ASSESSING THE SEISMIC PERFORMANCE OF A FIVE-STORY PREMODERN RC BUILDING IN ALBANIA USING PUSHOVER AND TIME HISTORY ANALYSES

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

BY

GLEDIS SHUAIPI

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

JUNE, 2024

Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Assessing the Seismic Performance of a Five-Story Premodern RC Building in Albania using Pushover and Time History Analyses"** and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

____

Assoc. Prof. Dr. Mirjam Ndini
Head of Department
Date: June 28, 2024

Examining Committee Members:

Dr. Armando Demaj (Civil Engineering) _________________

Dr. Marsed Leti (Civil Engineering) _________________

Dr. Julinda Keçi (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: Gledis Shuaipi

Signature: _______________

ABSTRACT

ASSESSING THE SEISMIC PERFORMANCE OF A FIVE-STORY PREMODERN RC BUILDING IN ALBANIA USING PUSHOVER AND TIME HISTORY ANALYSES

Shuaipi, Gledis

M.Sc., Department of Civil Engineering

Supervisor: Dr. Marsed Leti

Albania is undergoing continuous development, especially in terms of economic and society. The country has witnessed a notable increase in population growth, leading to a rise in construction activity with new infrastructure projects expanding daily where the equilibrium in the demand-offer ratio is not consistently upheld. However, a considerable portion of Albania's current stock comprises of structures designed and build during the communist era. Additionally, our country is well known to be in a seismic active region which has been hit by several earthquakes considering the recent one on November 26, 2019. Therefore, this study targets to examine the structural performance of a 5-story template reinforced concrete building in Albania designed during 1980's. Using advanced finite element method analysis (FEM) software Zeus-NL, the study employs two performance earthquake engineering methods, Pushover and Time History analysis.

The load bearing capacity of the building is estimated by the means of pushover analysis under uniform, inverted triangular and modal loading patterns in both orthogonal directions. Additionally, Time History Analysis was then performed to calculate the demand of each direction of the building. Based on the FEMA guidelines, the Immediate Occupancy (IO), Life Safety (LS) a Collapse Prevention (CP) is determined in the capacity cures. In the end, a comparison between the static curves and the dynamic response of the structure has been carried out. Finally, conclusions as well as recommendations for further studies on this typology of buildings.

Keywords: *Nonlinear Analysis; Seismic Performance; Zeus-NL; Reinforced-concrete structures, Limit States, Time History Analyses, Mid-Rise building.*

ABSTRAKT

VLERËSIMI I KAPACITETIT SIZMIK TË NDËRTESAVE 5 KATËSHE TIP BETONARME NË SHQIPËRI TË NDËRTUARA PARA ZBATIMITTË KODEVE MODERNE, ME ANË TË ANALIZAVE PUSHOVER DHE TIME HISTORY

Gledis, Shuaipi

Master Shkencor, Departamenti i Inxhinierisë së Ndërtimit

Udhëheqësi: Dr. Marsed Leti

Shqipëria është një vend i cili po zhvillohet cdo ditë gjithnjë e më shumë si në aspektin ekonomik dhe në atë social. Vendi ka dëshmuar një rritje të dukshme të rritjes së popullsisë, duke çuar në një rritje të aktivitetit të ndërtimit me projekte të reja infrastrukturore që zgjerohen çdo ditë, ku ekuilibri në raportin kërkesë-ofertë nuk ruhet vazhdimisht. Pavarësisht kësaj një pjesë të konsiderueshme të ndërtesave egzistuese sot e zënë banesat e ndërtuara në vitet e komunizmit, para zbatimit të kodeve moderne. Gjithashtu, vendi ynë dihet se ndodhet në një rajon aktiv sizmik i cili është goditur nga disa tërmete ndër vite ku më i fundit ndodhi në 26 nëntor 2019. Ky studim synon të shqyrtojë performancën strukturore të një ndërtese 5-katëshe beton arme në Shqipëri projektuar gjatë vitit 1980. Duke përdorur softwerin e avancuar të analizës së metodës së elementeve të fundme Zeus-NL, studimi përdor dy metoda inxhinierike të performancës së tërmeteve, analizën Pushover dhe Time History.

Kapaciteti mbajtës i ngarkesës së ndërtesës vlerësohet me anë të analizës Pushover duke përdorur ngarkese anësore në formë uniformë, trekëndësh i përmbysur dhe modale në të dy drejtimet e ndërtesës. Analiza e “Time History” u kryen më pas për të llogaritur kërkesen sizmike të ndërtesës. Bazuar në udhëzimet e standarteve FEMA, Okupimi i Menjëhershëm (IO), Siguria e Jetës (LS) dhe Parandalimi i Kolapsit (CP) janë përcaktuar në kurbat e kapacitetit. Në fund, është bërë një krahasim midis kubave te kapacitetit dhe kërkesës dinamike të strukturës. Së fundi, janë paraqitur konkluzione si dhe rekomandime për studime të mëtejshme mbi këtë tipologji ndërtesash.

Fjalët kyçe: *Ndërtesa Betonarme; Banesa TIP 83; Analiza Jolineare; Performanca Sizmike; ZEUS-NL, Analiza Time-History, Godina 5 katëshe*

Dedicated to my family.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

In structural engineering, the principal elements of a structure commonly include steel and concrete, as fundamental materials well known for their complementary mechanical properties and adaptable applications. Concrete, composed of cement and sand, provides compressive strength and durability, making it essential in load-bearing components like columns, beams, and foundations. Its moldability allows for complex designs. Steel, known for its resistance to corrosion, high tensile strength, and ductility is used to reinforce concrete [55]. Together, these elements create strong and long-lasting buildings, although the durability of these buildings is influenced over time by internal forces like temperature and weather conditions, as well as external forces such as earthquakes.

Earthquakes are natural disaster that often are accompanied with loss of life and destruction of infrastructure. For the past 3 years several significant earthquakes have stuck different regions over the world, having a great impact impacting not only the country where the epicenter is located but also causing widespread destruction in surrounding areas. During the period November 2019 and February 2023, several significant earthquakes occurred with devastating consequences. Indonesia unfortunately is a meeting point of several tectonic plates, leading to several earthquakes structing the country several within short periods of time. The most recent one took place on 21 November 2022 with a magnitude of 5.6 Richter, resulting in more than 335 confirmed deaths caused by collapsed buildings [46].

In February 2023, one of the most powerful recent earthquakes in Europe occurred in Turkey and Syria. Their territorial border was struck by a sequence of earthquakes, including magnitudes of 7.8 and 7.5, respectively. The earthquake doublet and their aftershocks had led to confirmed deaths of more than 50 000 in Turkey and 7 200 in Syria [56].

Albania as well experienced a devastating earthquake on 26^{th} of November 2019 causing at least 51 deaths and 3000 injuries, with significant damage along the Adriatic coastline and in Tirana.

Earthquake is considered the most significant hazards confronting engineering structures. The seismic ground motion directly impacts the entire structure affecting its foundation, columns, and beams. The consequences most of the time are really devastating, including significant damage to buildings and, in the worst cases, loss of life. Predicting how a structure will be affected by a specific ground motion magnitude is exceedingly important and crucial.

Estimation of the seismic performance of structures and facilities is very useful toa variety of interested parties. Performance-based earthquake engineering (PBEE) seeks to forecast that. PBEE strives to engineer buildings that achieve specific performance objective when subjected to a certain ground motion, taking into consideration randomness and uncertainty of materials, soil type and the lifespan of the structure thatis being studied.

1.2 Objectives and scope

The aim of this study is to evaluate the structural performance of a reinforced concrete building designed with premodern building codes, by employing non-linear static and dynamic analyses. By applying these analyses, it is obtained a simplified yet comprehensive understanding of the structural response to lateral loads and how the structure will deform, vibrate, and respond to different types of dynamic excitations since the idea behind time history analysis is to simulate the real-world dynamic behavior of a structure subjected to various dynamic loads over time. As previously stated, the building selected for this research is a template building widely spread across the country. The conclusions drawn from the analysis will hold significant value for Albania by providing insights into the effectiveness and adequacy of past construction standards. Understanding the strengths and limitations of these premodern codes is crucial for ensuring the safety of the country's infrastructure.

The evaluation of the seismic performance is conducted through three different analyses: Eigen Value analysis, Static Pushover analysis and Time History analysis. These analyses are sequentially performed in order to have a bigger picture on the characteristics of the structure.

After going through a detailed process of reviewing and understating the blueprints provided, an agreement was reached regarding the detailed specifications for various cities across Albania as outlined in the plans. This agreement was necessary considering that only one structural model will be utilized for the analyses.

An essential parameter such as the period of the building, is determined by adapting the Eigen Value analysis. The building capacity is estimated through Static Pushover and Time History analysis. In the Time History analysis twenty ground motions are selected to simulate the dynamic response of the structure under various realistic scenarios.

Limit states are defined step by step from the initial elastic behavior to the point of global instability or structural collapse.

In the concluding chapter the outcomes from the analysis are compared and summarized followed by recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Albania is a country with a strategic position that has been intertwined with the most important trade and transport routes for centuries. Historical facts prove that various empires throughout history have left lasting legacies in Albania. Urban planning and construction were at their peak during Zog's reign. During this period, significant buildings were erected, including institutions such as the University of Arts, the " Dëshmorët e kombit " boulevard, the ministries, and the "Bashkia e Tiranës ", all of which remain as legacies of the Italian architecture of that time [24].

One of the most significant periods in Albania's history, both economically and socially, was its communist era. From 1976 to 1992, Albania underwent a transition from private to state ownership. The leader at that time, pursued a policy of unification, reflected in the standardized design of houses built during those years. These structures, although uniform, exhibited specific characteristics tailored to each Albanian city [27].

The first standardized design template for a two-story adobe building was approved by Albanian governmental authorities in 1949. Subsequently, a wide variety of standardized design templates for buildings ranging from three to five masonry stories were implemented between 1963 and 1978. Since overcrowding of living units remained a problem, a concrete prefabricated panel system was introduced in the late 1970^{s}, providing around two thousand apartments annually [12].

The blueprints of these buildings are highly detailed, although their full implementation on the ground is subject to debate, given the significant shortages in every economic sector. During this transition period, every city developed according to the same ideology, resulting in widespread distribution of these structuresacross the country. While a considerable number of them have been restored, many have also suffered major damage over their lifespan. Their extensive distribution has led to the selection of these structures for nonlinear analysis, aiming to study their performance.

2.2 The seismic activity of Albania

Albania is in southern Europe, in the western part of the Balkan Peninsula on the Strait of Otranto. A strategic location where large-scale seismic events are very frequent. Albania is recognized as one of the most active seismic countries in the Mediterranean region, where in the last thirty years it was hit several times by devastating earthquakes, where 16 of them had a magnitude of M=5.5 and the intensity level on the Modified Mercalli Intensity scale 7 (Io=VII), 3 of M=6.0-6.5 (Io=VIII), and 2 of M=6.5-7.0 (Io=IX) [50].

The most devastating earthquake was recorded on April 15, 1979. Its epicenter was in the Adriatic Sea near the board of Albania-Montenegro, and it was recorded as one of the strongest shocks on our region during the 20th century. Its consequences were devastating by having 35 deaths and 382 injured. The number of the buildings that were damaged and collapsed reached to 17,122 leading to more than 100,000 people homeless. The area impacted the most was the region between Shkodër and Lezhë. This earthquake as the most devastating one was followed by many cracks on the ground surface [49, 13], liquifying phenomena and falling rocks on the hilled regions as shown in *Figure 1*.

Figure 1. Sand fountains during the earthquake of April 15, 1979 [12]

The seismicity of Albania is characterized from an intensive seismic micro activity: (1.0 < M < 3.0), from many small earthquakes (3.0 < M < 5.0) from medium-sized earthquakes (5.0 < M <7) and very strong earthquakes (M > 7.0) [32, 12].

The most recent earthquake in Albania was on 26 November 2019 with a magnitude of 6.4, earthquake has been recorded as the strongest in the last decades in our country, causing damages of intensity VIII to IX EMS (European Macro seismic Scale) in the epicentral region around Durrës [17].

The earthquake caused significant damage mostly to Durrës, the country's second-biggest town, Thumana, and the surrounding areas. Its epicentral intensity was VIII (Severe) on the Modified Mercalli Intensity scale. Numerous structures collapsed as a result of the earthquake, leaving numerous fatalities and extensive damage to both old and new construction. Some of these buildings, were already damaged by the first earthquake in September 2019, and then collapsed in the seismic event on the 26th of November. After being studied and expertise it was concluded that the structures damaged from the earthquake showed a poor seismic response, mainly caused by an inadequate seismic design, due to having almost no input from engineers and trusting everything on the knowledge of local artisans. Also changing the initial structure by adding more stories, using different materials and structural floors for the 1st and other levels, is a crucial factor that directly affects the longevity and durability of the structure [20].

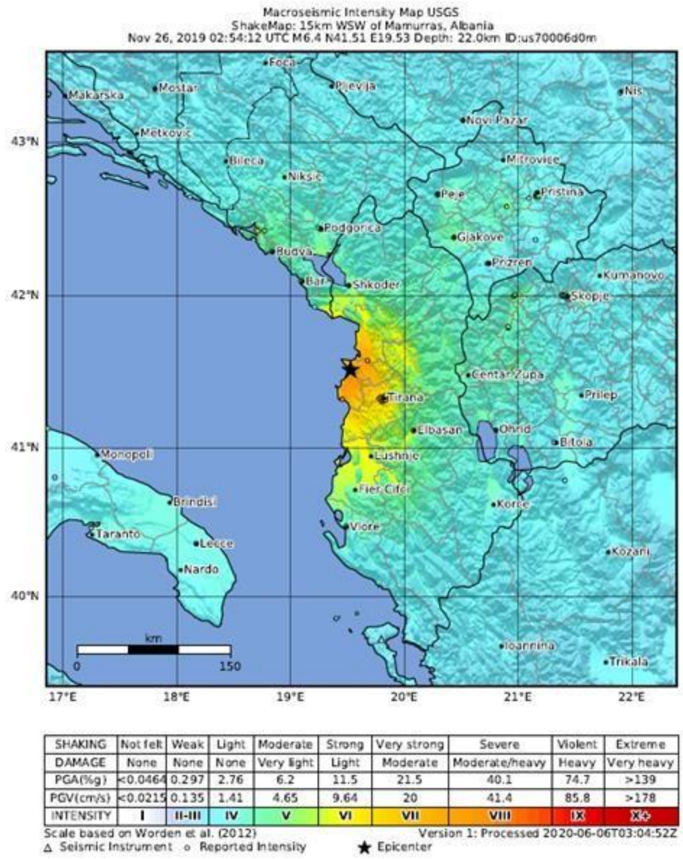


Figure 2. Earthquake of 26 November with epicenter in Mamurras [18]

2.3 Impact of Seismic events on pre-1990 masonry buildings

In terms of the country's residential building stock, both reinforced concrete (RC) and masonry structures continue to be prevalent. These structures are categorized into two different typologies: URM buildings (Unreinforced Masonry) with load bearing walls and CM buildings (Concrete- Masonry) made of load baring walls confined with RC tie elements [20]. After the earthquake of November, it was surveyed that both URM and CM buildings showed a good seismic performance.

These structures did not experience severe damages and they were not categorized as unsafe. Theirgood seismic performance is attributed to the good interlocking of the bearing walls in the URM buildings leading to no cracks on the edges of the structure. The good connection and stiffness of the RC slabs that distributes the lateral loads on the resisting walls, makes the structure to behave like a box. Meanwhile on the CM building the good seismic performance is provided by the efficient interactions between the masonry walls and the confining elements, ensuring that the structure is capable to sustain large deformations.

Despite the overall good performance for these structures, three URM buildings experienced structural failure in Thumanë [26]. The main cause of these failures was the poor mechanical properties oof the silicate bricks and the lack of connections between the prefabricated concrete slabs and the bearing walls failing in overturning. Another reason that leads to damage of the structure is the large interventions carried out with an inadequate seismic design [20]. This was stated on two buildings in Durrës *Figure* 3, where the first and second floor had experienced drasticmodifications. These considerable fluctuations led to tagging the structures as unsafe, however the inspections revealed that these structures had already severely deteriorated before the earthquake as a result of poor maintenance. This was stated by observing the presence of corroded and exposed reinforcements, crushed brick units and loss of painting. These factors can become the origin of damage and deteriorations, thereby exacerbating the seismic vulnerability of the structure over its lifetime.

Figure 3 Modifications made to the buildings in Durrës [20]

Figure 4. The structure collapsed in Thumanë [20]

2.4 Performance-Based Earthquake Engineering

Performance-Based Earthquake Engineering (PBEE) is a modern approach to earthquake engineering which focuses on evaluating and designing structures based on their performance during and after a seismic event. PBEE establishes specific performance target for structures that undergo different seismic hazard levels [52]. These objectives span to different limit states,from Immediate Occupancy (IO) to Life Safety (LS) and Collapse Prevention (CP) [24]. It is essential to properly understand and implement in the right way the limit states to the results given by the analyses.

The determination of the demand and capacity are the fundamentals of performance-based earthquake engineering, considering that detailed analysis of potential ground motion is conducted to understand the possible forces a structure might face during its lifespan [1]. The behavior of the structureis simulated by using advanced computational models where material properties and geometric configurations are incorporated. Nonlinear analysis methods are used in structural engineering to determine the behavior of the structure beyond elastic range. Non-Linear analysis considers the nonlinear behavior of materials and structural elements under varying loads, like ground motion, unlike linear analysis which only considers linear relationship between loads and deformations, leading to a realistic scenario [45].

The objective of earlier researchers has been to identify the most suitable techniques of analysis for assessing the performance of structures affected by earthquakes [40, 7, 29]. Thus, Nonlinear Static Analysis and Nonlinear Dynamic Analysis are introduced as the methods to determine the performance.

Nonlinear Static Analysis also known as Pushover Analysis considers geometric and material nonlinearities and progressively increases the lateral loads applied to a structure [39]. It identifies potential failure mechanisms and estimates structural capacity. Simultaneously Nonlinear Dynamic Analysis considers the time-varying behavior of structures subjected to seismic loads.It takes into account inertial forces, damping effects and nonlinear material behavior in order to accurately predict the structural response.

The progress that takes place in the area of in computational mechanics and computer technology continually broaden the scope and effectiveness of PBD procedures, enhancing their capabilities and utility.

2.5 Damage Limit States

When evaluating an existing building, the structure is analyzed by taking into consideration four distinct building performance levels for the existing or strengthened buildings, in addition to various level earthquake definitions [6].Building performance level against earthquakes is a combination of the performance of both nonstructural and structural components. Standards such as ASCE41 [4] and FEMA356 [24] offer guidance on three performance levels:

(a) Immediate Occupancy (IO); (b) Life Safety (LS); and (c) Collapse Prevention (CP) as shown in *Figure 5*.

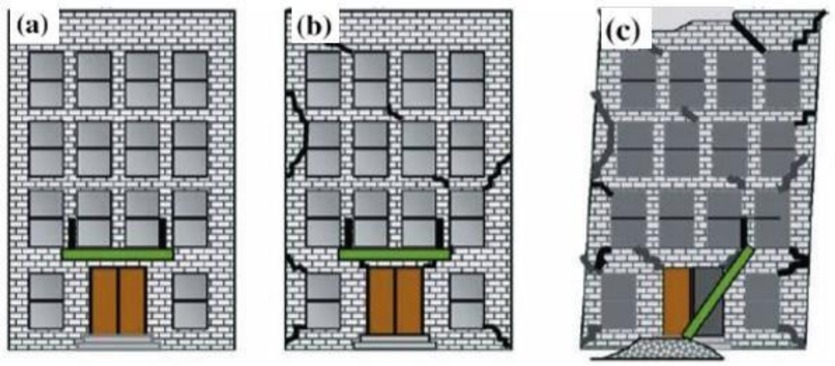


Figure 5. Performance levels, (a) Immediate Occupancy (IO),
b) Life Safety (LS); and (c) Collapse Prevention (CP)

- Immediate Occupancy: The structure experiences minor damages without any permanent drift, maintaining its original strength and stiffness. Minor cracking in facades, ceilings and structural elements might appear. The building space and systems are expected to be mostly usable. The concrete frame shows minor hairline cracks and limited yielding in a few locations, with no crushing. Meanwhile steel frames exhibit minor local yielding without buckling, fractures, or noticeable member distortion.

Figure 6. Immediate occupancy building performance level, moderate overall damage [3]

- Life Safety: This performance level aims to achieve a damage condition with a substantially low probability of endangering life safety, whether from structural damage or the falling of nonstructural components. The building experiences moderate overall damage. Gravity-loadbearing elements continue to function and there is no out of plane failure of walls. Concrete frame beams are extensively damaged with shear cracking and cover spalling in ductile columns and minor cracking in nonductile columns. Steel moment frames develop hinges, local buckling in some beams, and isolated moment connection fractures, though shear connections remain sound, and only a few elements suffer partial fractures.

Figure 7. Life safety occupancy building performance level, moderate overall damage [3]

- Collapse Prevention: This performance level primarily concerns the vertical load-bearing system, ensuring stability under vertical loads only. The building sustains severe damage, with little residual stiffness and strength retained in the structure however load- bearing columns and walls remain functional despite significant permanent drifts. The building is on the verge of collapse, with extensive damage to nonstructural components. Concrete frames develop hinges and extensive cracking on ductile elements. Steel frame beams and columns undergo significant distortion, with several moment connections fracturing [23, 24].

Figure 8. Collapse prevention level represents the total collapse of the structure [3]

The numerical analyses conducted according to the earthquake design criteria indicate that the existing system satisfies the requirements for the life safety performance level. For an earthquake event with a 10% probability of occurrence within 50 years, it is found that the shear strength of all walls in both directions of the masonry building is typically sufficient to withstand the shear forces generated during such seismic events. However, it is important to note that despite meeting the criteria for the "immediate usage performance level," certain deficiencies, such as not fully conforming to the definition of a masonry structure and identified irregularities, necessitate evaluation based on the "life safety performance level" rather than the "immediate usage performance level" [6].

Building performance levels usually consist of two main components: a structural performance level, which outlines the maximum allowable damage state of the structural systems, and a nonstructural performance level, which defines the maximum acceptable damage state of the nonstructural systems and components [6].

2.6 Analytical methods

To evaluate the seismic performance of a structure, it is necessary to conduct both nonlinear static and dynamic analyses. These analyses provide insights into how the structure responds to earthquake forces. In this study, both analyses were performed using Zeus-NL software [16], a package designed for both linear and nonlinear analysis in the field of structural engineering. Zeus-NL allows for the modeling and simulation of materials that exhibit nonlinear or linear properties, such as steel, concrete, or any other construction materials. Eigenvalue analyses, Static Pushover analyses and Time history analyses are the analyses conducted in this research.

2.6.1. Linear Analyses

Linear structural analysis is based on two fundamental assumptions, first one is material linearity – i.e., the structures are composed of linear elastic material, and geometric linearity implying that the structural deformations are so small that the equations of equilibrium can be expressed in the undeformed geometry of the structure. It assumes that the relationship between cause and effect to be proportional or linear. An important advantage of this relation is that the principle of superposition can be used to simplify the analysis. This principle states that the combined response due to several loads acting simultaneously on a structure equals the algebraic sum of the responses due to each load acting individually on the structure [5].

2.6.1.1. Linear Static Analyses

Linear Static Analyses involves applying equivalent static forces, like those from wind or earthquakes to a structure for design purposes. Linear static analysis makes the following assumptions: Static Assumption and Linearity Assumption. By Static assumption it is assumed that all loads are applied slowly and gradually until they reach their full magnitudes. After reaching their full magnitudes, loads remain constant (time-invariant), by assuming this it is neglected inertial and damping forces due to negligibly small accelerations and velocities. By Linearity Assumption it is assumed that the relationship between loads and induced responses is linear.

According to FEMA 356, the fundamental period of the building shall be determined according to Equation:

$$T = C_t * h_n * \beta$$

Where:

T = Fundamental period of structure

C_t = 0.018 for concrete moment-resisting frame

h_n= Height of the structure

β = 0.90 for concrete moment-resisting frame systems

2.6.1.2. Linear Dynamic Analyses

Linear dynamic analysis involves time-dependent applied loads, which can be deterministic (either periodic or non-periodic) or non-deterministic, meaning they can't be predicted precisely but can be described statistically. In this analysis, significant consideration is given to the accelerations and velocities of the system under excitation, requiring the consideration of inertial and damping forces. For linear dynamic analysis, the mass, stiffness, and damping matrices do not vary with time. If material nonlinearity is present, nonlinear dynamic studies become necessary since material properties are assumed to be linear otherwise.

The analysis of linear dynamic should be done in 3D unlike the linear static analysis, so each modal shape will have displacements in three directions. The natural period of the building and the natural frequency will be determined according to the equation:

$$\omega_n = 2\pi / T_n$$

Where:

ω_n = represents the natural frequency of the system (rad/s).

T_n= represents the period of the system (s).

2π is a constant representing the number of radians in one full revolution or cycle.

2.6.1.3. Eigenvalue analysis

Eigenvalue analysis can be considered as linear static analysis and linear dynamic analysis, it depends on the context in which the analysis is applied [30]. When it comes to determining the critical load at which he structure startsbecoming unstable, the eigenvalues represent the factor by which the applied load mustbe multiplied to reach a buckling state, a condition in which a structural component undergoes a sudden and significant change in shape due to compressive forces. In thiscase the eigenvalue analysis is used for buckling analysis, a component of linear staticanalysis.

In linear dynamic analysis, Eigenvalue analysis is used for modal analysis to determine the natural frequency of a structure and its mode shapes. In this case the eigenvalues correspond to the squared natural frequencies and the eigenvectors represent the mode shapes, helping to understand the behavior of the structure under dynamic loads [30].

2.6.2. Nonlinear Analyses

Nonlinear analysis consists in the incremental application of loads. Loads are not considered at a specific time, but they are increased gradually. The non-linear behavior may be caused by a single structure element or by a non-linear force-deformation relation in the whole structure. Compression or torsion elements, cable elements, material plasticity or non-linear hinges are some of the non-linear elements that can cause a structural non-linearity. These effects result in a stiffness matrix which is not constant during the application of the load, in contrary with linear static analysis. As a result, a different solving methodology is required for this type of analysis and therefore a different analytical model [20].

The structural engineering community is advancing towards a new generation of design and seismic procedures that incorporate performance-based structures, shifting away from simplified linear elastic methods towards more nonlinear techniques. There is a growing interest in developing performance-based codes for designing or rehabilitating buildings in seismically active areas. These codes often utilize an inelastic procedure known as pushover analysis.

Pushover analysis is an effective method to assess damage vulnerability of buildings. It involves conducting a series of incremental static analyses to create a capacity curve for the building [44]. Many researchers have been developing the approaches to apply the nonlinear static pushover analysis. The methods presented can be listed as (1) the capacity spectrum method (CSM) [58], (2) the displacement coefficient method (DCM) [23], (3) modal pushover analysis (MPA), [11]. These methods have minor variation in computation procedure.

The behavior of a structure under earthquake loads may be highly inelastic, making the global inelastic performance of RC structures to be dominated by plastic yielding effects, consequently the accuracy of the pushover analysis will be impacted by the capacity of the analytical models to incorporate these influences. The employment of the non-linear static analysis procedure involves four phases [7]:

1. Establish the mathematical model incorporating non-linear force-deformation relationships for the diverse components/elements.
2. Define an appropriate lateral load pattern and use the same pattern to define the capacity of the structure.
3. Define seismic demand through an elastic response spectrum.
4. Assess the performance of the building.

This process is also shown in the *Figure 9*:

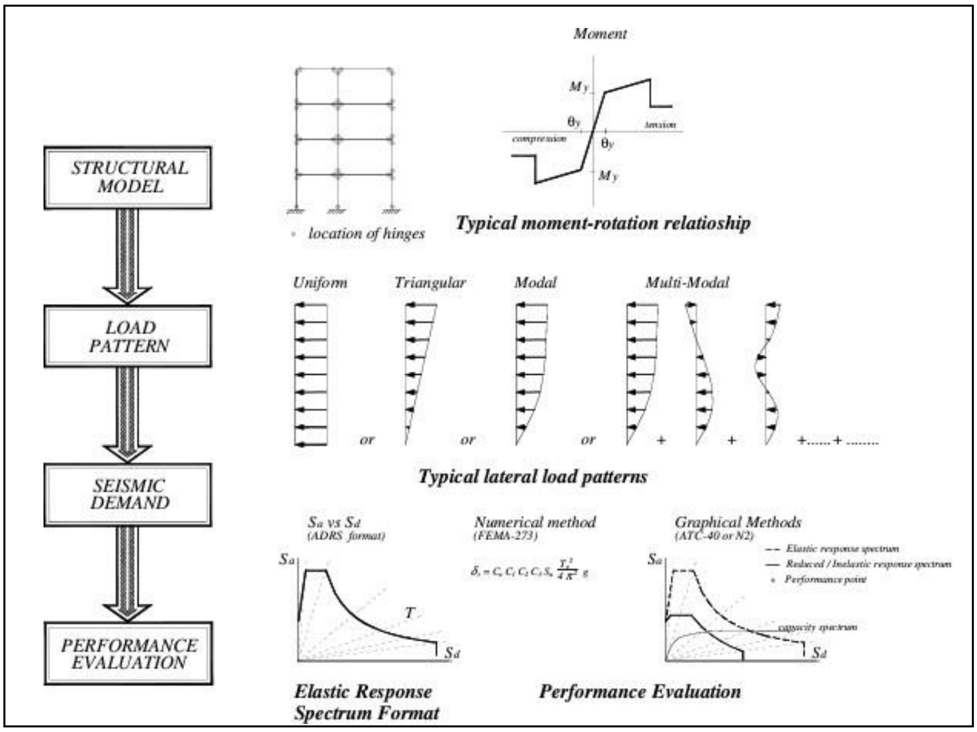


Figure 9. Determination of the capacity curve [7]

It must be underlined that the pushover analysis is approximate in nature and is based on static loading. Meaning that it cannot represent dynamic phenomena with a large degree of accuracy. It may not detect some important deformation modes that may occur in a structure subjected to devastating earthquakes, and it may exaggerate others. Other analyses are considered to be implemented in such cases.

2.6.2.1. Time History Analyses

The implementation of performance base design or seismic risk procedures require a reliable computing platform for accurately estimating both the capacity and demand of any structural system. Many of these computational tools are based on time history seismic analysis [22, 11, 27]. It is also referred as “nonlinear response history analysis”, or according to ASCE 41-06 (2007) as “nonlinear dynamic procedure” (NDP). Nonlinear dynamic analysis procedures may be categorized into the narrow-and broad-range assessment categories. These methods are acknowledged for their ability to yield reliable estimatesof structural performance under earthquake hazard; therefore, they are considered as the appropriate methods to be implemented and incorporated into such design and assessment frameworks [41].

In this method the structure being analyzed, is subjected to real ground motion records. These records are defined as a function of acceleration versus time. The total time of the analysis is the number of output time steps multiplying the output time step size. This is what makes time history analysis different from other approaches, as the inertial forces are directly determined from these ground motions and the responses of the structure are calculated as a function of time, considering the dynamic properties of the structure [31].

In most practical design and assessment situations only a narrow, single-point estimate of structural response is required. This is consistent with current seismic codes, that provide a design hazard spectrum with an exceedance probability of 10% in 50 years and require checking that structures do not sustain significant damage at this specific intensity level. Seismic codes like ASCE 7-10 (2010) and EN1998 (2005) require the use of ground motion records that match or exceed the design spectrum in the period range of interest. Structural demand specification varies with the number of seismic records used. When using 3 to 6 records, the highest peak recorded is considered the structural demand. If 7 or more records are used, the average of the peak responses can be considered as the structural demand.

2.6.2.3. Ground Motion Records

Choosing the appropriate seismic load for design and assessment purposes is a significant challenge due to the uncertainties that are associated with seismic excitations. A potential strategy for addressing this challenge is to consider the structure as being subjected to a set of records that are most probable to occur in the geographical region where the structure is located [41]. This strategy acknowledges the complex nature of seismic events, aiming to capture a range of probable scenarios that the structure may encounter during its lifespan. With the corporation of seismic records, designers and engineers can evaluate the response and performance of the structure under seismic hazard.

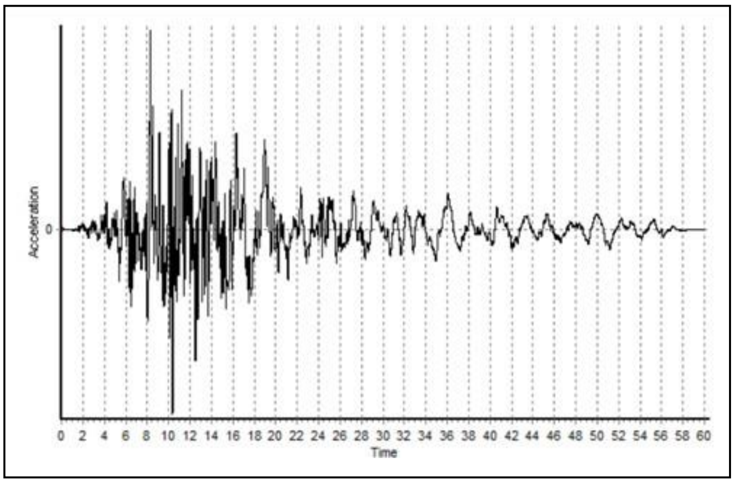


Figure 10. Accelerogram of an earthquake shown on Zeus-NL

2.6.2.4. Procedures for Conducting Time History Analysis

A systematic approach is followed to perform time history analysis:

Defining the Dynamic Loads: The first step in this type of analysis is the identification and characterization of the dynamic loads that the structural being studied, will be subjected to. The type of dynamic loads may include seismic records, wind profiles, or other relevant time-varying forces.

Developing a Mathematical Model: It is essential to develop a mathematical model of the structure using advanced software tools. This model must meet all the requirements of the real structure, it must accurately represent the physical properties and behavior of the structure.

Selecting Time History Records: Time history analysis relies on recorded seismic data. The next step would be the selection of the appropriate time history records that closely match the characteristics of the expected loading conditions. After being selected, these records are applied to the mathematical model.

Simulating the Structural Response: After applying the dynamic loads, the software conducts a numerical simulation aiming to predict the structural response over time. This involves solving a set of differential equations that dictate the motion and equilibrium of the structure.

Evaluating Structural Performance: The analysis results offer valuable insights into how the structure will behave under dynamic loads. The structural performance is evaluated by various parameters such as displacements, accelerations, stresses, and internal forces.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research aims to evaluate the seismic performance of a widespread structural topology in Albania. The chosen structure is representative of typical five story buildings found across the country. To achieve an understanding of the seismic behavior, linear and nonlinear analysis methods are implemented, specifically Eigenvalue analysis, Pushover analysis, Time history analysis. Eigenvalue analysis gives information regarding natural frequencies and mode shapes, pushover analysis helps to evaluate the ultimate load carrying progressive failure mechanism and time history captures the structure behavior under real and actual seismic loads. By integrating these analytical methods valuable insights are generated, contributing to improvement of overall structural resilience.

3.2 Designing the structural model in Zeus-NL

Zeus-NL is the software used to implement the analytical methods for the structure. It is a capable software to run linear and nonlinear analysis using finite-elements (FEM), a method used for solving complex structural engineering problems. It involves breaking down a large, complex structure into smaller parts. Each element's behavior is characterized by complex equations that describe the materials properties and their geometry. These small elements are interconnected at points called nodes that leads to creation of a mesh [9]. Since a structure is composed by at least 8 elements, if the simplest form of it is considered, Zeus-NL will generate aconsiderable number of nodes, making it hard to observe a specific column or beam on the generated structure.

The structure employed for this research comprises five symmetrical stories. To specify each component of the building with the respective materials and dimensions *Microsoft Excel 2013* was utilized, since Zeus provides the capability to copy and paste into its working space. First is needed to create the structure in Zeus and after the automatic options can be modified that Zeus attaches to the elements.

When working with Zeus it is optional to continue operating with an old file or to start a new template, that can be 2D or 3D. Subsequently, desired parameters, including the number of bays, stories, and frames, are selected and their respective dimensions are specified in millimeters after the box "Regular Structure" is checked as showed in *Figure 11*. Below the box the type of analysis to be performed later can be chosen.

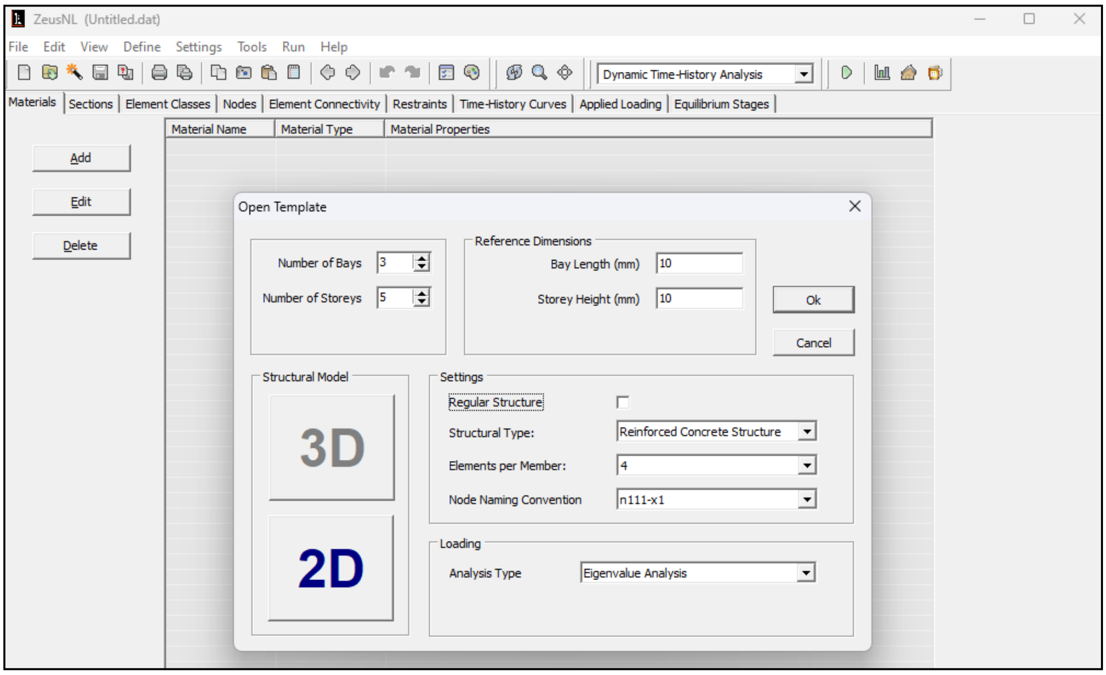


Figure 11. Template modification window on Zeus-NL

For a better understating of the behavior of the chosen building it was decided to implement the 2D plan along the X-axis and Y-axis .The dimension specified on Zeus will depend on the plan selected to perform the analyses. As shown in *Figure 12*, for each respective plan, the structures are promptly generated.

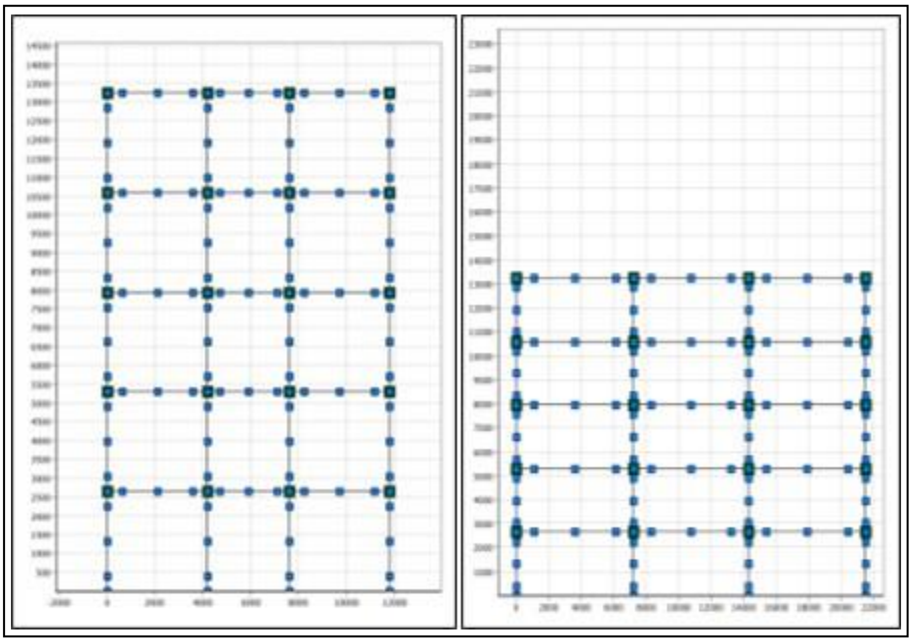


Figure 12. Structural model for frame Y and frame X

The characteristic of the geometry and material properties are elaborated in detail on the blueprints provided that will be explained further on subsequent sections. They are specified individually as shown in *Figure 13*, starting with materials, sections, element class, nodes, element connectivity and restrains. In "*section*" workspace, the sections of each beam and column of the building are specified by incorporating the number of reinforcements bars, their diameter, and their placement on the section. The "*rcrs*" stands for Reinforced concrete rectangular sections as the type of cross section implemented on structure.

Materials | Sections | Element Classes | Nodes | Element Connectivity | Restraints

Section Name	Section Type	Section Materials	Section Dimensions	Section Reinforcement
Col40x40	rcrs	rein unc conf	380. 350. 380. 350.	226. 175. 175. 113. 175. 0.
Col25x25	rcrs	rein unc conf	250. 220. 250. 220.	226. 110. 110. 113. 110. 0.
Col40x25	rcrs	rein unc conf	250. 220. 380. 350.	226. 110. 110. 113. 110. 0.
Col25x40	rcrs	rein unc conf	250. 220. 380. 350.	226. 110. 110. 113. 110. 0.
2BM25X30	rcrs	rein unc conf	500. 470. 380. 350.	2041. 235. 175. 1020.5 235. 0.

Add | Edit | Delete

Figure 13. Implementing sections of beams and columns

To assign the designed sections to the specified nodes, Microsoft Excel is employed. Initially, a filtering option is applied for the nodes on the respective plan, by separating each floor with their corresponding beams and columns as shown in *Figure 14*. This helps us by making it easier to allocate the position of a certain node.

Floor1				Floor2				Floor3			
node	column	x-beam	z-beam	node	column	x-beam	z-beam	node	column	x-beam	z-beam
n111	n111-y1	n111-x1	n111-z1	n121	n121	n121-x1	n121-z1	n131	n131-y1	n131-x1	n131-z1
n112	n111-y2	n111-x2	n111-z2	n122	n121-y2	n121-x2	n121-z2	n132	n131-y2	n131-x2	n131-z2
n113	n111-y3	n111-x3	n111-z3	n123	n121-y3	n121-x3	n121-z3	n133	n131-y3	n131-x3	n131-z3
n114	n112-y1	n112-x1	n112-z1	n124	n122-y1	n122-x1	n122-z1	n134	n132-y1	n132-x1	n132-z1
n211	n112-y2	n112-x2	n112-z2	n221	n122-y2	n122-x2	n122-z2	n231	n132-y2	n132-x2	n132-z2
n212	n112-y3	n112-x3	n112-z3	n222	n122-y3	n122-x3	n122-z3	n232	n132-y3	n132-x3	n132-z3
n213	n113-y1	n113-x1	n113-z1	n223	n123-y1	n123-x1	n123-z1	n233	n133-y1	n133-x1	n133-z1
n214	n113-y2	n113-x2	n113-z2	n224	n123-y2	n123-x2	n123-z2	n234	n133-y2	n133-x2	n133-z2
n311	n113-y3	n113-x3	n113-z3	n321	n123-y3	n123-x3	n123-z3	n331	n133-y3	n133-x3	n133-z3
n312	n114-y1	n114-x1	n114-z1	n322	n124-y1	n124-x1	n221-z1	n332	n134-y1	n134-x1	n231-z1
n313	n114-y2	n114-x2	n114-z2	n323	n124-y2	n124-x2	n221-z2	n333	n134-y2	n134-x2	n231-z2
n314	n114-y3	n114-x3	n114-z3	n324	n124-y3	n124-x3	n221-z3	n334	n134-y3	n134-x3	n231-z3
n411	n211-y1	n211-x1	n211-z1	n421	n221-y1	n221-x1	n222-z1	n431	n231-y1	n231-x1	n232-z1
n412	n211-y2	n211-x2	n211-z2	n422	n221-y2	n221-x2	n222-z2	n432	n231-y2	n231-x2	n232-z2
n413	n211-y3	n211-x3	n211-z3	n423	n221-y3	n221-x3	n222-z3	n433	n231-y3	n231-x3	n232-z3
n414	n212-y1	n212-x1	n212-z1	n424	n222-y1	n222-x1	n223-z1	n434	n232-y1	n232-x1	n233-z1
	n212-y2	n212-x2	n212-z2		n222-y2	n222-x2	n223-z2		n232-y2	n232-x2	n233-z2
	n212-y3	n212-x3	n212-z3		n222-y3	n222-x3	n223-z3		n232-y3	n232-x3	n233-z3
	n213-y1	n213-x1	n213-z1		n223-y1	n223-x1	n321-z1		n233-y1	n233-x1	n331-z1
	n213-y2	n213-x2	n213-z2		n223-y2	n223-x2	n321-z2		n233-y2	n233-x2	n331-z2
	n213-y3	n213-x3	n213-z3		n223-y3	n223-x3	n321-z3		n233-y3	n233-x3	n331-z3
	n214-y1	n214-x1	n214-z1		*n224-y1*	n224-x1	n322-z1		n234-y1	n234-x1	n332-z1
	n214-y2	n214-x2	n214-z2		n224-y2	n224-x2	n322-z2		n234-y2	n234-x2	n332-z2
	n214-y3	n214-x3	n214-z3		n224-y3	n224-x3	n322-z3		n234-y3	n234-x3	n332-z3
	n311-y1	n311-x1	n311-z1		n321-y1	n321-x1	n323-z1		n331-y1	n331-x1	n333-z1
	n311-y2	n311-x2	n311-z2		n321-y2	n321-x2	n323-z2		n331-y2	n331-x2	n333-z2
	n311-y3	n311-x3	n311-z3		n321-y3	n321-x3	n323-z3		n331-y3	n331-x3	n333-z3

Figure 14. Filtering and sorting the elements of the structure

As soon as the floors are organized another filtering option is applied on the *"Element Number*" column of the table as shown in *Figure 15*. The cross section of the elements can be easily modified to represent the blueprints. In other words, "*bmx1313*" is located on the 3rd floor of the building and has the cross section "*bm 20x25*" indicating that its dimensions are 20 mm and 25 mm.

Element Number	Section	Node Numbers
bmx1211	bm30x25	n121 n121-x1 nsn1001
bmx1212	bm30x25	n121-x1 n121-x2 nsn1001
bmx1213	bm30x25	n121-x2 n121-x3 nsn1001
bmx1214	bm30x25	n121-x3 n221 nsn1001
bmx1311	bm20x25	n131 n131-x1 nsn1001
bmx1312	bm20x25	n131-x1 n131-x2 nsn1001
bmx1313	bm20x25	n131-x2 n131-x3 nsn1001
bmx1314	bm20x25	n131-x3 n231 nsn1001
bmx1411	bm20x25	n141 n141-x1 nsn1001
bmx1412	bm20x25	n141-x1 n141-x2 nsn1001
bmx1413	bm20x25	n141-x2 n141-x3 nsn1001
bmx1414	bm20x25	n141-x3 n241 nsn1001
bmx1511	bm20x25	n151 n151-x1 nsn1001
bmx1512	bm20x25	n151-x1 n151-x2 nsn1001
bmx1513	bm20x25	n151-x2 n151-x3 nsn1001
bmx1514	bm20x25	n151-x3 n251 nsn1001
bmx1611	bm20x25	n161 n161-x1 nsn1001
bmx1612	bm20x25	n161-x1 n161-x2 nsn1001
bmx1613	bm20x25	n161-x2 n161-x3 nsn1001
bmx1614	bm20x25	n161-x3 n261 nsn1001

Figure 15. Elements are assigned as shown for each node and section

3.3 Load Calculation

The most influencing loads in a structure are those exerted by each individual element within the structure. Zeus-NL that does not calculate the masses automatically, it is needed to calculate each element individually and to add them manually. This software considers two types of masses: dmass (distributed mass) and lmass (lumped mass). Dmass represents the mass distributed through the structure. It is assigned to the elements based on their physical properties. Lmass on the other hand represents the concentrated mass at specific nodes on the structure. It resembles the load sum of multiple elements at a specific location or node. They both play the same role in Zeus-NL by specifying the total load of the structure. In this research the mass calculated and used is Lmass as more efficient and less time-consuming method.

The elements that are considered in this research are: beams, columns, and slabs. Walls are not included as the focus is more toward reinforced-concrete structures. Slabs depending on the dimensions are considered as one-way and two-way. The selected structure incorporates both types of slabs. Calculation of the load in each node can be determined in two steps.

First, the type of slabs is specified based on their length-to-width ratio. The dead load coefficient is taken as one, meanwhile live load coefficient is set to two and then multiplied by 30%. Multiplying these coefficients with concrete unit weight, slab thickness, determines load per unit area in kilonewtons per square meter (kN/m²). This value is multiplied by the height of each geometric shape, as illustrated in *Figure 16* to determine the distributed load for each shape. To convert it into point loads the distributed load is considered equivalent to the height of the shape. By multiplying this height with other dimensions, the area is calculated, resulting in the load being expressed in kilonewtons (kN). These calculations are conducted using *Microsoft Excel*.

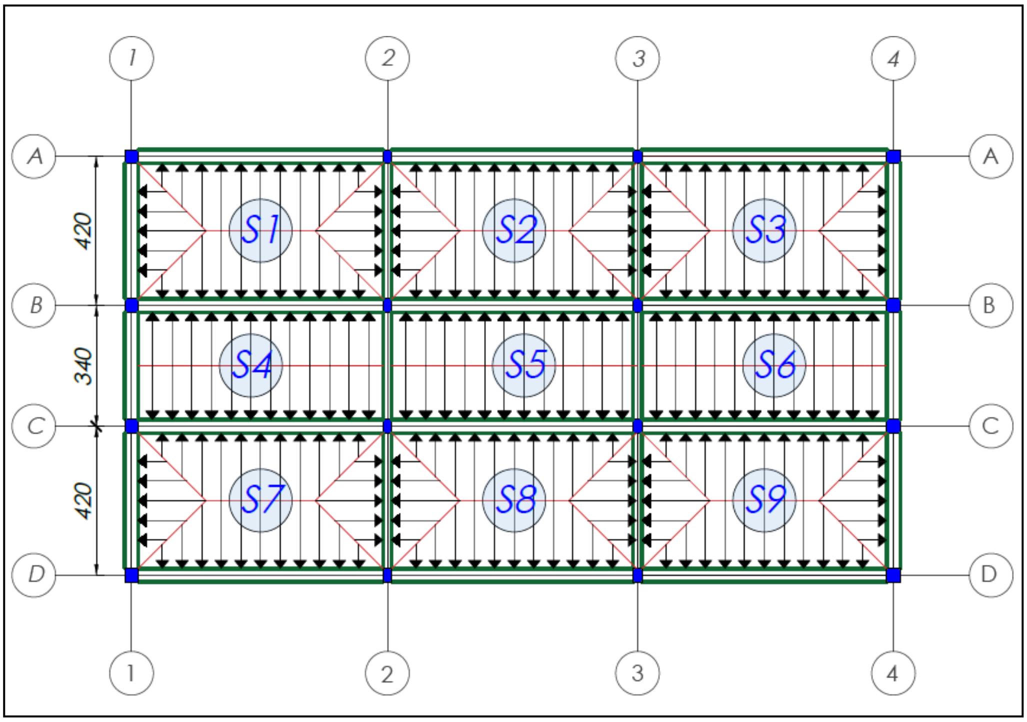


Figure 16 The allocation and arrangement of slab types within the structural layout

Table 1 Load Calculation

LOAD CALCULATION		
Conc. Unit weight	20	[kN/m³]
Slab thickness	0.15	[m]
Gk =	3	unit weight x thickness
Qk =	2	live load
Load [kN/m²] =	5	1*Gk+1*QK

On the *Table 2* below outlines the calculation of the point loads using Microsoft Excel formulas. Initially, the shapes present on the slab are determined based on the slab dimensions. The allocation of slabs in the plan is indicated by labels S1, S2 etc. For Two-Way slabs, shapes are donated as "triangular" for triangular shape and "trapezoid" for trapezoidal shape. Meanwhile, for one-way slabs, the shape is represented as "rectangular" for rectangular. At “Base” the longest beam of the respective slab is determined. Ultimately, the point loads are calculated. First value represents the point load from the triangular shape, followed by the value for the point load from the trapezoidal shape. As observed the values are similar to each other due to the symmetry of the plan.

Table 2 Point Load calculations based on the dimensions of the slab

POINT LOAD			
Slab No.	Shapes	Base (cm)	Point Load (kN)
S1	triangular, trapezoid	7.21	6.83, 16.65
S2	triangular, trapezoid	7.05	6.83, 16.65
S3	triangular, trapezoid	7.21	6.83, 16.65
S4	rectangular	7.21	18.98
S5	rectangular	7.05	18.98
S6	rectangular	7.21	18.98
S7	triangular, trapezoid	7.21	6.83, 16.63
S8	triangular, trapezoid	7.05	6.83, 16.63
S9	triangular, trapezoid	7.21	6.83, 16.65

Next step involves assessing the loads coming from beams and columns. This entails multiplying the volume of each beam or column by the concrete unit weight, as well as by the live load and dead load coefficients, where live load is removed for the beams at the top floor. These values are added to point loads evaluated above concluding into the lmass of each node *Table 3*. Mass1 is the concentrated mass for the nodes situated at the edge of the structure, mass2 is the concentrated mass for the nodes that are located in the second and third bay of the structure, mass3 is related to the nodes at the edge but at the top floor where live load is removed and mass4 is connected with nodes in the middle bays at the top floor.

Table 3 Loads coming from beams and columns

LOAD CALCULATION		
Beam1	13.52	[kN]
Beam2	7.875	[kN]
Column1	7	[kN]
Column2	4.375	[kN]
Column3	11.2	[kN]

Table 4 Calculation of Lumped masses

X		Y	
mass1	6.05	**mass1**	6.27
mass2	12.16	**mass2**	12.5
mass3	2.23	**mass3**	2.5
mass4	8.46	**mass4**	8.8

3.4 Analyses conducted on Zeus-NL

Zeus-NL is a powerful software in which can be performed all necessary analyses to evaluate the seismic performance of a building [16]. As previously described, the necessary analysis selected for the scope of this research are: “Eigen Value” analyses, “Pushover” analyses and “Time History” analyses.

3.4.1. Eigen Value analyses procedure

After all the elements of the structure have been specified, eigen value analysis will perform a dynamic linear analysis to determine the natural frequency of a structure and its mode shapes. The deformed structure will visually appear on the "Deformed Shape Viewer", and it will change for every mode as shown in *Figure 17*.

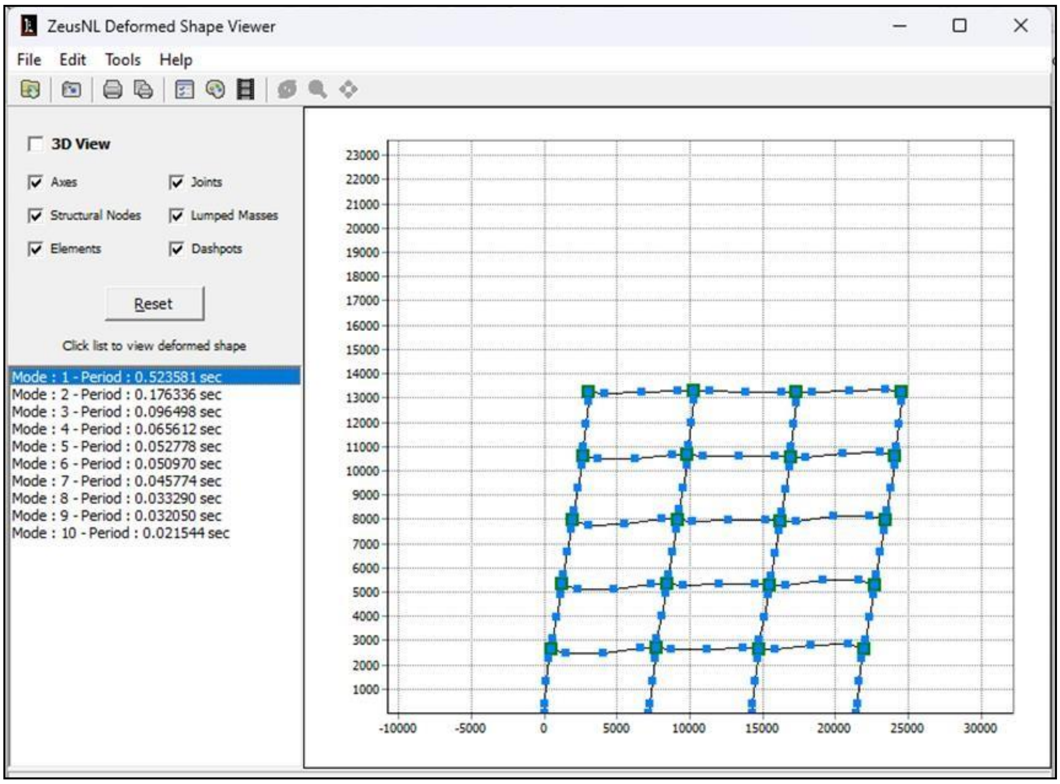


Figure 17. Performing Eigenvalue analysis on Zeus-NL

3.4.2. Pushover analyses procedure

Nonlinear static pushover analysis determines the capacity curve of the structure. The lateral load pattern representing seismic forces is incrementally applied to the structure, starting from the base, and progressing going upwards. To generate pushover curves, it's crucial to use a method called modal combinations to improve the accuracy of the behavior of the structure. In this method, three different lateral loads patterns are considered: uniform (rectangular distributed load), triangular (upside-down triangular), and modal.

In Zeus-NL it is a must to select the type of analysis since the beginning, so the initial step is to select Static Pushover Analysis as the one to be performed. Sections and materials must be assigned with the respective elements but lmass is neglected and removed since Static Pushover analysis uses a load pattern.

For uniform load pattern, at the "*applied load*" bar on Zeus, the loads are modified so the proportional loads will have the same value.

For triangular load pattern the "*proportional loads*" are modified by taking into consideration the number of stories. The coefficients for a five-story building would be two, four, six, eight and ten.

The modal load pattern is related to the response of the building evaluated on the Eigen-Value analysis. Deformations on the first mode are taken into consideration and the ratio between them will determine the values for "*proportional loads*". The pushover curves are developed using a set of data that represents the x and y axis on the graph. After running the analysis and opening "*Z-Beer*", user can select the type of graph desired to be generated. Base shear- Drift, Story Shear-Drift and Moment – Curvature are the options provided by Zeus. For the scope of this study, static pushover analyses are plotted using maximum base-shear ratio vs the maximum global drift ratio. In Z-Beer monitor, the foundation nodes are placed for the base shear calculation and for the "Up Node" "Down Node" node n461 and n411 are specified. It is needed to represent the height of the building so even if other nodes on different bays would be specified, the results would be the same.

3.4.3 Time History analysis

This analysis simulates the ground motions to the structural model, evaluating its behavior. After the analysis is specified, Zeus gives the option to choose a ground motion desired by the user. For the scope of this study twenty different real and current ground motions.

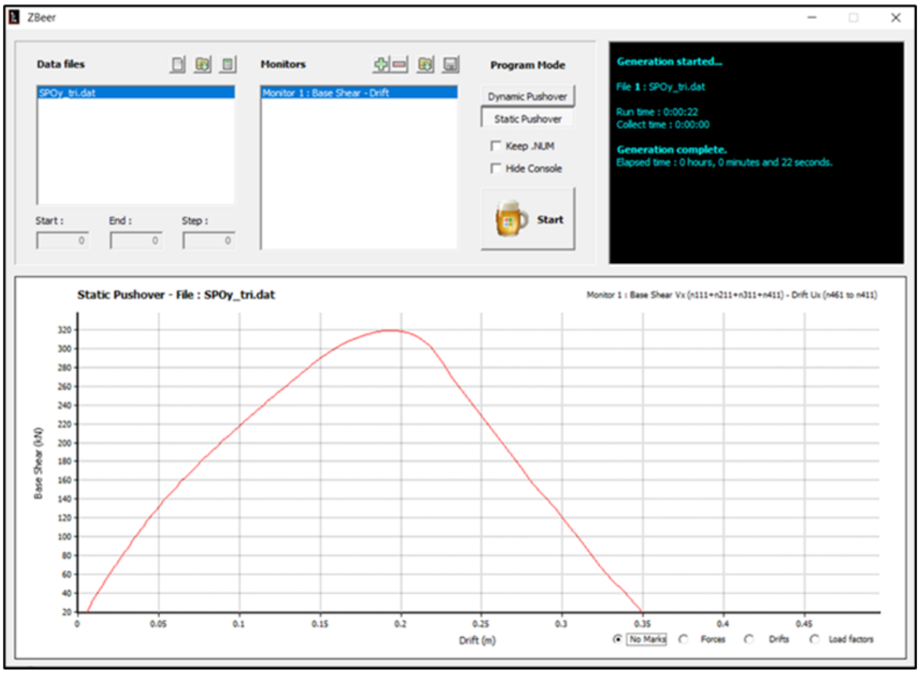


Figure 18. Pushover Analysis on Zeus-NL

3.4.4 Selection of Ground Motions records

Selecting the right ground motions that closely match the characteristics of the expected loading conditions, is crucial for the Time History Analysis. Twenty different ground motions are taken from the Pacific Earthquake Engineering Research Center (PEER) and from the U.S Geological Survey (USGS) [43], that are most probable to occurin the geographical region where the structure is located, aiming to capture the range of probable scenarios that the structure may encounter during its lifespan. The list of the ground motions selected with peak ground acceleration from 0.042g to 3.50 g are specified on *Table 5*.

Table 5. Ground motions selected to be performed in Time History Analysis

No	***Event***	***Station***	***Year***	***Ø°***	***PGA (g)***
1	Erzincan	Turkey, Erzincan	1992	90	0.488

2	Imperial Valley	Westmoreland Fire Station	1979	90	0.074
3	Loma Prieta	Agnews State Hospital	1989	90	0.159
4	Loma Prieta	Coyote Lake Dam Downstream	1989	285	0.179
5	Loma Prieta	Hollister South & Pine	1989	0	0.371
6	Loma Prieta	Sunnyvale Colton Ave	1989	270	0.207
7	Imperial Valley	Chihuahua	1979	282	0.254
8	Imperial Valley	Plaster City	1979	45	0.042
9	San Fernando	LA, Hollywood Stor. Lot	1971	180	0.174
10	Northridge	LA, Hollywood Storage FF	1994	360	0.358
11	San Fernando	LA, Hollywood Stor. Lot	1971	90	0.210
12	Spitak	Armenia, Gukasian	1988	90	0.207
13	Superstition Hills	Wildlife Liquefaction Array	1987	360	0.200
14	Tabas	Iran, Dayhook	1978	280	3.500
15	Loma Prieta	WAHO	1989	0	0.377
16	Loma Prieta	WAHO	1989	90	0.638
17	Northridge	LA, Baldwin Hills	1994	90	0.239
18	Friuli	Italy, Tolmezo	1976	270	0.345
19	Corinth	Greece, Corinth	1981	0	0.264
20	Kocaeli	Turkey, Duzce	1999	180	0.427

Each frame is subjected to the twenty ground motions records. Conversely, with pushover analysis, lumped mass is taken into consideration making the results more representative of the selected structure. Different graphs can be generated from running the time history analysis. On Zeus Post-Processor can be determined the X-axis and Y-axis, giving different variations that contribute on understanding the seismic response of the structure. For the scope of this study, it is necessary to have a unification of the axis with those specified on Pushover Analysis. Therefore, the relationship between Base Shear and Drift will be plotted on the axes of the graphs.

Graphs generated by Zeus for Time history analysis provide information regarding the maximum drift and maximum shear that the structure experiences. After each frame is subjected to the twenty ground motions sets, the maximum shear and maximum drifts values are plotted into one graph, along with the capacity curve, in order to analyze their relationship.

3.5 Defining performance levels

Performance-Based Earthquake Engineering states the need to calculate and implement the performance levels into the curves already generated, in order to evaluate the seismic respond and performance of the structure chosen. These performance levels are specified and guided through [23, 24]. For the scope of this study only structural limit states are considered: Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP). Steps on determining them are specified on [23, 24] based on the composing of the structure, soil characteristics and the earthquake hazard level. Different structures have unique procedure on calculating the performance levels.

Zeus-NL does not automate the determination of plastic hinge formations in structural elements. Consequently, performance levels will be assigned directly in the capacity curve of Pushover analysis, based on research and empirical observations [46].

Immediate Occupancy limit state (IO) is set to occur at the ending of the linear part of the capacity curve and the beginning of the nonlinear part of the curve This performance level determines the highest performance levels specified in seismic design criteria. Life Safety is identified as the midpoint between IO and CP based on various studies. For the CP limit state, guidelines suggest considering a 20% drop in the maximum base shear force to indicate the collapse prevention region [46].

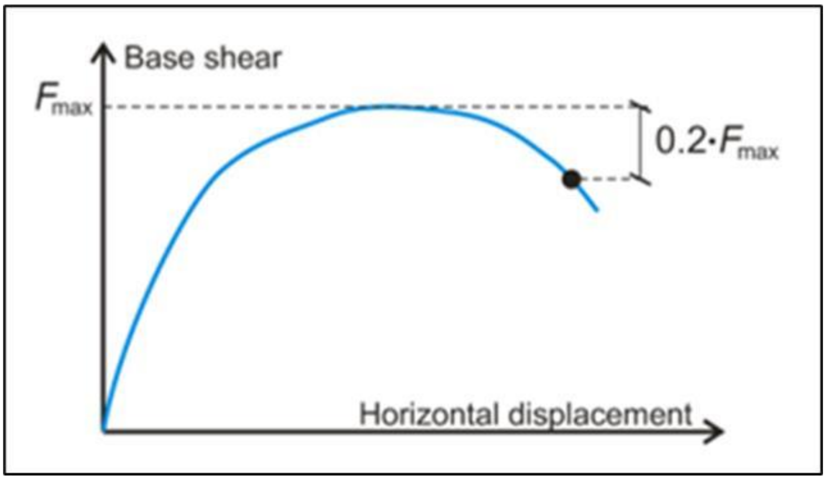


Figure 19 Defining the Collapse Prevention (CP) Limit State at the Structural Level according to previous studies [46].

CHAPTER 4

ANALYTICAL MODELLING IN ZEUS-NL

4.1 Software Overview

Zeus-NL is a software developed by Elnashai at the Mid-America Earthquake Center, University of Illinois at Urbana-Champaign. It is a powerful computer program that has a strong computational background on running linear and non-linear, static, and dynamic analysis, by taking into consideration P-delta effects and geometrical nonlinearity. Zeus-NL offers both two- and three-dimensional finite element analysis capabilities, developed for earthquake engineering applications, by using the finite element method (FEM) a method that involves breaking down a large, complex structure into smaller parts. Every element's behavior is evaluated by complex equations that describe the materials geometry and their properties. Zeus-NL is an accurate, and fast processing software that is able to provide a wide list of analysis. In the sections below a summary of information extracted from its Manual [15]. is provided.

4.2 Modelling in Zeus-NL

Zeus-NL is an efficient and user- friendly computer program that possesses the ability to predict large displacements and accelerations of various complex or non-complex frames by using the fiber approach on material models and elements. This approach divides and monitors the elements cross-section into several fibers such as unconfined concrete fibers, confined concrete fibers and steel fibers as shown in the *Figure 20* [15]. Zeus-NL is able to model reinforced concrete, steel,and composite structures under static and dynamic forces. Compared to other software's, its working space is simple and easy to be understood. Another advantageis its capability to copy and paste the properties and specifications desired by the user.

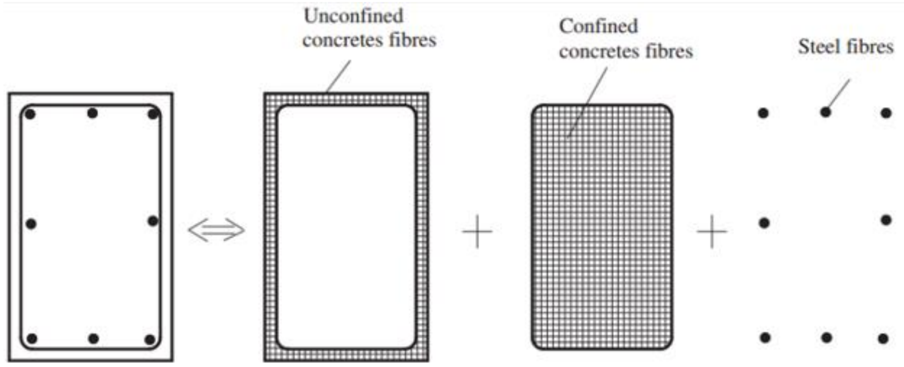


Figure 20 Breakdown of a RC rectangular section into several fibers

4.3 Analyses performed in Zeus-NL

Zeus-NL provides in its software library a list of analysis, as being able to perform both linear and nonlinear analysis. User can select among seven different analyses to be applied on the structure, such as:

Eigenvalue Analysis

▪ Static Constant Load Analysis

▪ Static Pushover Analysis

▪ Static Adaptive Pushover Analysis

▪ Static Time-History Analysis

▪ Dynamic Time-History Analysis

▪ Incremental Dynamic Analysis.

The type of analysis to be conducted can be selected on the main window that shows after the user starts a new project in Zeus-NL. As shown in the *Figure 21*, the analysis can be navigated at the end, on the "*Loading'* category.

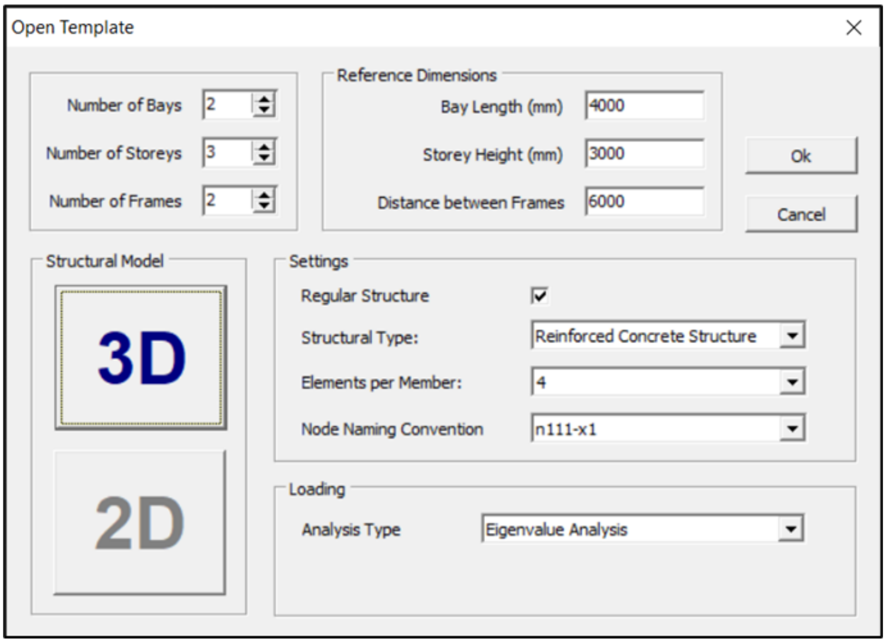


Figure 21 A graphical user interface of the Zeus-NL window upon initializing a new project

4.4 Materials

Zeus-NL provides a wide range of different materials that can be used in the modelling phase. The material library includes concrete materials defined as con1, con2, con3, con4 and frp1 and steel materials defined as stl0, stl1 and stl2. These materials can be modified in order to apply the properties of the structure selected by the user. It must be highlighted that there is a limitation when naming the properties, such as space, special characters or more than eight characters. The label will be shown as red indicating that there is something to be changed. Zeus does not run the analysis if there is an error on the inputs, so it is very important to carefully define and modify them since all the modules are related with each other. It doesn't even allow you to define the sections before materials. It operates via some rules that if not followed the software will end up showing an error prompt and the analysis will not start executing. After the materials are defined user can link them to the respective element sections.

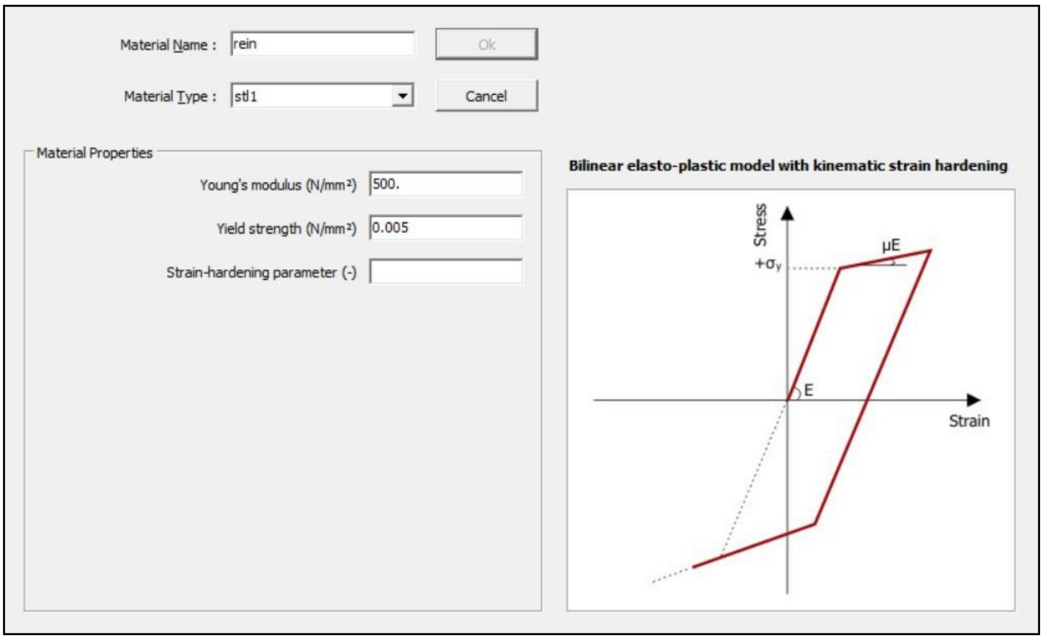


Figure 22 The Material Properties dialog box

4.5 Sections library on Zeus-NL

The section module in the Zeus-NL libraries, user can have access to a wide range of section types including steel, reinforced concrete (RC), and composite sections. These include rectangular solid sections, circular solid sections, circular hollow sections, symmetric and asymmetric I- or T-sections, composite I-sections, as well as various configurations of reinforced concrete sections. Each section is characterized by specific dimensional parameters and materials which will be used in that section. Users have the flexibility to create multiple sections for defining element classes, each with its unique name and specific properties. Same as on the materials definition, attention should be paid on the labeling the section by avoiding space and special characters. On the section properties dialog box, user can link the propriate material with reinforcement, confined region, and unconfined region.

It is crucial to understand how a section is going to be reinforced with steel bars on Zeus. Bars are separated in groups of three, representing their area, depth, and distance from the section centroid. As sections are typically symmetrical, it's only necessary to specify bars in the quadrant 123 only, because the software will automatically be generating on the other quadrant of the section.

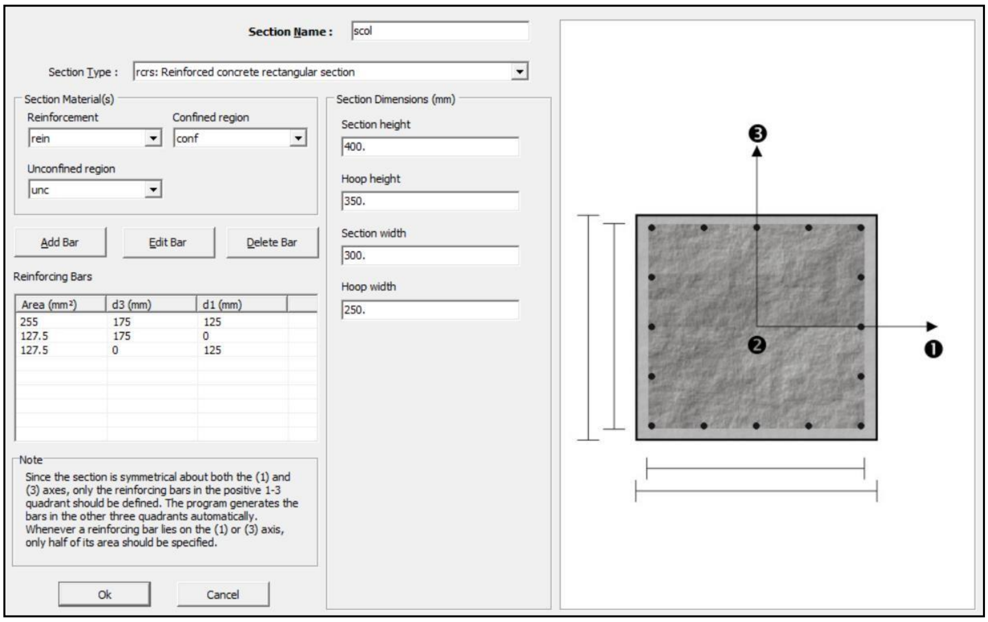


Figure 23 The Section Properties dialog box

4.6 Element Classes

A structure is composed by several different elements that must be assigned with the right properties in order to represent the structure selected for the research. Software provides a group of extra elements used for the modelling process, labeled as Element Classes, that are used to determine the element connectivity to make possible the connections of beams and columns with their respective properties.

Cubic. Cubic elasto-plastic 3D beam-column element.

- Joint. 3D joint element with uncoupled axial, shear and moment actions.

- Lmass. Lumped mass element used in dynamic and eigenvalue analyses.

- Dmass. Cubic distributed mass element.

- Ddamp. Dashpot viscous damping element used in dynamic analyses.

- Rdamp. Element that models Rayleigh damping for dynamic analyses.

Above is presented the element class library where the most used elements in this research will be Cubic elasto-plastic 3D beam-column element, since the structure is modelled in three dimensions.

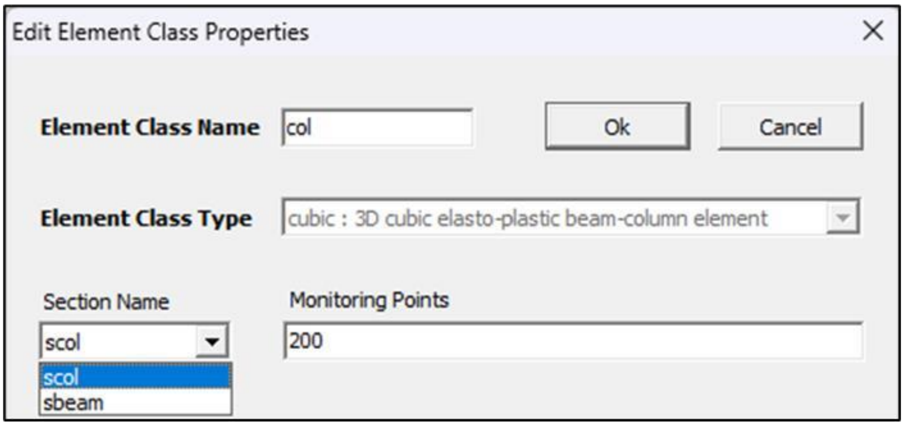


Figure 24 Element class properties window

4.7 Nodes

Modelling in Zeus-NL requires the specification od nodes with their respective coordinates used as intermediaries. Nodes help to allocate an element in the plan. There are two types of nodes: structural and non-structural. Structural nodes are responsible for connecting element sections, while non-structural nodes define local axis orientation. Two structural nodes are used for each element to define their boundaries. The third node involved belongs to the non-structural category that defines the orientation of the member, for example a rotation due to the longitudinal axis. The coordinates of each node are given in three axis X, Y and Z for a 3D modelling and X and Y for a 2D modeling of the structure. Nodes can be deleted, added, and modified any time.

4.8 Element Connectivity

In this section, all components of the structure are specified. Nodes, sections, and materials are combined to form complete structural members like beams and columns. Typically, each element requires three nodes for connection, along with an element name. By default, element numbers follow a specific format, for example: 'col111' for columns and 'bmx121' for beams. The prefix 'col' denotes columns and 'bm' represents beams, while the numbers indicate the location. For instance, 'bmx121' indicates a beam oriented in the x-direction, located in the 1st frame and 1st bay on the second story of the building. First number determine the location on the frame, second number determines on which floor is this beam or column located and the thirst number indicates the bay.

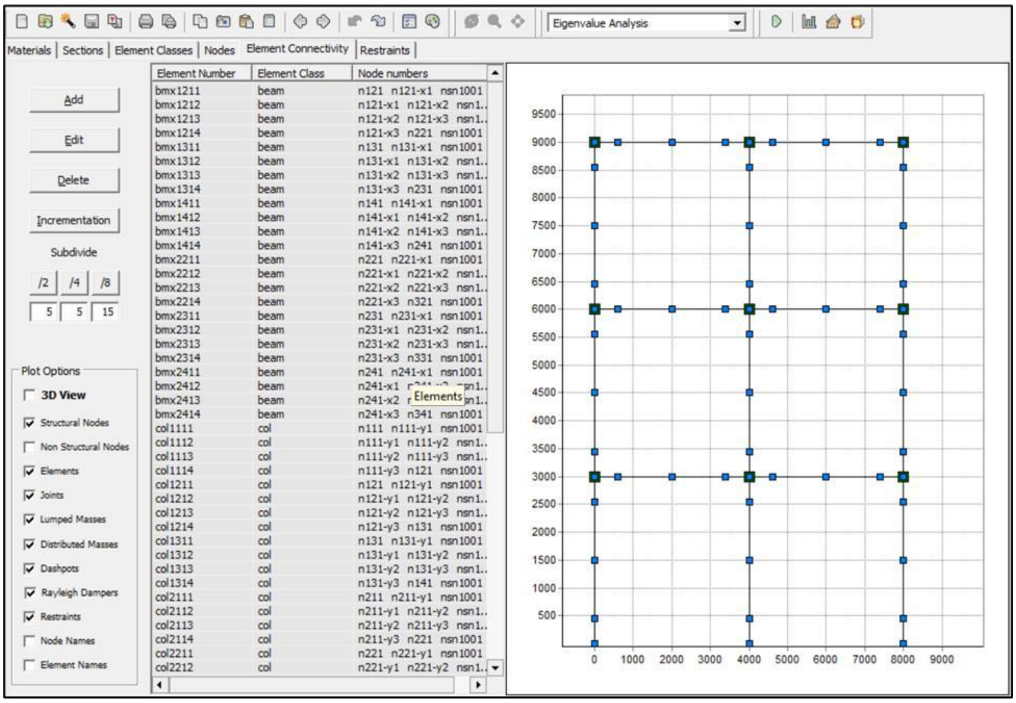


Figure 25 Element connectivity example for a 2D frame

4.9 Restrains

Nodes that need to be restrained are the ones connected with the ground. Zeus-NL generates them automatically after the user has specified the dimensions of the frame, but attention should be paid when a modification of the nodes is made after the structure is being generated by Zeus. In this case the restrains must be added manually, otherwise a different representation of the structure in the analysis will be evaluated.

Therefore, the user must be very careful to properly conduct the modelling process in Zeus NL software to avoid further calculation mistakes.

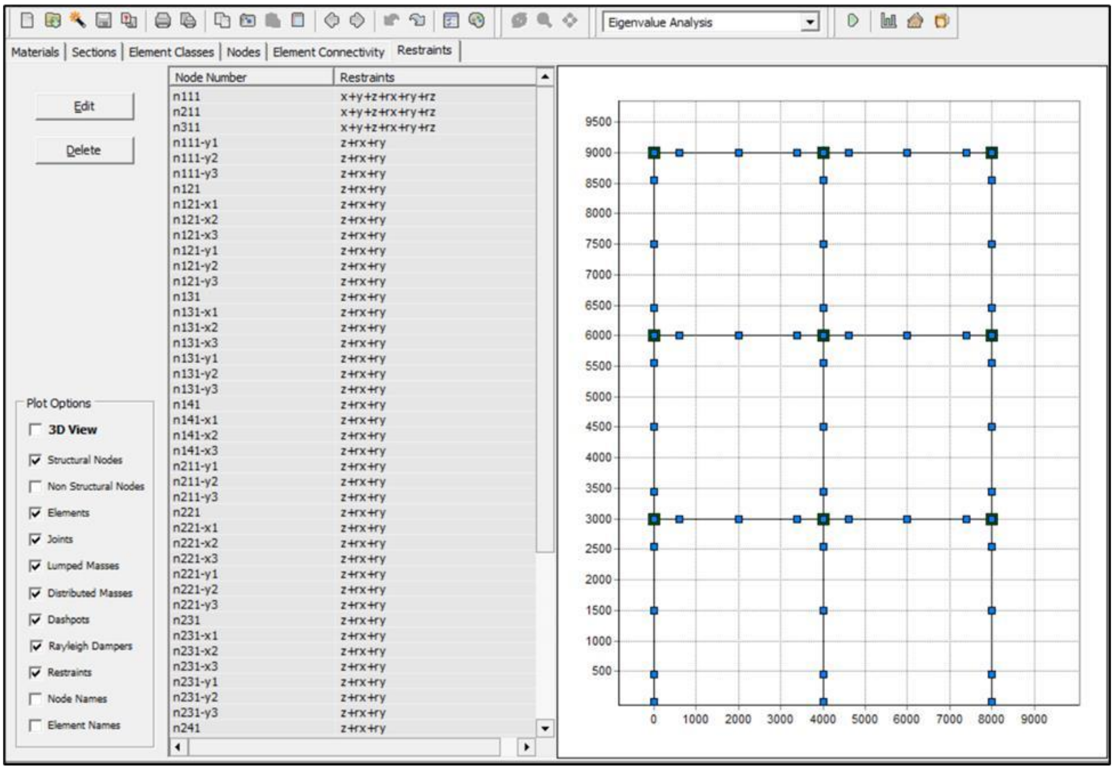


Figure 26 The 2D frame, restrained

CHAPTER 5

CASE STUDY BUILDING

5.1 General

In this chapter, detailed information regarding the selected building is given. Details are observed on the blueprints endured by "ARKIVI QËNDROR TEKNIK I NDËRTIMIT" (AQTN) institution, located in Tirana. The selected building represents the reinforced concrete buildings, that are designed with premodern codes causing to be continuously threatened by earthquakes that may occur in the country. These structures were designed during communism era in Albania, where to save time and money, a template building was designed. As it is seen on the *Figure 27*, these buildings were built in different cities maintaining the same configuration but implementing unique details for each city depending on their soil condition, geographic conditions etc.

NR	EMERTIMI	NJESIA	TIRANE	BURREL	ERSEKE	LAÇ (KRUJE)	PERMET	PUKE	RRESHEN	SKRAPAR	B. CURRI	BERAT	DURRES	ELBASAN	FIER	GRAMSH
1	PUNIME SHTRESASH (NEN SHTRESE)	Lek	2418	1975	2373	1864	1710	3120	1913	1798	1823	1610	2290	1660	2536	1634
2	-"- MURATURE	-"-	69731	84636	92572	74181	73 411	99549	81.176	80 406	82297	70721	68398	70279	74.997	76104
3	-"- BETON E B/ARME	-"-	70717	71.526	77694	68470	67158	80888	69965	66 545	69703	671 93	73.825	66717	74.819	65909
	SHUMA (1 ÷ 3)	-"-	142866	158137	172639	144515	142279	183557	153054	148749	153823	139524	144513	138656	152352	143647
4	PUNIME DHEU (ÇMIME UNIKE)	-"-	2139		VLEFTA ESHTE E NJEJTE PER TE GJITHA RRETHET.											
5	-"- HEKUR BETONI (ÇMIME UNIKE)	-"-	41829	41829	41.914	41829	41829	41914	41829	41829	43830	43378	43378	43378	43378	43378
6	-"- H/IZOLIMI (TARACA) (-"-)	-"-	17372		VLEFTA ESHTE E NJEJTE PER TE GJITHA RRETHET.											
7	-"- SHTRESASH (DYSHEME) (-"-)	-"-	33735	33735	33396	33735	33735	33 396	33735	33735	33396	33735	33735	33735	33735	33735
8	-"- SUVATIMI (-"-)	-"-	47337		VLEFTA ESHTE E NJEJTE PER TE GJITHA RRETHET											
9	-"- DYER DRITARE (-"-)	-"-	37460	37460	52072	37460	37460	52072	37460	37460	52072	37460	37460	37460	37460	37460
10	-"- TE NDRYSHME (-"-)	-"-	9455	9455	7783	9455	9455	7783	9455	9455	6602	8274	8274	8274	8274	8274
11	-"- H/SANITARE	-"-	26573	VLEFTA ESHTE E NJEJTE PER TE GJITHA RRETHET.												
12	-"- ELEKTRIKE + TELEFONIE	-"-	16018													
	SHUMA (4 – 12) (ME ÇMIME UNIKE)	-"-	231918	231918	244604	231918	231918	244604	231918	231918	245339	232286	232286	232286	232286	232286
	SHUMA GJITHSEJ (1 ÷ 12)	-"-	374784	390055	417243	376433	374197	428161	384972	380667	399.162	371810	376799	370942	384638	375933

Figure 27 Cost Specifications for constructing a building across different cities

The 5-story building, which lacks plan irregularities, serves as representative sample for this research. To evaluate the seismic performance of the structure, several linear and nonlinear static and dynamic analysis are performed.

5.2 Description of the Building

The template building used for this study is a 5-story, symmetrical, reinforcement concrete building. Each story is identical with a height of 2.80 m resulting in an overall building height of 14 m. The building sections are designed according to the regulations set by the Council of Ministers in 1977, with specific provisions for both cold and warm climates, depending on the geographical location in Albania.

This template building is built as isolated constructions with regular plan and regular elevations. Openings of the structure have regular layout and to transfer the gravitational loads, concrete lintels over the openings are commonly used. The floor systems are reinforced concrete slabs. The wall thickness is 380 mm in the first two stories and 250 mm for the three remaining, while partition walls have thickness of 120 mm. They are made of solid fired clay bricks with 250 × 125 × 60 mm dimensions or silicate bricks with dimensions 250 × 125 × 65 mm, with inner holes to reduce the weight of the building.

The structure consists of reinforced-concrete columns with typical cross section of 380 × 380 mm and reinforced concrete beams with depth of 250 mm or 380 mm, depending on the wall thickness.

In *Figure 28* is presented the elevated view of the structure. As seen the structure appears simple and symmetrical where for the purpose of our analyses two main directions of the building are considered, X and Y. Plan views for both directions are provided in *Figure 30*. After employing sections, materials and weights in Zeus, the results are compared two each other to give a more comprehensive understanding of the structure.

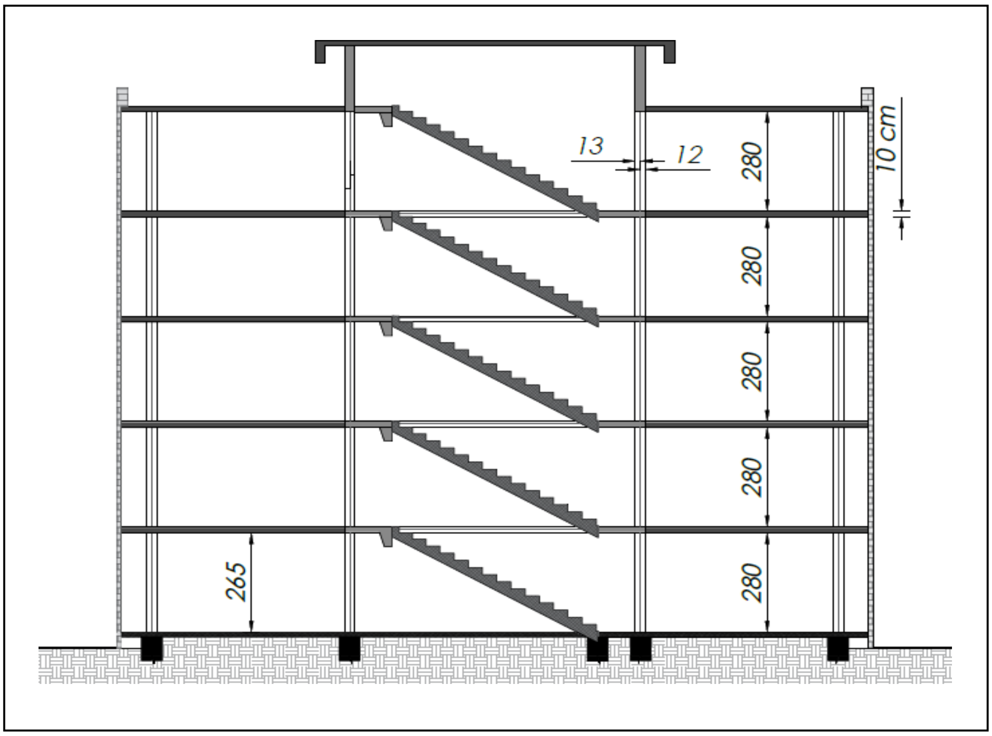


Figure 28 Elevated view of the structure (Units in centimeter)

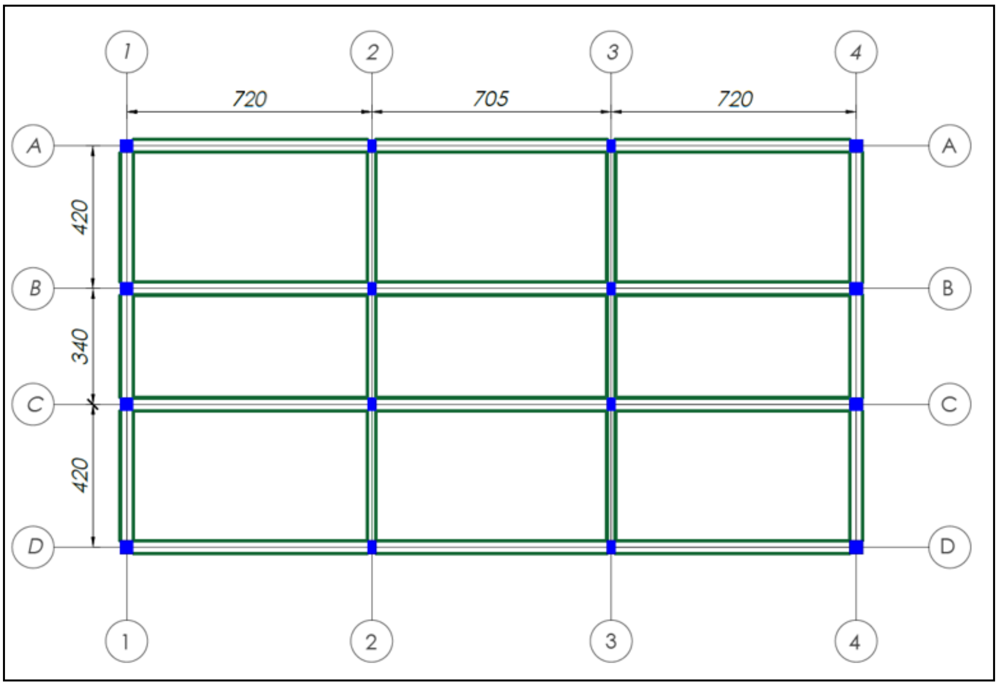


Figure 29 *Plan view for the five-story structure. (Units in centimeter)*

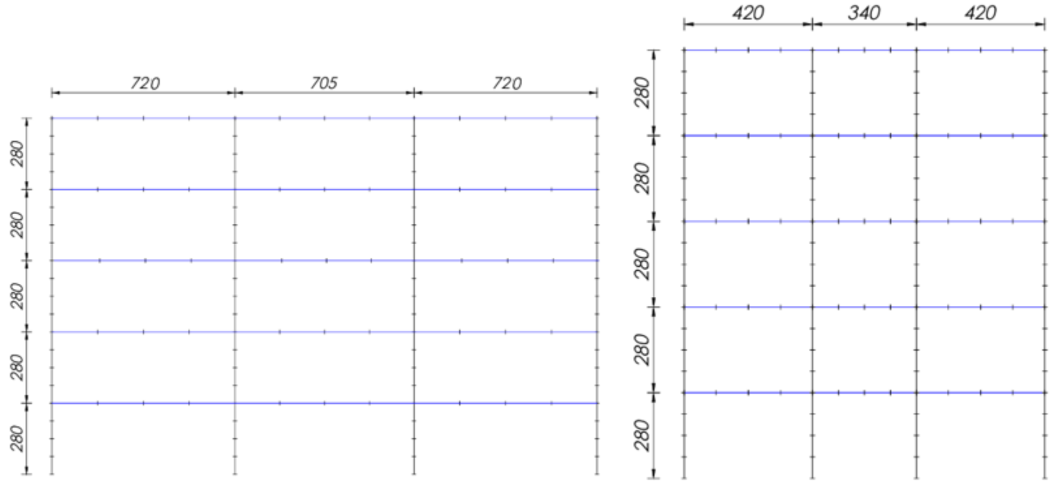


Figure 30 Story structure elevation in Y-direction (left) X-Direction (right) (Units in centimeter)

5.3 Material Classes

The specifications of material properties are outlined at the very beginning of the structure's blueprints, where it is noted that two different concrete classes were employed in various members of the structure. Concrete which corresponds to C16/20, is used in columns, beams, and slabs. For the steel reinforcement used in these buildings, the blueprint specified it as “Ç-3” with a strength capacity of 2100 Kg/cm^2.

5.4 Structural Members

An engineering structure typically is composed by beams, columns, slabs, and partition walls. However, for the purpose of our current research, partition walls are not taken into consideration. Our focus lies solely on the weight distribution from slabs to beams and columns. This selective approach stems from the limitations of

Zeus, a powerful yet simplified software lacking in detailed building modeling capabilities. Consequently, columns and beams are the main elements modeled in Zeus-NL to assess the seismic performance of the structure. Calculations are made by using Excel software, incorporating factors such as dead and live loads, as well as the self-weight of the slabs.

5.4.1 Beams

Beams are integral horizontal structural elements that serve a fundamental purpose in construction by providing essential support for loads, which they effectively transfer to columns, walls, or other structural components. They play a crucial role in distributing the weight of a building or structure evenly. Within this structure, the beams have a rectangular form and are crafted from reinforced concrete with dimensions and reinforcement that varies based on the structural frames.

Two types of beams are implemented into the structure. First beam element is composed of 8 Ø10 steel bars and have the dimensions of 38 cm by 50 cm. Second beam element is composed the same by having 8Ø10 steel bars and have the dimensions of 38 cm by 50 cm as shown in *Table 6*, whereas *Figure 31* demonstrate beam elements used in this study. For their cross sections AutoCAD software is used with the help of a program generated by Engineers and Architects Alumni Association (EAAA) [14]. The reinforced concrete section generator provides the drawings on AutoCAD automatically after the dimensions and the reinforcement are specified.

Table 6 Detailed Beam Specifications and Reinforcement

Beam	***Beam Dimensions***	***Longitudinal***	***Transverse***
BM38X50	38*50 cm	8 Ø10	Ø6 every 20cm
BM50x25	50*25 cm	8 Ø10	Ø6 every 20cm

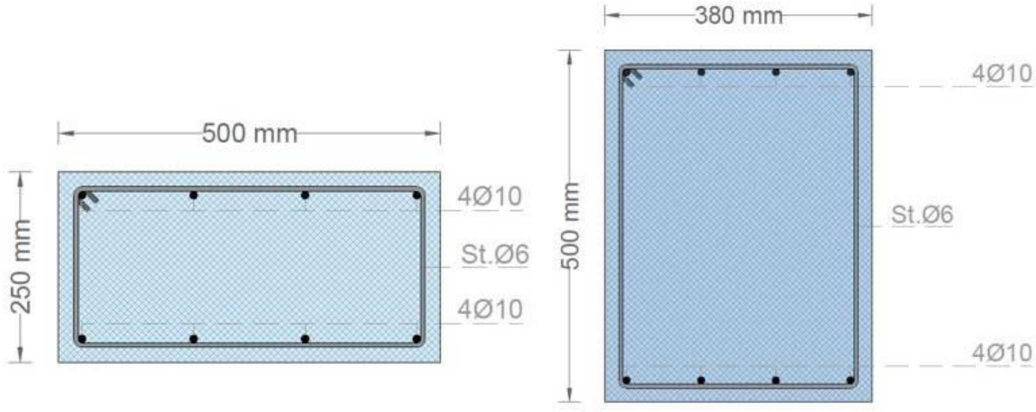


Figure 31 Cross sections of the beams implemented in the structure

5.4.2 Columns

Column is a vertical structural element that primarily supports loads and transfers them to the structure's foundation or other structural elements, such as beams or slabs. They play a crucial role in providing stability and strength to buildings. In this study columns rectangular in shape and are constructed from reinforced concrete. Three different columns are represented in the structure, each featuring unique dimensions in their cross-sectional areas and diverse arrangements of reinforcement. These characteristics do not change only from one frame to another but also differ from floor to floor within the structure.

Table 7 Detailed Column Specifications and Reinforcement

Column	*Column Dimensions*	*Longitudinal*	*Transverse*
Col38x38	38*38 cm	4 Ø14	Ø6 every 20cm
Col25x25	25*25 cm	4 Ø14	Ø6 every 20cm
Col38x25	38*25 cm	4 Ø14	Ø6 every 20cm

The structure comprises four columns with varying dimensions and reinforcement configurations. The first column, measuring 38 cm x 38 cm, is reinforced with 4 Ø14 steel bars and spans the first three floors. The second column 25 cm x 25 cm utilizes 4 Ø14 reinforcement bars and supports the subsequent two floors of the mid-rise building. The third column, with dimensions of 38 cm x 25 cm, also features 4 Ø14 reinforcement bars and is employed across the first three floors within a different frame. A tabulated representation is given *Table 7* on and their cross--section details are provided, with measurements indicated in millimeter (mm) in *Figure 32*.

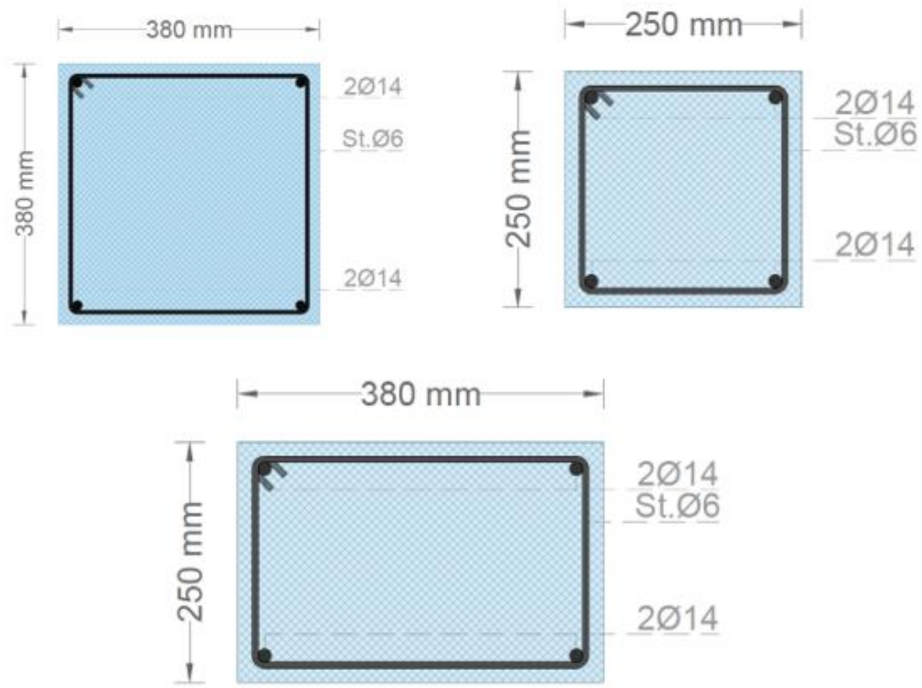


Figure 32 Cross section of the columns implemented in the structure

5.4.3 Slabs

Zeus is a powerful software that has several limitations when it comes to building design. One such limitations is its inability to account for slabs. However, calculating the weight contributed by slabs is crucial since the total mass of the building is a significant factor that plays an important role on linear and nonlinear analyses. Its concrete layer thickness is 10 cm.

Based on the structure's dimensions of Length and Width, there are nine different types of slabs. Depending on the condition where the ratio of Length to Width (L/b) is less than or greater than 2, three are classified as One-Way, and six are designated as Two-Way. *Figure 33* illustrates the distribution of the loads for slab One-Way and Two-Way.

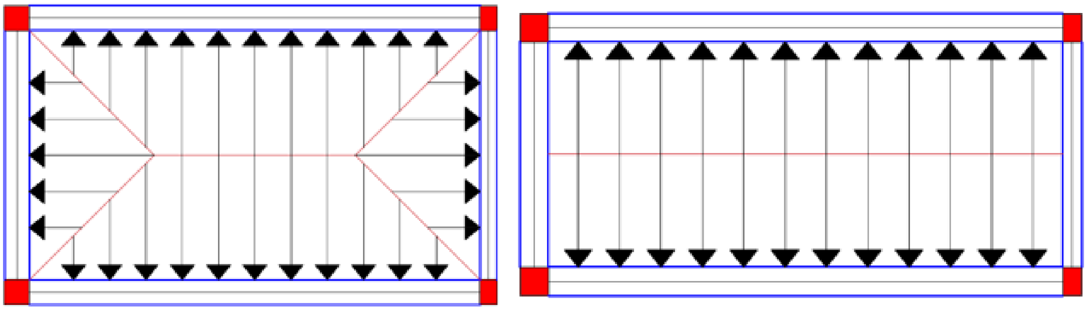


Figure 33 Load distribution in Two-Way Slab (left) and One-Way Slab (right)

CHAPTER 6

INTERPRETATION OF RESULTS

6.1 General

In this chapter are presented all the outcomes from the analyses conducted on the structure, as explained in Methodology Chapter. To evaluate the seismic performance of the structure, the results are interpreted based on the analysis method chosen. In conclusion, a comparison is made between each analytical method, offering a deeper insight into the structural response to seismic loads.

6.1.1. Eigenvalue Analyses

Evaluating the natural frequencies of a structure and its mode shapes its crucial on interpreting different spectra of a structure. For the scope of this study, period of the structure is very important as it indicates whether all the materials, sections and nodes on Zeus-NL are correctly assigned or not. Zeus-NL provides the first ten periods of the structure, attaching it with the respective deformations.

Period of the structure is evaluated by implementing both directions of the structure: x frame, y frame. The ”rule of thumb” practice of dividing the number of stories of a building by ten to estimate its period is commonly employed to reinforced concrete (RC) and steel-frame buildings, particularly mid-rise and high-rise structures [4]. It is anticipated that the structure will possess a natural frequency of 0.5 (sec). The results for each direction of the building are reflected on *Table* 8.

Table 8 Fundamental Period of Vibration across Different Structural Models

Mode	X-Frame	Y-Frame
1	0.531694	0.506003
2	0.179067	0.180626
3	0.097966	0.107117

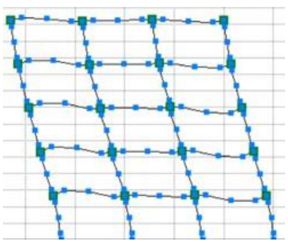
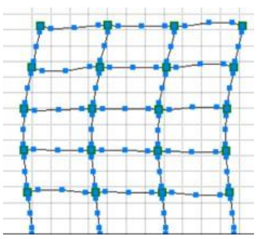
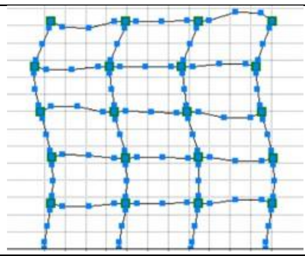
In the primary mode, the fundamental periods of the X and Y frame are relatively close. However, X-Frame slightly edges out as the longer period. This implies that X direction of the structure exhibits more flexibility compared to the Y direction [4].

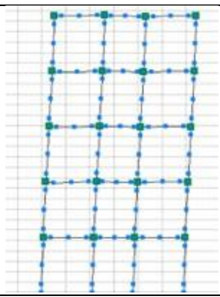
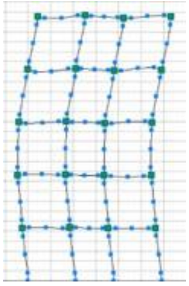
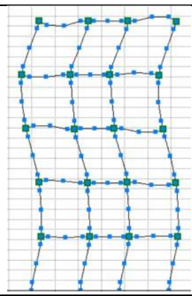
In the second mode, periods on both directions are nearly identical. This indicates similar stiffness characteristics during this mode.

In the third mode, the fundamental periods are closely aligned but not the same value, indicating Y-Frame to be slightly more flexible than X-Frame.

As observed the natural frequency of the building is as expected, verifying the structural model created on Zeus-NL. On *Table* 9 below is demonstrated the deformed shape for the first three periods. The third mode deformation figure is crucial on the next analysis, which will be performed following confirmation that all frames are properly designed.

Table 9 First Three modes for X and Y frame

	Mode 1	***Mode 2***	***Mode 3***
X-Frame			

Y-Frame			

6.1.2. Static Pushover Analysis Results

Pushover analysis estimates the capacity curve of the selected building, that for the scope of this study is represented by both X and Y direction. This analysis was employed on both frames for Uniform, Triangular and Modal load pattern, generating six capacity curves.

The outcomes of pushover analysis are related to the specific load pattern applied during the analysis process. A uniform load pattern which represents the rectangular pattern is the first one applied. After the structural model is created, Zeus-NL gives the opportunity to assign the unified load pattern as point loads at the nodes. To perform the pushover analysis with the inverted triangular pattern, instead of the unified values it is needed to conduct the coefficients of a decreasing load from the top to the bottom. Meanwhile, to perform the analysis using modal load pattern the coefficients are taken from the deformation figure of the structure on the first mode.

Pushover analyses are generated for both frames X and Y respectively. Maximum base shear ratio is calculated as the maximum base shear over the weight of the building, maximum global drift is calculated as the maximum rood drift over the height of the building. To check the behavior of the structure the capacity curves are plotted in the same graph. The *Figure 34* and *Figure 35* illustrate the pushover graphs plotted from the extracted results.

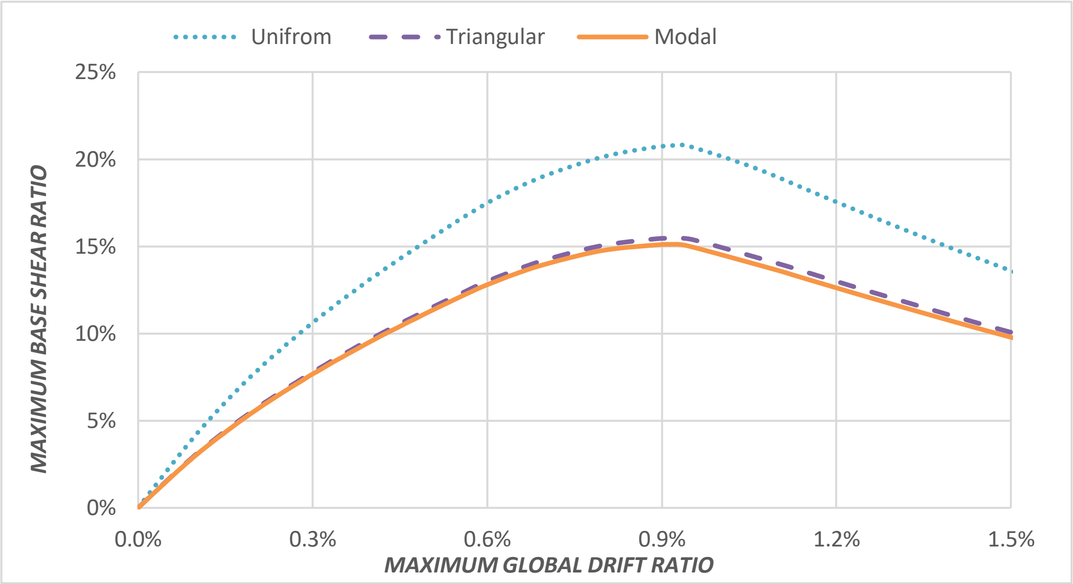


Figure 34 Capacity curves for frame X

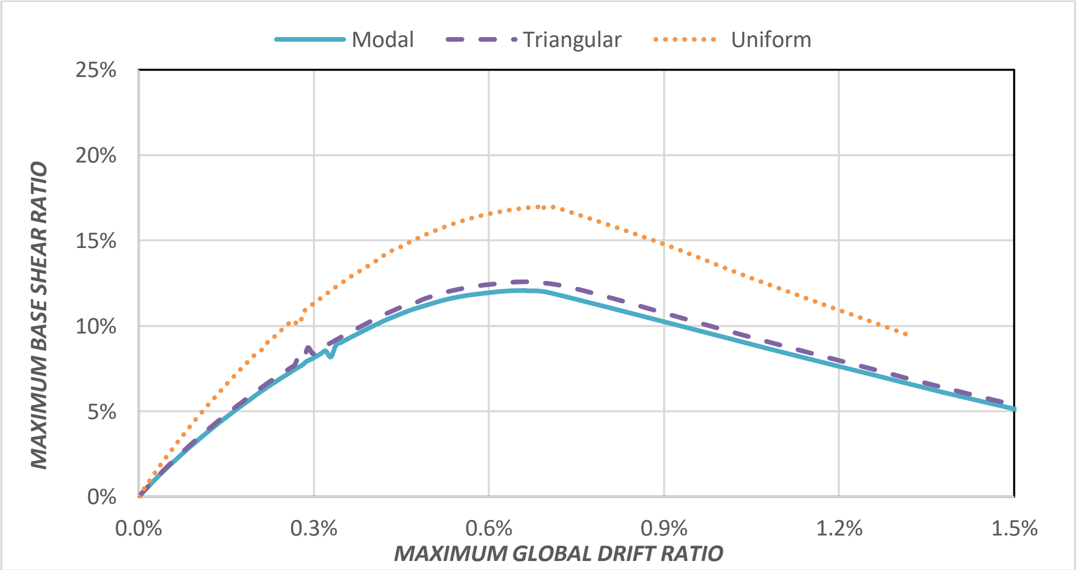


Figure 35 Capacity curves for frame Y

The uniform load pattern indicates the highest base shear ratios in both x and y directions. In the x-direction, the maximum base shear ratio in frame X reaches approximately 23% and after this point, the base shear ratio decreases as the drift ratio increases, showing a reduction in structural capacity due to potential inelastic behavior. In Y direction, the maximum base shear ratio reaches around 17% at a global drift ratio of 0.7%.

This demonstrates that the building undergoes significant base shear forces under uniform loading in both directions.

The pushover with inverted triangular load pattern represents a more realistic behavior of the structure because this load pattern simulates a gradually increasing lateral load distribution. It captures the progressive yielding and redistribution of forces that occur as the structure undergoes increasing levels of deforming. In the x-direction, the maximum base shear ratio reaches about 15% at a drift ratio of 0.9%. The transitioning to a smoother curve demonstrates a shift in stress distribution, leading to improved structural performance under realistic seismic loading conditions. The y-direction shows a maximum base shear ratio of approximately 13% at a drift ratio of 0.7%. Under uniform loading in X and Y direction, the building undergoes significant base shear forces. However, x-direction shows higher forces and displacements indicating a more substantial response.

The modal load distribution which corresponds with the building's deformations indicated on the first mode shape, provides the most realistic scenario by incorporating the building's dynamic properties. In the x-direction, the maximum base shear ratio is approximately 15% at a drift ratio of around 0.93%. Similarly, in the y-direction, the maximum base shear ratio is about 14% at a drift ratio of 0.75%. This lower base shear ratio compared to the x-frame indicates that the building exhibits a more efficient and controlled response under modal loading in the y-direction.

Upon careful observing the graph’s curves it is stated that the rectangular pattern curve reaches higher strength capacity than triangular and modal pattern curves, meanwhile “Triangular” and “Modal” follow the same trend by being very similar and close to each other. Several researchers in the previous studies have been observing similar trends [45, 19]. It is concluded that it is not suitable to use the uniform load pattern for determining the capacity curve of low-rise and mid-rise buildings [45, 19]. The reliable load pattern would be triangular or modal load patterns as it underestimates the capacity of the building. However modal load pattern is considered as the most appropriate load pattern since it is derived from the structure’s dynamic characteristics, such as: mode shapes and participation factor, which evaluates the influence of vibrational modes on structural behavior [19].

6.1.3. Time History Analyses

Time history analyses are performed by using a set of twenty real ground motion records taken from the Pacific Earthquake Engineering Research Center (PEER) and from the U.S Geological Survey (USGS). As explained in the Methodology Chapter, these ground motions are performed on each direction of the building. The max base shear and maximum global drift are the values taken from each time history curves. *Table 10* and *Table 11* below gives these values for x and y directions respectively.

Table 10 Maximum response of the X frame

Rec. No	*Event*	*Station*	*PGA (g)*	*Max drift (m)*	*Max Vb (KN)*
1	Erzincan	Turkey, Erzincan	0.48	0.97	399.61
2	Imperial Valley	Westmoreland Fire Station	0.07	0.03	177.22
3	Loma Prieta	Agnews State Hospital	0.15	0.07	269.01
4	Loma Prieta	Coyote Lake Dam Downstream	0.17	0.06	310.49
5	Loma Prieta	Hollister South & Pine	0.37	3.32	393.27
6	Loma Prieta	Sunnyvale Colton Ave	0.21	0.12	322.26
7	Imperial Valley	Chihuahua	0.25	0.12	348.26
8	Imperial Valley	Plaster City	0.04	0.01	107.72
9	San Fernando	LA, Hollywood Stor. Lot	0.17	0.06	273.16
10	Northridge	LA, Hollywood Storage FF	0.35	0.12	358.78
11	San Fernando	LA, Hollywood Stor. Lot	0.21	0.11	329.53
12	Spitak	Armenia, Gukasian	0.21	0.18	379.44
13	Superstition Hills	Wildlife Liquefaction Array	0.22	3.43	385.76
14	Tabas	Iran, Dayhook	3.5	0.11	396.83
15	Loma Prieta	WAHO	0.37	0.12	372.54
16	Loma Prieta	WAHO	0.63	0.17	394.31
17	Northridge	LA, Baldwin Hills	0.23	0.01	119.22
18	Friuli	Italy, Tolmezo	0.34	0.11	372.92
19	Corinth	Greece, Corinth	0.26	0.09	392.27
20	Kocaeli	Turkey, Duzce	0.42	1.15	396.68

Table 11 Maximum response of the Y frame

Rec. No	***Event***	***Station***	***PGA (g)***	***Max drift (m)***	***Max Vb (KN)***
1	Erzincan	Turkey, Erzincan	0.48	1.52	2292.97
2	Imperial Valley	Westmoreland Fire Station	0.07	0.05	165.84
3	Loma Prieta	Agnews State Hospital	0.15	0.11	260.41
4	Loma Prieta	Coyote Lake Dam Downstream	0.17	0.17	322.28
5	Loma Prieta	Hollister South & Pine	0.37	0.21	322.53
6	Loma Prieta	Sunnyvale Colton Ave	0.21	0.17	313.24
7	Imperial Valley	Chihuahua	0.25	0.14	309.69
8	Imperial Valley	Plaster City	0.04	0.01	78.64
9	San Fernando	LA, Hollywood Stor. Lot	0.17	0.05	182.04
10	Northridge	LA, Hollywood Storage FF	0.35	0.13	300.46
11	San Fernando	LA, Hollywood Stor. Lot	0.21	0.19	321.72
12	Spitak	Armenia, Gukasian	0.21	0.22	307.88
13	Superstition Hills	Wildlife Liquefaction Array	0.20	0.24	338.64
14	Tabas	Iran, Dayhook	3.51	0.12	290.46
15	Loma Prieta	WAHO	0.37	0.14	312.78
16	Loma Prieta	WAHO	0.63	0.21	324.42
17	Northridge	LA, Baldwin Hills	0.23	0.08	43.81
18	Friuli	Italy, Tolmezo	0.34	0.09	324.16
19	Corinth	Greece, Corinth	0.26	0.1	293.45
20	Kocaeli	Turkey, Duzce	0.42	8.26	1967.7

Upon closer inspection of the seismic data collected from various earthquakes, it is observed that two particular events, which took place in Turkey, displayed values that are not appropriate and expected value for a seismic ground motion in the same region as Albania. Specifically, the shear values recorded at the "Turkey, Duzce" station and the "Turkey, Erzincan" station on frame y are 1967.7 kN and 2292.97 kN, respectively. These values derivate form the overall range observed for seismic activities occurred in Albania agreeing to exclude these two ground motions from the graphical representation below. Graph representation will include the capacity curve, which illustrates the building's ability to withstand seismic forces, along with the time history results of the adjusted data set. Each of the time history results represents one earthquake circled and labeled in numbers which corresponds to the index provided in *Table 10* and *Table 11.*

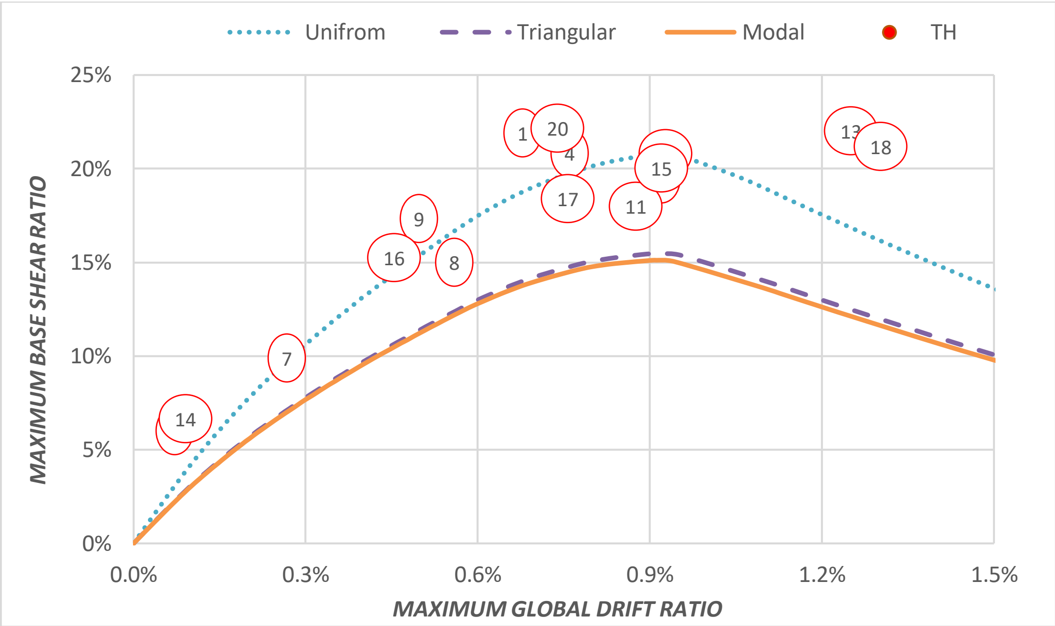


Figure 36 Capacity curve and time history analysis results for frame X

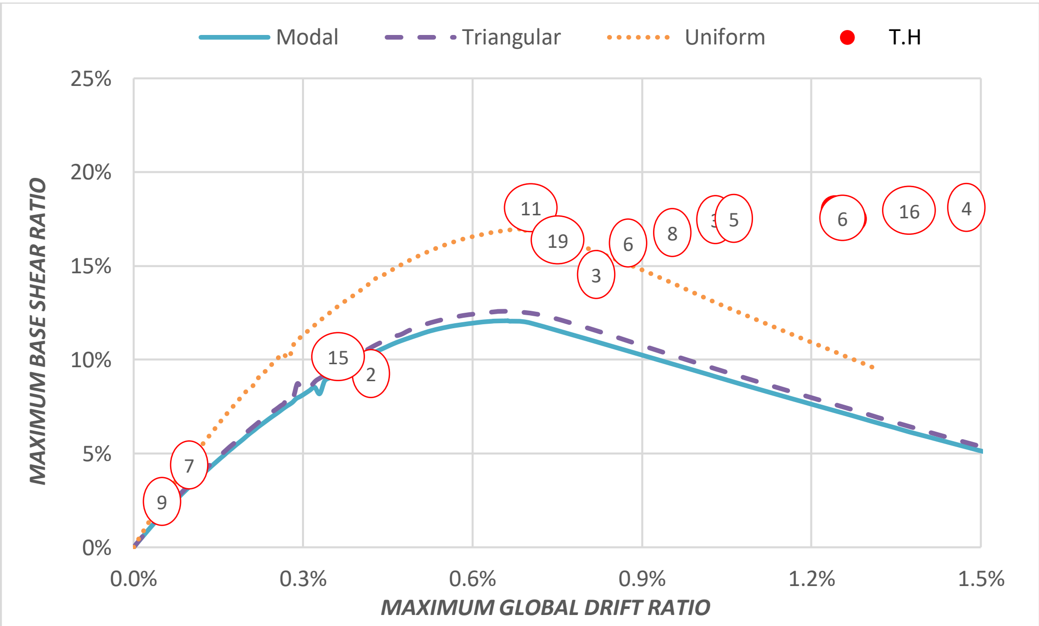


Figure 37 Capacity curve and time history analysis results for frame Y

As seen on the graphs, the majority of the earthquakes exceed the base shear capacity on the selected building, especially for the triangular and modal capacity curves. Meanwhile, the uniform pattern, underestimates the demand of a few earthquakes. This happens as the uniform pattern load does not fully captures the variability in ground motion as it distributes the loads uniformly along the building height. The uniform load pattern overestimates the capacity of the structure.

6.2 Limit States

FEMA 356 [24] offers guidelines for assessing structural performance levels. Different structures have different guidelines on evaluating them.

The building performance levels for the chosen structure will be determined directly on the capacity curves, since software Zeus-NL does not automatically provide the formation of plastic hinges in the structural elements. In the *Figure* 38 is shown the placements of the Immediate Occupancy (IO), Life Safety and Collapse Prevention(CP) limit states, on the capacity curve together with the time history analysis results for frame X.

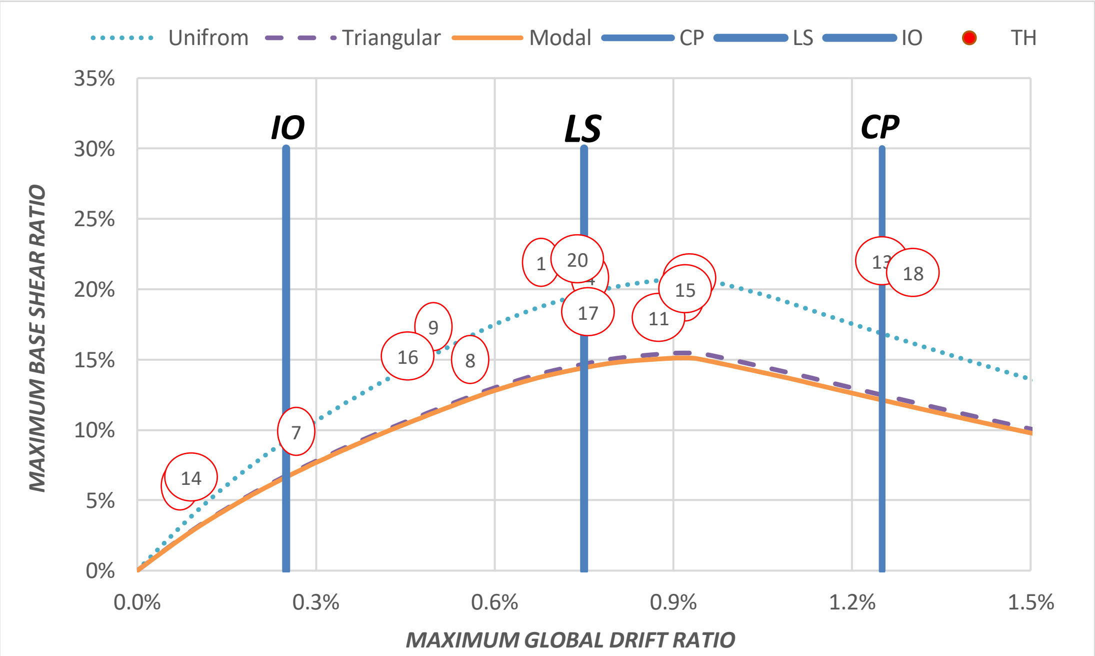


Figure 38 Capacity curves, limit states and the sets of ground motion for frame X

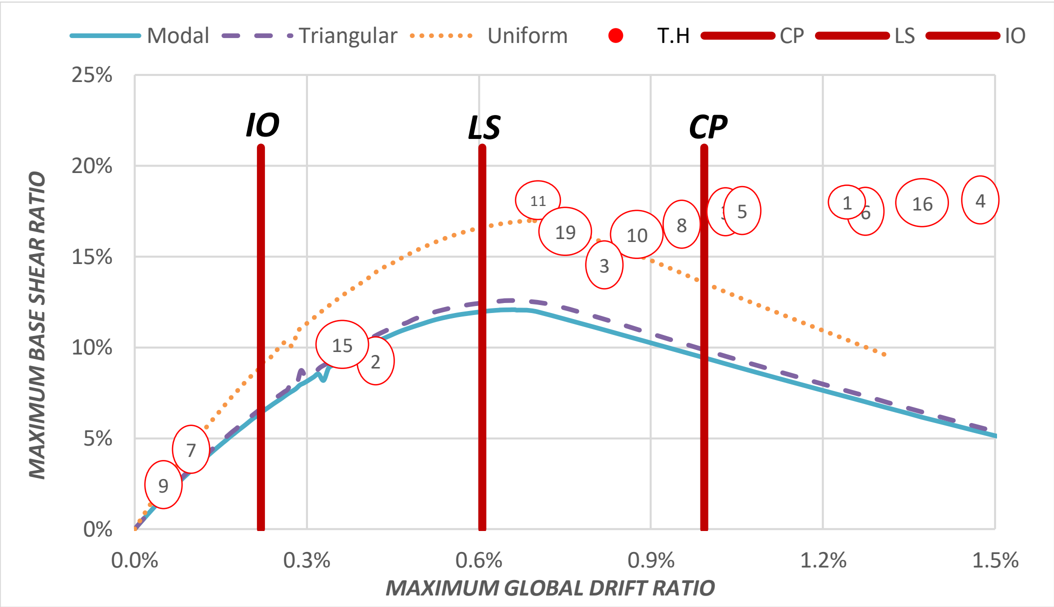


Figure 39 Capacity curves, limit states and seismic records for frame Y

Based on the graphical representation several key conclusions can be drawn for each direction of the structure.

In the **Y** direction of the structure, it is observed that *(San Fernando, Hollywood Stor (9); Imperial Valley Chihuahua (7)* earthquakes are positioned in the modal and triangular pattern capacity curve, occurring before the Immediate Occupancy (IO) limit state. This indicates that demand from these seismic loads aligns with the building's anticipated capacity as per the capacity curve. This close estimation suggests that the pushover curve for modal and triangular provides a reasonable estimation of the building's behavior under seismic loads. The structure experiences minimal damage and remains safe for occupancy.

Earthquakes *(Loma Prieta WAHO (15); Imperial Valley Westmorland (2)* lay between Immediate Occupancy (IO) and Life Safety (LS) limit state. For these earthquake demand, the building sustains moderate damage but still remains safe, even though considerable repairs are needed.

(San Fernando LA, Hollywood (10); Corinth Greece, Corinth (19); Imperial Valley Plaster City (11) are positioned just before Collapse Prevention (CP) limit state.

For these demands structure would experience severe damages but still prevent collapse, enduring that the building would remain standing. The remaining of earthquakes involved in this analysis lie beyond the CollapsePrevention (CP) limit state.

The target for residential buildings is the Life Safety (LS) performance level. In Y direction is it observed that more than 80% of the ground motions exceed this target performance level.

Observations on **X** direction of the structure indicate that *(Northridge, Hollywood Storage (14); Imperial Valley Plaster City (9); Loma Prieta Sunnyvale Colton (7)* occur before the Immediate Occupancy (IO) limit state.

Earthquakes *(Loma Prieta Agnews State (16); Loma Prieta Coyote Lake (9); Imperial Valley Westmor (8); San Fernando, Hollywood Stor (1)* fall between Immediate Occupancy (IO) and Life Safety (LS) limit state. However, it is observed that they are aligned with the uniform load pattern, which overestimates the capacity of the building.

The target performance level is reached by more than 50% of the ground motions records, resulting in a better structural performance than frame Y.

After observing the X and Y frame's seismic responses, it can be determined that the building shows poor seismic performance. As illustrated by the target performance level of Life Safety, most of the seismic ground motions exceed this limit state by experiencing higher global drift values. This determine that the building leads to potential damage due to its insufficient lateral stiffness and strength.

CHAPTER 7

CONCLUSIONS AND RECOMANDATIONS

7.1 Conclusions

The scope of this study is to determine the seismic performance of a mid-rise reinforced concrete template building that is widely spread across the country. This building exhibit symmetry in X and Y directions and is composed of reinforced concrete members which corresponds to concrete C16/20 and steel material as 2100 Kg/cm² (Ç3). Three types of analysis such as: Eigenvalue, Static Pushover and Time History were used to get sufficient data to determine the structure's behavior. Eigenvalue analysis was used to ensure that all modal masses are assigned properly and to verify the period of the building. Static pushover analysis was used to measure the structuralcapacity by plotting the base shear and roof drift values in X and Y directions. The dynamic time-history analysis was conducted using a set of twenty ground motion records selected with a range from 0.042g-3.5g peak ground acceleration. Based on the values gathered by the analyses performed and the generated graphs the followingconclusions are made:

1-From the Eigen value analysis, the natural frequency and mode shapes of the structure are determined using Zeus- NL software. Zeus does not calculate the self-weight of the slabs, column, and beams so it is needed to calculate and carefully connect the concentrated loads, known as lumped mass, with the respective elements of the structure. The values provided for the natural period adhere with the structure configuration, as expected.

2-Static Pushover Analysis curves are determined based on the proportional load applied and the frame chosen for the structure. It is observed that the uniformly distributed load pattern is higher than triangular and modal loading patterns. This behavior is studied by other researchers [19] leading to the conclusion that modal load pattern is considered as the most appropriate load pattern since it is derived from the structure's dynamic characteristics.

3- The performance levels are defined by FEMA 356, where for different structures different guidelines are followed. For the scope of the research building performance levels are determined directly on the capacity curves, where the direct adjustment for collapse prevention limit state was implemented.

4- For Time-History analysis, twenty different ground motions are performed individually for each frame, resulting in 40 set of values (max drift vs max base shear). The majority of the earthquakes exceed the base shear capacity on the selected building, especially for the triangular and modal SPO curves. However, some ground motion laid on the capacity curve for the unform pattern load, and this was due to its ability to underestimate the demand of a few earthquakes.

5- Ground motions sets, limit states and capacity curves were combined in one graph for each frame. It is observed that for both directions the dynamic results are mostly distributed on the uniform distributed load pattern or above it. Meanwhile, after observing their location with the limit states defined it is concluded that most of the seismic ground motions violate these limit states leading to potential damage due to its insufficient lateral stiffness and strength.

6- To conclude it is stated that the template building designed with premodern codes in Albania, shows very poor seismic performance, being at risk for collapsing in the scenario of a future earthquake in the country.

7.3 Recommendations for future research

This study considered a reinforced concrete building to evaluate the seismic behaviors designed by old building codes and being symmetrical in both directions.

1- Since the considered structure is symmetrical, another study ca be done by assuming that the structure has different configurations on both directions.
2- A problem stated during this research was to understand what was specified on the blueprint, since it was a template building and had a lot of details on each element but knowing the difficulties socially and economically these buildings are not implemented in real life as they are in the blueprints. So, another different and very unique study can be done by analyzing how the structure is in the blueprints and how it is in real life.
3- All the analysis performed in this study can be implemented for another building in Albania. In the end a comparison between the two structures can be evaluated.
4- This study evaluates the performance of a mid-rise reinforce concrete building. Another possible study would be to consider the performance evaluation of steel structures under the effect of the same set of seismic ground motions.
5- Future studies should integrate detailed geotechnical assessments to better understand the influence of soil-structure interaction on seismic performance. This includes analyzing different soil types and their impact on ground motion amplification and building response.
6- Research into the aging and deterioration of construction materials over time like steel and concrete, especially concrete and steel, can provide crucial data for more accurate modeling and assessment of existing buildings' seismic performance. Long-term monitoring and testing of materials from buildings of different ages would be beneficial.

REFERENCES

[1] Ahmed Ghobarah, “Performance-based design in earthquake engineering: State of development”, Engineering Structures, 878-884 (2001)

[2] Aliaj Sh., Koçiu S., Muco B., Sulstarova E., "SEISMICITY, SEISMOTECTONICS AND SEISMIC HAZARD ASSESSMENT ALBANIA", Akademia e shkencave e Shqiperise, Tiranë, (2010)

[3] Article “Performance Levels of Buildings Against Earthquakes”, The Constructor site

[4] ASCE, ‘Seismic rehabilitation of existing buildings’, Reston, VA: American Society (2007).

[5] Aslam Kassimali, “Linear Analysis of Structural Systems”, STRUCTURAL ENGINEERING AND GEOMECHANICS (2012)

[6] Baris Sayin, BarisYildizlar, Cemil Akcay, Tarık Serhat, Bozkurt, “General Perspectives on Seismic Retrofitting of Historical Masonry Structures.”, Failure Analysis and Prevention book, chapter 8, (2017)

[7] Bento R., Falcão S., Rodrigues F., ‘Non-Linear Static Procedures in Performance Based Seismic Design’, 13th World Conference on Earthquake Engineering (p. paper No. 2522). Vancouver, B.C., Canada: 13 WCEE (2004).

[8] Bilgin H, Shkodrani N, Hysenlliu M, Ozmen H.B, Işık E and Harirchain E., "Damage and performance evaluation of masonry buildings constructed in 1970s during the 2019 Albania earthquakes," Engineering Failure Analysis, vol. 131, January (2022).

[9] C.W. Groetsch, Encyclopedia of Physical Science and Technology (Third Edition), 2003

[10] CEN, (2005) Eurocode 8: Design of structures for earthquake resistance, EN 1998, European Committee for Standardization, Brussels.

[11] Chopra AK, Goel RK, Report No PEER 2001/03, A modal pushover analysis procedure to estimate seismic demands for buildings: Theory and preliminary evaluation, Pacific Earthquake Engineering Research Centre, University of California, Berkeley, California. (2001)

[12] Denada Veizajm Gjergj Islami, “SHTESA, TIRANA. SPONTANEOUS ELEMENTS, AGAINST AND WITHIN THE COMMUNIST ARCHITECTURE”, Conference Paper, Canadian Centre for Architecture (2019)

[13] Dibra, Z., "Disa dukuri të lëngëzimit të truallit nga tërmeti i 15 prillit 1979", Tërmeti i 15 prillit 1979, 404-414 (1983)

[14] EAAA, Engineers and Architects Alumni Association https://sites.google.com/view/etriplea, 2024

[15] Elnashai A.S., Papanikolaou V., Lee D.H., ‘ZEUS-NL User Manual, Mid-Amerika Earthquake Center, University of Illinois at Urbana-Champaign (2002).

[16] Elnashai, A.S. ‘Zeus NL - A system for Inelastic Analysis of Structures’, Urbana–Champaign: Creating a Multi-hazard Approach to Engineering (2002).

[17] Eutizio Vittori, Anna Maria Blumetti, Valerio Comerci, Pio Di Manna, Luigi Piccardi, Dashamir Gega, Ismail Hoxha, “Geophysical Journal International”, Volume 225, Issue 2, 1174–1191 (2021)

[18] USGS, Science for a changing world. https://earthquake.usgs.gov/earthquakes/browse/significant.php?year=2010

[19] F. Khoshnoudian, S. Mestri, F. Abedinik, “Proposal of lateral load pattern for pushover analysis of RC buildings, CMCE, Vol. 2,169-183, (2011)

[20] F. Naeim, “Earthquake excitation and response of buildings”, Encyclopedia of Vibration, Pages 439-461 (2001)

[21] Fabio Freddi, Viviana Novelli, Roberto Gentile, Enes Veliu, Stoyan Andreev, Anton Andonov, Federica Greco & Emiljano Zhuleku “Observations from the 26th of November 2019 Albania earthquake: the earthquake engineering field investigation team (EEFIT) mission”, Bulletin of Earthquake Engineering, Volume 19, pages 2013–2044 (2021)

[22] Fajfar P., ‘Structural Analysis in Earthquake Engineering – a breakthrough of simplified non-linear methods’, 12th European Conference on Earthquake Engineering, Elsevier, London, UK, (2002).

[23] FEMA (2000a), ‘Recommended seismic design criteria for new steel moment-frame buildings’, Washington, DC.: Federal Emergency Management Agency, (2000)

[24] FEMA 356., ‘Prestandard and commentary for the seismic rehabilitation of buildings’, Washington: federal emergency management agency (2000).

[25] Gazeta Panorama, Chronicle, “Arkitektura Italiane në Shqipëri, nga koloniale në trashëgimi” (2013)

[26] Gerassimos A. Papadopoulos, Apostolos Agalos, Panayotis Carydis, Efthimios Lekkas, SpyridonMavroulis, and Ioanna Triantafyllou “The 26 November 2019 Mw 6.4 Albania Destructive Earthquake”, (2020)

[27] Giovenale, P., Cornell, C.A., Esteva, L. “Comparing the adequacy of alternative ground motion intensity measures for the estimation of structural responses”, Earthquake Engineering and Structural Dynamics; 951-979 (2004).

[28] Gjergji Islami , Andronira Burda, “Architecture in socialist Albania: Re-reading in the rethorical perspective of Enver Hoxha's textual language”, Conference: IFAU (2019)

[29] Güler K., Arslan Y., Güler M.G., ‘The seismic performance evaluation of a reinforced concrete building by using linear and non-linear methods’, The 2nd European Conference on Earthquake Engineering. Macedonia (2010).

[30] József Szala, “USE OF EIGENVALUE ANALYSIS FOR DIFFERENT LEVELS OFSTABILITY DESIGN”, Conference: SDSS‘Rio 2010 STABILITY AND DUCTILITY OF STEEL STRUCTURES, January (2001)

[31] Kalpak.A.Zagade, Aniket.Patil, Abhijeet.Galatage, “A REVIEW PAPER ON TIME HISTORY ANALYSIS / NON-LINEAR DYNAMIC ANALYSIS OF HIGH RISE BUILDING USING ETABS”, International Journal of Creative Research Thoughts, Volume 9, July 2021

[32] Karnik V., Seismicity of European Area, Part I: Prague (1969)

[33] Lee and S. W. Stewart “Principles and applications of Microearthquake Networks” (1981)

[34] Leti, M., Bilgin, H., "Estimation of the seismic demand and capacity of RC buildings using nonlinear analysis procedures”, 2017 ICCE, International Conference of Civil Engineering. Tirana, Albania," (2017)

[35] Mahir Badanagki, Feng Li, and Christian Armstrong, “Comparison Between

Newmark Time History Analysis and Finite Element Method for Estimating Seismically Induced Slope Displacement”, (2020)

[36] Marsed Leti, Huseyin Bilgin, "Investigation of seismic performance of a premodern RC building typology after November 26, 2019, earthquake," Structural Engineering and Mechanics, vol. 89, no. 5, pp. 491-505, (2024)

[37] Mehmed Causevis, Sasa Mitrovic “Comparison between non-linear dynamic and static seismic analysis of structures according to European and US provisions”, Bulletin of Earthquake Engineering, 467-489

[38] Melsi Labi," Historia e “Via Egnatia”, Rruga që bashkonte Perëndimin me Lindjen, Gazeta Ballina, 12-25 (2016)

[39] Mohiuddin Ali Khan Ph.D., P.E., C. Eng., M.I.C.E, “Pushover Equivalent Static Analysis”, Earthquake-Resistant Structures, 283-315 (2013)

[40] Mwafy A.M., Elnashai A.S., ‘Static pushover versus dynamic collapse analysis of RC buildings’, Eng. Struct., vol. 23, 407-424 (2001).

[41] Nikos D. Lagaros, Chara Ch. Mitropoulou and Manolis Papadrakakis , “Time History Seismic Analysis”, Encyclopedia of Earthquake Engineering, January (2013)

[42] Nikunj Mangukiya, Arpit Ravani, Yash Miyani, Mehul Bhavsa,” Study of “P-Delta” Analysis for R.C. Structure”, Recent Advances in Civil Engineering for Global Sustainability (2016)

[43] OpenSees., ‘Open System for Earthquake Engineering Simulation’, Retrieved from Pacific Earthquake Engineering Research Center: opensees.berkely.edu (2002).

[44] P. Poluraju, Nageswara Rao “International Journal of Earth Sciences and Engineering” ISSN 0974-5904, Volume 04, No 06 SPL, pp. 684-690, October (2013)

[45] R. Bento, S. Falcão, F. Rodrigues, “Non-Linear Static Procedures in Performance Based Seismic Design”, 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 16, Paper No. 2522 (2004)

[46] Rejec, K., & Fajfar, P., "Simplified Nonlinear Seismic Analysis of RC Buildings," Earthquake Engineering & Structural Dynamics, vol. 43, no. 2, pp. 199-217, (2014)

[47] S. P. e. al., A conjugate fault revealed by the destructive Mw 5.6 (November 21,

2022) Cianjur earthquake, West Java, Indonesia, Direct Science, https://doi.org/10.1016/j.jseaes.2023.105830, 2023.

[48] Sebastião, F., ‘Performance Based Seismic Design – An application to a Reinforced Concrete Structure’, MsC Thesis, Instituto Superior Técnico, Portugal, (2002).

[49] Seeram Madhuri, Pramod Kumar “Response of asymmetric reinforced concrete building sunder directional seismic loads”, Asian Journal of Civil Engineering, (2023)

[50] Shehu V., Dhima N., Ndikimi i kushteve inxhiniero-geologjike në perhapjen e intensitetit te tërmetit të 15 prillit 1979 në rajonin Shkodër-Lezhë: Ne: Tërmeti i 15 prillit 1979, 387-404 (1983)

[51] Siasi Kociaj, “Risque, Nature Et Societe. Seminaire, Delphes”, 231-245 (1996)

[52] Steven L. Kramer “Performance-Based Earthquake Engineering: Opportunities and Implications for Geotechnical Engineering Practice”, Geotechnical Earthquake Engineering and Soil Dynamics IV (2008)

[53] T. Guardian, "The Guardian," 2020. [Online]. Available: https://www.theguardian.com/world/2019/nov/26/albania-earthquake-rescuers-search-rubble-after-most-powerful-tremor-in-decades. [Accessed 2024].

[54] Xiangzhao Chen, Xiaoting Wang, Zhiguang Zhou, Rapid report of seismic damage to hospitals in the 2023 Turkey earthquake sequences, ScienceDirect, https://doi.org/10.1016/j.eqrea.2023.100234, 2023.

[55] Yousuf Dinar, Samiul Karim, Ayan Barua, Ashraf Uddin “P- Delta Effect in Reinforced Concrete Structures of Rigid joint”, Journal of Mechanical and Civil Engineering, 42-49 (2013)

[56] Yuxin Cai, Wolong Zhang, Linwen Yu, Kai Yang, “Characteristics of the steel-concrete interface and their effect on the corrosion of steel bars in concrete.”, Construction and Building Materials, (2020)

[57] Zhe Qu, Feijian Wang, Xiangzhao Chen, Xiaoting Wang, Zhiguang Zhou, Rapid report of seismic damage to hospitals in the 2023 Turkey earthquake sequences, ScienceDirect, 2023.

[58] ATC-40, Seismic Evaluation and Retrofit of Concrete Buildings,1996