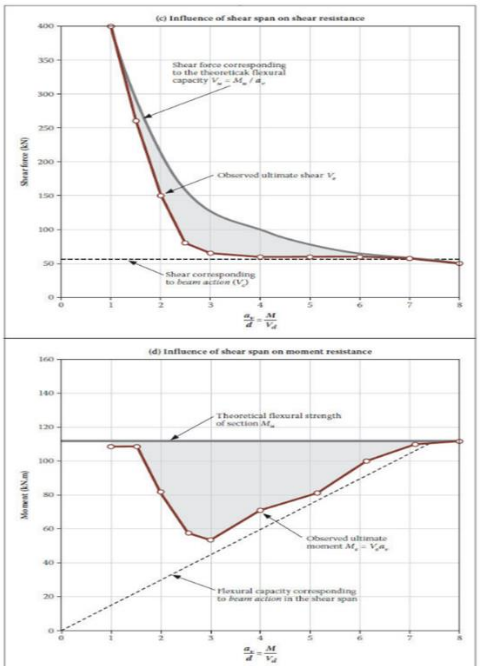

Figure 3 Moments and shear according to depth ratio (Leonhardt, 1965)

2.4 Cobiax and Flat Slab Deflection

Compared with a solid slab, the hollow front sphere in the Cobiax slab affects and reduces its rigidity. In the "Cobiax Technical Manual 2006", in the "Rigidity and Deflection" section the stiffness factor of a Cobiax slab compared to a solid slab of the same thickness is shown. The values are based on performed in the flexed state I (unruptured), assuming the vertical center position of the balls and the balls are fixed at 50 mm from down to up of the slab.

The existence of a sphere in deflection state II (cracked) was investigated by laboratory bending tests on TUD. The results show that the reduction factor in state I is the decisive factor. The stiffness factor is calculated based on the 2nd moment of the area ICB (for Cobiax slabs) and ISS (for solid slabs).

Taking the abovementioned factors into account, and considering the reduction in the weight of the Cobiax slab, the calculation regarding the deflection of the Cobiax slab can be estimated. These are the observations:

Although the stiffness has been reduced, for the same load, the absolute deflection of the Cobiax slab is still less than one of the solid slabs of the same thickness, unless the applied load is 1.5 times more than the static load.

In ordinary buildings, the ratio of applied load to static load is usually under 1.5. This proves that the total defect rate of Cobiax slabs is lower than that of solid slabs. Therefore, a smaller depth can be specified.

2.5 Slab analysis methods

The groundwork of limit state analysis is that due to plasticity, bending moments and shear forces can be redistributed before reaching the limit load, rather than predicted by elastic analysis. The reason for this is that once the tension steel yields, the torque changes little with the additional curvature. Once the high-stress areas of the slab reach the yield moment, they tend to keep the same rates of a moment capacity close to the bending strength, and the curvature will further increase. Then, with more load increase, the yield of the slab reinforcement will extend to the next parts of the slab.

Ultimate State and Ultimate Limit State are different. The Ultimate State (US) involves excessive deformations or deformations that are over the limit values that lead the component near collapse. Plasticity of the structure and residual deformations are also present. The ULS instead is a condition that must be satisfied to achieve the demand for strength and stability under loads. If bending, shear and tensile or compressive stresses are under the limits, then the US is satisfied. We can set the terms of the limit criteria using stresses. In this state, if the structure is concluded as safe then the “Magnified Loads < Reduced Resistances”. For a structure to be classified as safe, the ULS must be fulfilled.

2.5.1 Serviceability limit state (SLS)

2.5.1.1 Limit state of deflection, cracking and vibration

After calculating for ULS, a calculation for Service Limit State must be done. The purpose is to prove that under the action of characteristic design load and/or under certain magnitude of applied deformation, settlement, vibration or temperature gradient, etc., the structural behavior conforms to and must not exceed the SLS design standard value specified. Limits of stress, deflections, rotations, flexibility, dynamic behavior and crack width checks that are part of durability and the structure’s ability to fulfill daily functions are criteria that should be checked. Other limits that might affect structural design should be checked too, such as acoustics. In terms of serviceability, a structure must be able to withstand daily loads to fulfill the serviceability limit state criteria. This check should be done when the structural behavior is purely elastic.

Flat slabs can be analyzed by four other ways: yield line, grid analogy, equivalent frame or finite element.

2.5.1.2 Yield Line:

The yield line is an upper limit method, and the ultimate load can be determined by the collapse mechanism. The folding mechanism consists of flat parts separated by plastic hinge lines. When the wrong collapse mechanism is selected, the ultimate resistance torque between the plastic hinges will be exceeded. The upper limit method causes the final load to be too much or correct. Therefore, it is essential for the right collapse mechanism to be chosen, so as not to overestimate the final load. This method is not suitable for pre-stressed slab design (Marshall & Robberts, 2000).

2.5.1.3 Equivalent Frame:

This method closely simulates the real behavior of the slab through the column and beam system analyzed in two span directions. This method considers vertical and horizontal loads on the slab (Marshall & Robberts, 2000).

2.5.1.4 Grillage Analysis

A grillage is very applicable for irregular flat slabs, while equivalent frame analysis is not applicable (Marshall & Robberts, 2000).

2.6 Post tensioned flat slabs and waffle slabs

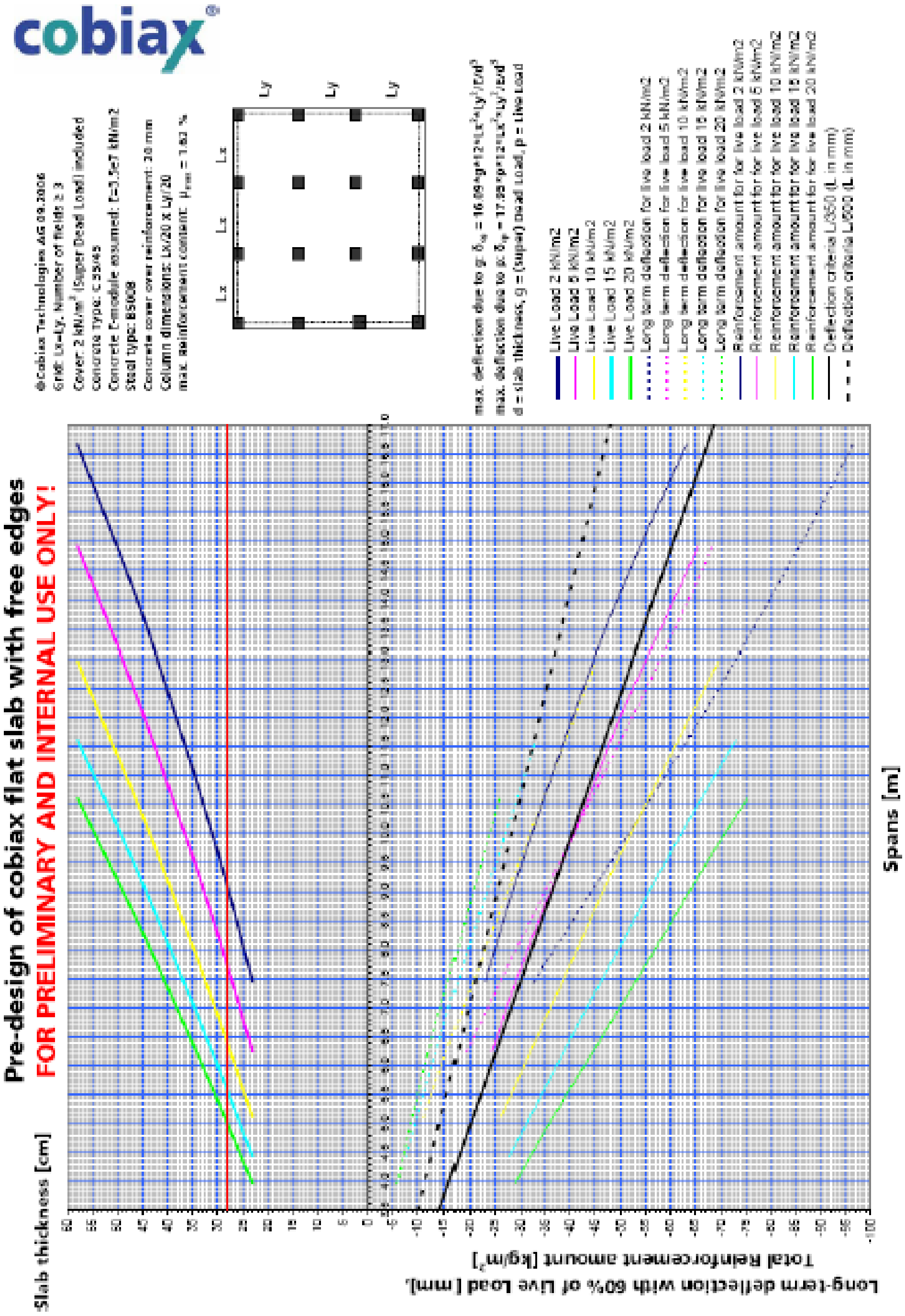

Figure 4 Design Chart of Cobiax

Waffle slabs were designed with 25% solid areas surrounding columns, the same as Cobiax slabs. Waffle slabs with spans up to twelve meters are economical and the economical downside of these type of slabs are the cost of formwork, the fact that the floors will be thicker, according to Goodchild. Cobiax slabs are slightly different from waffle slabs. Figure 3 show a design chart of a waffle slab. However, Goodchild's studies and Cobiax design methods have similarities with one another when discussing economic conditions.

Various slab thicknesses can significantly influence reinforcement weight. The higher the thickness, the more weight will the slab have. When calculating for the calculation of reinforcement, a 10% extra was allowed for wastage, curtailment and lapping of bars, which was taken after the required tension reinforcement, and not on provided, to create smooth curves. Reinforcements were accepted as fy = 460 MPa for tension steel and fyv = 250 MPa for shear steel.

The results of Goodchild's design could withstand weather and aggressive conditions to a low level of exposure and 1-hour fire rating in accordance with BS 8110. The cube strength of the concrete was 35 MPa and the density was calculated to be 24 kN/m3.

The live loads, chosen in accordance with BS 6399, were:

2.5 kPa Parking and Office load

5.0 kPa Specified office loadings and areas where groups would meet

7.5 kPa Storage rooms loading

10.0 kPa High specification storage loading

The superimposed DL was 1.5 kPa for finishes and services. Goodchild further assumed a load of 10 kN/m perimeter cladding.

Formwork, reinforcement and concrete costs were estimated to be up to 90% of the structure's cost. Site constraints, incentives or penalties for early or late completion respectively, labor and crainage on site, and foundations are also factoring that add to cost. When designing for a raft foundation instead of pile, it would be better to use this slab system. Since there are many similarities in properties between Cobiax flat slabs and waffle slabs, it can be said that their design might be similar for both of them, and 25% solid zone surrounding the columns can be allocated for Cobiax slabs too. The major disadvantages of this waffle slabs, regarding economic conditions, for slabs of up to twelve meters, are expensive formworks, floor thicknesses, and slow fixing of reinforcement.

2.7 Implementation of the Cobiax Slabs

2.7.1 Labor on site

It is necessary that the implementation of the works is done under controlled climate conditions and by following rigorously plans and drawings. Sensitive works like architectural concrete finishes, placement of radiant tubing and junction boxes should always be done under controlled conditions. By doing these processes as advised, there are great advantages to it. For the reduction of site labor and formwork there are less reductions. The precast Cobiax decks are transported by trucks directly onto the site and are placed by cranes directly onto shoring. Then the conduit is installed and additional reinforcement is done. The structure is ready for concrete pouring. The edges are shored with steel plate edge forms that are calculated to accept curtain wall anchor pockets. These types of slabs can either be cast in-situ or combined with semi-precast elements.

2.7.2 In-situ concrete

In situ application of Cobiax slabs is done by placing the lower reinforcement, inserting the PE voids and closing the form by adding the second reinforcement. The order of works is by placing first frames, then distance holders , reinforcement nets, void formers and finally pouring concrete.

2.7.3 Combination with semi-precasted elements

This method is done by placing the PE voids in a prefabricated slab and transported into a construction site. The same method of production as in situ is used in prefabricated slabs too. The PE voids are inserted between the double reinforcement. The most traditional method is in-situ, done by following the requirements but they can also be done as fully precast, in a combination of precast elements or incorporated as industrially manufactured. The voids are placed between the reinforcement and concrete is poured and top. The formwork and the bottom reinforcement are placed first. Then distance device is then placed between the bottom and the top reinforcement and the voids are put in place and the top reinforcement are placed. The voids are kept from moving by the formers. Concrete pouring can be done in two ways. The first way is by pouring it in two stages. One method is by pouring the entire concrete in one stage. The voids are kept in place using wires as to avoid buoyancy. The second method is by pouring one layer, letting it dry and then pouring the second layer. The second method Creates cold joints to make sure that the unit works as one whole, the horizontal shear resistance of cages to cold joints is used.

Figure 5 Transportation of Cobiax from factory to site

Figure 6 Different size of Cobiax balls (Zielstattstrasse 27)

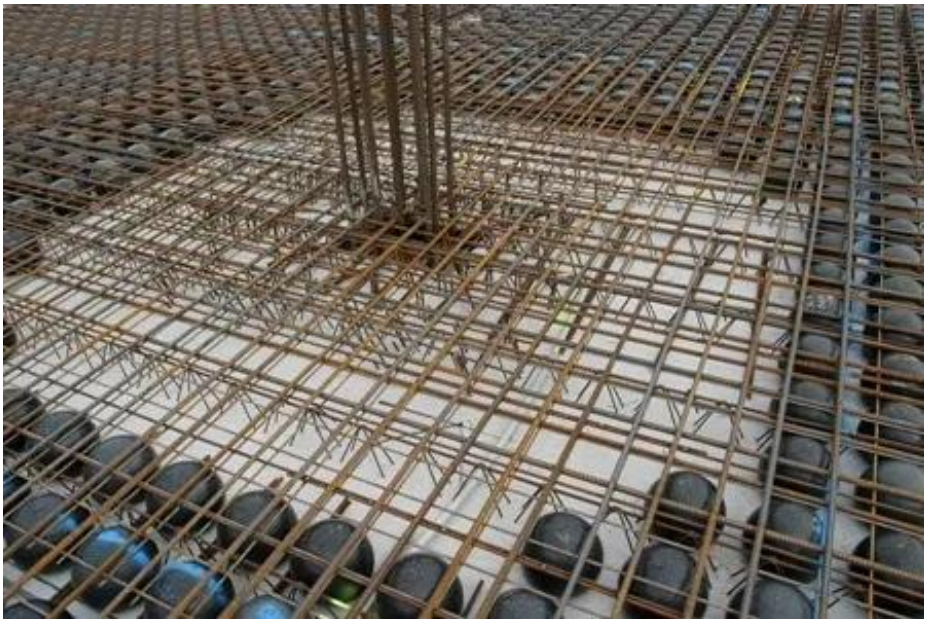

Figure 7 Area of the slab that is not constructed with Cobiax (Zielstattstrasse 27)

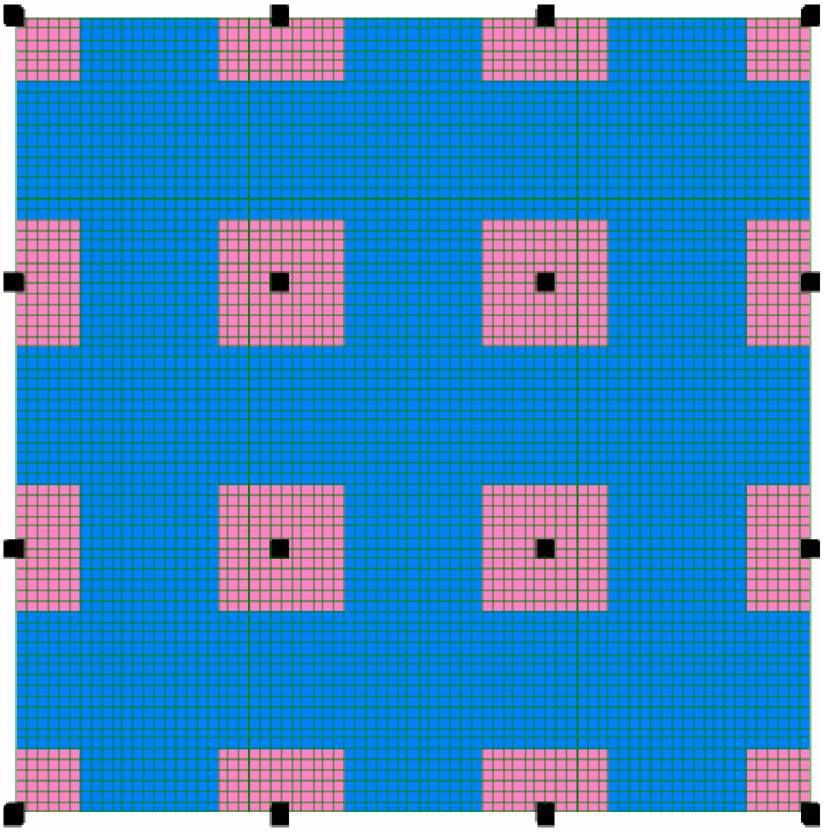

Figure 8 Blue area shows the areas of Cobiax placement

CHAPTER 3

CASE STUDY

3.1 Introduction

This chapter compares shear forces, moments, deflection occurring in the structure in two cases, by using software SAP 2000. This compression's aim is to determine if the Cobiax slab reduce the total force that the superstructure load over the foundation slab. A simple structure is taken in study in order to simplify the calculations, No columns were taken in consideration for any of the slab systems for the analyzed model.

In this chapter the modelling process is described step by step in order to provide a clear idea of comparing the two models.

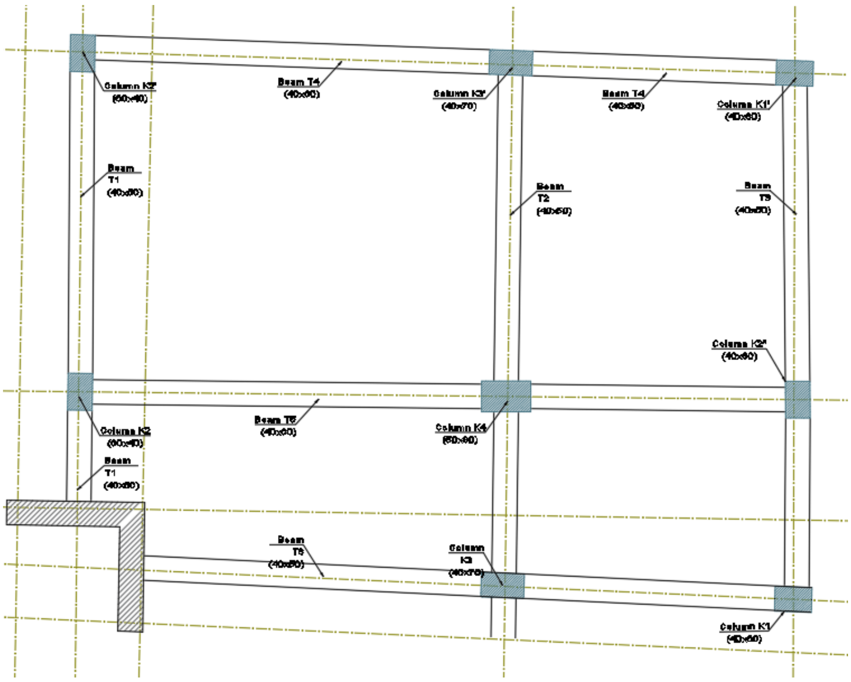

Figure 9 Column Plan of the structure

3.2 Modelling process

In order to compare the monolithic slab building with Cobiax slab building a four-story building is modelled in SAP 2000 with monolithic slab of thickness 18 cm, which is obviously a considerable high load for the structure's foundation to carry . Before starting with the structure elements, the materials are defined in the software. Two types of concrete are considered for the structure, C 30/37 for the foundation slab and C 20/25 for columns, beams and the slabs of superstructure.

Normal three-meter-high story's and large floor areas where possible were taken into consideration.

After modelling the structure in SAP 2000 several times with different columns dimension, the most adaptable version is with columns of dimensions 400 mm x 60 mm, 400 mm x700 mm and 500 mm x 800 mm. All the joints of columns and slabs were assumed to be pinned. This process created a more conservative slab design, because of lack of moments were carried by the columns. The building is assumed to be with three stories', because this creates very small cost differences for the different slabs analyzed, whether it is in columns and foundation.

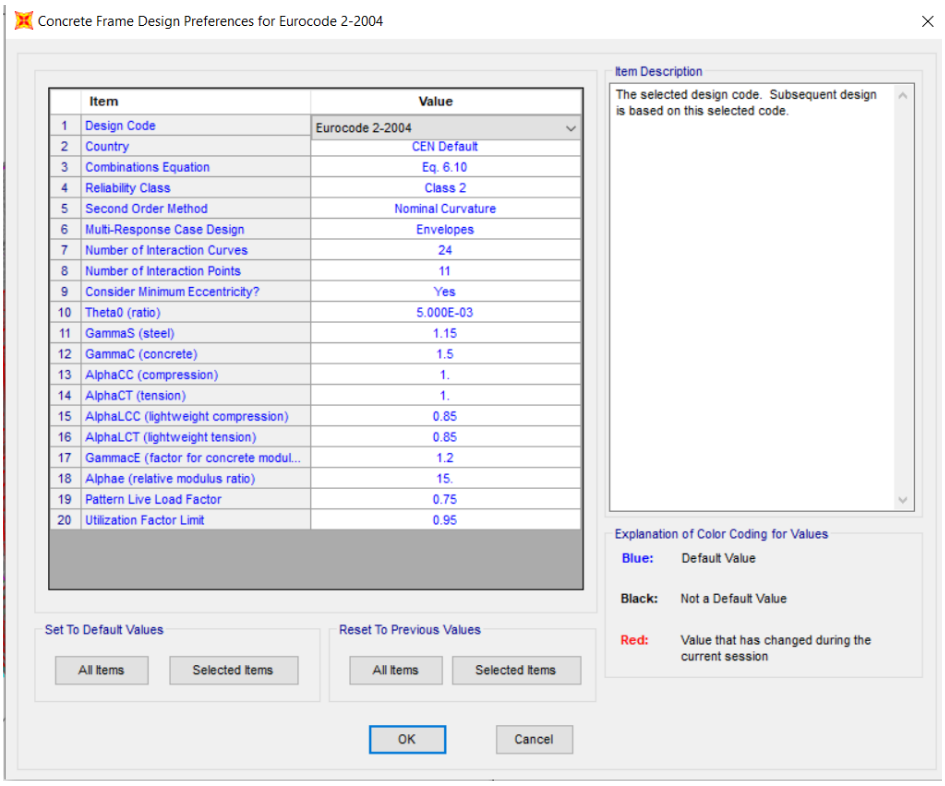

Figure 10 Analysis Parameters

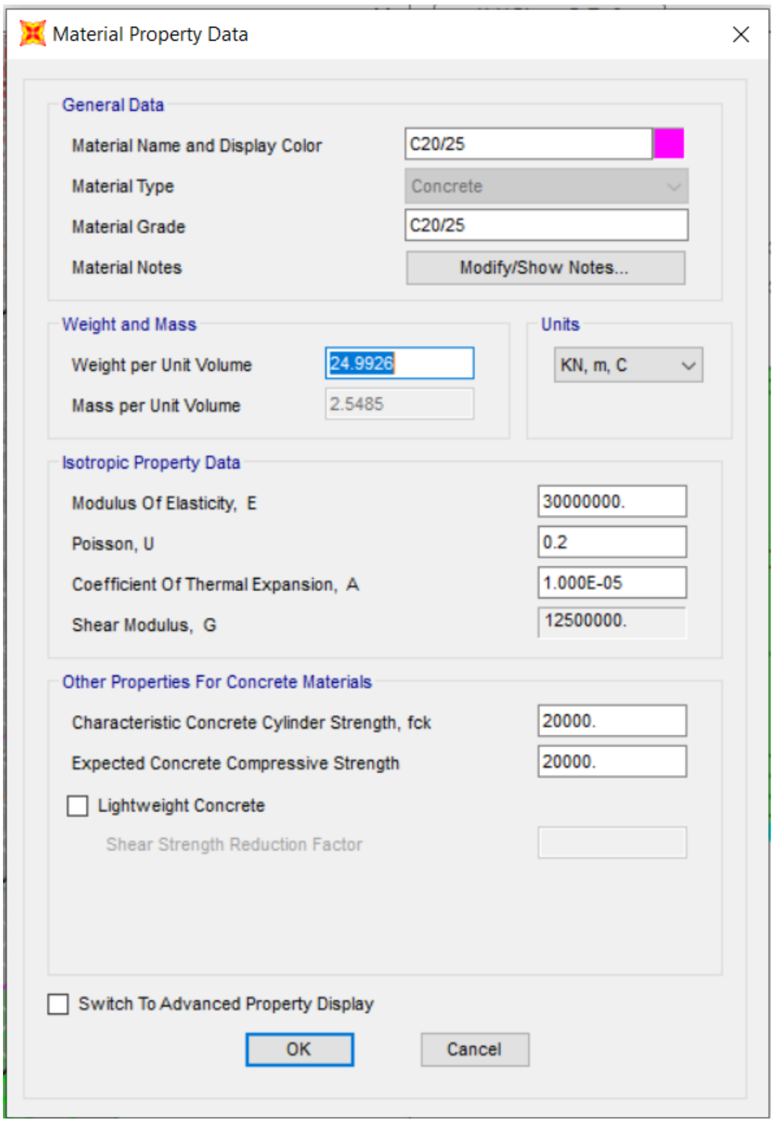

Figure 11 Material Properties of C20/25

Reinforcement

The cover dimension was selected as 25 mm, to satisfy the over 2-hour fire exposure requirements for fire protection. Always according to Eurocode 2 min. reinforcement specifications, the reinforcement was taken at a minimum but never under the required quantity. The design should be done such that the provided reinforcement is more than the required reinforcement and never under but it would be better to be kept to a minimum. For the sake of cost analysis, by using the amount of reinforcement provided instead of the exact amount required we can create a better simulation. In this case the reinforcement chosen for each slab was 5% more than the amount required. It should be known that to know the exact amount of reinforcement is not possible when interpreting a finite element contour plot. 125 mm or 300 mm increment were provided for spacings. These are standard spacings used in Reinforced concrete members design. Where double reinforcement is required, the spacings were set to have the same increment.

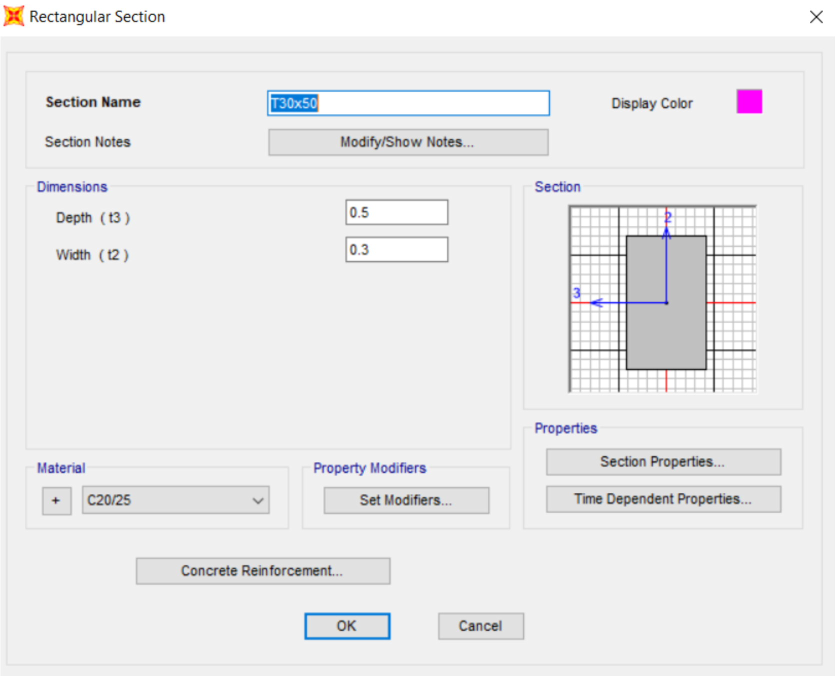

Figure 12 Beam 1 cross section properties

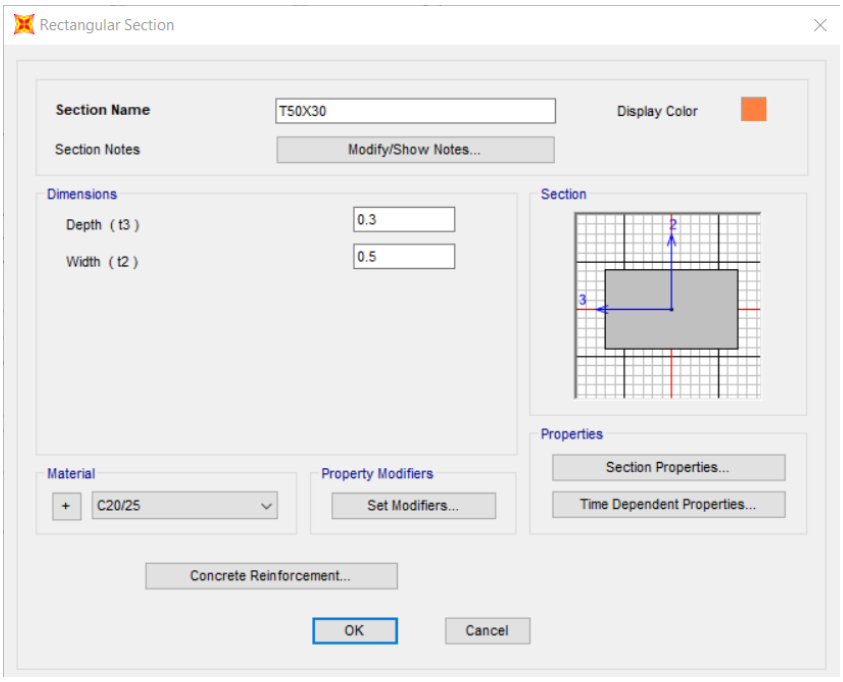

Figure 13 Beam 2 cross section properties

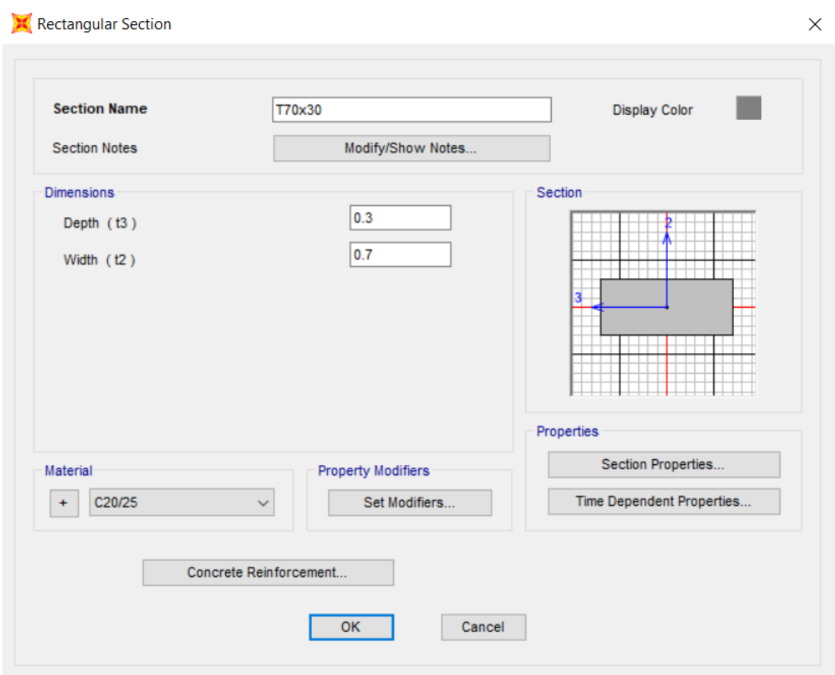

Figure 14 Beam 3 cross section properties

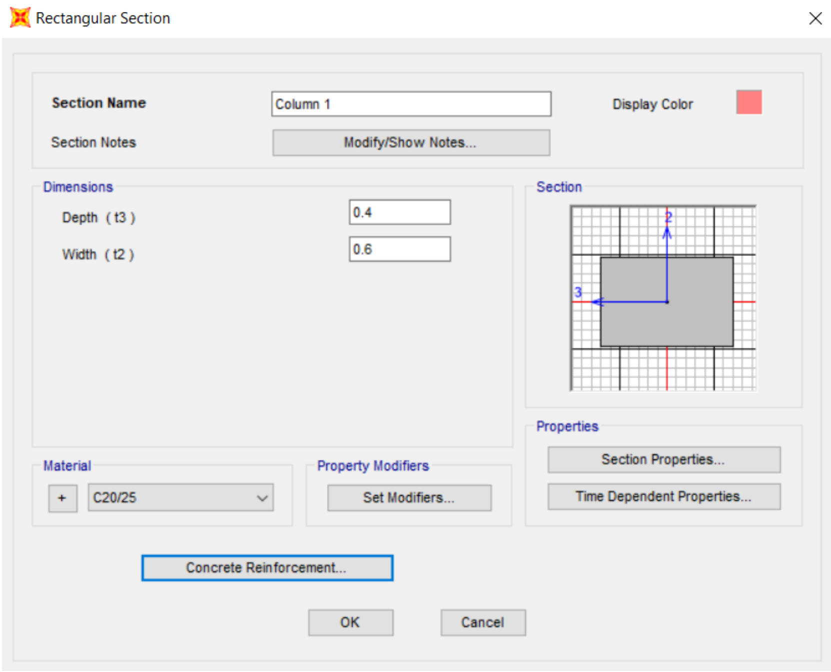

Figure 15 Column 1 cross section properties

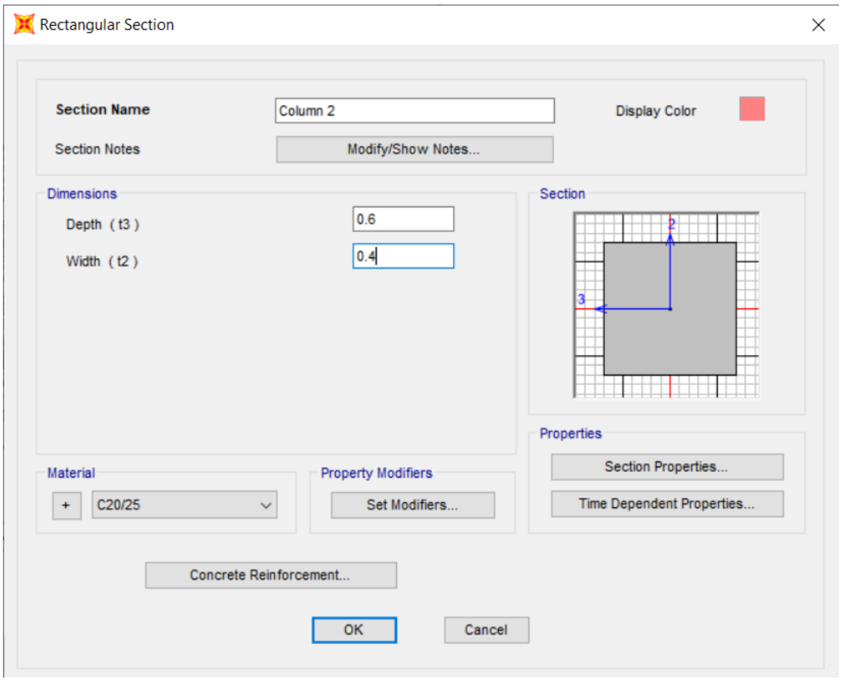

Figure 16 Column 2 cross section properties

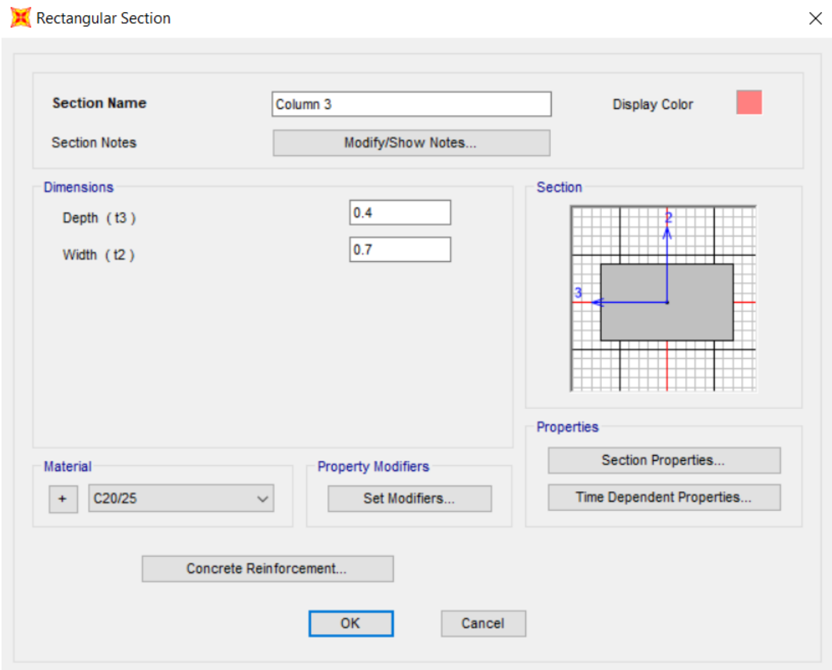

Figure 17 Column 3 cross section properties

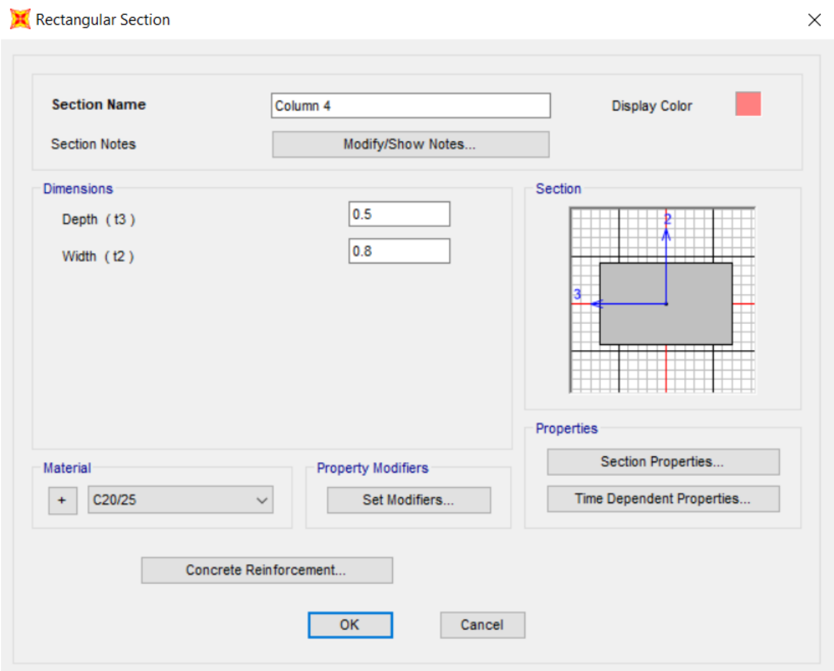

Figure 18 Column 4 cross section properties

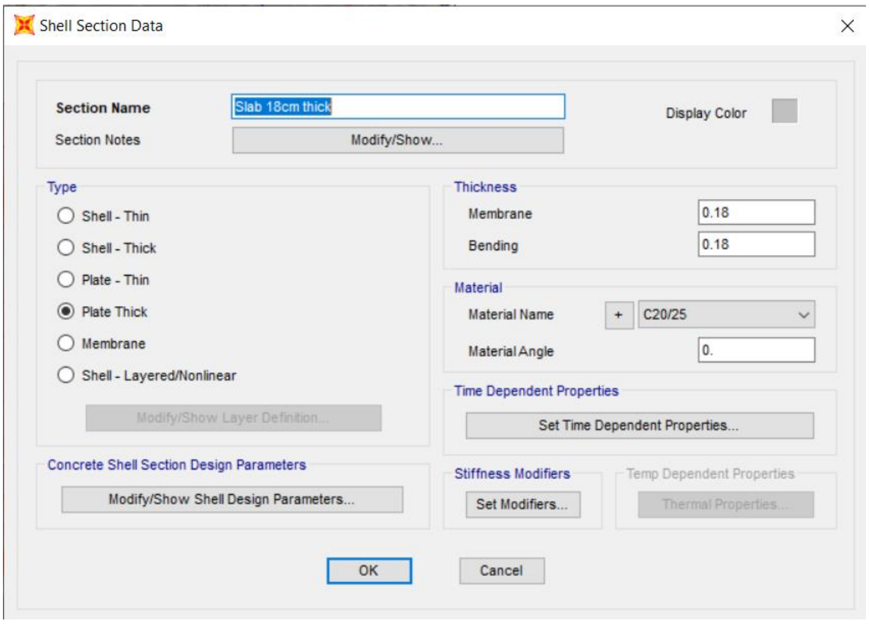

Figure 19 Slab Properties

After designing the slabs, the foundation slab is designed to be 70 cm thick and the type of concrete is C20/25, but it will not be considered in the weight calculation of the building.

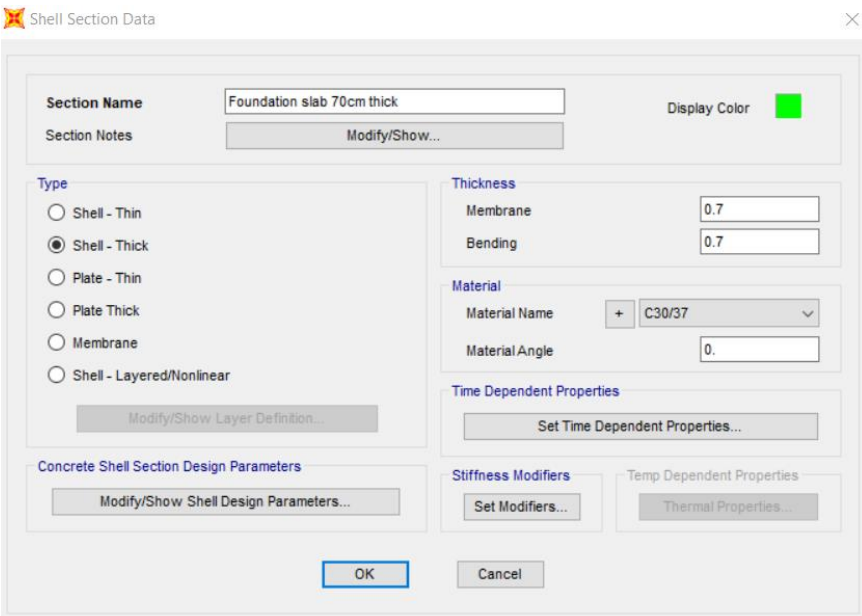

Figure 20 Foundation Slab Properties

After drawing the model with the preview's parameters, we assign the joint restraints as fixed supports which exerts forces acting in all directions and prevents all translational movements (horizontal and vertical)and all rotational movement of a member.

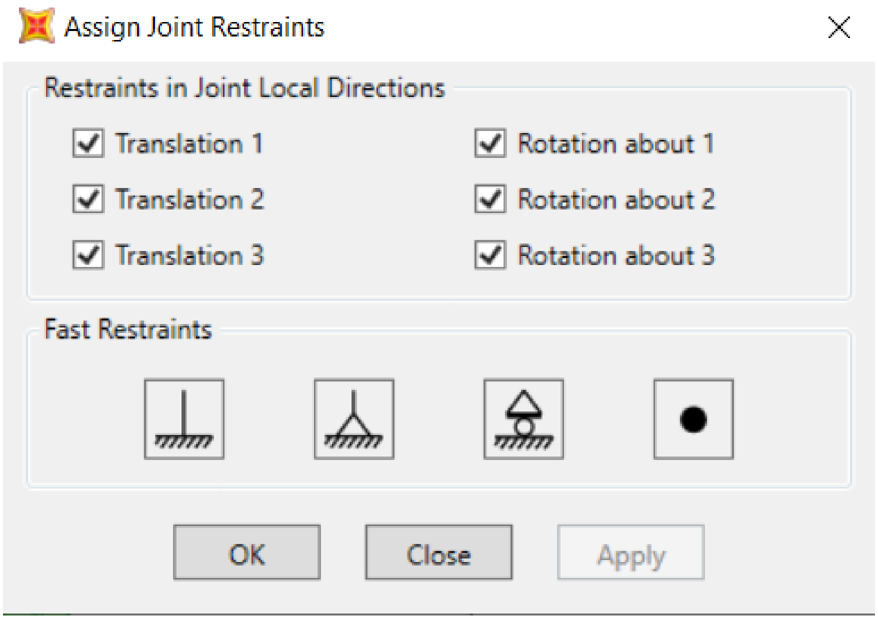

Figure 21 Joint restrains

3.2.1 Loads

Certain load cases analysis results are shown by summing load combinations. In linear analysis the summation is often suitable and results are superimposed, such as with 1.35 * Dead Load + 1.5 * Live Load. For nonlinear analysis, the best option is by combining load patterns and load cases, then use the latter to calculate response envelopes. These results in displacements, forces in joints and internal forces and stresses. Combination 1 was the only load combination considered for the Ultimate Limit State. These ULS combinations were used for both models and no pattern loading was inducted on any of the models to simplify cost comparisons.

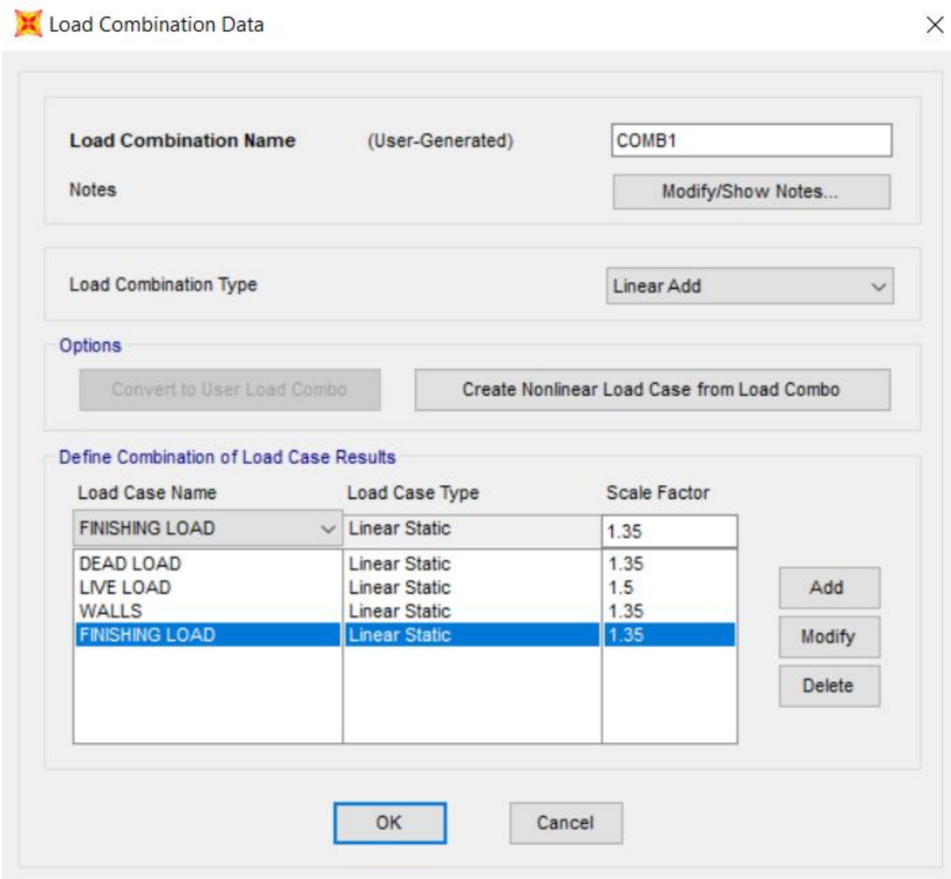

Figure 22 Combination 1 applied in the modeling structure

The loads that are taken into consideration are given below:

Dead load

Live load 2 KN/m2

Walls load 1 KN/ml

Finishing load 3.2 KN/m2

Two others combination are taken into consideration for the structure. The earthquake in x direction and y direction.

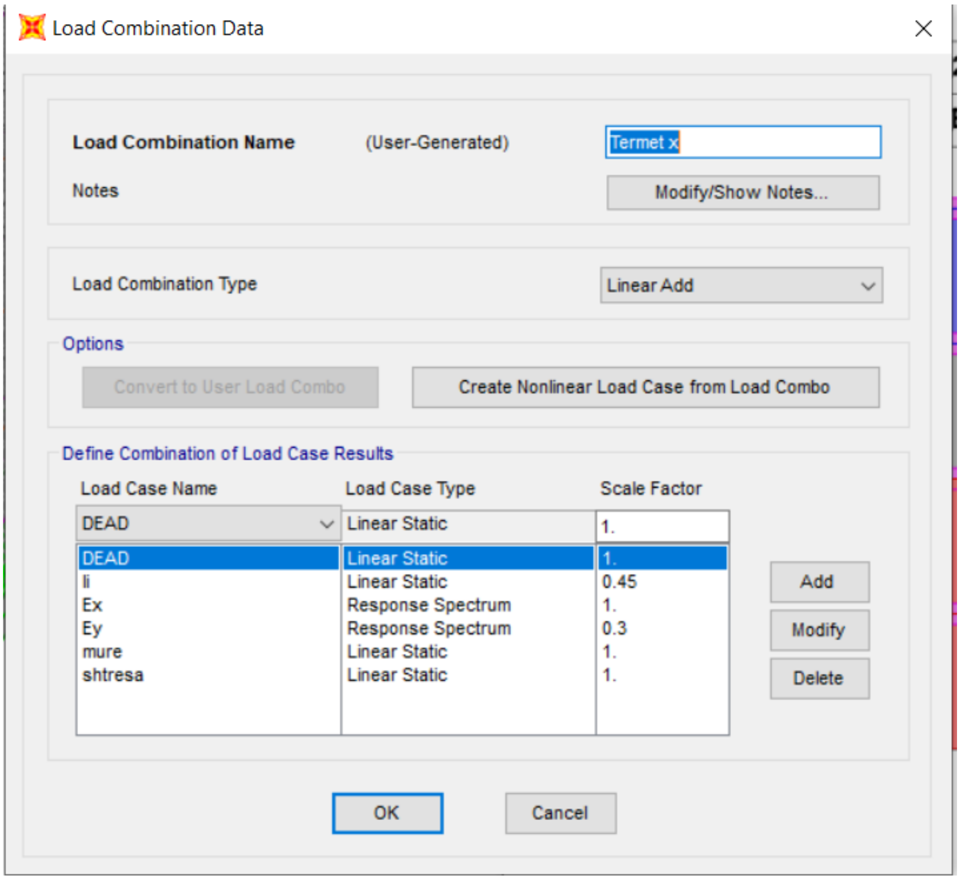

Figure 23 Earthquake combination in X direction

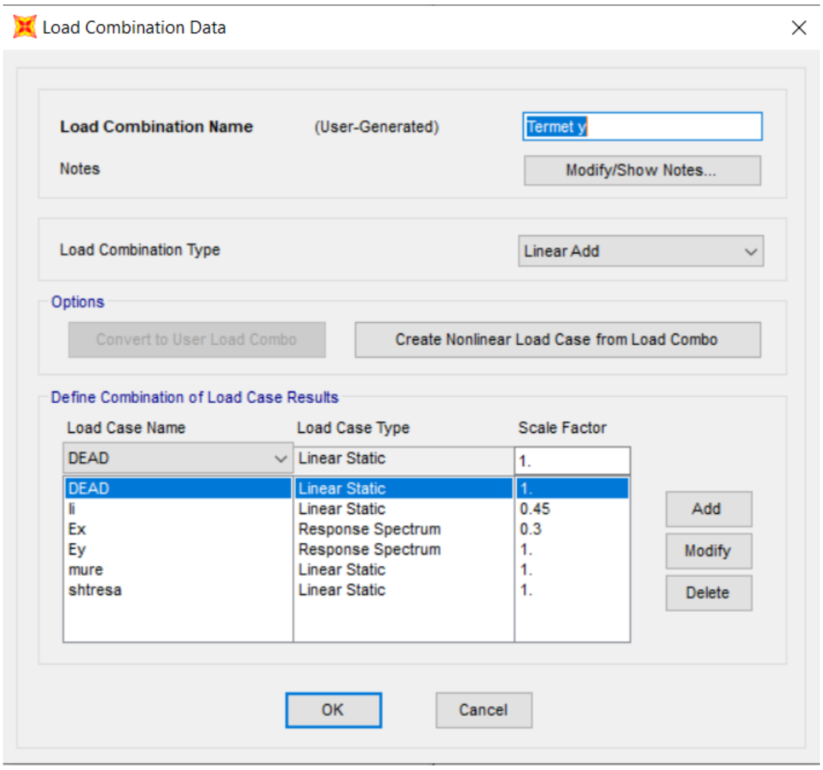

Figure 24 Earthquake combination in X direction

According to Probabilistic Seismic Hazard Maps for Albania a study by Shyqyri Aliaj, John Adams, Stephen Halchuk and Eduard Sulstarova an average ground acceleration for Albania is taken 0.22. Ag=0.22

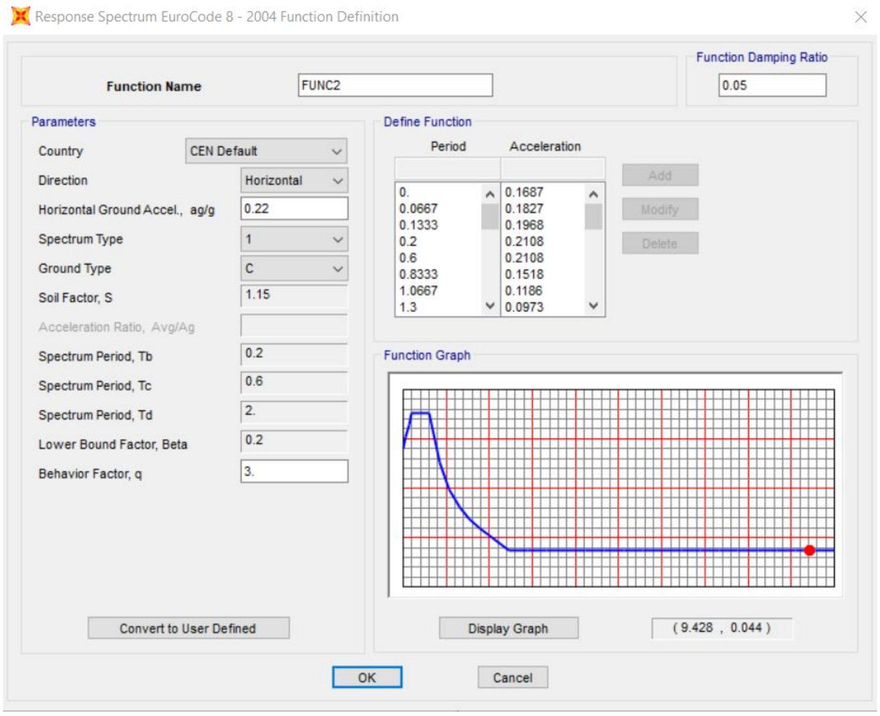

Figure 25 Ground acceleration spectrum

The spectrum shown in Fig. 22 which pertains to the boundary condition of significant damage according to SSH EN 1998-3, is used to estimate the seismic capacity for the design earthquake (6.1).

After applying all the loads, the deformed shape is given below.

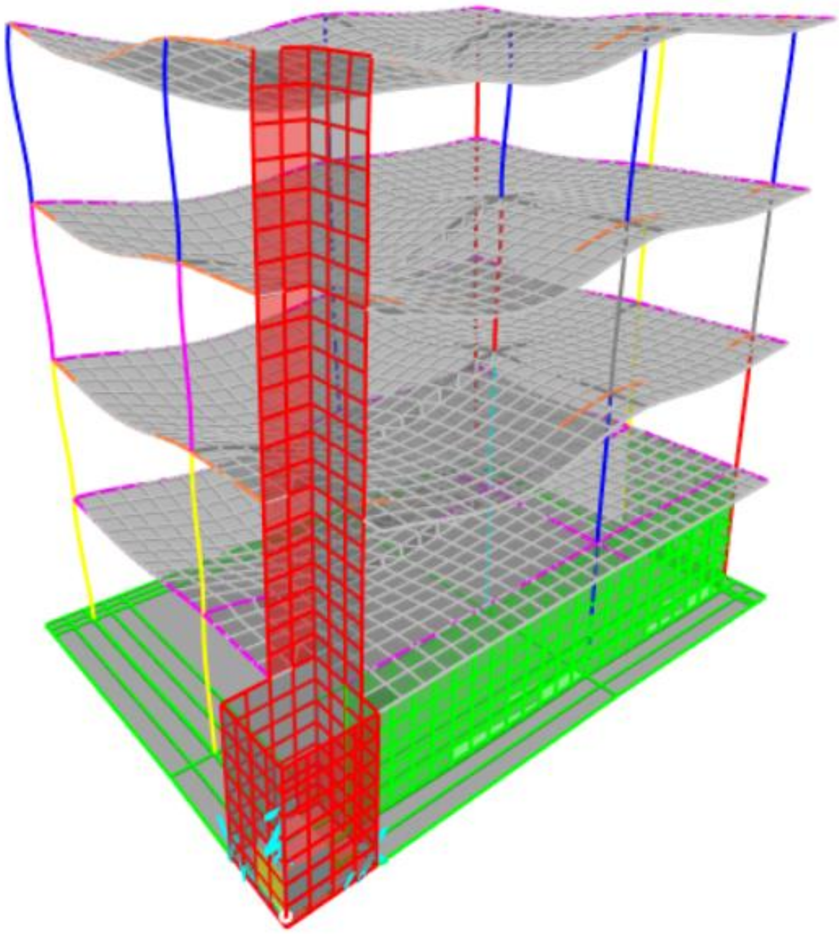

Figure 26 Deformed shape under load of combination 1

3.3 Axial Load of the structure

In order to calculate the total load of the structure the axial load of each columns is calculated by the software SAP 2000. In the end these loads are going to be compared with the axial load in second case when the slabs will be substituted with Cobiax slabs.

3.3.1 Reinforcement of the structure

According to the reinforcement area results from the software, the reinforcement details are given below. For the reinforcement of the columns steel bars of diameter 16 mm are chosen. Based on steel area required the cross section of the columns is given below.

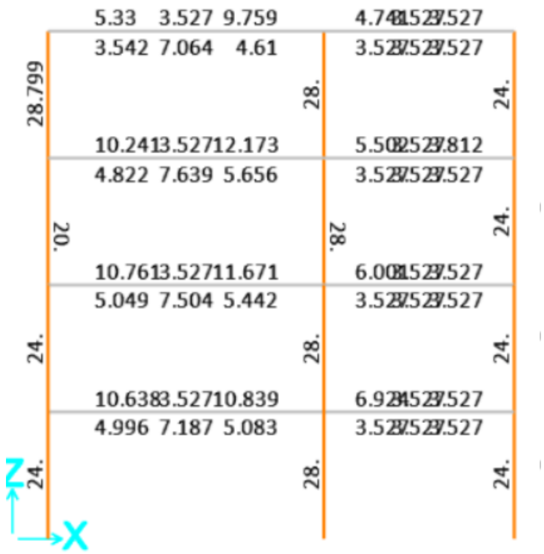

Figure 27 Reinforcement area for each element in cm2/m2

According to resulted areas the reinforcement for each column is made in double reinforcement. In Appendix A are given all the reinforcement detail of each member of the structure.

3.4 Modelling Cobiax Slab in SAP 2000

To model in sap2000 Cobiax slabs we have to calculate the weight of the Cobiax slabs as if it were a monolithic slab reducing the height of the slabs. By choosing C20/25 concrete we calculate the load for 1m2 of the slab in first model that we considered before.

Table 1 Properties of concrete according to EN1992-1-1

General material properties for reinforced concrete according to EN1992-1-1 §3.1

Material Property	Value
Density ρ	≈ 2500 kg/m^3
Unit weight γ	≈ 25.0 kN/m^3
Modulus of elasticity E_{cm} (secant value between σ_c = 0 and 0.4f_{cm})	see table above
Shear modulus G (in the elastic range)	$G = E / [2 \cdot (1 + \nu)]$
Poisson's ratio ν (uncracked concrete)	0.2
Poisson's ratio ν (cracked concrete)	0.0
Coefficient of linear thermal expansion α	10 ×10^{-6} °K^{-1}

Load=ρ*thickness

Load=2500kg/m3*0.18m = 450kg/m2

Before designing the structure in SAP 2000 another software is used in order to find the right shape of Cobiax used for the slab. Based on Cobiax official website calculations the load of the slab is reduced by 160 kg/m2 so for the same slab we will assume a load of 290 kg/m2 which is converted in a monolithic slab of a thickness 11.6 cm. Since the load of the slab is reduced the load transferred to the columns is smaller than in first case so the columns dimension may be reduced.

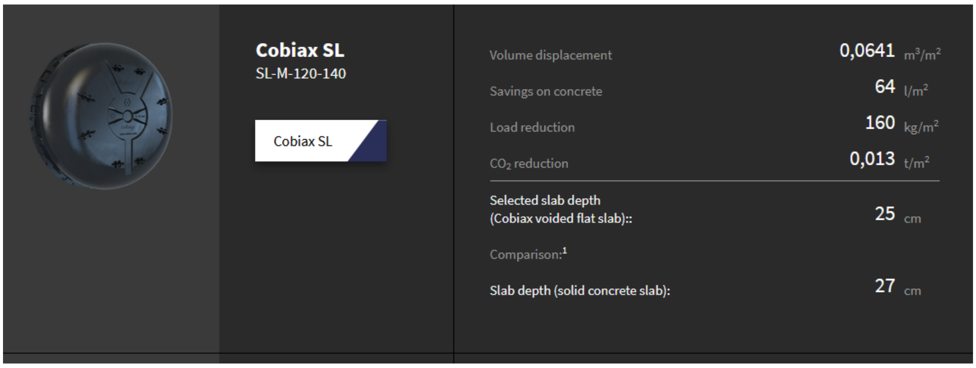

Figure 28 Cobiax Slim Line parameters

Table 2 COBIAX slab parameters

Cross-section and parameters of the Cobiax slab		
Input		
Slab depth h_d Execution method Concrete top cover	24,80 In-situ concrete 3,00	cm cm
Concrete bottom cover	4,00	cm
Total depth of top reinforcement	2,40	cm
Total depth of bottom reinforcement Cobiax void former system Void former height	2,40 SL-M-120-140 10,00	cm cm
Void former horizontal width	31,50	cm
Axial spacing of void formers	35,00	cm
Support height h_u	12,00	cm
System height h_k Concrete grade Cylinder compressive strength f_{ck}	12,50 C 25/30 25,00	cm N/mm²
Concrete density	25,00	kN/m³
Output		
Load reduction with void formers	1,32	kN/m²
Slab dead load in areas with void formers g_k	4,88	kN/m²
Concrete savings in areas with void formers	0,053	m³/m²
Stiffness reduction factor	0,97	-
Ultimate limit moment	144,17	kNm/m
Reduction of CO_2	0,011	to/m²

Table 3 Shear resistance of COBIAX slab

Verification of the shear resistance of the Cobiax slab (based on EC 2 (BS EN 1992-1-1:2004)		
The concreting joint has to be verified if for the in-situ execution method the slab is cast in two layers in order to avoid buoyancy. A reduced joint surface is used for this verification.		
Cobiax shear factor	0,50	-
Cross-section of flexural strength	2,00	cm^2/m
reinforcement $A_{s,l}$		
$C_{Rd, c}$	0,12	
k	1,97	-
k_1	0,15	-
ρ_1	0,0009	-
γ_c	1,50	
$V_{Rd, c}$	66,60	kN/m
$V_{Rd, c, Cobiax}$	33,30	kN/m

Table 4 Fire resistance of Cobiax

Proof of fire resistance		
(according to homologation)		
Static system biaxial 1,5 <= l_y/l_x <= 2,0		
Diameter bottom reinforcement	6,00	mm
Cover void former	74,00	mm
Center distance	43,00	mm
Fire resistance grading	R 30	

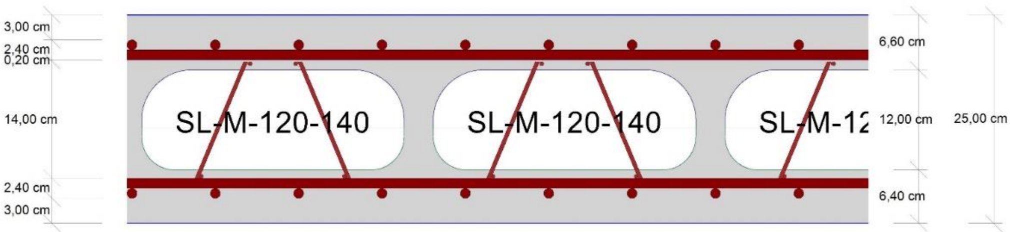

Figure 29 Cross section of Cobiax slab with slim line

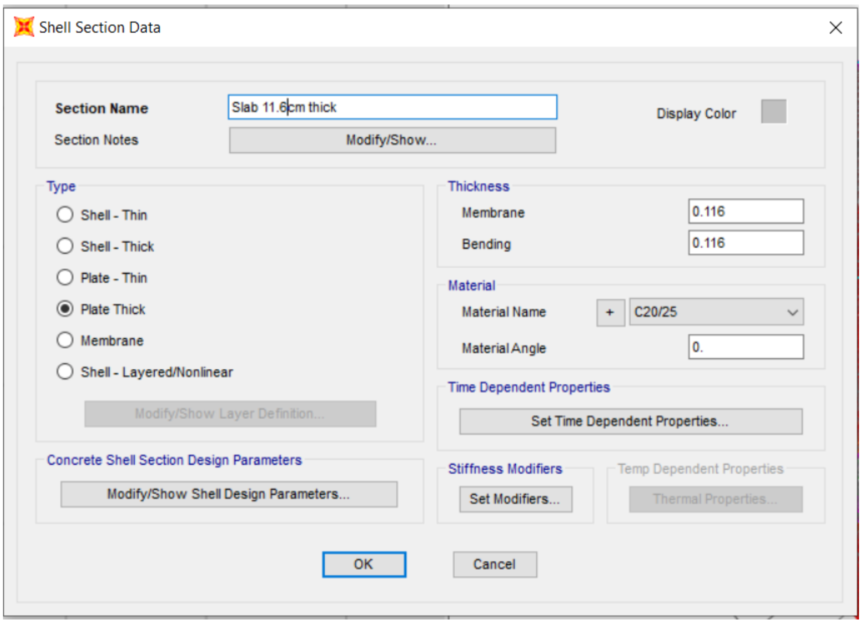

Figure 30 Monolithic slab used to study Cobiax Slab

As in the first case, also in the second case the columns and the beams of the structure, and the only member of the structure that has changed is the slab thickness.

3.5 Results

In appendix are given all the results of the axial force that is generated from the software SAP 2000. In the table 10 all these results are reflected in order to compare them for each column the forces in both cases.

Table 5 Axial Load compression

Column	Axial Load in 1st Case (KN)	Axial Load in 2nd Case (KN)
K1	565	95
K1’	775	176
K2	1236	343
K2’	305	238
K2’’	640	197
K3	1731	446
K3’	481	400
K4	1038	570

The load of the structure in case with Cobiax slab are smaller, which means that the building with lightweight slabs such as Cobiax are more accessible and affordable.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Quantity for reinforced concrete slabs

To estimate the cost of the structure all the reinforcement details are prepared in order to give a compression as accurate as possible. For the first case with monolithic slabs the concrete volume is calculated for beams, columns and slabs. The transportation is not considered in my evaluation, only the volumes for the materials needed. Also, labor is not considered since there are different process in both cases. According to the details that are shown in Appendix A each member is considered in the cost evaluation. Reinforcement bars, stirrups, spacers are count for the steel.

Table 6 Measurement sheet of columns of dimensions 40x60

Column K1, K1', K2 & Column K2'					
No.	Length (m)	Diameter (mm)	Quantity	Weight per meter (kg/m)	Total weight (kg)
1	2.9	16	12	1.58	54.984
2	3.1	16	12	1.58	58.776
3	2.4	16	12	1.58	45.504
4	3	16	12	1.58	56.88
5	3.5	16	8	1.58	44.24
6	3.5	16	4	1.58	22.12
7	2.97	16	8	1.58	37.5408
8	2.97	16	4	1.58	18.7704
9	1.96	8	110	0.395	85.162
10	1.44	8	110	0.395	62.568
11	1.5	8	110	0.395	65.175
Total weight for 1 Column					**551.7202**
Total weight for 5 Columns					**2758.601**

Table 7 Measurement sheet of columns of dimensions 40x70

Column K3 & Column K3'					
No.	**Length (m)**	**Diameter (mm)**	**Quantity**	**Weight per meter (kg/m)**	**Total weight (kg)**
1	2.9	16	14	1.58	64.148
2	3.1	16	14	1.58	68.572
3	3.55	16	14	1.58	78.526
4	3.05	16	14	1.58	67.466
5	3	16	14	1.58	66.36
6	2.65	16	14	1.58	58.618
7	1.66	8	220	0.395	144.254
8	0.52	8	110	0.395	22.594
Total weight for 1 Column					**570.538**
Total weight for 2 Columns					**1141.076**

Table 8 Measurement sheet of columns of dimensions 50x80

Column K4					
No.	**Length (m)**	**Diameter (mm)**	**Quantity**	**Weight per meter (kg/m)**	**Total weight (kg)**
1	2.9	16	20	1.58	91.64
2	3.1	16	20	1.58	97.96
3	3.9	16	20	1.58	123.24
4	4	16	20	1.58	126.4
5	3.05	14	20	1.21	73.81
6	2.65	8	330	0.395	345.4275
7	1.66	8	110	0.395	72.127
Total weight for 1 Column					**930.6045**

Table 9 Measurement sheet of beams with dimensions 50x30

Beam T1, T3, T4 & T6					
No.	**Length (m)**	**Diameter (mm)**	**Quantity**	**Weight per meter (kg/m)**	**Total weight (kg)**
1	5.93	18	5	2	59.3
2	3.84	18	5	2	38.4
3	3.18	16	5	1.58	25.122
4	6.38	16	5	1.58	50.402
5	1.56	8	48	0.395	29.5776
6	1.14	8	48	0.395	21.6144
Total weight for 1 Beam					**224.416**
Total weight for 12 Beam					**2692.992**

Table 10 Measurement sheet of beams with dimensions 70x40

Beam T2 & T5					
No.	**Length (m)**	**Diameter (mm)**	**Quantity**	**Weight per meter (kg/m)**	**Total weight (kg)**
1	2.7	18	7	2	37.8
2	5.5	18	7	2	77
3	4.08	18	7	2	57.12
4	4.9	16	7	1.58	54.194
5	6.68	16	7	1.58	73.8808
6	2.16	8	64	0.395	54.6048
7	1.34	8	64	0.395	33.8752
Total weight for 1 Beam					**354.5996**
Total weight for 6 Beam					**2127.5976**

For the slab reinforcement, an average percentage of 75 kg/m^3 is considered. The foundation slab is not considered since it will be the same in both cases. Four other slabs have the same dimensions of 10.69 m x 13.31 m x 0.18 m.

The volume for all the slabs is 102.44 m3 so the wight of the steel is going to be taken 7683.3 kg.

4.2 Quantity estimation for Cobiax sabs

To calculate the cost for slabs with Cobiax some extra information were needed since it is not in Albanian market yet. The columns and beams of the structure are not changed so only the concrete and steel volumes of the slabs will change. The foundation slab is not considered since it will be the same in both cases. Four other slabs have the same dimensions of 10.69 m x 13.31 m x 0.2 m. For the width of this slab the volume of the Cobiax is 0.075 m3/m2. So, the total volume of the Cobiax for the slabs is $43m^3$. This will reduce the volume of concrete with 43 m3.

The volume for all the slabs with depth 20 cm is 113 m3 if it was a monolithic slab, but using Cobiax the concrete will be reduced to 70 m^3.

CHAPTER 5

CONCLUSION

5.1 Conclusions

By using the 3 D model in software Sap 2000 the estimation is more accurate, for different cases of the structure elements. As it is clearly reflected in table 10 the axial load of each column in the first case is bigger than the axil force in second case. Which means that the total load of the structure is lighter in the structure with Cobiax slabs.

This study was focused in the pros and cons of reinforced concrete Cobiax slabs. These slabs are a new way of designing and implementing low weight slabs into construction. Although very new to the market, they pose a great advantage to the future of construction. Similar to waffle slabs, Cobiax slabs have much less concrete than flat reinforced concrete slabs. Thus, the self-weight of the structure as a whole is greatly decreased, but the stiffness would be almost the same as that of solid slabs. This decrease in weight manages for larger spans up to 20m. Cobiax slabs are also great acoustic insulator and have better fire resistance than flat slabs. Although Cobiax slabs require good workmanship and the materials need to be especially designed, I believe it is a good way to improve the construction of modern-day structures.

5.2 Recommendations for future research

Cobiax slabs have no concrete guidelines compared to flat slabs. There should be further research conducted on Cobiax slabs. Their use in Albania is extremely limited as it is not very known. I believe there should be a further market and implementation capacity study in Albania, regarding the benefits and disbenefits of using Cobiax slabs.

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APPENDIX

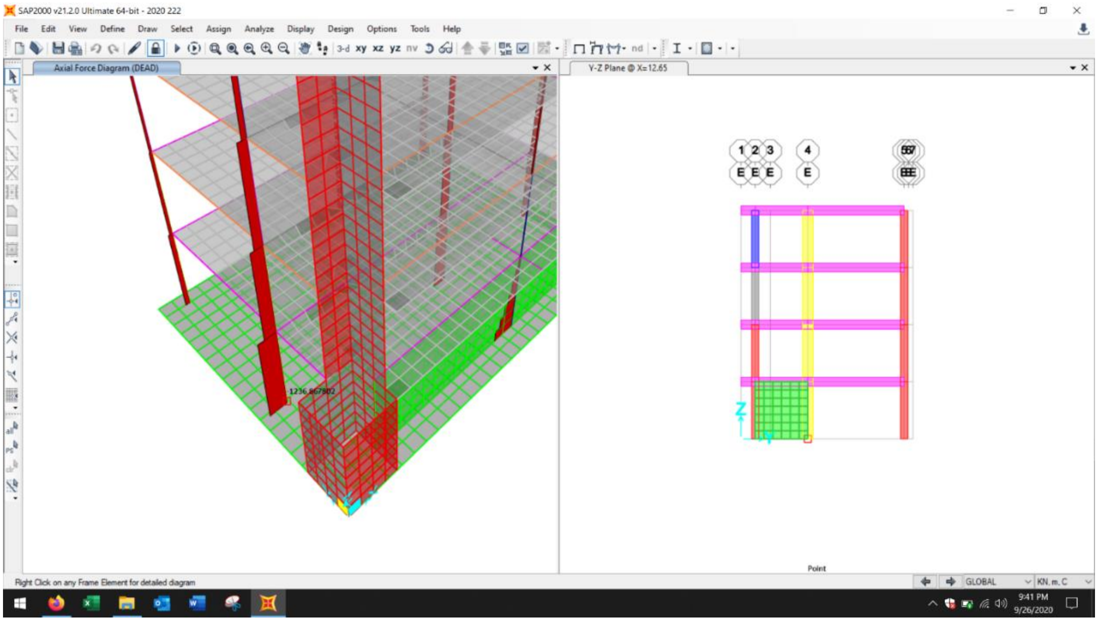

Figure 31 Axial Load on Column K2 for the second case

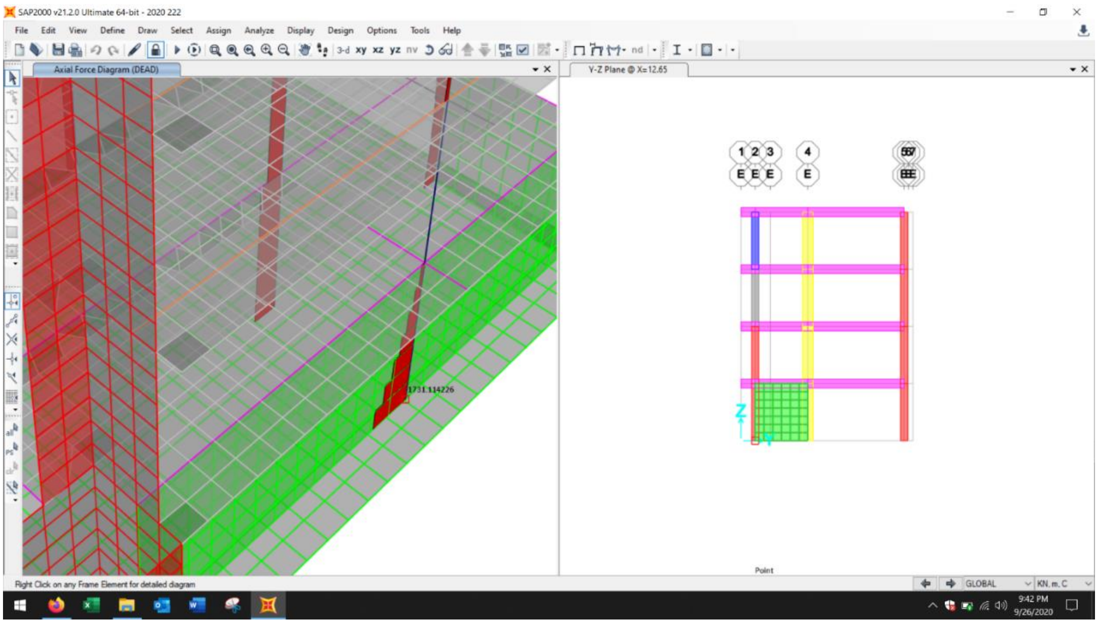

Figure 32 Axial Load on Column K3 in the second case

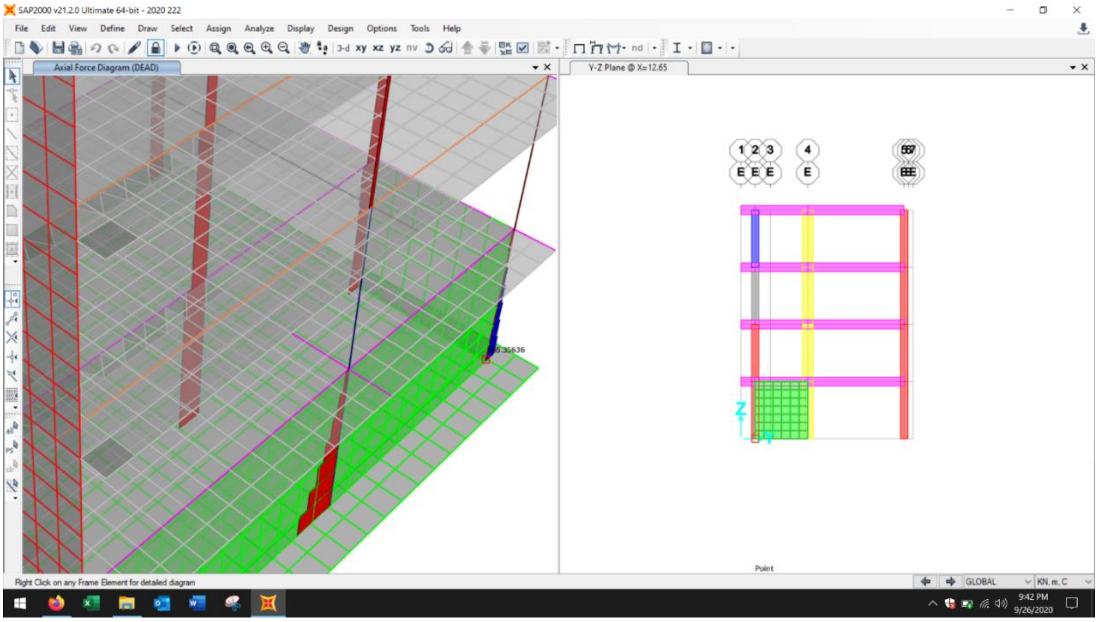

Figure 33 Axial Load on Column K1 in the second case

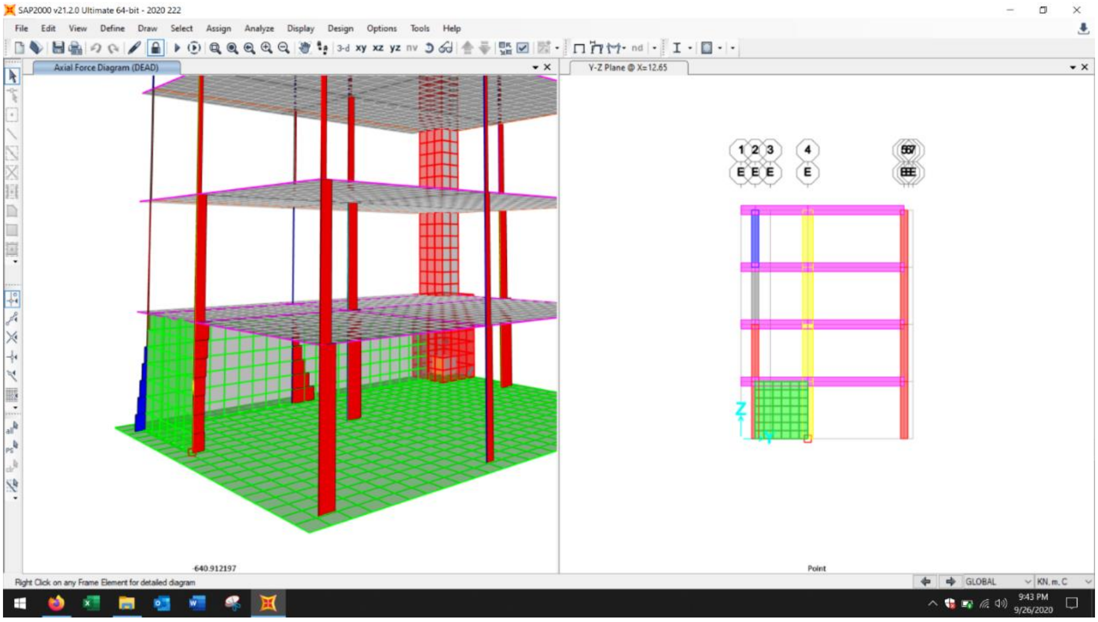

Figure 34 Axial Load on Column K2 in the second case

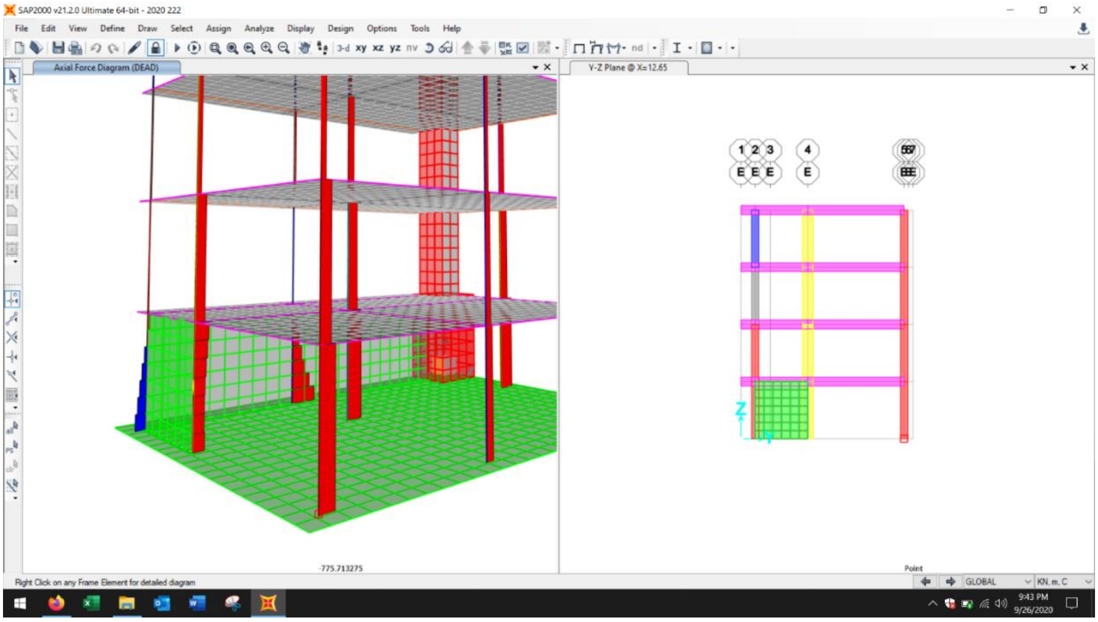

Figure 35 Axial Load on Column K1' in the second case

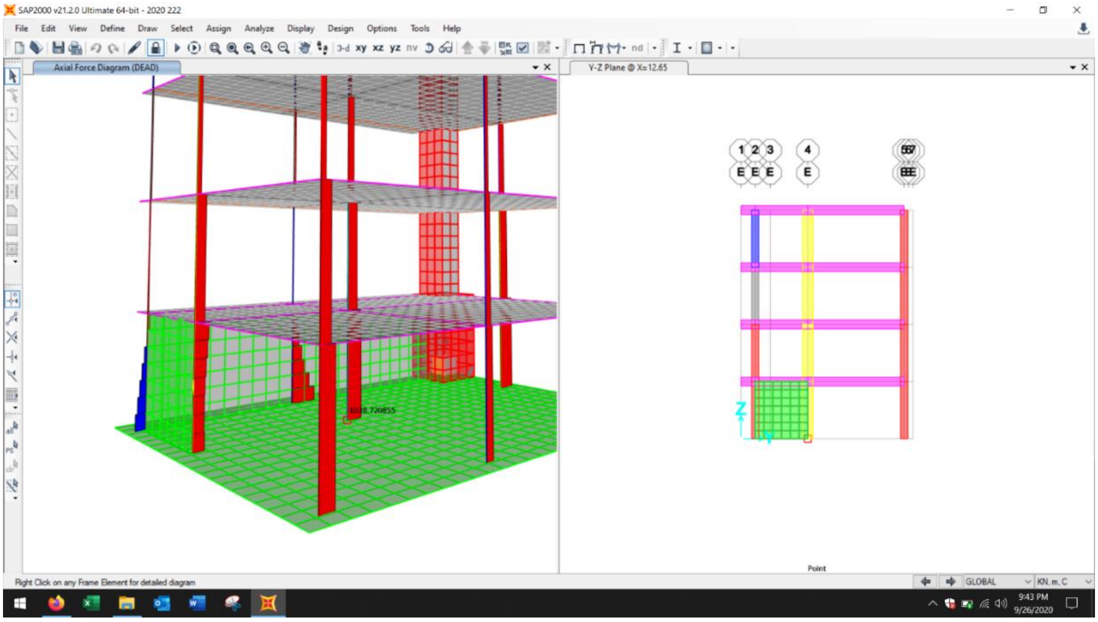

Figure 36 Axial Load on Column K4 in the second case

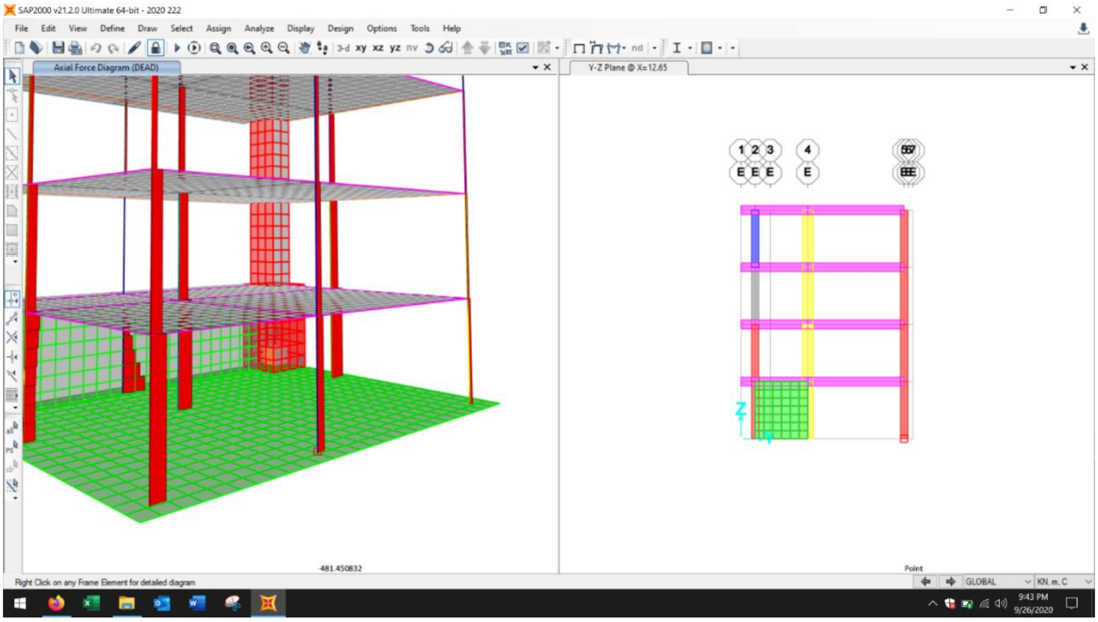

Figure 37 Axial Load on Column K3' in the second case

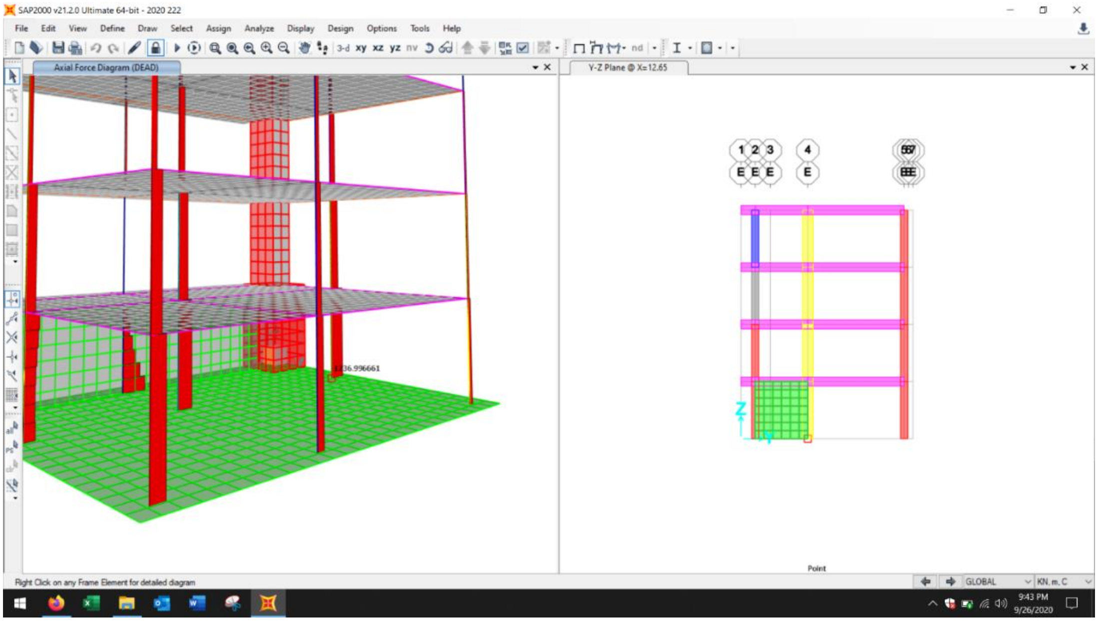

Figure 38 Axial Load on Column K2 in the second ***case***

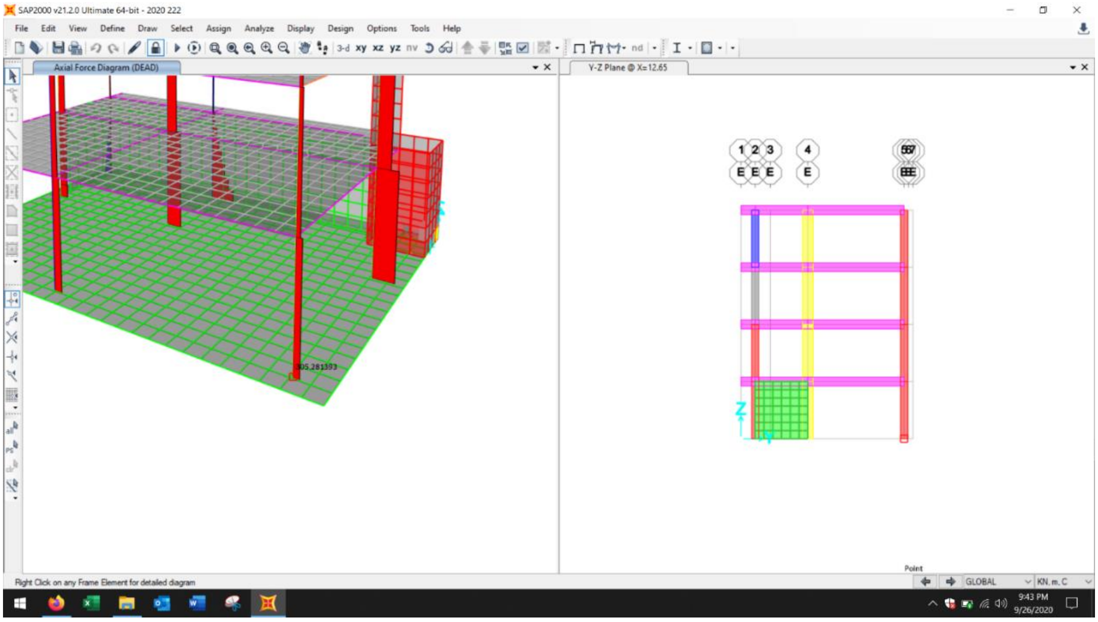

Figure 39 Axial Load on Column K2' in the second case

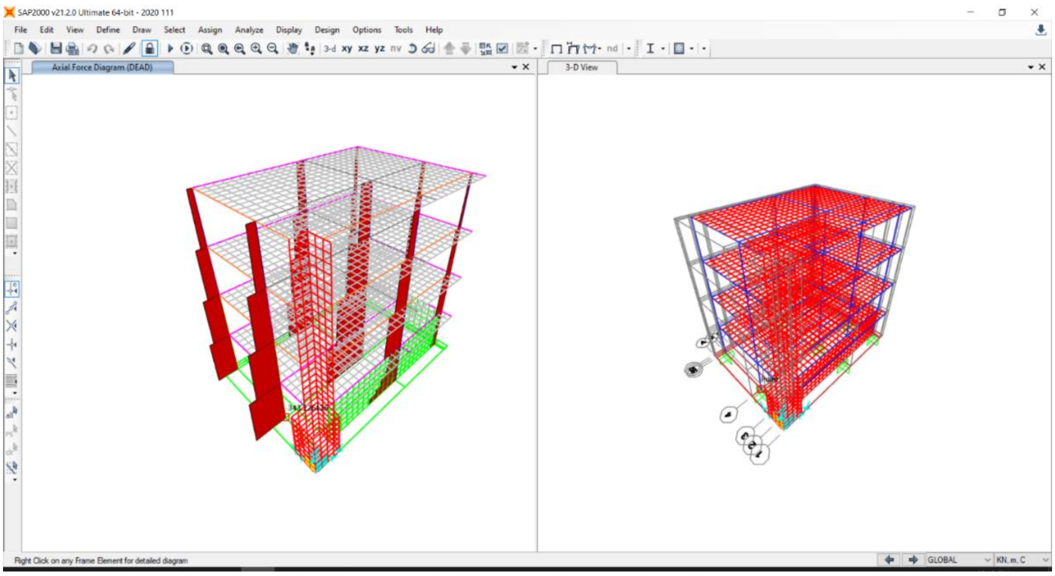

Figure 40 Axial Load on Column K2

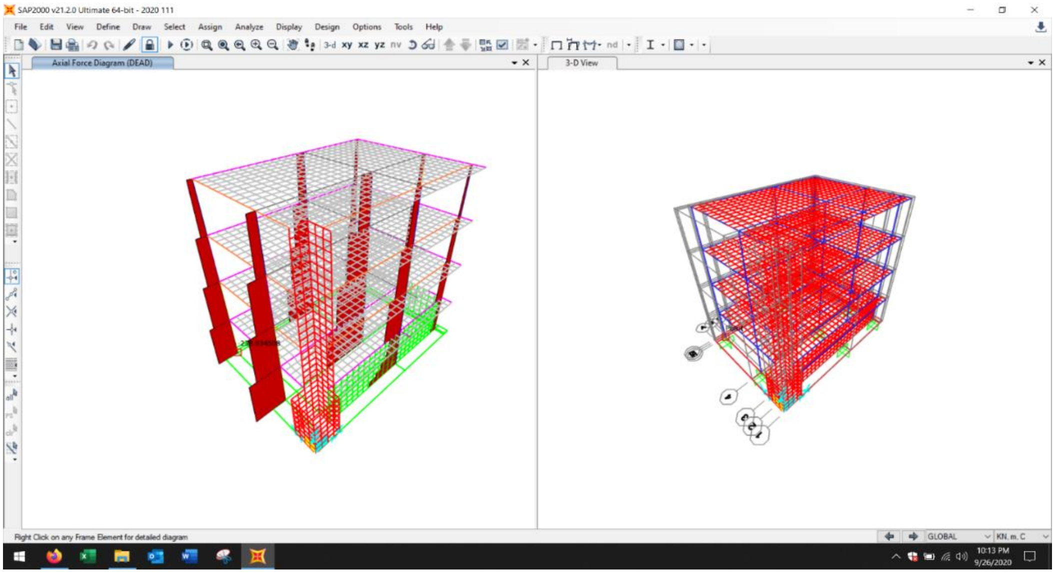

Figure 41 Axial Load on Column K2'

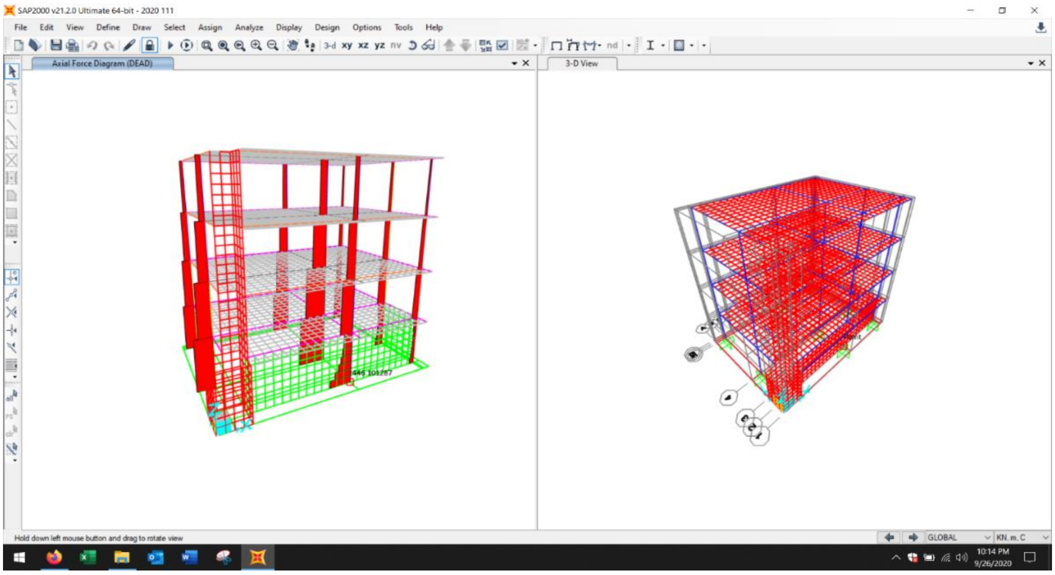

Figure 42 Axial Load on Column K3

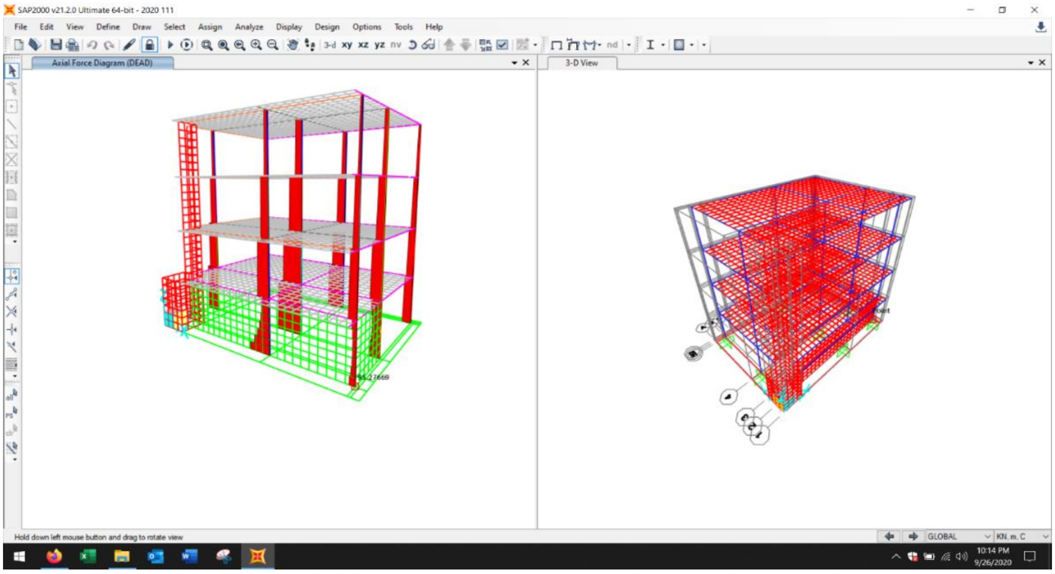

Figure 43 Axial Load on Column K1

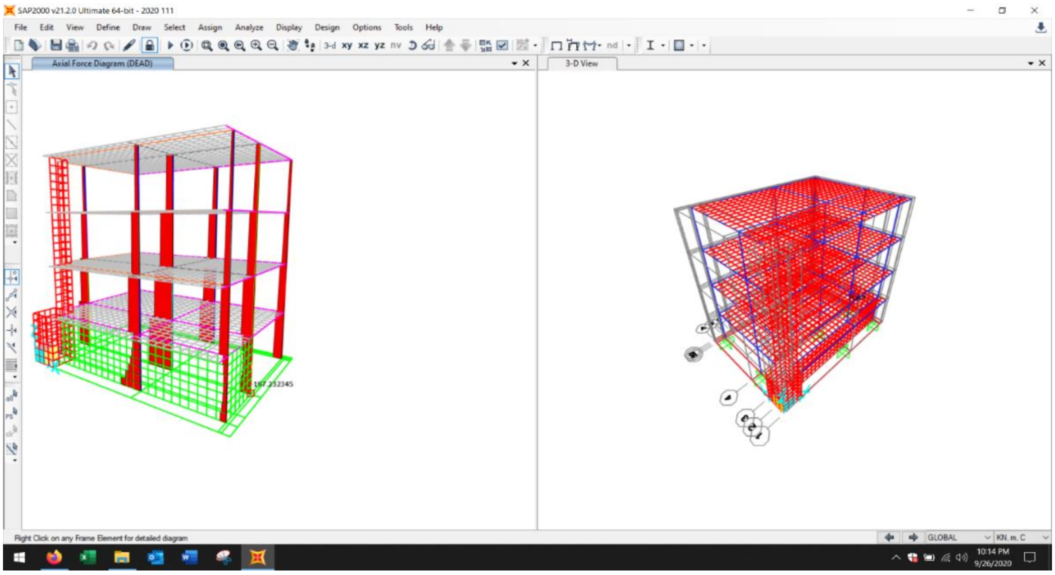

Figure 44 Axial Load on Column K2

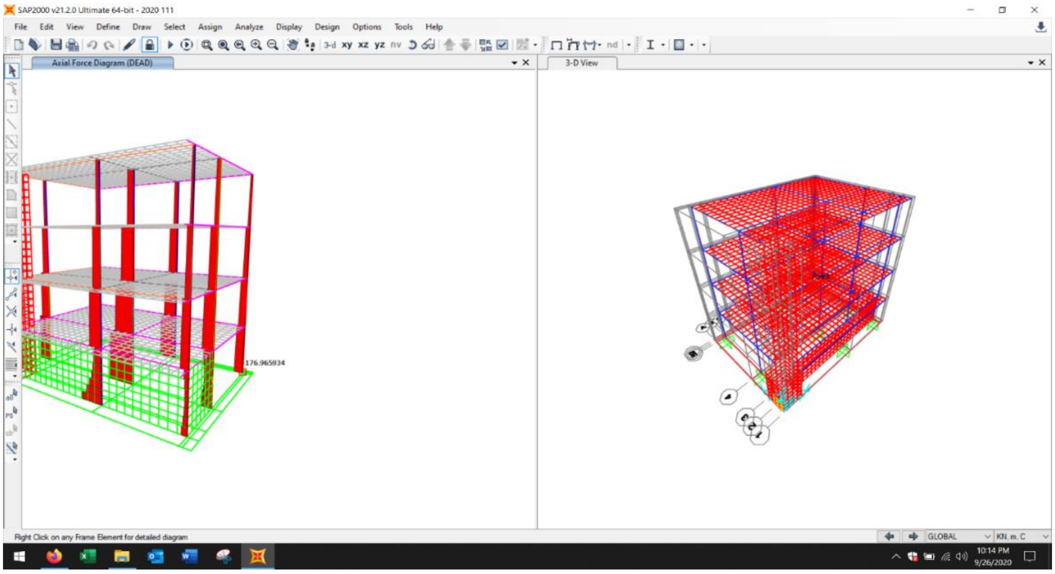

Figure 45 Axial Load on Column K1'

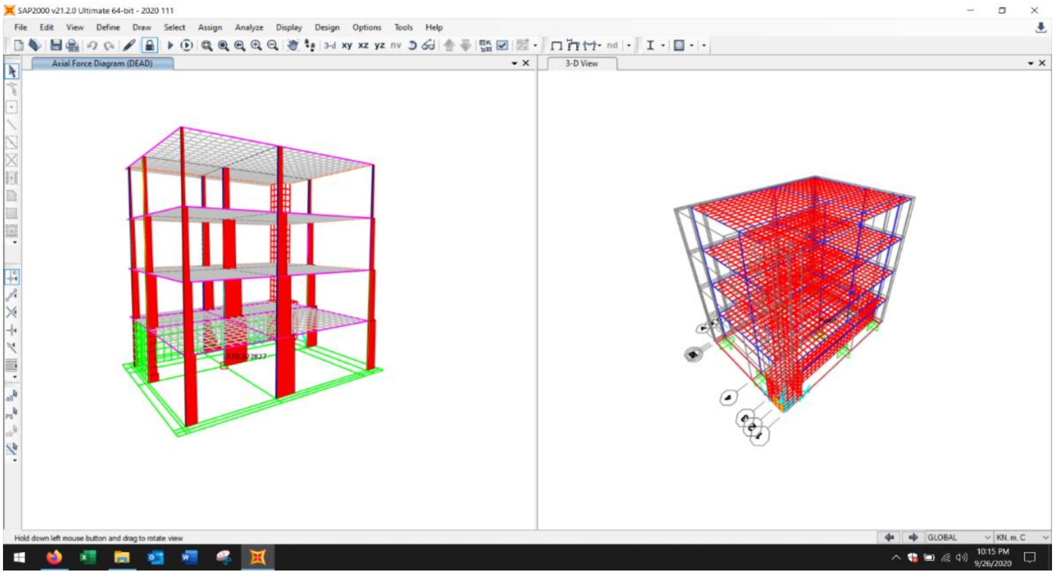

Figure 46 Axial Load on Column K4

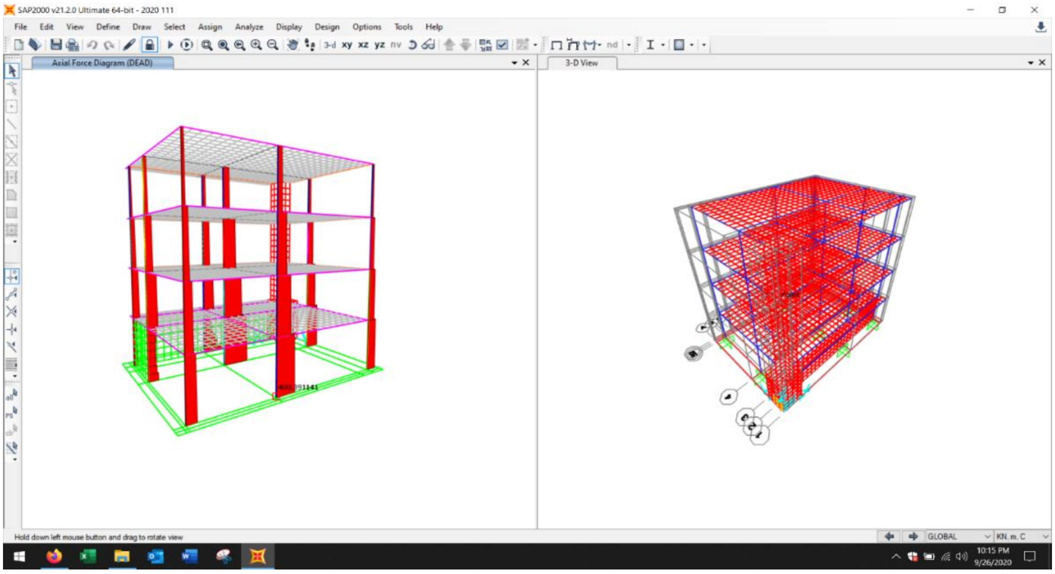

Figure 47 Axial Load on Column K3'

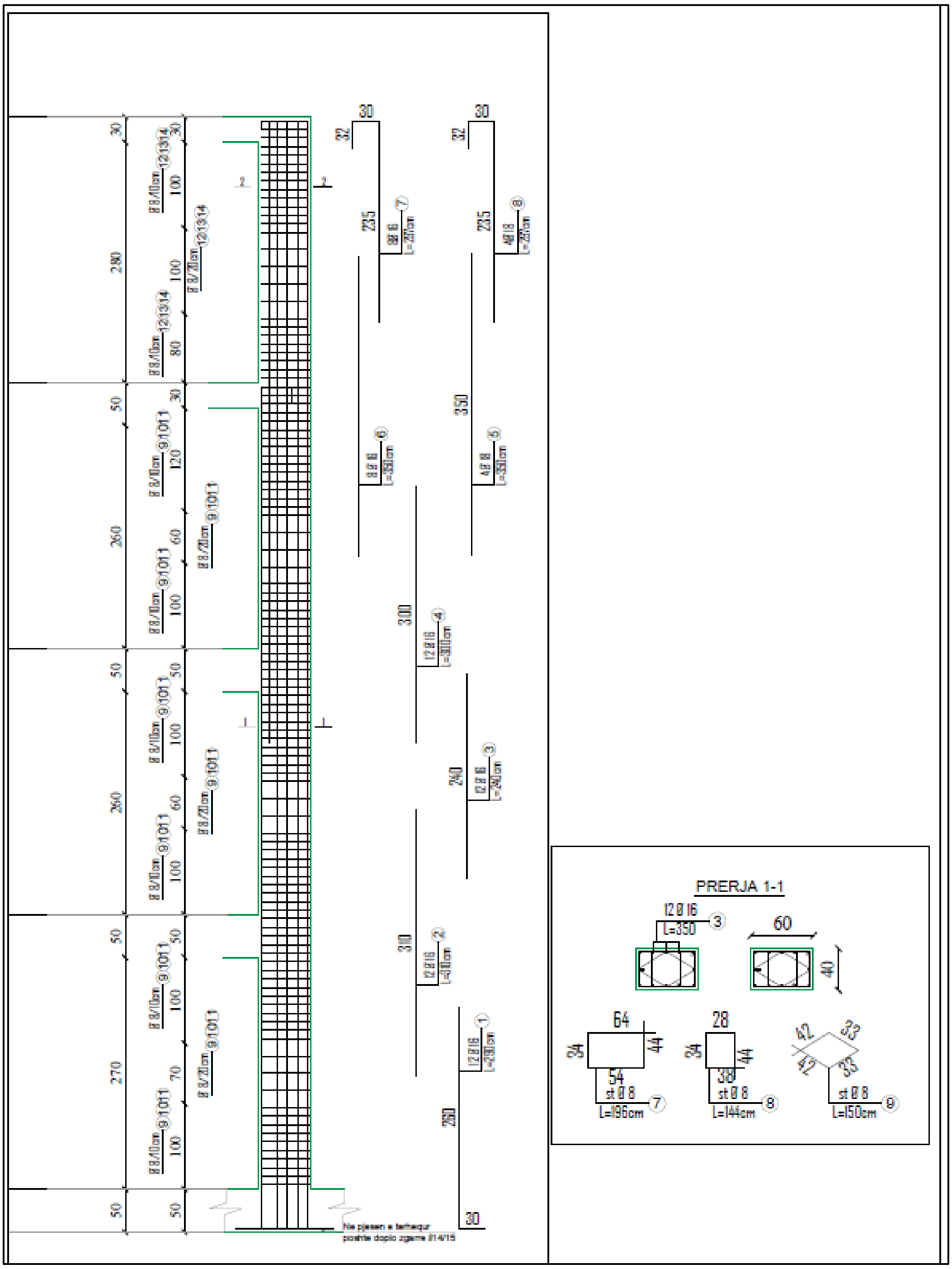

Figure 48 Column K1 reinforcement

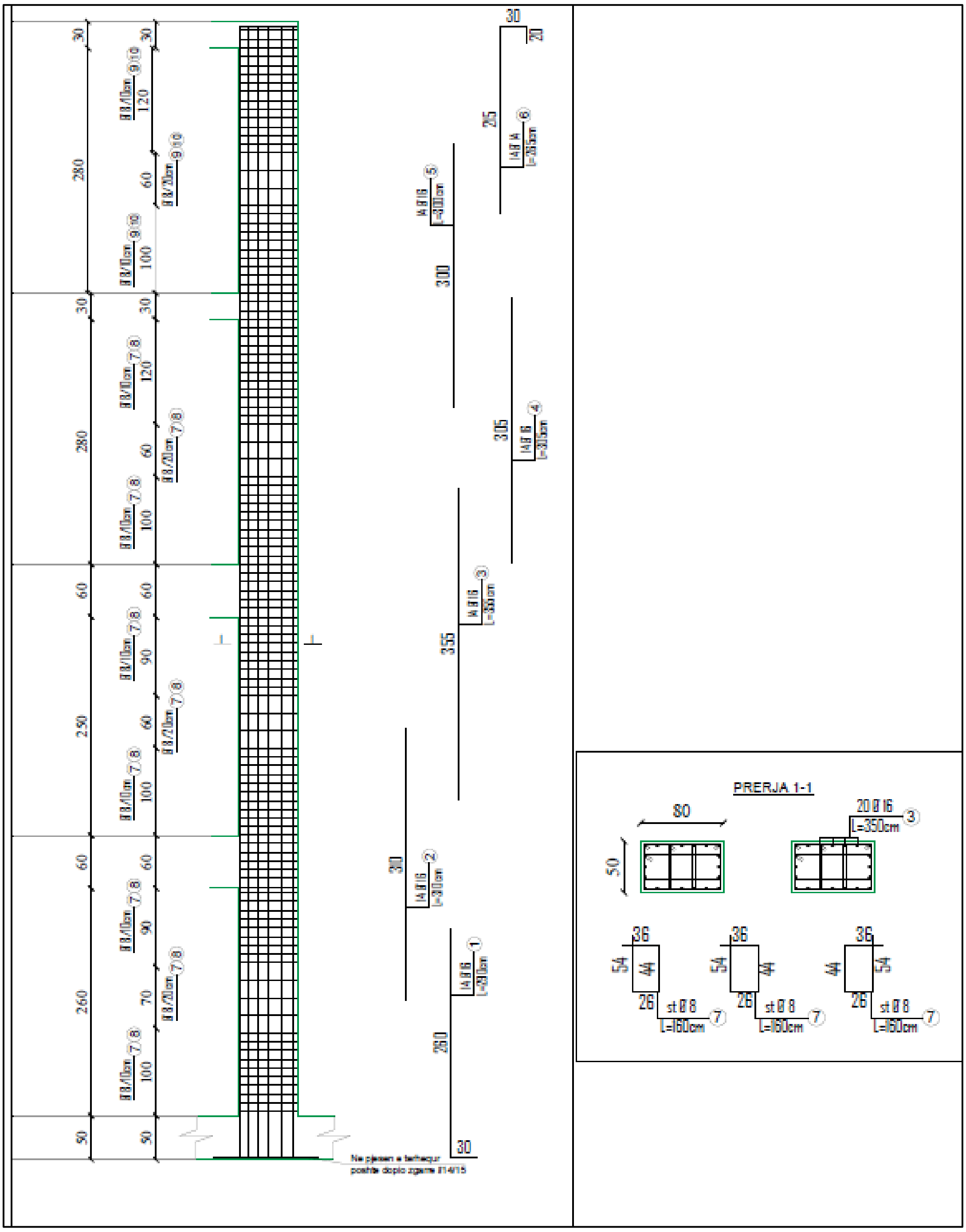

Figure 49 Column K3 reinforcement

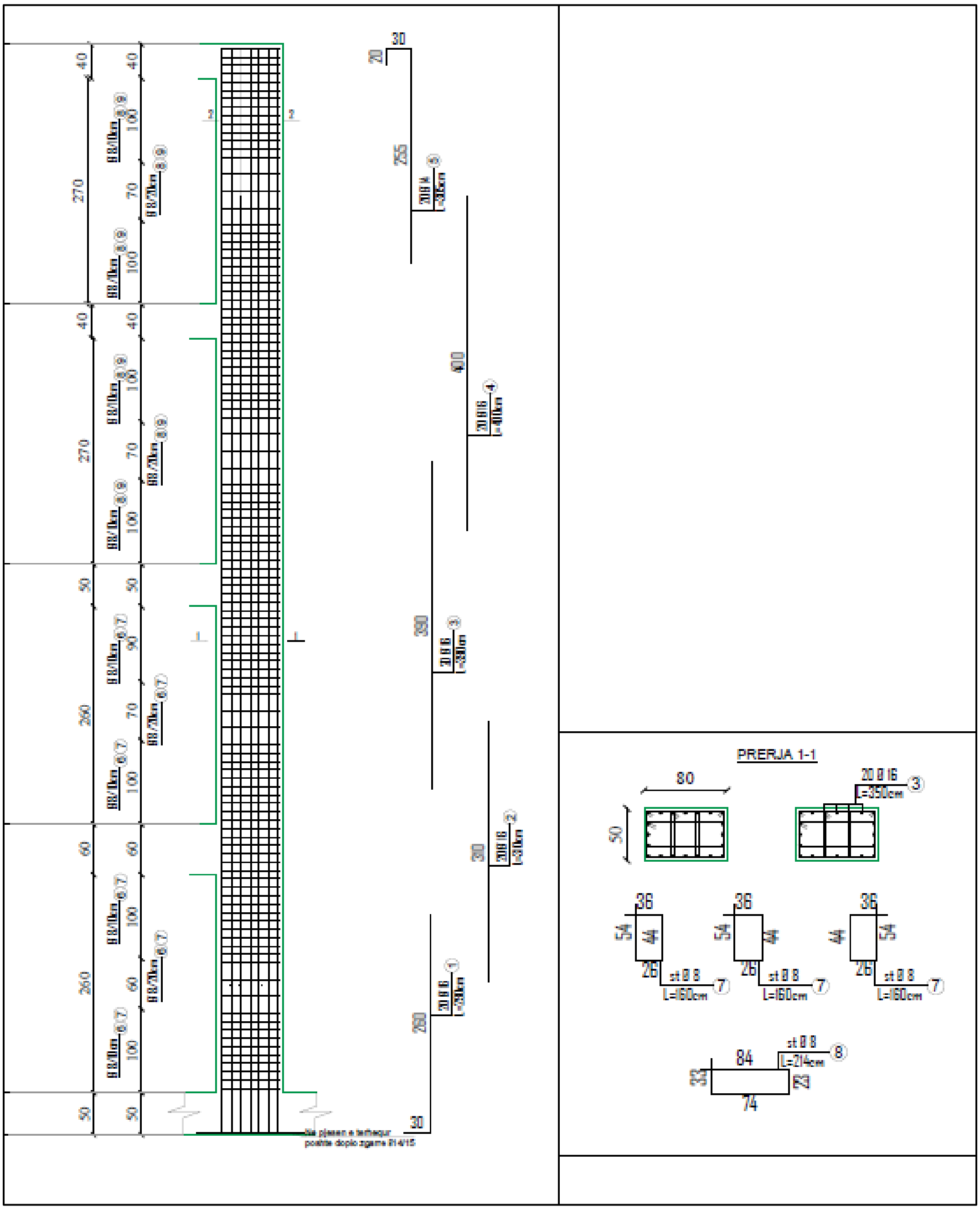

Figure 50 Column K4 reinforcement

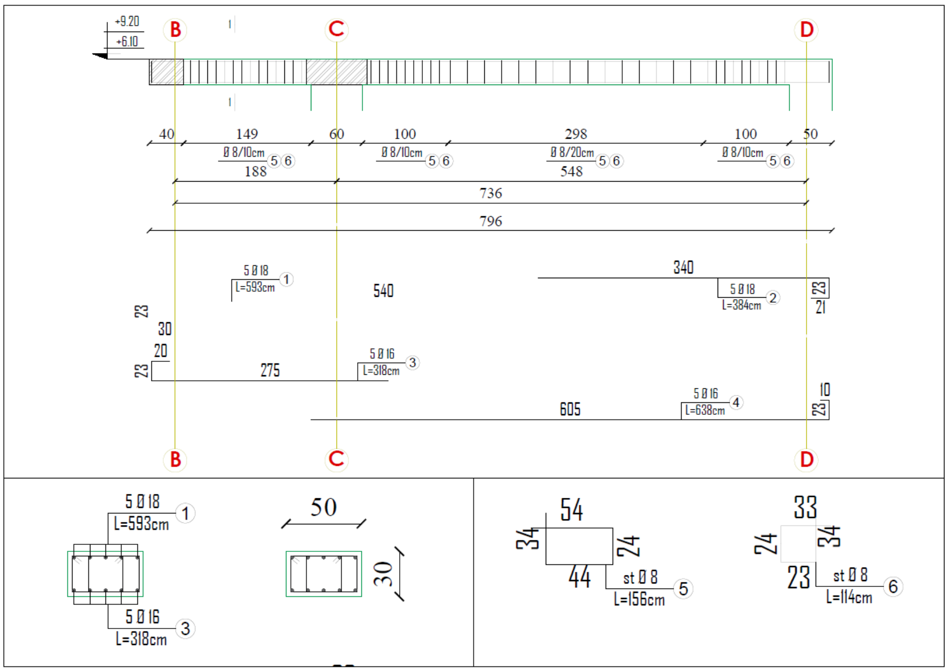

Figure 51 Beam T1, T3, T4 & T6 reinforcement

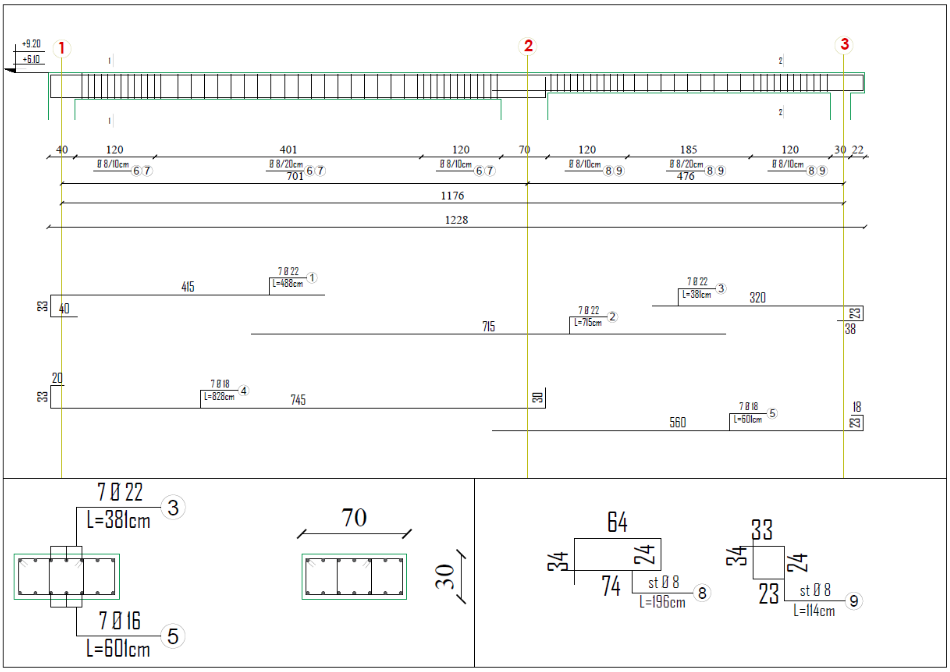

Figure 52 Beam T2 & T5 reinforcement