SEISMIC PERFORMANCE EVALUATION OF AZEM HAJDARI ELEMENTARY SCHOOL

A THESIS SUBMITTED TO
THE FACULTY OF ARCHITECTURE AND ENGINEERING
OF
EPOKA UNIVERSITY

BY

BESNIK RUÇI

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

JULY, 2023

Approval sheet of the Thesis

This is to certify the I have read this project entitled: **“SEISMIC PERFORMANCE EVALUATION OF AZEM HAJDARI ELEMENTARY SCHOOL**, and that in my opinion it is fully adequate, in scope and quality, as project for the degree of Master degree**.**

____

Assoc. Prof. Dr. Miriam Ndini
Head of Department
Date: June 2023

Examining Committee Members:

Assoc. Prof. Dr. Hüseyin Bilgin (Civil Engineering) ________________

Dr. Begmyrat Kulmedov (Civil Engineering) ________________

Dr. Marsed Leti (Civil Engineering) ________________

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.

Name Surname: BESNIK RUÇI

Signature: ______________

ABSTRACT

SEISMIC PERFORMANCE EVALUATION OF AZEM HAJDARI ELEMENTARY SCHOOL

Ruçi, Besnik
M.Sc., Department of Civil Engineering
Supervisor: Dr. Marsed Leti

Seismic performance evaluation plays a critical role in assessing the structural integrity and safety of buildings, particularly in earthquake-prone regions such as Albania. This study focuses on evaluating the seismic performance of Azem Hajdari Elementary School, a reinforced concrete building, by employing advanced analysis techniques. The research utilizes the pushover nonlinear analysis method to estimate the structural capacity and the capacity spectrum method for demand calculation, both implemented with the aid of SAP2000 software.

The study begins with the development of a finite element model of the Azem Hajdari Elementary School within the SAP2000 environment. The model is constructed based on the as-built plans and specifications, incorporating plan details. Subsequently, a pushover analysis is performed to assess the capacity of the building. Pushover analysis involves gradually increasing the base shear, simulating the distribution of lateral forces during an earthquake, and measuring the corresponding structural response. The results obtained from the pushover analysis are used to establish the capacity curve, which represents the relationship between the applied load and the corresponding deformation capacity.

Furthermore, the capacity spectrum method is employed to determine the seismic demand on the structure based on ATC-40. By analyzing the intersection points between the capacity curve and the spectrum, the corresponding demand is estimated. This provides valuable insights into the building's ability to withstand seismic forces.

The findings of the study are presented in terms of the capacity curves, demand spectra, and the performance levels achieved by the Azem Hajdari Elementary School. The results indicate that the building exhibits adequate capacity to resist seismic forces with a satisfactory level of performance to ensure life safety limit state.

Keywords: *Reinforced Concrete Building, Nonlinear Analysis, Structural Behavior, Azem Hajdari elementary school, SAP2000*

ABSTRAKT

VLERËSIMI I PERFORMANCËS SISMIKE TË SHKOLLËS FILLORE "AZEM HAJDARI"

Ruçi, Besnik

Master Shkencor, Departamenti i Inxhinierisë së Ndërtimit

Udhëheqësi: Dr. Marsed Leti

Vlerësimi i performancës sizmike luan një rol kritik në vlerësimin e integritetit strukturor dhe sigurisë së ndërtesave, veçanërisht në rajonet e prirura ndaj tërmeteve si Shqipëria. Ky studim fokusohet në vlerësimin e performancës sizmike të Shkollës Fillore Azem Hajdari, një godinë prej betoni të armuar, duke përdorur teknika të avancuara analize. Hulumtimi përdor metodën e analizës jolineare pushover për të vlerësuar kapacitetin strukturor dhe metodën e spektrit të kapacitetit për llogaritjen e kërkesës, të dyja të zbatuara me ndihmën e softuerit SAP2000.

Studimi fillon me zhvillimin e një modeli me elemente të fundme të Shkollës Fillore Azem Hajdari në mjedisin SAP2000. Modeli është ndërtuar në bazë të planeve dhe specifikimeve të ndërtuara, duke përfshirë detajet e planit. Më pas, kryhet një analizë shtytëse për të vlerësuar kapacitetin e ndërtesës. Analiza shtytëse përfshin rritjen graduale të prerjes së bazës, simulimin e shpërndarjes së forcave anësore gjatë një tërmeti dhe matjen e përgjigjes strukturore përkatëse. Rezultatet e marra nga analiza shtytëse përdoren për të vendosur lakoren e kapacitetit, e cila paraqet marrëdhënien ndërmjet ngarkesës së aplikuar dhe kapacitetit përkatës të deformimit.

Për më tepër, metoda e spektrit të kapacitetit përdoret për të përcaktuar kërkesën sizmike në strukturë bazuar në ATC-40. Duke analizuar pikat e kryqëzimit ndërmjet lakores së kapacitetit dhe spektrit, vlerësohet kërkesa përkatëse. Kjo siguron njohuri të vlefshme për aftësinë e ndërtesës për t'i bërë ballë forcave sizmike.

Gjetjet e studimit janë paraqitur në lidhje me kurbat e kapacitetit, spektrat e kërkesës dhe nivelet e performancës të arritura nga Shkolla Fillore Azem Hajdari. Rezultatet tregojnë se ndërtesa shfaq kapacitetin e duhur për t'i rezistuar forcave sizmike me një nivel të kënaqshëm të performancës për të siguruar gjendjen kufitare të sigurisë së jetës.

Fjalët kyçe: *Ndertesë prej betoni të armuar, Analiza jolineare, Sjellja strukturore, Shkolla fillore Azem Hajdari, SAP2000* .

ACKNOWLEDGEMENTS

I would like to give a special thank you to my supervisor, Dr. Marsed Leti, for his constant direction, inspiration, and support during the entirety of my thesis. I genuinely appreciate his wide range of knowledge, attention to detail, and time, effort, and ongoing support he has provided to enhance my graduate level experience.

I am grateful for friendly atmosphere of the Civil Engineering Department and all kind and helpful professors that I have met during my course.

I would like to thank my parents and sister. Without their love, patience and support, I could not have completed this study.

Finally, I wish to thank many friends for the encouragement during these difficult years, especially, Kevin Zace, Henri Cela.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Background (Problem Statement)

One of the most often utilized building materials in the modern construction sector is concrete. After Portland cement was invented in the 19^{th} century, it quickly gained a lot of popularity. Cement, sand, and aggregates are combined with water to create concrete.

In modern engineering, the concrete material is frequently employed in projects like buildings, bridges, dams, etc. Any shape can readily be created by molding fresh concrete because it is less expensive than other building materials, reinforced concrete construction is widely used, particularly in developing nations. Reinforced concrete has emerged as the ideal material for residential construction as a result of the rapid growth of urban populations in industrialized nations. On the other hand, external forces effect directly to the structure performance, resulting in a decrease of the element durability. This study investigates the seismic performance of Azem Hajdari elementary school located in Paskuqan, Kamez municipality, using nonlinear analyses procedures.

Problem Statement

The purpose of this study is to assess structural seismic performance using nonlinear analysis procedures. To achieve this scope, static nonlinear pushover analysis is utilized to estimate the capacity of the Azem Hajdari school. On the other hand, the demand calculations are based on the Capacity Spectrum Method from the "Seismic Evaluation and Retrofit of Concrete Buildings" guideline [ATC-40] [1]. The analysis procedures are executed in SAP2000 package while the modelling stage is conducted in 3D [SAP2000] [2]. Furthermore, based on the provisions of Eurocode-8 and FEMA guidelines, the performance points are located in the capacity curve of the building in both x- and y-directions.

Objectives and Scope

The main purpose of this study is to evaluate seismic performance of an elementary school called Azem Hajdari, located in the north of Tirana. The structure is selected as a midrise one, composed of 6 stories, reinforced concrete building constructed during 2022. The seismic performance estimation of the structure will be done using nonlinear analysis under the suggestions of modern guidelines. Therefore, eigenvalue, static pushover, capacity spectrum method is performed to achieve the objectives of this study. As a final point, the conclusions are summarized based on the findings made from the analysis results, while recommendations for future research is given in the last chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nonlinear Static Procedure (NSP) [3] of analysis also known as Pushover analysis is a simple method of non-linear behavior under seismic loads. The principle of Pushover anlysis involve the determination of the capacity of the structure. Although seismic demand provides an estimate of the ramifications of earthquakes, seismic capacity demonstrates the ability of a structure to handle these effects. With the use of software programs like SAP2000, which are known to be user friendly, (SPO) can be performed.

The PA analysis recommended in Eurocode 8 (EC8) [4] is a modified form of N2 method. Capacity Spectrum Method (CSM) procedures described in ATC-40 (later improved in FEMA 440) [5]. The method described in EC8 is a Target Displacement approach, although different from that of the Displacement Coefficient Method (DCM) described in FEMA 356 [6] (also later improved in FEMA 440). CSM has the advantage of being graphical nature, providing the ability to visualize the relationship between demand and capacity in the process of determining the point where this capacity spectrum "breaks through" the earthquake demand.

The aim of the performance-based design is to avoid the collapse of the structures and to ensure the acceptable safety factor against global instability due to expected strong ground motions. On the past experience, significant factors which influence the global collapse are the P-Δ effect and shear capacity of the element, which accordingly are initial point of the collapse.

2.2 Limit State

The phases that the building goes through during an earthquake before it completely collapses are shown by performance levels like immediate occupancy, life safety, and collapse prevention. The performance points selected for the structural assessment in this study are shown in the figure below accordingly:

- Immediate Occupancy (IO)
- Life Safety (LS)
- Collapse Prevention (CP)

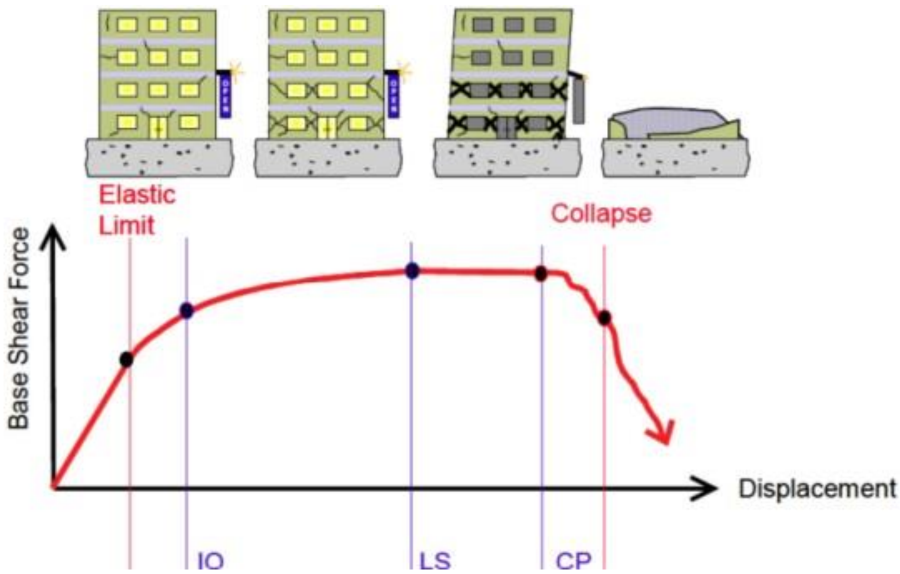


Figure 1. *Limit States of Building*

2.2.1. Immediate occupancy (IO)

The level of the building that is safe to occupy and is still unharmed, or where minor problems may occur but are easily fixable, is indicated by the immediate occupancy limit state.

2.2.2 Life Safety (LS)

Although there should be significant post-earthquake damage to the structure at this level, it is still far from total or partial collapse. However, the state of the elements should be severely harmed as a factor in why there is a chance of endangering life. Even if the building can be repaired, doing so would not significantly reduce the overall cost compared to having it completely rebuilt.

2.2.3 Collapse Prevention (CP)

Opposite to the life safety level, the post-earthquake damage should cause the structure to completely collapse or partially collapse. The structure will suffer significant damages as a result, as well as a decline in the stiffness and strength of the seismic load. Despite the fact that the structure's thorough damages make rehabilitation impractical.

2.2.4 Global Instability (GI)

Global Instability level represents the total collapse of the structure. [FEMA-350, 2000 [7]; FEMA-351, 2000] [8].

2.3 P-Δ Effect

The seismic performance of buildings is significantly impacted by the P delta effect. Building elements and components need to be made to withstand P-impacts, according to (FEMA 356 [2000]). The P- or P-delta effect describes rapid changes in ground shear, overturning moment, and/or axial force distribution near the base when a suitably tall building or structural component is subjected to a critical lateral displacement. When analyzing tall structures, one of the most crucial aspects to take into account is the structural height. The building's structure becomes more important as the building's height increases. Numerous studies have demonstrated that the structural height significantly affects the P-Delta number [9].

2.4 Linear Analysis

Analysis is referred to as a static linear analysis when applied forces and displacements have a linear connection.

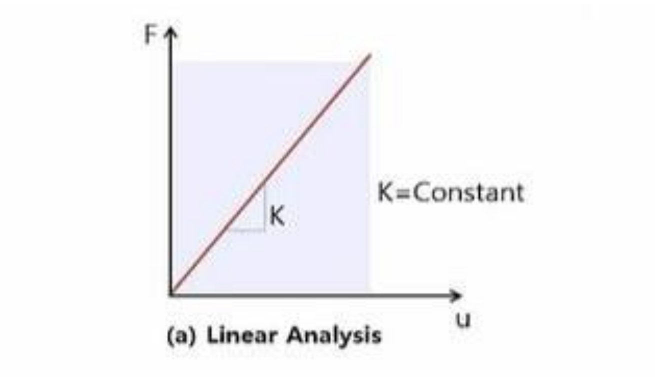


***Figure 2**. Linear Analysis obtained from Sample Graph*

2.5 Nonlinear Analysis

When there is a nonlinear connection between the applied forces and displacements, the analysis is nonlinear. Nonlinear effects can result from geometric nonlinearities (large deformations) and material nonlinearities (elastic-plastic substance) [10].

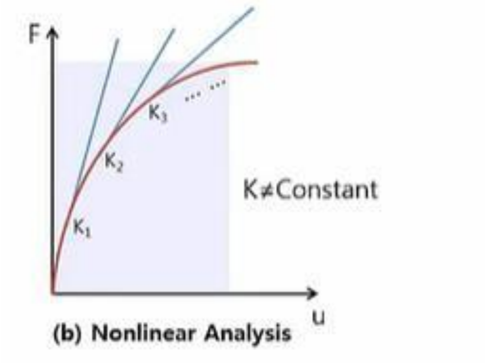


***Figure 3**. Nonlinear Analysis obtained from Sample Graph*

2.6 Analysis Preformed

Eigen Values: Eigenvalue analysis provides dynamic attributes of a structure by resolving the characteristic equation made up of mass and stiffness matrices. Some of the dynamic aspects to take into account are natural modes (or mode shapes), natural periods (or frequencies), and modal participation parameters. In SAP2000 by default the first 12 modes of the building are derived from the Eigen value analysis.

Pushover Analysis: The Pushover Analysis (PA) was used in response to the need for an easy method of predicting a structure's non-linear behavior under seismic loads while evaluating its capacity. It can help to show how buildings experience increasing failure and to pinpoint the mode of eventual failure. Simply said, PA [11] is a non-linear analysis method for determining a structure's strength capacity above its elastic limit (also known as the Limit State) and up to its maximum strength in the post-elastic region.

Capacity Spectrum Method: Is a simplified non-linear static analysis method used to estimate the maximum displacement and maximum base shear for the structure under seismic load effect using pushover analysis. Considering the guidelines of ATC-40 the performance point is calculated using the spectra from Eurocode and plotted together with capacity curve of the structure in x- and y-directions.

Conlcusions: By using three analyses—eigenvalues, pushover analysis, and capacity spectrum method—this research aims to discuss the seismic performance of a template known as Building_1. At the same time, additional tools such as Microsoft Excel and SAP2000 were used to conduct the study in a correct manner.

CHAPTER 3

CASE STUDY BUILDING

3.1 Introduction

For an entire country's urbanistic planning to advance, construction history is regarded as being essential. The building considered in this thesis is of a reinforced concrete (RC) structure which is built in 2022, who the invesitor of this project is Kamza municipality. This reinforced concrete structure (RC) was constructed in accordance with the unique structural design code known as Eurocode that was carried out within the European UNION (EU) [12]. Eurocode is now widely used to specify the types of building materials that are utilized throughout Europe, and it is intended to replace all other construction codes in those regions. Overall, implementing Eurocode standards in building design and construction is crucial for producing a built environment that is more resilient and sustainable. As the world continues to face the challenges of climate change and urbanization, these standards will play a critical role in ensuring that our buildings are safe, efficient, and able to adapt to changing conditions.

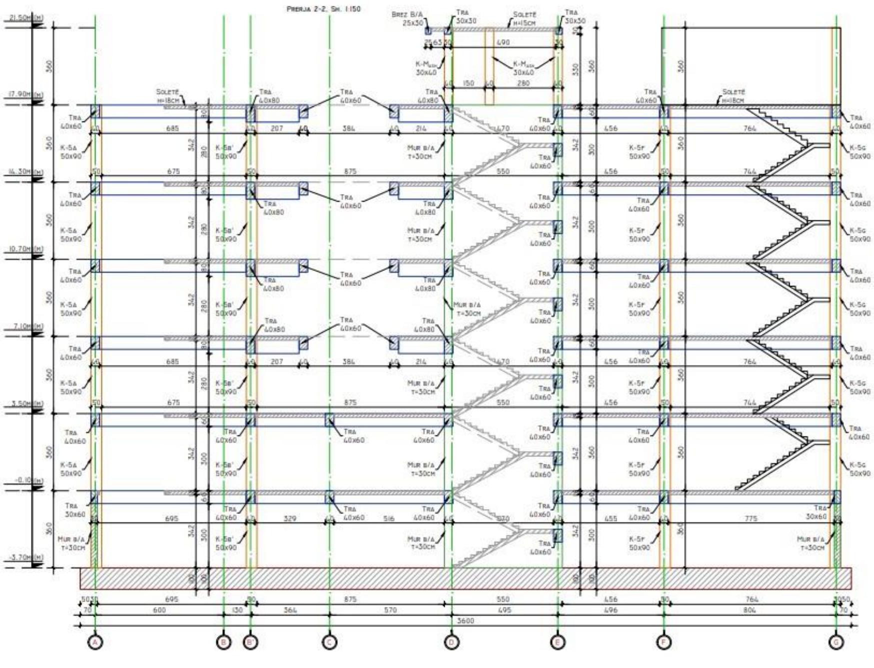


Figure 4. *Elevation View of Building*

3.2 Building Planimetry

The building consists of 7 frames in the longitudinal direction and 10 frames in the transverse direction. The planimetry is composed of classrooms, gym, laboratory, toilets etc. It covers a building surface of 1540 m^2. It is designed according to Eurocode standards therefore it is expected to show a good seismic performance. The plan of the building is shown in the figure below from the project data.

***Figure 5**. Planimetry of Building*

3.3 Beam and column cross-section

Columns are the vertical load carrying elements which play the vital role in the building performance. In this study, four element configurations are used to model the columns for structure. All elements represent different dimensions in the cross section of the columns as well as different configuration of reinforcement. Columns size 50x90, 40x80, 40x100, 40x120, 40x30 cm. As far as the reinforcement of the column is concerned, the stirrups have a diameter of 10Φ, and the longitudinal steel bars have a diameter of 22 mm.

A beam is a long and sturdy horizontal structural element that is designed to carry loads or weight from one support to another.The building consist of one kind of beam 60*40 cm. The reinforcement of beam, the stirrups have different diameters 8Φ, 10Φ and the longitudinal steel bars have a diameter that starts from 18Φ, 20Φ and 22 Φ mm.

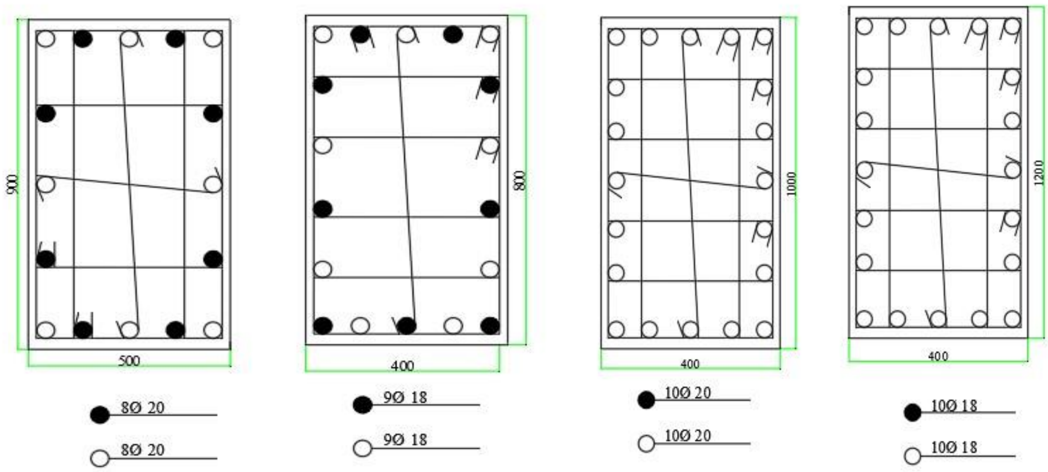


***Figure 6**. Column Detail*

Whereas, for Building the details show that the beam cross-section is 600x400mm, as shown in figure 7.

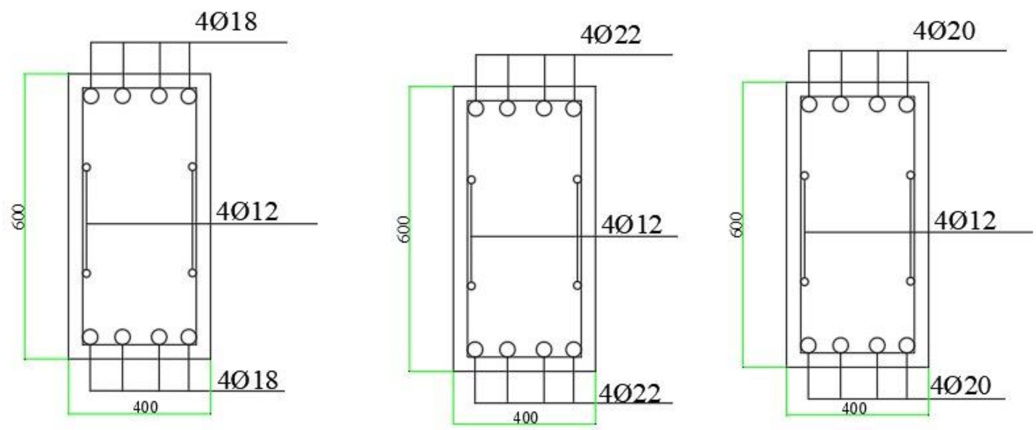


Figure 7. *Beam Detail*

3.4 Footing

A mat foundation, also known as a raft foundation, [13] is a large concrete slab that is used to distribute the weight of a building or structure evenly over a large area of soil. It is useful in controlling the differential settlement.In Figure 7 red line shows the contour of the foundation, it covers 1540 m^2 and a thickness 0.8 m. Reinforced with steel bar diameter 20Φ and concrete grade C30/37.

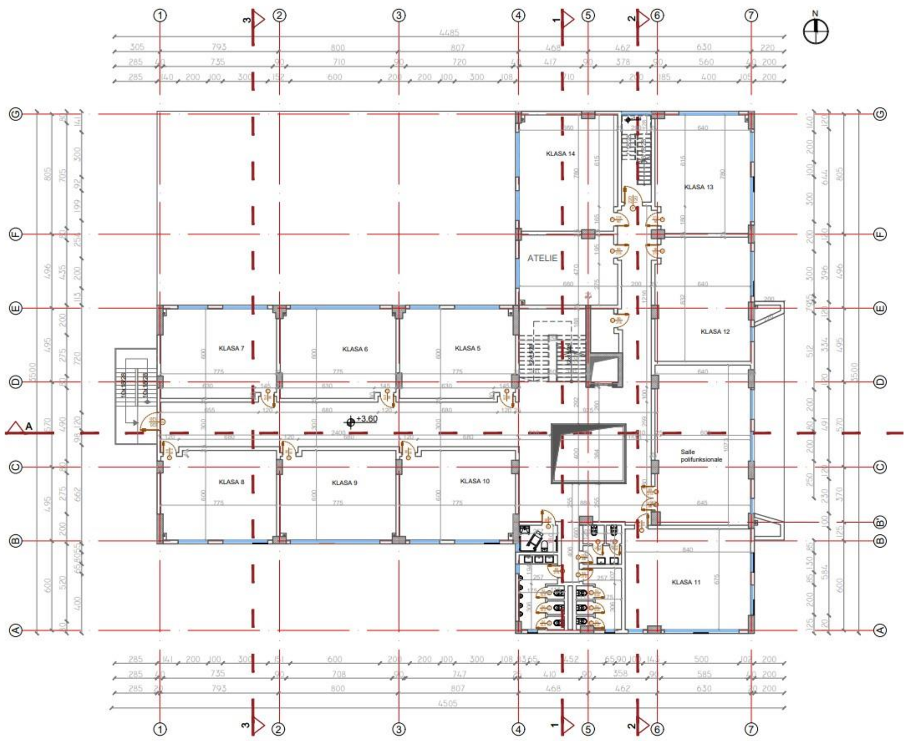


Figure 8. *Foundation Detail*

3.5 Construction materials specific

Eurocode displays the concrete's strength and correlates to the letter C. The first number figure depicts the typical strength of a cylinder, and the second one, that of a cube. The concrete strength class displays both the characteristic tensile strength and compressive strength for a cube or cylinder sample in MPa. The scope of use of a concrete corresponds to C30/37 in Eurocode [14], is the construction of large-sized structures and heavy foundations, the construction of monolithic structures, walls. It would be a good indicator to see the real strength of concrete by considering some core drilling tests in the laboratory experiments, however taking the samples for such a new building would be a challenging task. Therefore, the material characteristics to be modelled are used those from the plan details.

CHAPTER 4

MODELLING STAGE

4.1 Introduction

The 3D structure will be developed in this chapter while accounting for the material properties, the size of the beams and columns, and all other steps necessary for SAP2000 to model the structure in all of its complexity. The method for the present study consists of three stages. In the first stage, the structure is modeled in the analysis package of SAP2000. Furthermore, the second stage involves mainly the application of pushover analysis in the structure for the derivation of capacity curve plotted as (base shear, V_b vs roof top displacement, Δ_{rt}). In the third stage, the Performance Point is obtained using the capacity spectrum method utilized to estimate the demand of the building. The sections below demonstrate a guide of the modelling stage used in this study step by step in the SAP2000 software.

4.2 Grid Modelling

- Grid Only template from the File / New Model menu and confirm that the units are in KN, m, and C.

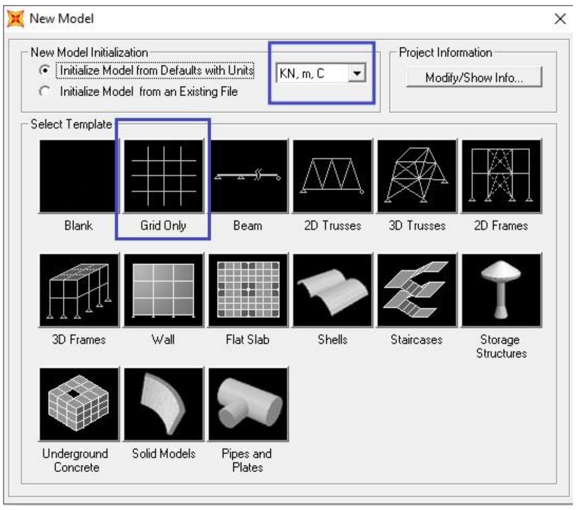


***Figure 9**. Grid option*

- Define/Coordinate Systems/Grid**.**

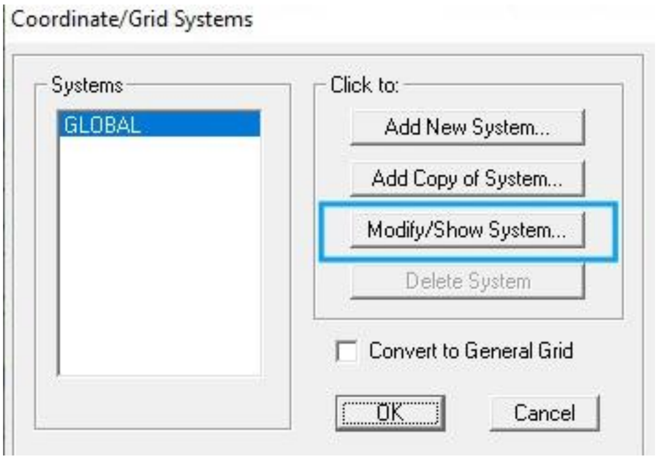


***Figure 10**. Modify/Show System*

- The grid data can be modified in the following places using these commands: Grid ID, Spacing, Line Type, Visibility, Bubble Location, as well as the grid color. It also confirms that the KN, m, and C units are still selected. The grid in Fig. 10 can be created by setting the grid display to Spacing and entering the distance from each axis under the spacing column.

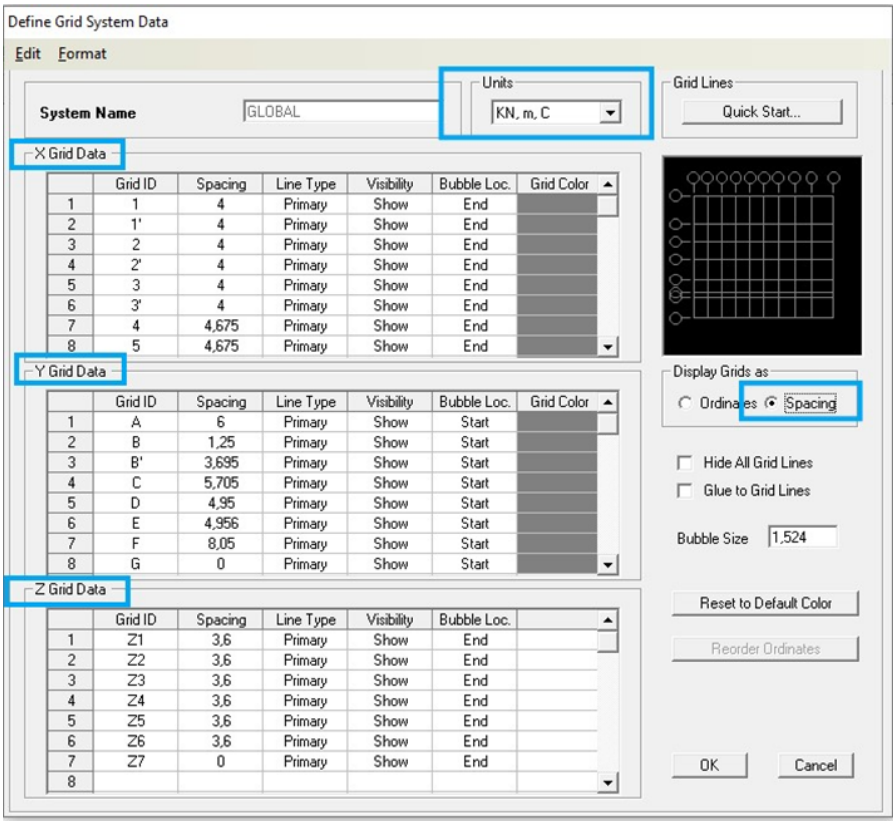


***Figure 11**. Representation of a 3D grid system in SAP2000*

4.3 Define Material

- Use the Material command on the Define menu to define, add, or modify a materials attribute.

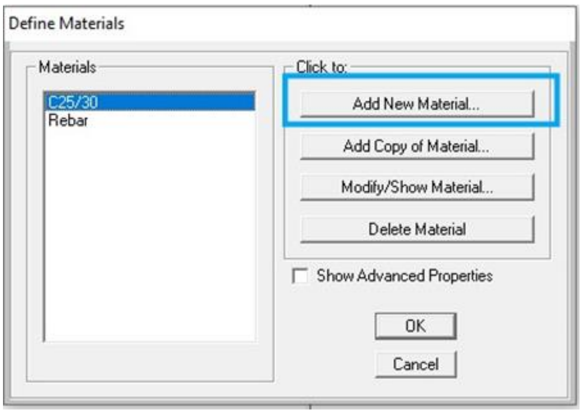


Figure 12. *Define Materials*

- By selecting "add new material," the list of materials used for the structure can be created. Each mentioned material's specifications and/or qualities, such as the name, unit weight, and units, are changeable.

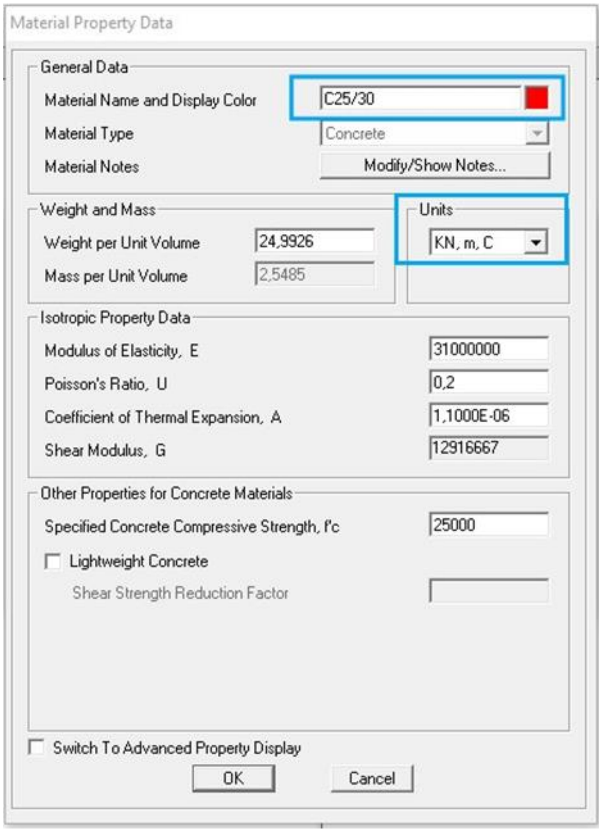


Figure 13. *SAP2000 window for editing the Material Property Data*

4.4 Define Frame Sections

• After the materials have been established, these materials can subsequently be used to specify frame parts. Define the menu/section properties/frame sections to display the frame properties from **Figure 14**.

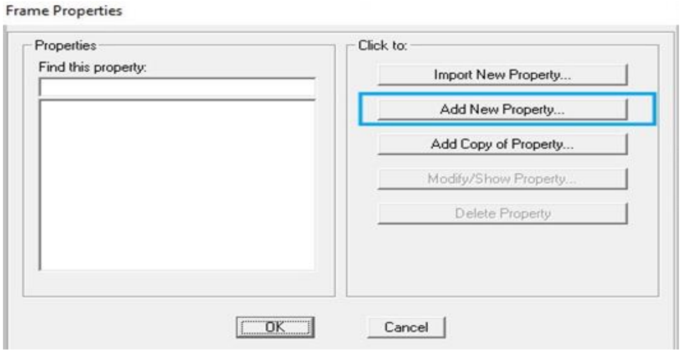


***Figure 14**. Created/Define Frame Properties*

- Add new property.

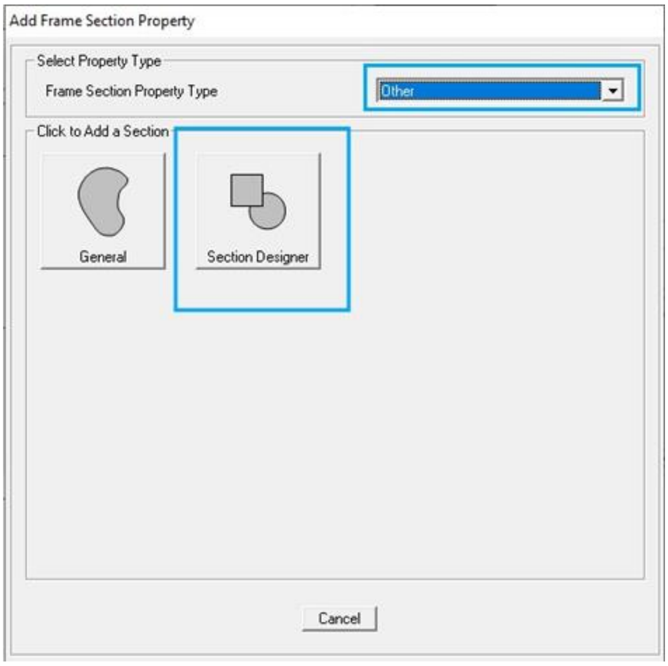


***Figure 15**. Sample of Section Designer window in SAP2000*

- In the section design command, the frame for beams is being modeled. As illustrated in Figure 15, define the section name, connect the material that was previously described under the section design command, and then click Section Designer to create the beam's features.

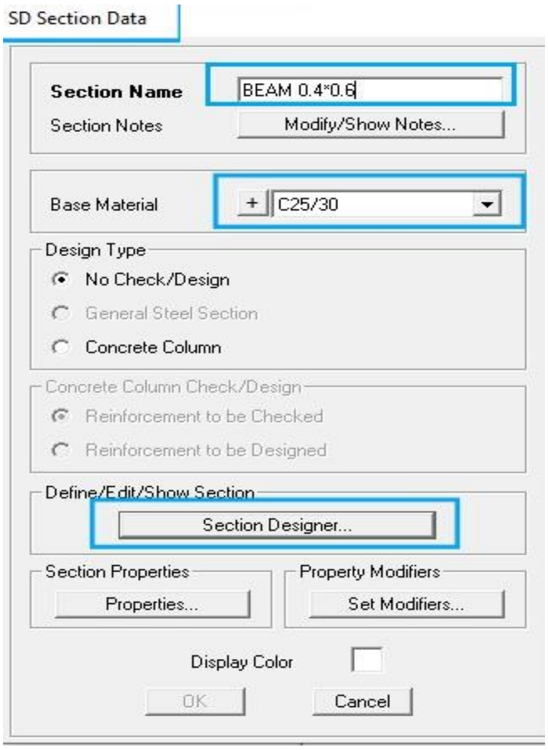


Figure 16. *Link the material with the Section Designer*

- Define the rectangle command's cross-sectional shape according to fig. 16.

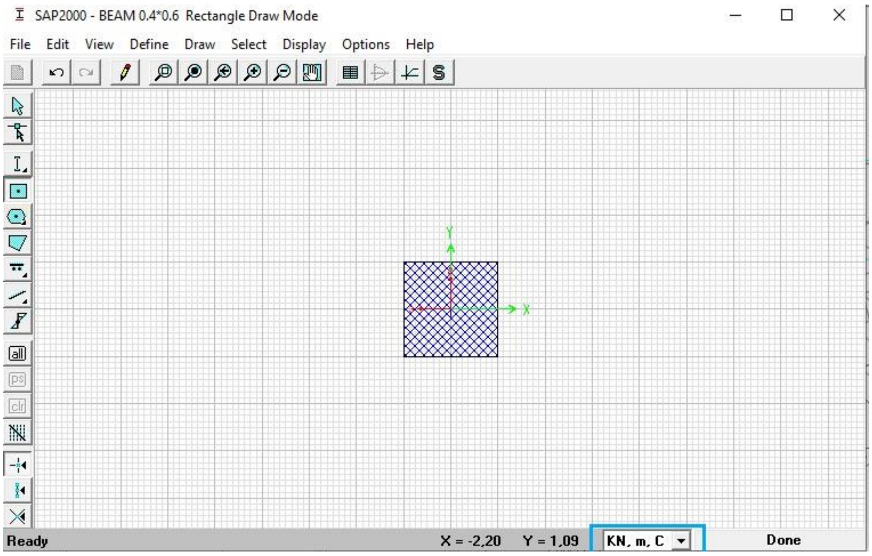


Figure 17. *Illustration of a cross-section in section designer window of SAP2000 package*

- The previously selected material for the cross section link dictates its dimensions, which are depicted in Figure 17, ensuring that the concrete beam's units remain KN, m, and C.
- The exact same procedure is followed to define the column frame.
- The reinforcing details can be changed by clicking Modify/Show Property at the defined frame properties.

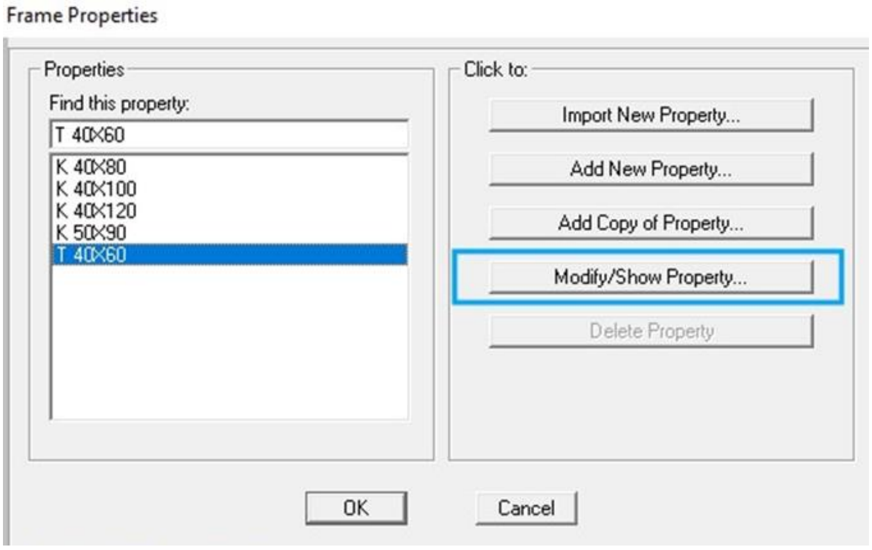


Figure 18. *Frame properties, Modify*

4.5 Reinforcment Detail

As explained in the previous chapters, the diameter of the confinement bars is used in the plan details as 10mm diameter while the longitudinal ones as 20 mm diameter. These details are reflected in the analytical model through the steps illustrated as follows:

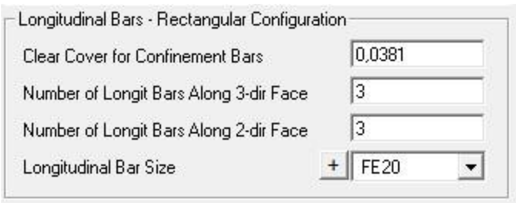


Figure 19. *Reinforcment detail for Longitudinal Bars*

Figure 20. *Reinforcment detail for Confinement Bars*

4.6 Add Frame Objects

- Select Draw Frame/Cable/Tendon button.

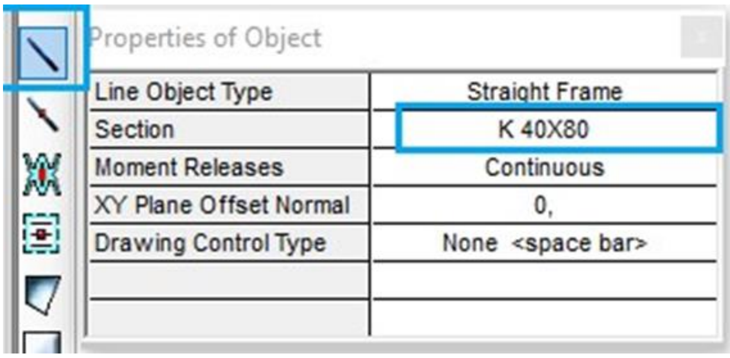


Figure 21. *Draw, Frame Section on Grid*

- Create the beam and column frames to simplify the view and minimize errors, then switch the plane view to a xy, xz, and yz view as necessary.

Figure 22. *Plane views*

4.7 Ad Restrains

- The frame's supports are defined at this stage. Check to see if the X-Y Plane @ Z=0 view is open. The Joint Restraints form will appear after selecting the supports using the left-to right selection method and clicking the Assign menu > Joint > Restraints command.

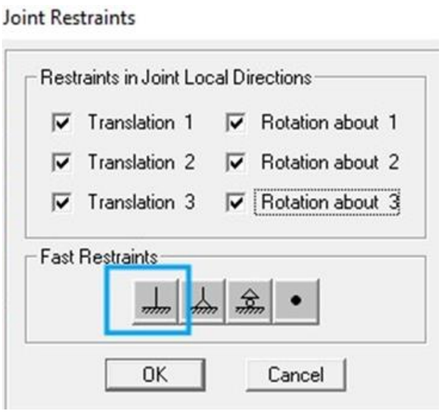


***Figure 23**. Joint Restrains*

4.8 Define Load Patterns

- Selecting the Define menu > Load Patterns command will bring up the Define Load Patterns form for fig. 22.
- After providing the load pattern's name, type, and self-weight multiplier, click Add new load.
- Remember that the self-weight multiplier for the default case is set to 1. This indicates that this load pattern will automatically incorporate the self-weight of each member at 1.0 times.

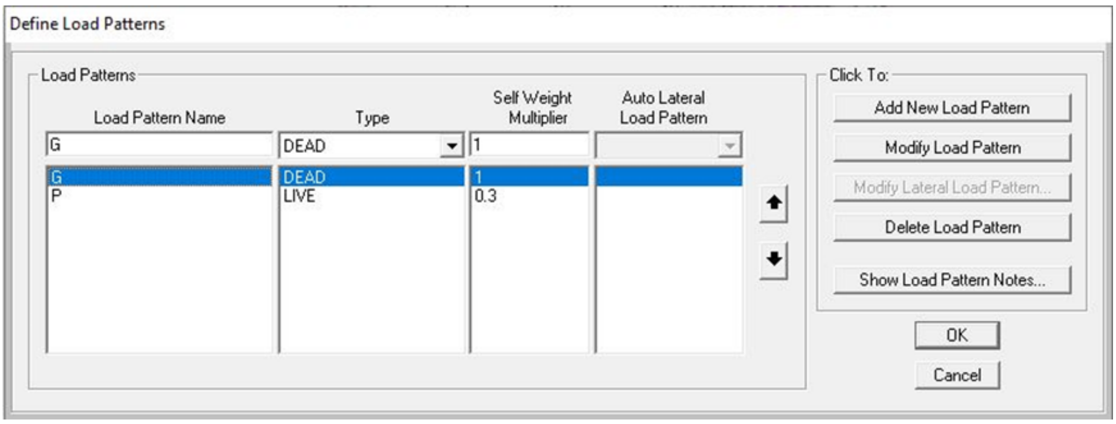


***Figure 24**. Load Patterns window from SAP2000 software*

4.9 Slabs

- SAP2000 offers a list of elements that can be used in the modelling stage among which, slabs are also included. However, for simplicity, instead of modelling slabs, their loads are assigned directly to the beams. The calculation of the slab load is done considering one- way or two- way slab types. Their loading shape and magnitude is reflected in the mathematical model prepared in SAP2000. Figures 25, 26 shows below:
- Consider the second point as the greatest point load and the fourth point as 0 for calculating triangular loads.

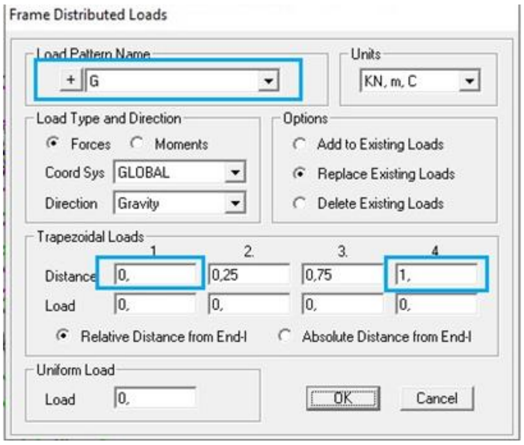


Figure 25. *Trapezoidal Load*

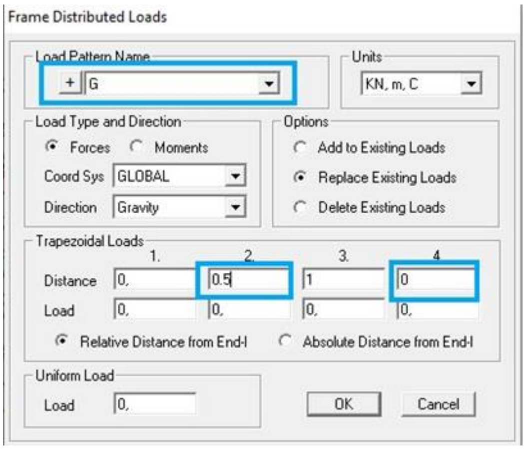


Figure 26. *Triangular load*

4.10 Constrain

- Choose the slabs using the left-to-right selection. Select Assign/Joints/Constraints to switch from the body to the diaphragm and add a new constraint in the z direction.

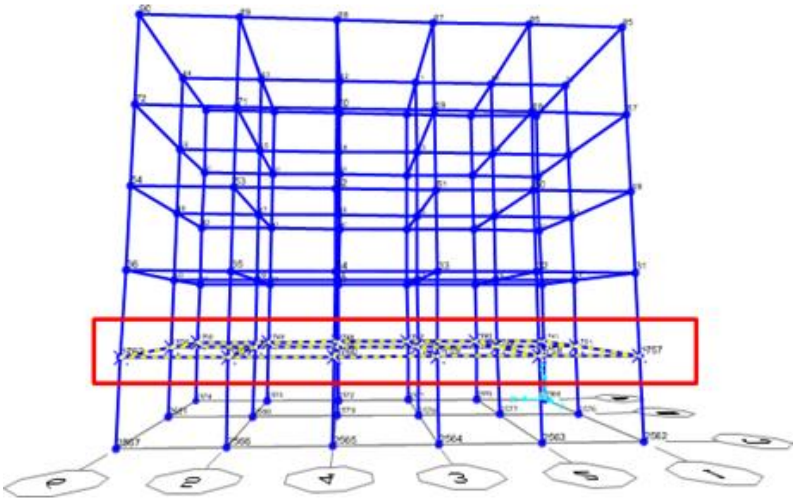


Figure 27*. Constrained Slab of Stories*

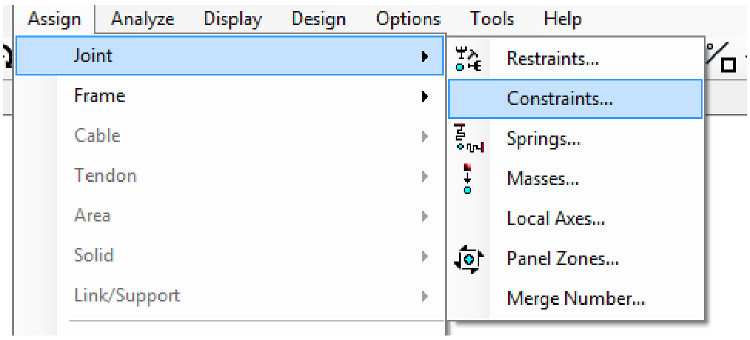


Figure 28*. Joint Constraines assigned for each slab*

- To constrain the slab after changing from the body to the diaphragm, click add new constrain.

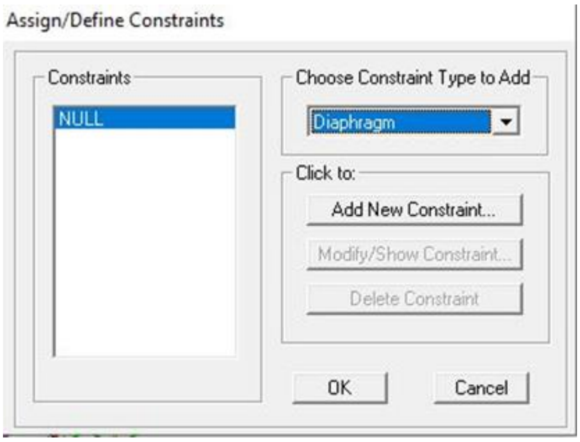


Figure 29. *Type of Constraint*

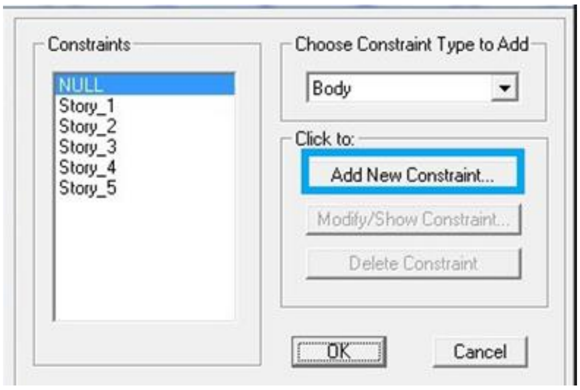


Figure 30. *Add Constrain for each story*

- The other Storys in the building model are given the diaphragm according to the same process.

4.11 Replicated

- The distribution of the slab load is used as the basis for the first-floor model, which accounts for each beam and determines whether it is loaded from two slabs or just one.

Pick the frame of the floor. By choosing the Edit menu > Replicate command, the form shown in Figure 34 will be displayed.

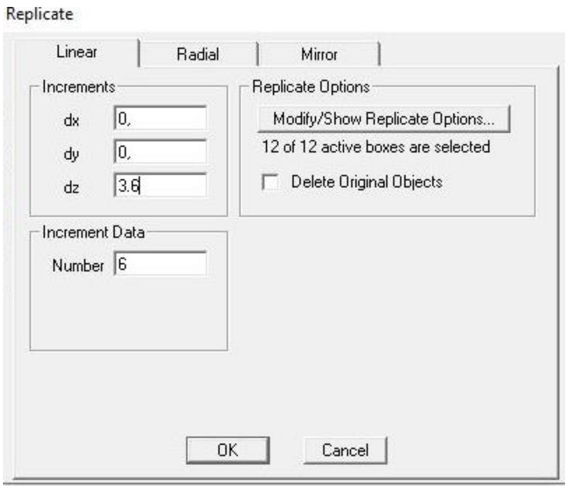


Figure 31. *Replicate*

- While the increment data in "dz" shows the floor height, the increment data in "dz" defines the number of floors. The 3.6 m columns on the top floor need to be renovated.

CHAPTER 5

METHODOLOGY

5.1 Utilization of MS Excel for load calculation

This step takes into account the load calculations for each of the slab using the dead and live load. The calculations are necessary as the slabs won’t be included in the analytical model done in SAP2000. Therefore, each of the slab load will be distributed into its surrounding beams as distributed loads. Considering the slab types as one way or two way, the distributed load can be uniformly lying over the beam, in the shape of triangle or trapezoidal. For this reason, the calculations are performed using MS Excel and then applied in the SAP2000 software. The following sections illustrate the calculation examples used in this thesis.

5.1.1 One way – Two ways slab

The lengths of the slab's short and long sides are taken into consideration by the Lx and Ly ratio in the given planimetry to establish if the slab is one way or two way. A slab is regarded as one way if the ratio is greater than 2, and as two ways in all other cases. [15]

$$\frac{Ly}{Lx} > 2 \qquad \textbf{Equation 1}$$

Figure 32. *Labeling the slabs from the plan layout for load calculation*

Each slab has two trapezoid distributions and two triangular distributions because the slabs are two ways. The weight of each shape is transferred to the beam. The respective areas need to be taken into account when calculating the weight. Under loading, a two-way slab will exhibit trapezoidal and triangular deformation on all four of its sides.

Firstly, the weight of the slab is calculated the slab thickness and unit weight of concrete.

Table 1: Given data to calculate the loads

Concrete U.W γc	**25**	**kN/m^3**
Slab thickness (t)	**0.18**	**m**
Regular Column Height	**3**	**m**
Live load	**2**	**kN**

$$Ly \bullet Lx \bullet \gamma c \bullet t \qquad \textbf{Equation 2}$$

Slab category	Long Side [m] [Ly]	Short Side [m] [Lx]	Slab Type	Slab Weight[kN]
S1	8	4.95	two-way slab	19.16
S2	8	5.7	two-way slab	21.19
S3	8	4.67	two-way slab	18.35
S4	8	6.3	two-way slab	22.65
S5	4.95	4.67	two-way slab	15.62
S6	6.3	4.95	two-way slab	17.81
S7	5.7	4.67	two-way slab	16.56
S8	6.3	5.7	two-way slab	19.40
S9	6.3	6	two-way slab	19.96

Table 2. The load calculations for different slabs in the building

Since the weight of the slab is determined without taking the weight distribution in trapezoidal and triangular shapes into account, these shapes will now be calculated, defining the loads that the slab places on the beams.

Formulas:

For triangular load:

$$\frac{(Lx)^2}{4}$$ **Equation 3**

$$\underline{Ly \bullet (Ly - Lx) \bullet Lx4}$$ **Equation 4**

Table 3: Shape weight for triangular and trapezoidal shapes

Slab	Long Side[m]	Short Side[m]	Triangle/Trapezoid	Shape Weight [kN]
S1_Triangle	8	4.95	Triangle	8.05
S1_Trapezoid	8	4.95	Trapezoid	11.11
S2_Triangle	8	5.7	Triangle	9.26
S2_Trapezoid	8	5.7	Trapezoid	11.93
S3_Triangle	8	4.67	Triangle	7.6
S3_Trapezoid	8	4.67	Trapezoid	10.75
S4_Triangle	8	6.3	Triangle	10.24
S4_Trapezoid	8	6.3	Trapezoid	12.41
S5_Triangle	4.95	4.67	Triangle	7.6
S5_Trapezoid	4.95	4.67	Trapezoid	8.02
S6_Triangle	6.3	4.95	Triangle	8.05
S6_Trapezoid	6.3	4.95	Trapezoid	9.76
S7_Triangle	5.7	4.67	Triangle	7.6
S7_Trapezoid	5.7	4.67	Trapezoid	8.96
S8_Triangle	6.3	5.7	Triangle	9.26
S8_Trapezoid	6.3	5.7	Trapezoid	10.14
S9_Triangle	6.3	6	Triangle	9.75
S9_Trapezoid	6.3	6	Trapezoid	10.21

5.2 Eigen Values Analysis

Analysis of Eigen values is thought of as the study of the dynamic qualities of structures under vibration. In general, it employs the structure's mass and stiffness to determine different periods while analyzing the dynamic response of the structure.

5.2.1 Mass Source

The structure's mass, or self-weight, as well as additional mass from surface loads and line loads—typically, dead load (DL) plus love load (LL)— [16]are calculated by the mass source. It is crucial to confirm the mass source in SAP2000 since the model analysis uses the structure's mass and stiffness. The name of the mass source can be specified using the Define/Mass Source/Modify/show Mass source/ and the options to activate just Specific Load Patterns. When employing the supplied load patterns, only the specified loads at the load pattern will be taken into account.

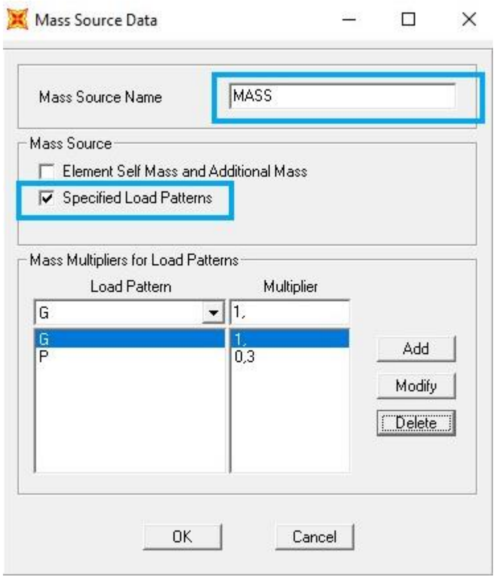


Figure 33. *Assigning mass source data for dead and live load in SAP2000*

The multiplier is 1 for dead load as it multiplies the dead load of the structure by coefficient 1, for, live load we specify it as 0.3.

5.2.2 Load Patterns

Dead load and live load are the two loads that are specified at load pattern definition. Specificate the self-weight multiplier for each load pattern.

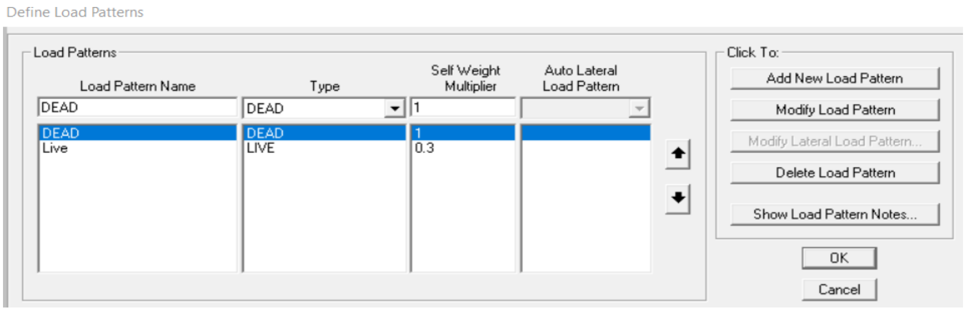


Figure 34. *Self- weight load patterns*

A self-weight multiplier controls what is included of structural self-weight in a specific load pattern. Usually, only the load pattern that represents the structure's self-weight (dead load) is given a self-weight multiplier of 1; all other load patterns are given a multiplier of 0.3.

5.2.3 The Eigen Values Analysis Modelling

Define, Load Cases, add a new Load Case named as gravity. The load case type, load pattern and scale factor as shown below in fig 32.

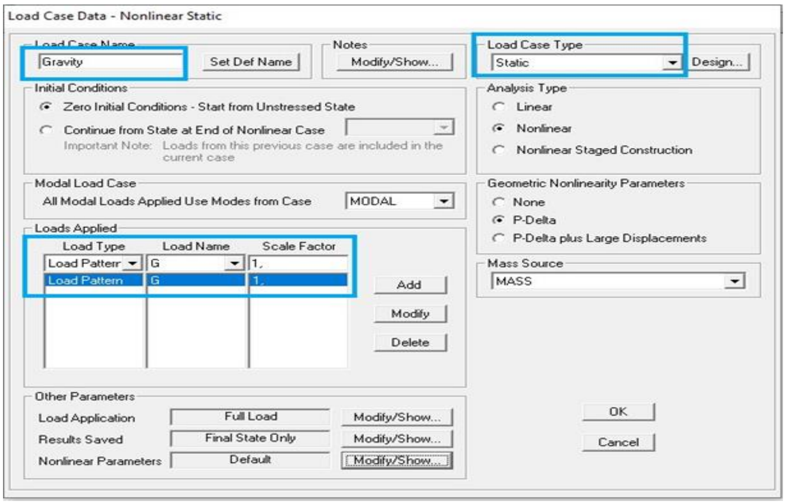


***Figure 35**. Load Case Data*

Set the minimum and maximum number of modes when defining a new load case under the Modal Load case type. The mass source has already been established. In this instance, doing Eigen Vectors kind of Modes is of relevance.

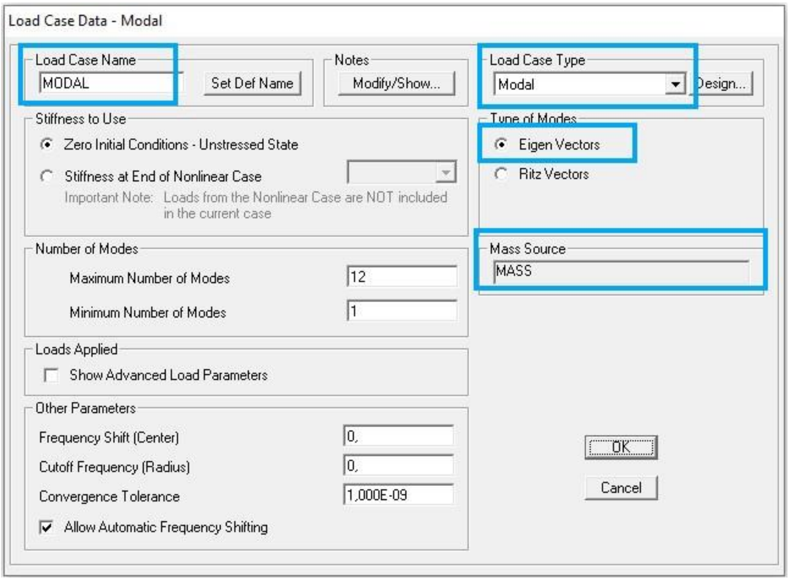


Figure 36. *Modal Case*

Run the analysis and check the deformed shape under **Modal**.

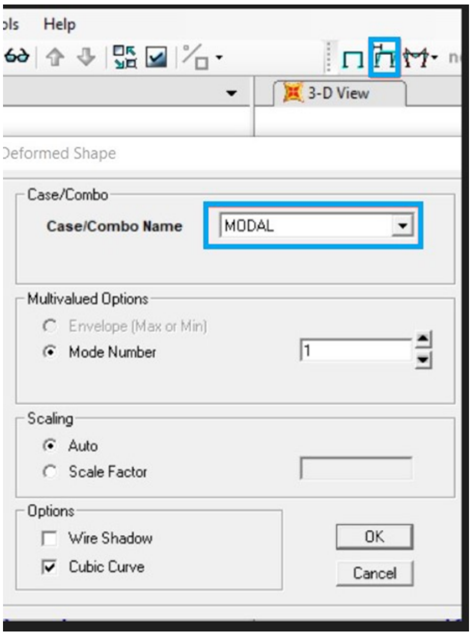


Figure 37. *Deformed shape*

The deformation that a component would exhibit at its natural frequency of vibration is known as a mode shape. In the y direction, x direction, and for torsion, SAP2000 displays the phrases mode shape or natural vibration shape. After the analysis has been run, mode shapes are displayed. Click on deform shape and check the wire shadow option, too.

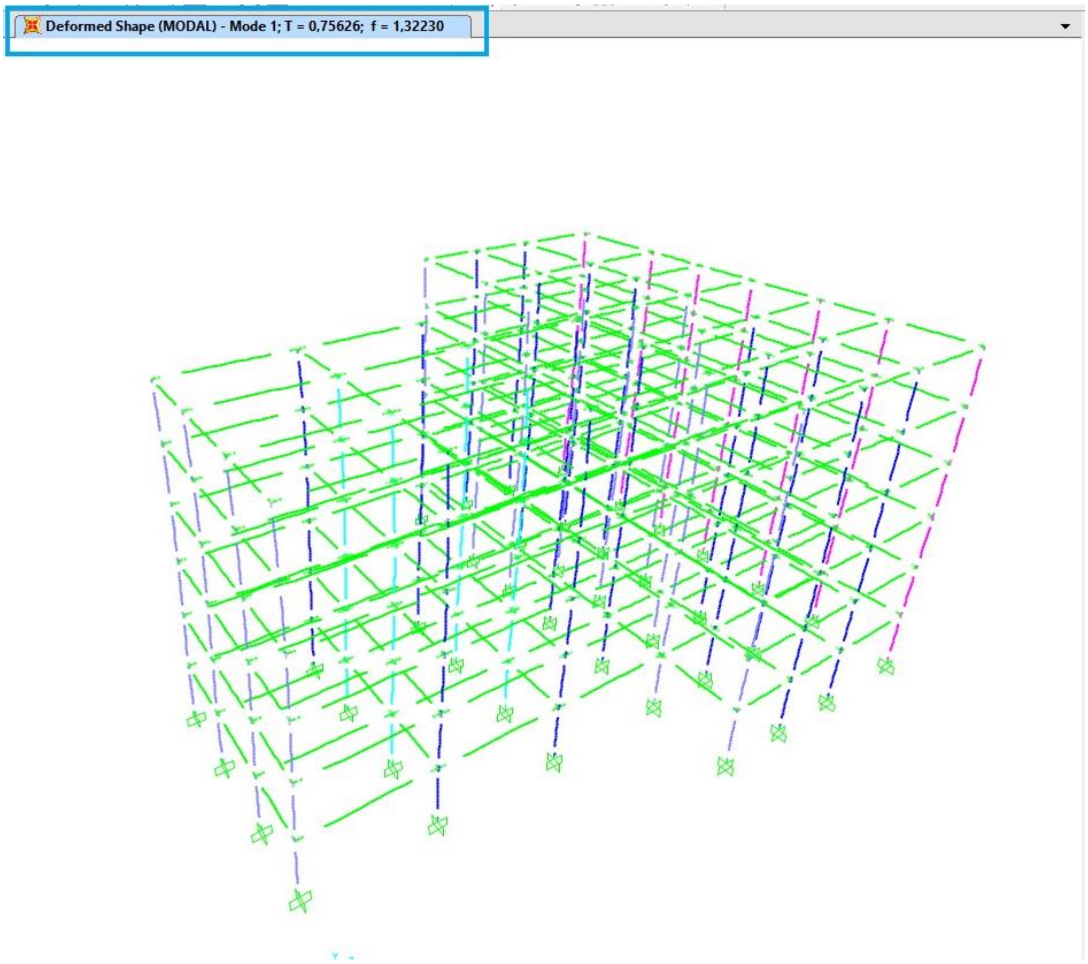


Figure 38. *Frequency and Period of the building for Mode 1*

The period as well as the deflection in the relevant plane are shown for the first three options when the arrow next to start animation is clicked. The first mode is in the X direction, the second is in the Y direction, and the third mode is in the Z direction (torsion).

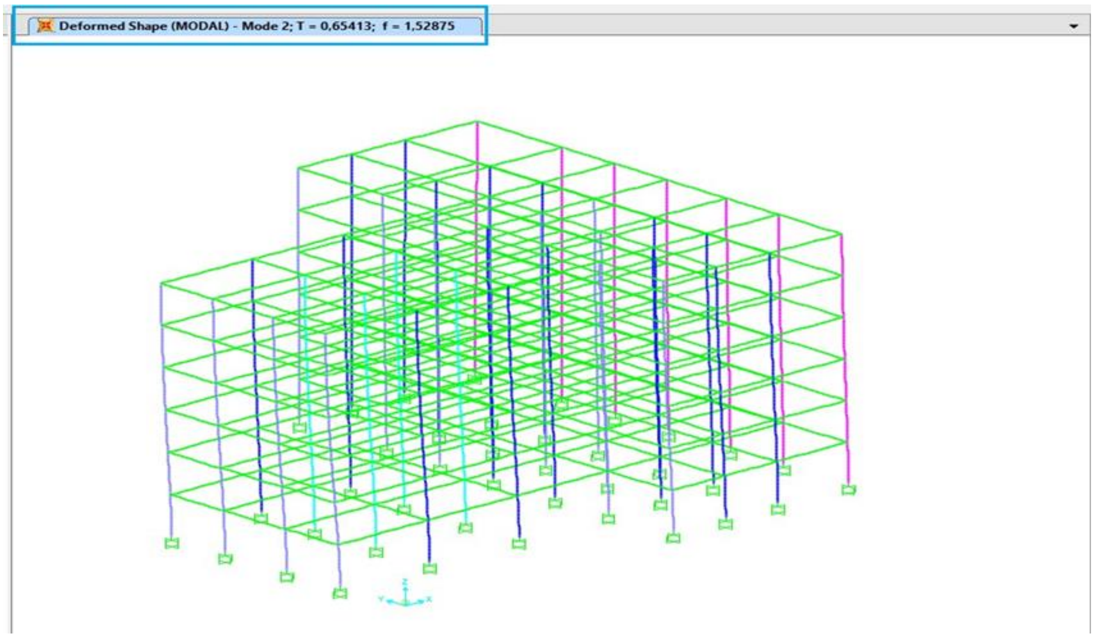


Figure 39. *Frequency and Period of the building for Mode 2*

5.3 Pushover Analysis

Pushover analysis identifies crucial portions likely to reach limit state during earthquakes while providing realistic estimations of deformation capacity for inelastic behavior of building models. This research is anticipated to offer important insight into the behavior of the structure after surpassing the elastic limit. Pushover analysis is first and foremost based on the presumption that the initial mode of vibration and mode shape, or the first few modes of vibration, regulate the reaction of the structure and that this form is continuous throughout the structure's elastic and inelastic response.

5.3.1 Modelling Stage for Pushover Analysis

In this subchapter the procedure followed in order to perform Pushover Analysis will be shown.After the structure has been modelled a new load case needs to be added.

Define material/ Load Cases/ Add a new load case named as gravity.

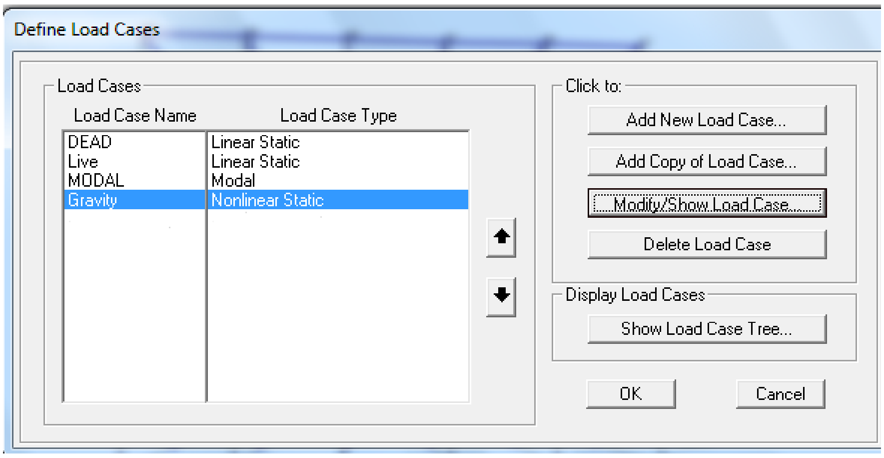


Figure 40. *Pushover Analysis/ Define Load cases.*

At gravity load case, the analysis type, load case, initial conditions and loads applied are specified.

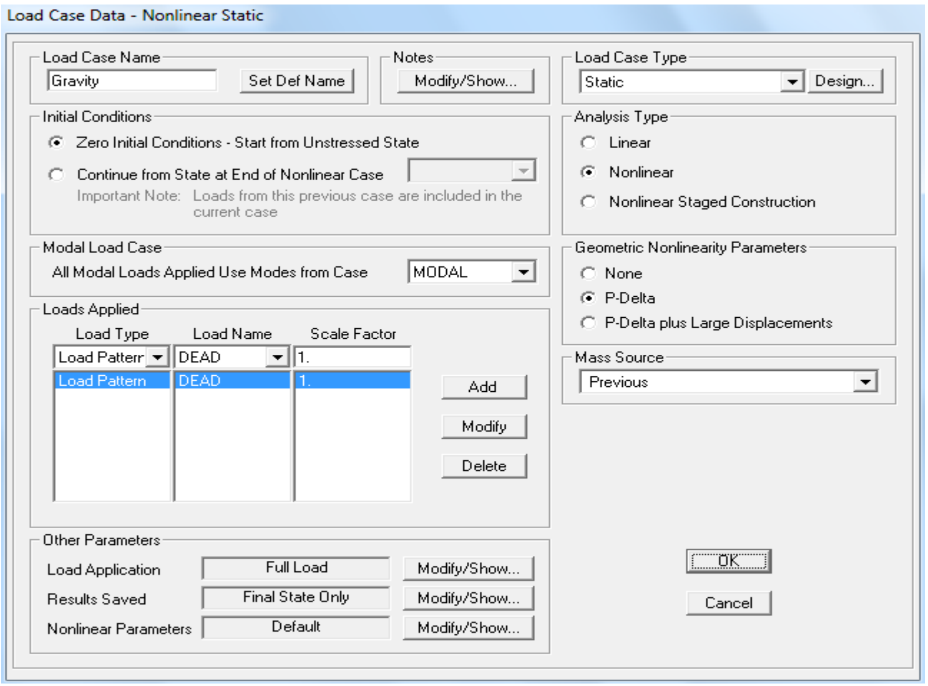


Figure 41. *Gravity Load Case /Specifics*

One of the most important steps to perform the pushover analysis is to add hinges in beams as wellas in columns.

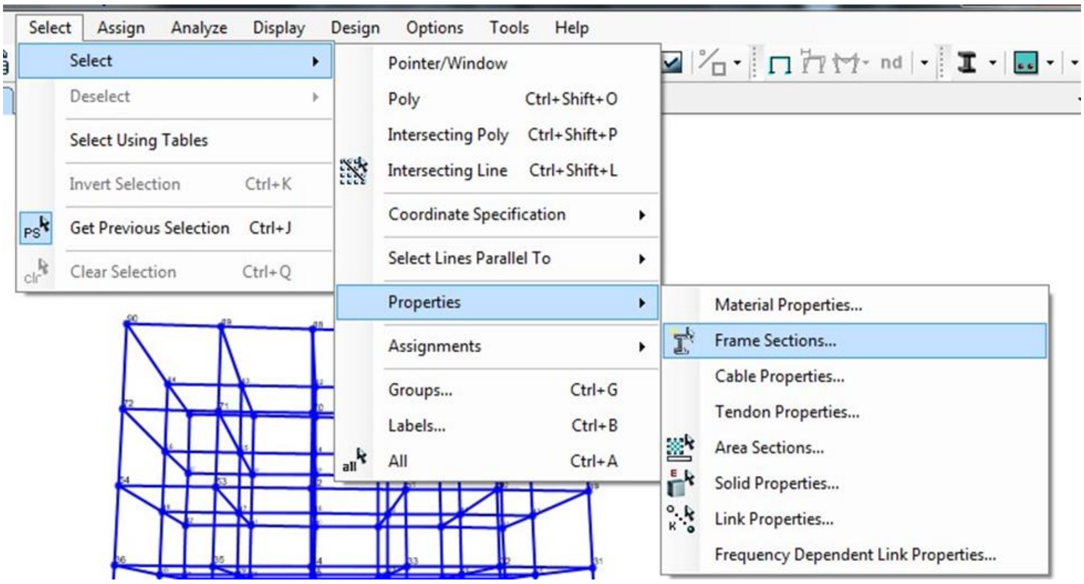


Figure 42. *Frame Sections*

Select under **Properties**, **Frame Sections** the created frame sections can beselected. In this case the two defined frame sections are beams and columns which can be selected.

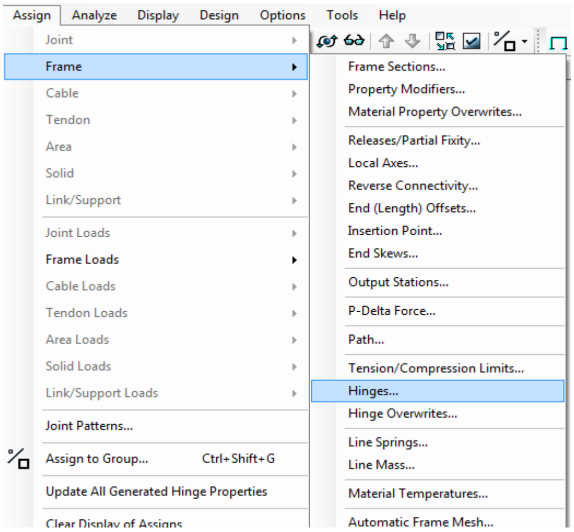


Figure 43. *Hinges*

For the beam the hinge property defines to Auto M3 hinges one in 0 and the other one on 1 relativedistance.

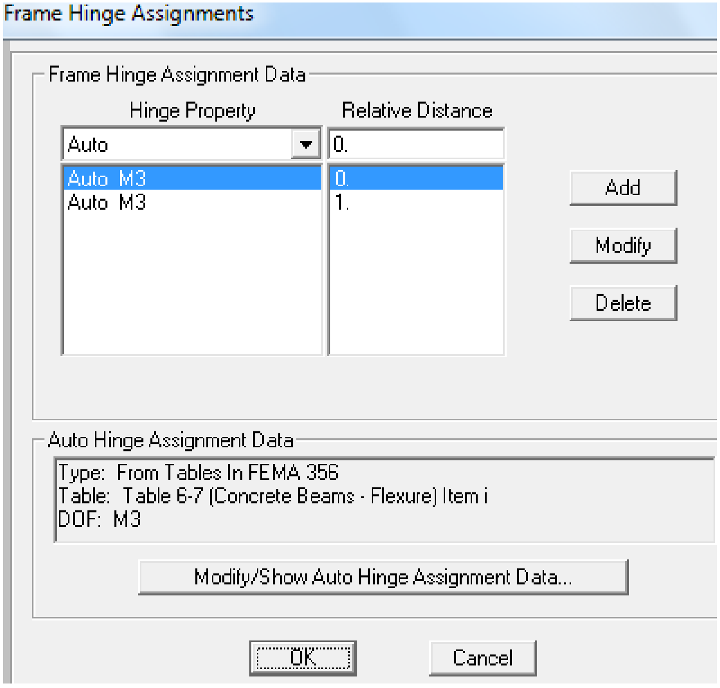


***Figure 44**. Auto M3 beams, hinges*

The modified hinges can be modified defining the hinge type and the degree of freedom as well asthe **Case/Combo** as **Gravity.**

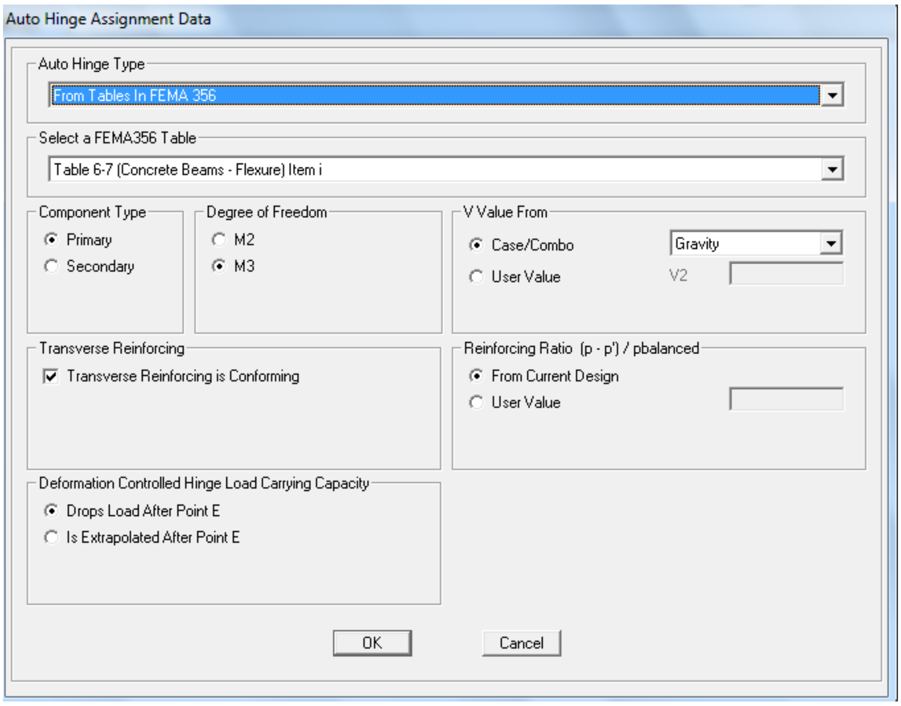


***Figure 45**. Hinges, Beam properties*

Same procedure is followed for the next frame section, column.

Another Load Case needs to be added in order to successfully perform the analysis. Under

Define/ Load Cases/ Add a new Load case/ add the load case named as **Pushover Analysis**

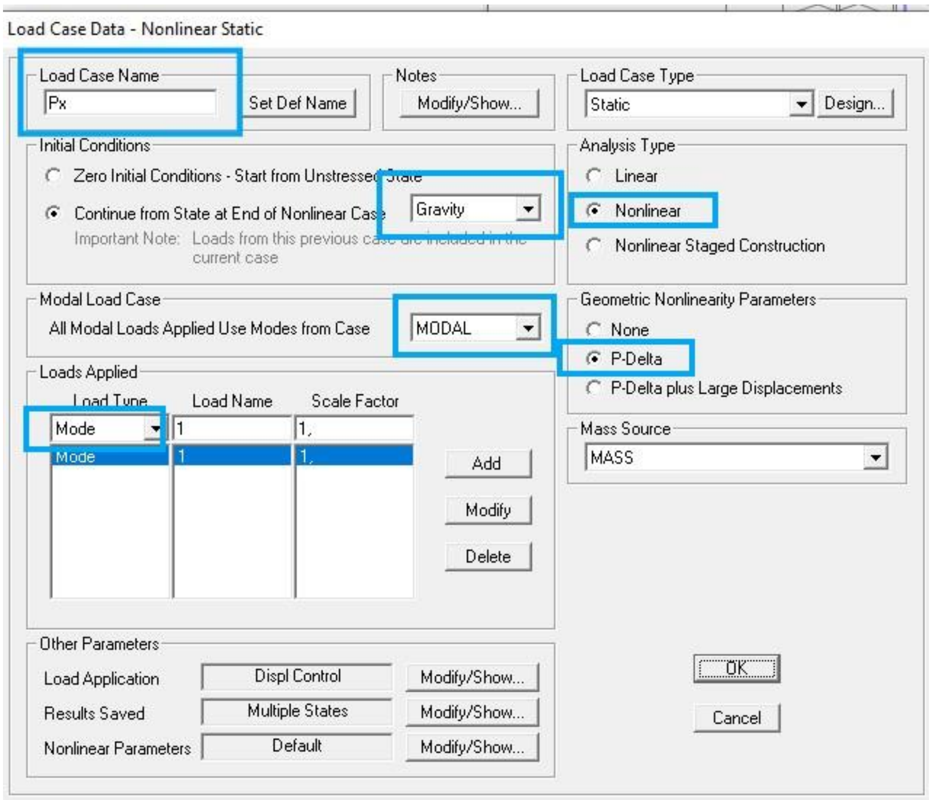


***Figure 46**. Pushover Load Data Case*

In the added load case, some parameters need to be specified so under **Other Parameters** section, at **Load application** click **modify and specify the load application control.**

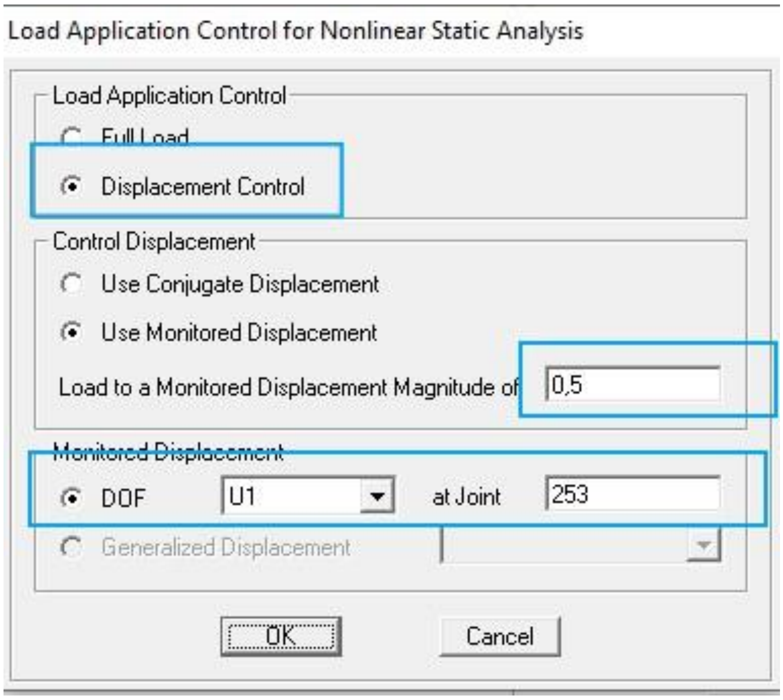


Figure 47. *Load application option*

All loads defined are: Dead, Live, Modal, Gravity, and Pushover Analysis.

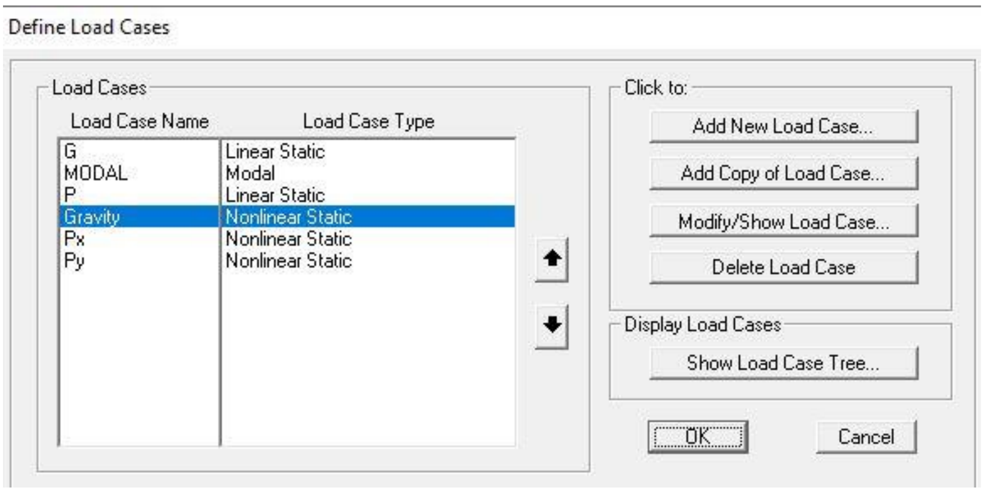


Figure 48. *Load case/Pushover*

Run the Analysis, under the deformed shape select pushover Analysis.

5.3.2 Pushover Curve

The displacement and base force data from the pushover curve can be imported into Excel after running the analysis in SAP2000. The load-deformation curve of the base shear force vs the horizontal roof displacement of the building, known as the "Pushover Curve," illustrates the nonlinear behavior of the structure. After the analysis is run through the modelling steps it has been specified x- (U1) direction, so another run needs to be performed showing the base force and displacement curve.

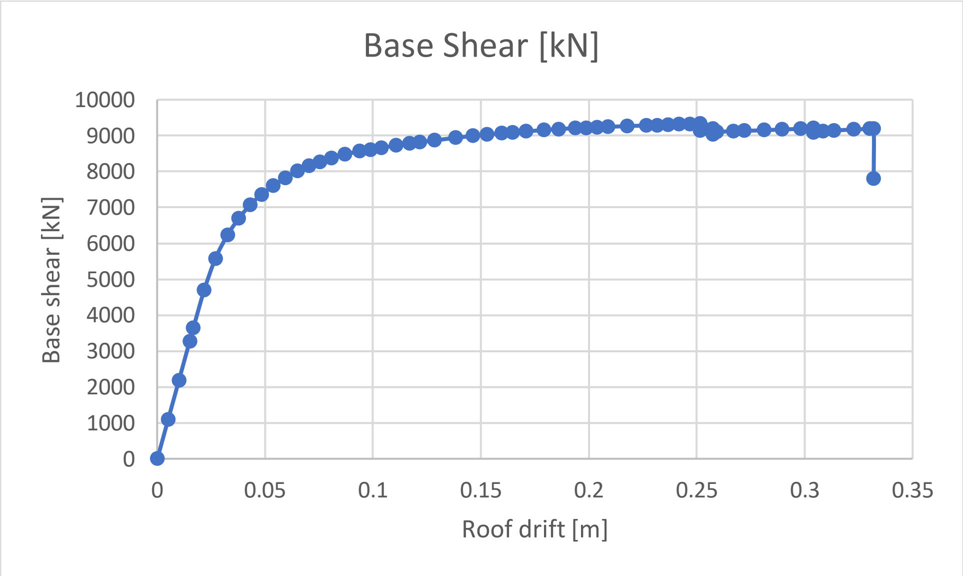


Figure 49. *Capacity curve of the building in x-direction*

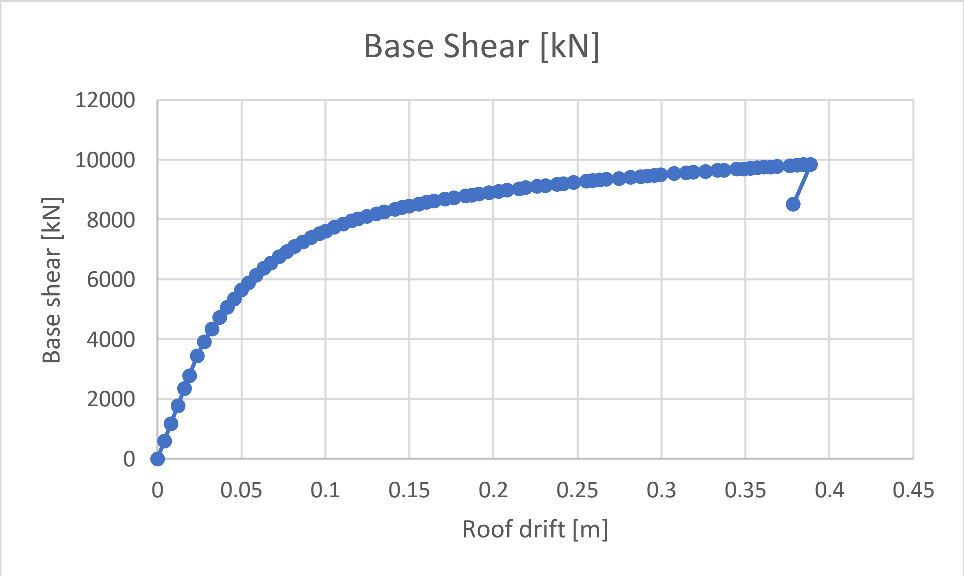


Figure 50. *Capacity curve of the building in y-direction*

5.3.3 Hinges

As a structure approaches its ultimate strength under cyclic stress, hinges are locations on the structure where one expects cracking and yielding to occur in substantially increased intensity so that they show high flexural (or shear) displacement [17]. A hinge essentially depicts the localized force-displacement relationship of a member during its elastic and inelastic phases when subjected to seismic pressures.'Immediate Occupancy' (IO), 'Life Safety' (LS), and 'Collapse Prevention' (CP) are non-linear states for these hinges that are specified as being within their ductile range. This is typically accomplished by splitting the Pushover curve into four sections and designating the states of each individual hinge as IO, LS, and CP (even if the structure as a whole has these states determined by drift limits.

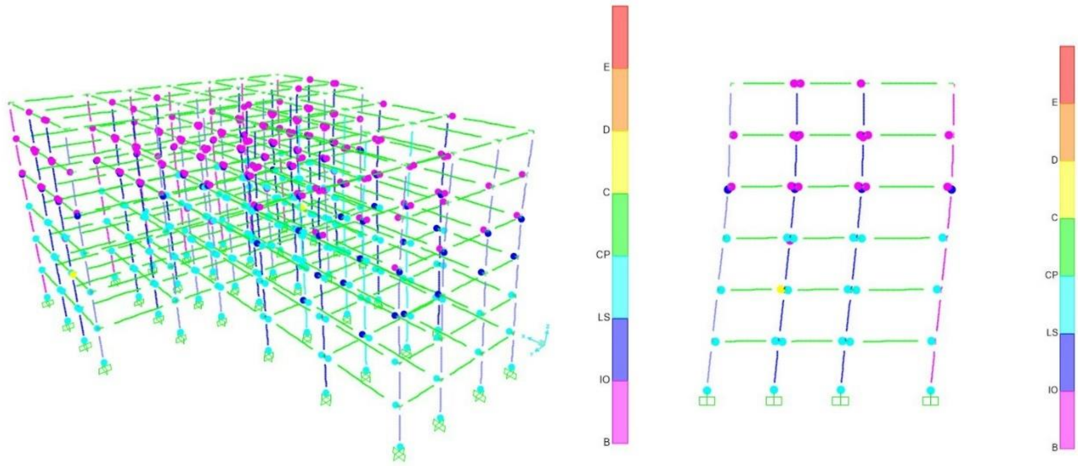


***Figure 51**. Hinges developed during the SPO Analysis.*

5.3.4 Performance Levels

The performance based design defines different levels of the structural damages during a seismic action. The prediction of the structural performance due to earthquake loadings is defined as performance target. Different levels of the performance design and seismic action are given (FEMA-356: 2000).

The building's performance level is determined by the intersection of the demand and capacity curves, as well as the hinge formed by the beams and columns, in the Pushover Analysis.

Table 4: Performance levels, meaning in a Nonlinear Analysis

Performance Levels		Description
Operational	Fully Functional	Components that are structural and non-structural have not sustained any substantial damage. The building is fit for its intended usage and normal occupants.
Immediate occupancy	Operational	The building has not sustained any substantial damage and still has nearly all of its stiffness and strength from before the earthquake. If utilities were available, most nonstructural elements would operate securely. Although in a limited way, the building may still be used for its intended purpose.
Life Safety	Life Safe	Damage to structural components that significantly reduces rigidity, but there is still a margin of safety. Nonstructural components are fastened but may not work. Until repairs can be made, occupancy can be prohibited.

Immediate occupancy (IO), life safety (LS), and collapse prevention (CP) are all taken into account in this research. The pushover curve's axis is normalized in the x direction by the ratios of displacement to building height, and in the y direction by the ratio of base force to building weight, in order to construct the graph correctly. Furthermore, the performance levels are placed directly in the capacity curve of the building generated after the pushover analysis. The IO, LS and CP points can be defined based on different guidelines. For this study, the VISION 2000 [18] is taken into consideration. The performance levels are taken while considering the roof displacements normalized by the building height as 10% for IO, 60% for LS and 90% for CP. As shown from the figures below, the location of the limit states is shown in the pushover curve for both directions of the building.

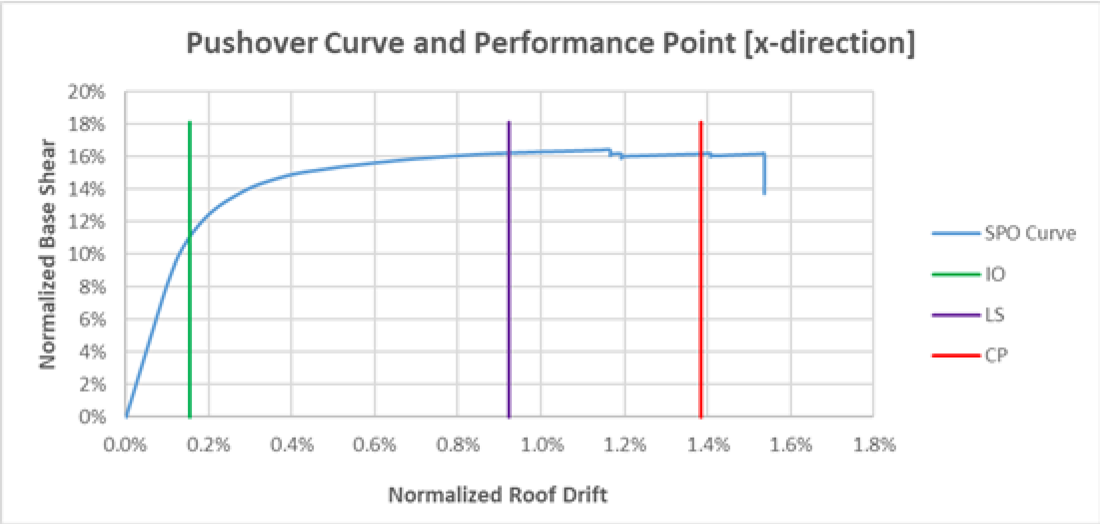


***Figure 52**: Pushover curve together with the performance levels in x-direction*

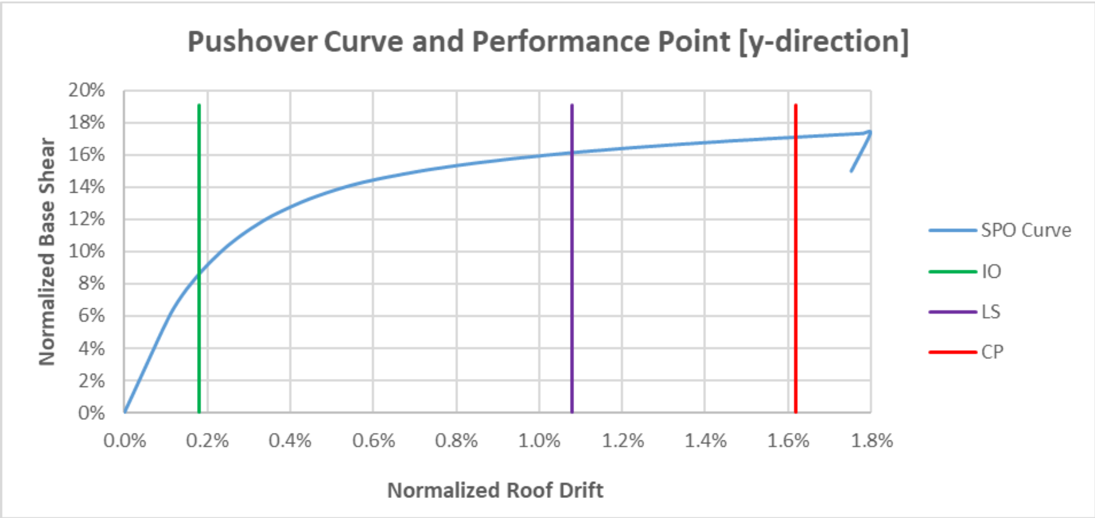


***Figure 53**: Pushover curve together with the performance levels in y-direction*

The pushover curves show the capacity of the structure in both directions. However, the pushover without the demand would be meaningless. Therefore, the demand calculations must be done for both directions of the building. In this study, the capacity spectrum method is used for demand calculations of the selected building.

CHAPTER 6

CAPACITY SPECTRUM METHOD

6.1 Evaluation of Performance of template Design

The Method of Capacity Spectrum (CSM) (ATC-40,1996), the method of Displacement Coefficients (DCM) (FEMA-273,1997) [19] and N2 Method (Fajfar and Gasperic, 1996) [20] are considered the main nonlinear static analysis procedure to define the performance point of the buildings. The evaluation of performance of the selected building is done based on the Capacity Spectrum Method. This method evaluates the maximum displacement by considering an intersection point between capacity curves of the building with a reduced response spectrum. However, the CSM method requires to convert the capacity curve and demand the response spectra in Acceleration Displacement Response Spectra (ADRS) format. The method of conversion is based on the guidance of ATC-40 according to procedure A.

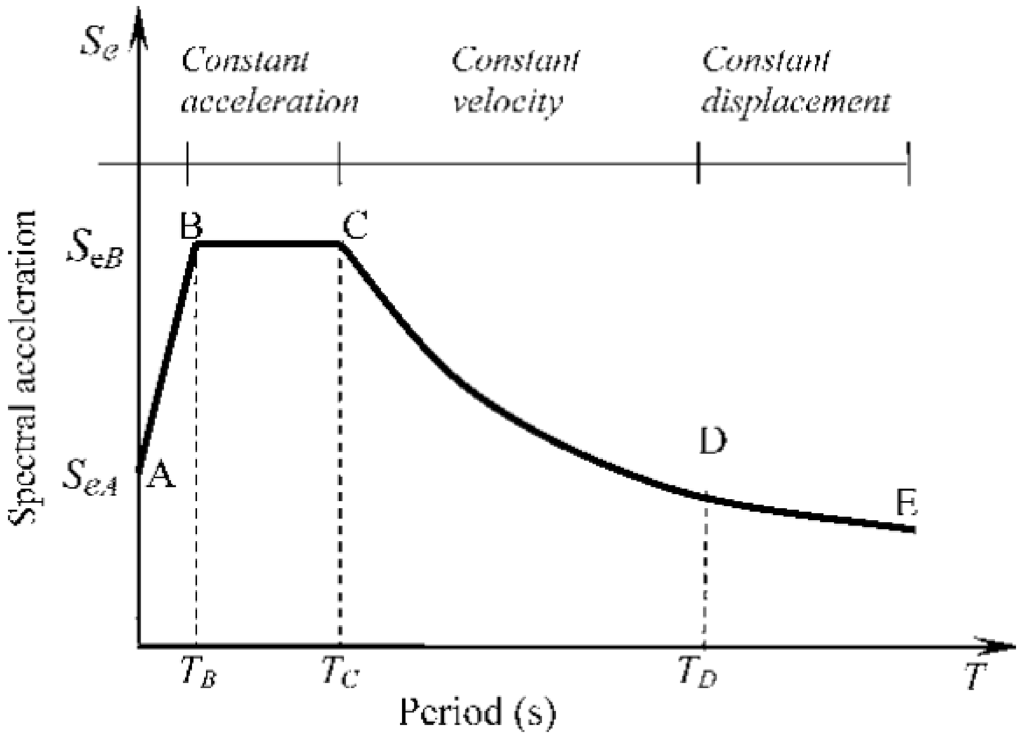


Figure 54. *Response spectra shown with corner periods (EC-8)*

6.1.1 Determination of the Performance Point

The response spectra used in this study to calculate the performance point is based on EC-8 standards. The EC-8 provides five corner period which are calculated using the equations as shown below:

For $0 \leq T \leq T_B$ $S_{E(T)} = a_g * S * (1+ T/TB * (\eta*2.5-1)$ **Equation 5**

For $T_B \leq T \leq T_C$ $S_{E(T)} = a_g * S * \eta*2.5$ **Equation 6**

For $T_C \leq T \leq T_D$ $S_{E(T)} = a_g * S * \eta*2.5*(TC/T)$ **Equation 7**

For $T_D \leq T \leq 4_S$ $S_{E(T)} = a_g * S * \eta*2.5*(TC*TD/T^2)$ **Equation 8**

Furthermore, the parameters of EC-8 to define the response spectra are as follows:

Table 5: Structural Performance Levels and Damages for vertical and horizontal elements (FEMA 356).

Parameters	**EC-8**
Structure Type factor	1.4
Structure Importance factor	4
Type of the Soil	C
Acceleration	0.35

To construct the capacity spectrum using the pushover curve it is important to convert the base shear and roof displacements to first mode spectral acceleration. The following equations are used to conduct this step:

$$S_{ai} = \frac{\frac{V_i}{W}}{a_1} \qquad \textbf{\textit{Equation} 9}$$

$$S_{di} = \frac{\frac{\Delta_{roof}}{W}}{PF_{1^*}\phi_{1,roof}} \qquad \textbf{\textit{Equation} 10}$$

The PF_1 and α_1 stand for modal mass participation factor and first natural mode of the building respectively. To calculate these two parameters, the following formulas are provided in the guidelines of ATC-40:

$$PF_1 = \frac{\Sigma_{i=1}^{N}(w_i\phi_i)/g}{\Sigma_{i=1}^{N}(w_i\phi_i^2)/g} \qquad \textbf{\textit{Equation} 11}$$

$$\alpha_1 = \frac{[\Sigma_{i=1}^{N}=(w_i\phi_i)/g]^2}{[\Sigma_{i=1}^{N}w_i/g][\Sigma_{i=1}^{N}(w_i\phi_i^2)/g} \qquad \textbf{\textit{Equation} 12}$$

Furthermore, the bilinearization of the pushover curve must be done in regard to the reduction of the spectral demand. The bilinearization is conducted by equalizing the area above and below the pushover curve with respect the the bilinearization lines as shown in the figure below:

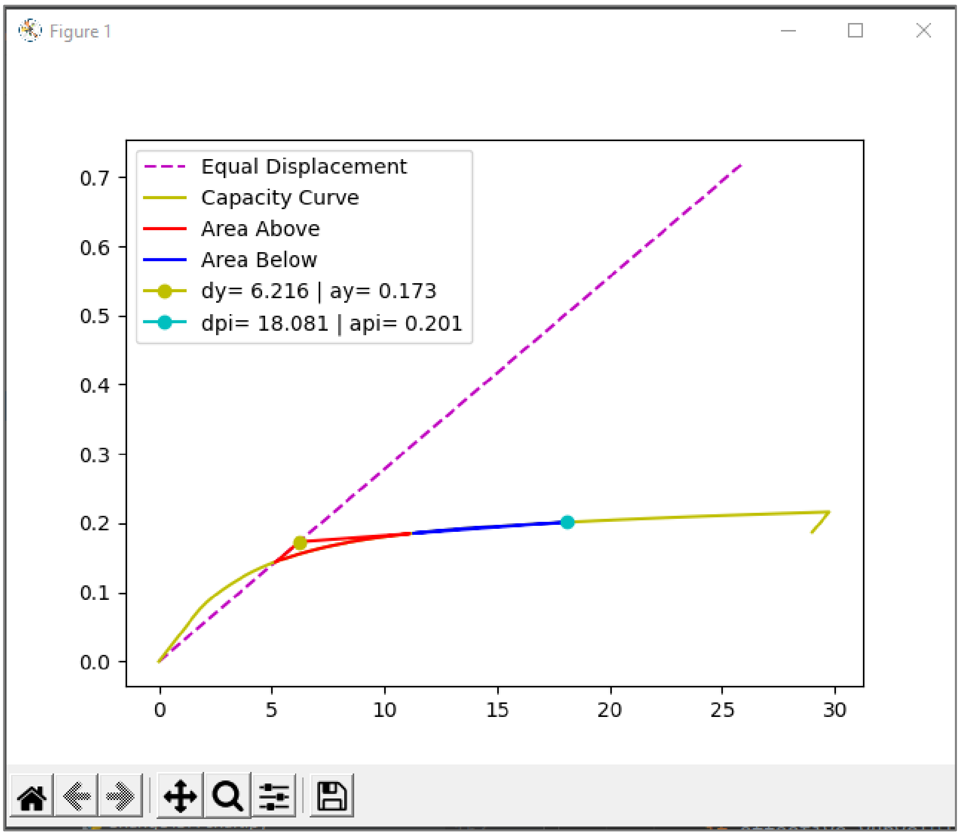


Figure 55: *Bilinearization of the pushover curve*

The dy, ay and dpi and api points are used according to the ATC-40 guidelines to reduce the spectral demand for the calculation of the performance point. According to the procedures given in the standard, if the api,dpi and intersection of the reduced graph with the pushover curve is between 0.95 dpi and 1.05 dpi then the point is accepted. The entire process is an iterative one which makes the entire proces timeconsuming. For that reason, a ready script is utilized to calculate the performance point [21]. As shown in the figures, the performance point is calculated efortless from the given tool.

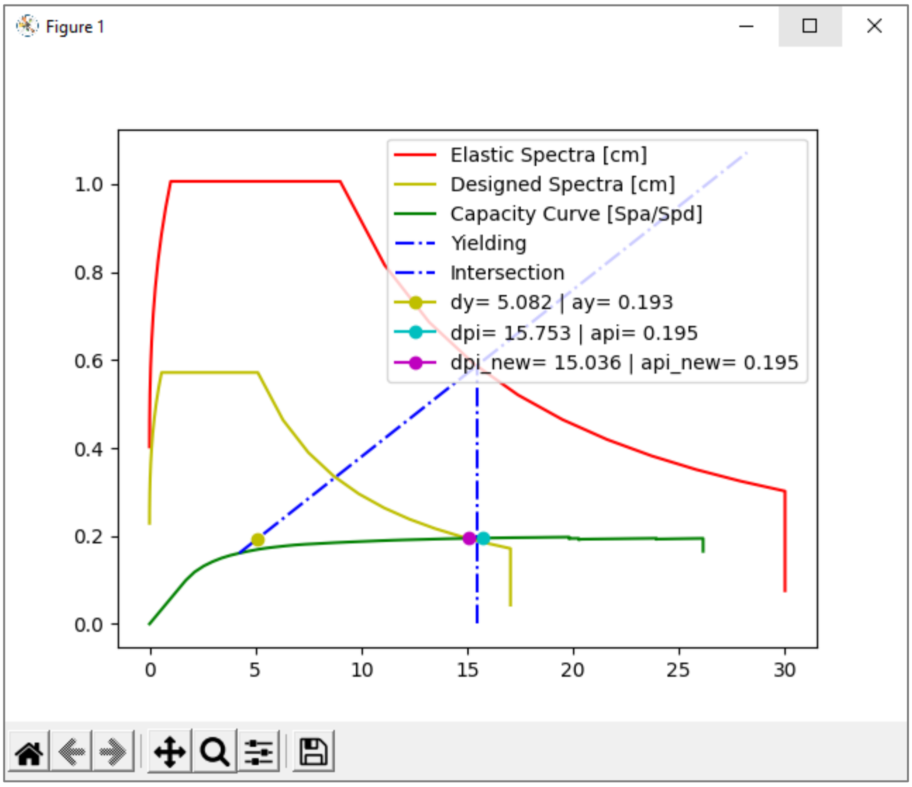


Figure 56*: Calculation of the performance point using the capacity spectrum method for x-direction.*

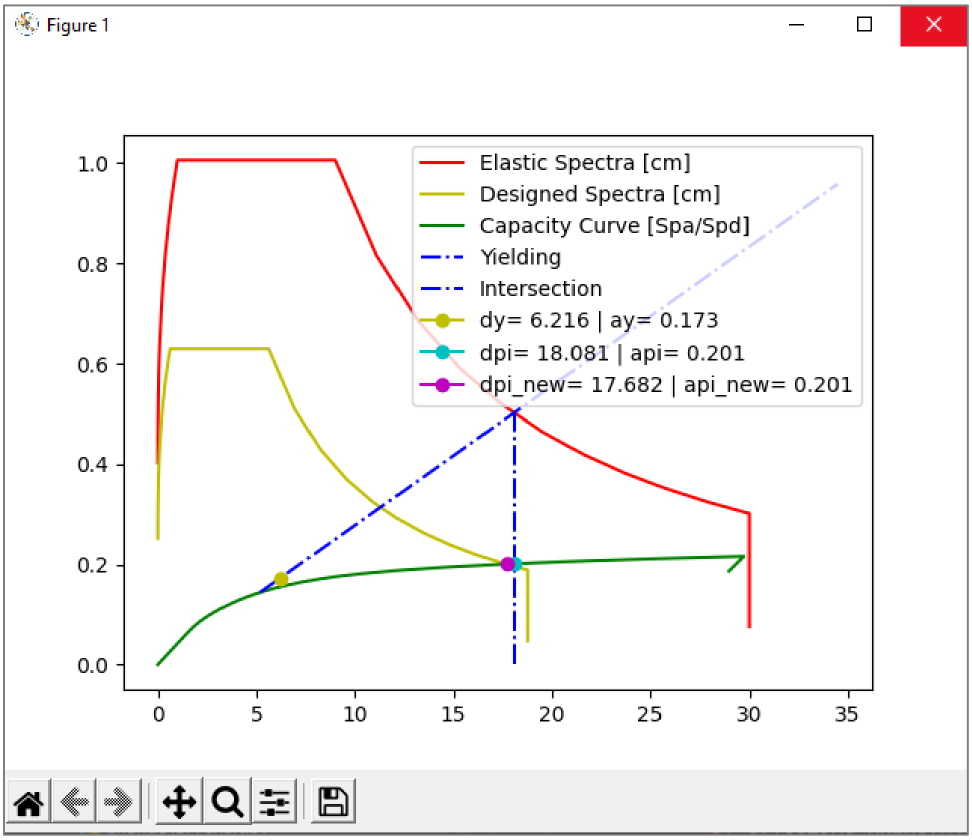


Figure 57*: Calculation of the performance point using the capacity spectrum method for y-direction.*

In addition, comparing the performance point from the capacity spectrum method with the LS performance level would be a good comparison for the life safety ensurance. The figures below show the pushover curve plotted together with the performance point:

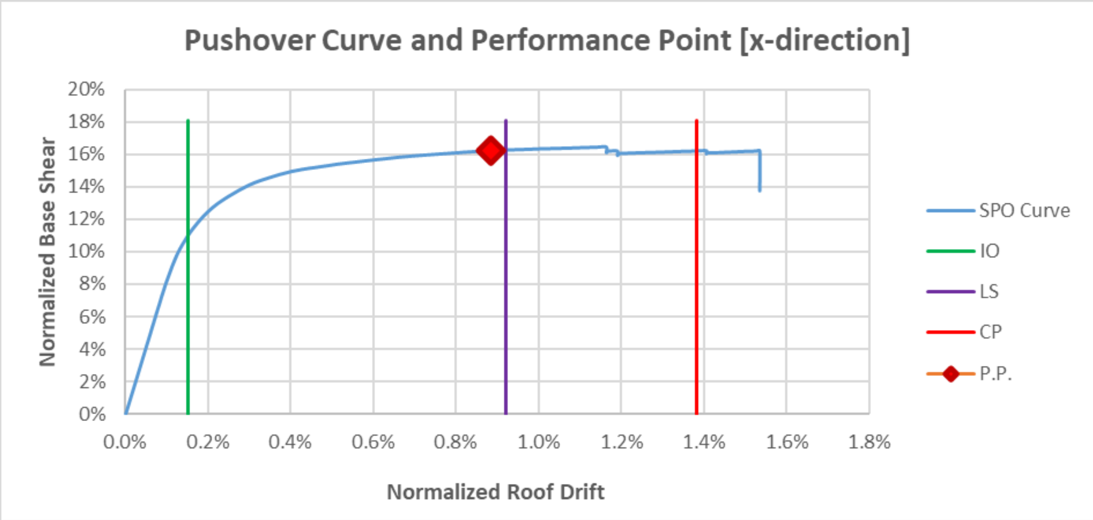


Figure 58: *Capacity curve with limit states and performance point for y-direction*

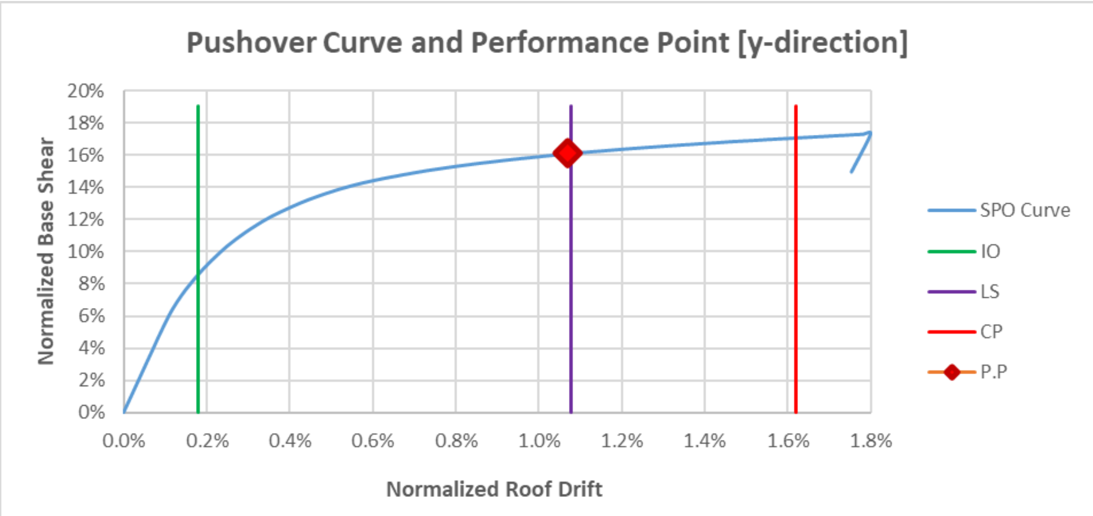


Figure 59: *Capacity curve with limit states and performance point for y-direction*

As shown in the figures above, the performance point presented in the same graph with capacity curve of the building shows a clear information on the performance of the structure as belong to the exceedance of limit states. From both directions, it is shown that the performance point is located in the region of life safety performance level. This means that the structure is in the region of life safety. Nevertheless, the graphical view of the data demonstrates that the performance point is very close to exceeding the LS limit state.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

The seismic performance evaluation of Azem Hajdari elementary school is conducted in this thesis using nonlinear analysis procedures. The capacity of the structure is estimated using pushover analysis. The demand calculations are done based on the capacity spectrum method and the spectra was calculated based on the parameters from the EC-8. The limit states are located in the pushover curve as immediate occupancy IO, life safety LS and collapse prevention CP for the performance evaluation of the building. Finally, while comparing the demand calculated by the ATC-40 standard with the limit states in the pushover curve, it is concluded that the seismic performance of the structure is located in the life safety performance level.

The analysed building must be designed with higher importance factor compared to residential buildings. Generally, for school and hospital buildings under the design earthquake loading for a return period of 75 years, the ensurance of immediate occupancy performance level is expected as shown in figure 60.

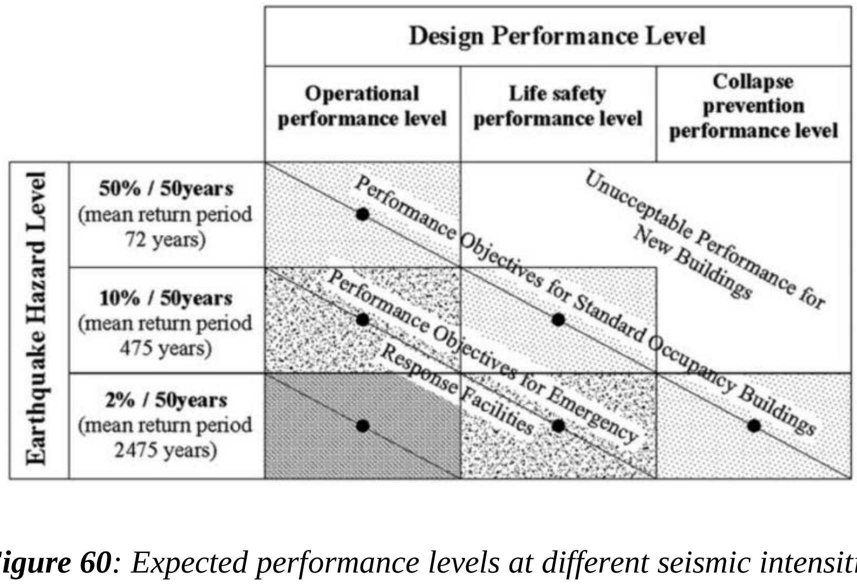


Figure 60: *Expected performance levels at different seismic intensities.*

The results gathered from the the analyses performed in this thesis show that the building exceeds the immediate occupancy performance level. Moreover, it is shown that the life safety threshold is almost exceeded in the y direction of the building. This can be interpreted by the fact that usually the engineering practice in our country utilizes the linear analyses procedures instead of the nonlinear one which are more aqurate in the design stage. Finally, it can be concluded that the Azem Hajdari school did not satisfy the target performance level (IO).

5.2 Recommendations for future research

The study can further be improved by providing time history nonlinear dynamic analyses using a set of ground motion records. Furthermore, a detailed methodology of the retroffiting procedures for schools and hospitals could play an important role for such typologies in Albanian engineering practice.

REFERENCES

[1] R. W. .. Niewiarowski, "CSM-ATC40, ‘SEISMIC EVALUATION AND RETROFITTING OF BUILDINGS AND STRUCTURES.".

[2] I. CSI (Computer and Structures, "SAP2000. “Integrated software for structural analysis and design”, Computers and Structures Inc.,. n.d".

[3] R. BENTO, "NON-LINEAR STATIC PROCEDURES IN PERFORMANCE BASED SEISMIC DESIGN".

[4] E. 1998-1:2004, "Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings".

[5] K. ELWOOD, "Effects of Strength and Stiffness Degradation on".

[6] A. S. O. C. ENGINEERS, "FEMA 356., ‘Prestandard and commentary for the seismic rehabilitation of buildings’, Washington: federal emergency management agency (2000).".

[7] Ronald O. Hamburger, "FEMA-350., ‘Recommended seismic design criteria for new steel moment-frame buildings’, Washington DC: Federal Emergency Management Agency (2000).".

[8] W. J.Hall, "FEMA-351., ‘Recommended seismic evaluation and upgrade criteria for existing welded steel’, Washington DC: Federal Emergency Management Agency (2000).".

[9] A. Pattar, "P-DELTA EFFECT ON MULTI-STOREY BUILDINGS".

[10] P. A. O. H. “. M. o. R. C. n. C. A. R. _. (. Maekawa K., "“Nonlinear Mechanics of Reinforced Concrete”. n.d.Manual, CSI_ Anlaysis_ Reference _. (n.d.).".

[11] H.-W. UNIVERSITY, "Themelis, S. “Pushover analysis for seismic assessment and design of structures”. 2008.".

[12] E. 1998-3:2005, "Eurocode 8: Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings".

[13] C.-M. M. a. Y.-Y. Chen, "Research on the differential settlements of mat".

[14] E. 1992, "Eurocode 2 - Design of concrete structures;".

[15] N. Tosic, "One-two Way SLAB. New Eurocode 2 provisions for recycled aggregate concrete and their implications for the design of one-way slabs.".

[16] S. A. M. M. M. H. Mourad M. Bakhoum, "Dead-Live Load.Comparison of actions and resistances in different building design codes.".

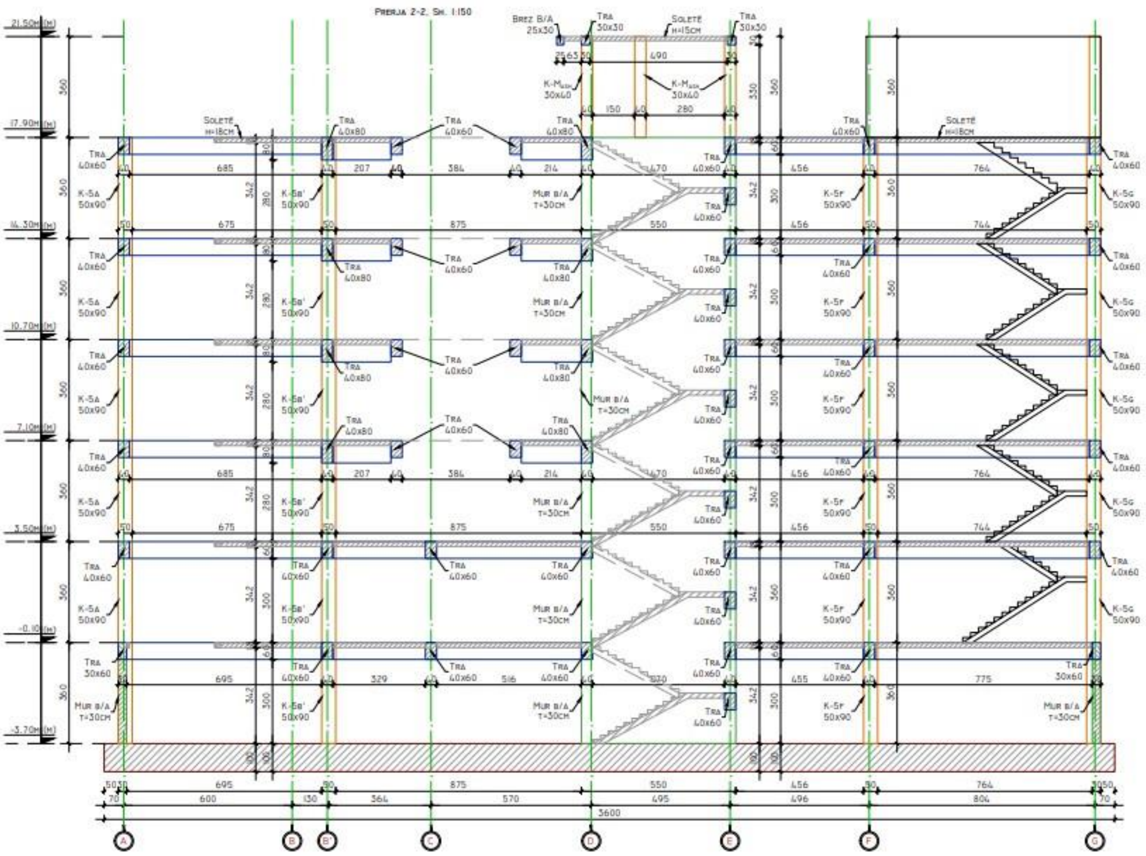
[17] K. Neena Panandikar Hede, " “Effect of variation of plastic hinge length on the results of nonlinear analysis”. n.d.".

[18] S. E. A. o. California, "Vision 2000, Performance based seismic engineering of buildings, vols. I and II: Conceptual framework".

[19] E. Zeller, "NEHRP GUIDELINES FOR THE SEISMIC REHABILITATION OF BUILDINGS".

[20] P. FAJFAR, " ‘On the relation between the near collapse limit state at the element and structure level .".

APPENDIX



Elevation View of Building

Planimetry of Building