SEISMIC PERFORMANCE EVALUATION OF A FIVE STORY RC TEMPLATE BUILDING IN ALBANIA THROUGH NONLINEAR ANALYSIS

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Approval sheet of the Thesis

This is to certify that we have read this thesis entitled **"Seismic Performance Evaluation of a Five Story RC Template Building in Albania Through Nonlinear Analysis"** 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: 28 June 2024

Examining Committee Members:

Dr. Begmyrat Kulmedov	(Civil Engineering)	________________
Dr. Armando Demaj	(Civil Engineering)	________________
Dr. Marsed Leti	(Civil Engineering)	________________

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Name Surname: Joana Biba

Signature: _______________

ABSTRACT

SEISMIC PERFORMANCE EVALUATION OF A FIVE STORY RC TEMPLATE BUILDING IN ALBANIA THROUGH NONLINEAR ANALYSIS

Biba, Joana

M.Sc., Department of Civil Engineering

Supervisor: Dr. Marsed Leti

Over the past few years, Albania has faced significant seismic events causing varying degrees of damage to RC buildings. Many of these buildings were constructed before the implementation of modern seismic codes, increasing the risk posed by frequent seismic activity in the region. Therefore, it is crucial to evaluate the performance of existing reinforced concrete (RC) buildings, especially those lacking seismic detailing.

Furthermore, Albania's ongoing economic and social development has led to increased construction activity. A significant portion of the current housing stock consists of buildings constructed during the communist era, particularly between 1980 and 1983. These buildings are spread across Albania and were built based on unique geological considerations. Therefore, a comprehensive assessment of their operational capacity according to Albanian construction standards is required.

The structural performance of a 5-story reinforced concrete building is evaluated using finite element analysis software Zeus-NL. The load bearing capacity of the selected template is done using the nonlinear static analysis, Pushover. The application of pushover is achieved using uniform, triangular and modal loading patterns. Additionally, the demand calculation is considered based on the capacity spectrum method (CSM). Furthermore, the limit states are defined in the Pushover curves as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) based on the modern guidelines of FEMA 356. Lastly, the performance evaluation of the building is conducted based on the outputs of analyses.

At the end, key findings and limitations are presented, along with suggestions for further investigation.

Keywords: *Nonlinear Analyses, Seismic Performance Assessment, RC Template Building in Albania, Zeus-NL, Capacity Spectrum Method, Premodern Code designs*

ABSTRAKT

VLERËSIMI I PERFORMANCËS SIZMIKE TË NJË NDËRTESE MODEL PESË KATËSHE BETONARME NË SHQIPËRI PËRMES ANALIZAVE JOLINEARE

Biba, Joana

Master Shkencor, Departamenti i Inxhinierisë së Ndërtimit

Udhëheqësi: Dr. Marsed Leti

Gjatë viteve të fundit, Shqipëria është përballur me ngjarje sizmike që kanë shkaktuar dëme të konsiderueshme në ndërtesat betonarme. Shumë nga këto struktura janë ndërtuar pa respektuar kodet sizmike, duke rritur rrezikun e dëmtimit nga aktiviteti sizmik i shpeshtë në rajon. Prandaj, është thelbësore të vlerësohet performanca e ndërtesave ekzistuese betonarme, veçanërisht atyre që u mungojnë detajet sizmike.

Zhvillimi ekonomik dhe social i vazhdueshëm ka rritur aktivitetin ndërtimor në Shqipëri, duke rezultuar në një pjesë të madhe të stokut aktual të banesave që përbëhet nga ndërtesa të ndërtuara gjatë epokës komuniste, veçanërisht midis viteve 1980 dhe 1983. Këto ndërtesa, të shpërndara në të gjithë vendin, janë ndërtuar mbi bazën e konsideratave të veçanta gjeologjike dhe kërkojnë një vlerësim të gjithanshëm të kapacitetit të tyre operacional në përputhje me standardet e ndërtimit shqiptar.

Performanca strukturore e një ndërtese me 5 katëshe betonarme është vlerësuar duke përdorur softuerin e analizës me elementë të fundëm Zeus-NL. Kapaciteti mbajtës i modelit të zgjedhur është vlerësuar duke përdorur analizën statike jolineare, Pushover. Zbatimi i analizës Pushover është realizuar duke përdorur modele ngarkimi uniforme, trekëndore dhe modale. Për më tepër, llogaritja e kërkesës është bërë bazuar në metodën e spektrit të kapacitetit (CSM). Gjithashtu, gjendjet kufitare janë përcaktuar në kurbat e analizës Pushover si Perdorimi i Menjehershem , Siguria e Jetës dhe Parandalimi i Kolapsit, bazuar në udhëzimet moderne të FEMA 356. Së fundi, vlerësimi i performancës së ndërtesës është kryer bazuar në rezultatet e analizave.

Në fund, paraqiten gjetjet kryesore dhe kufizimet, së bashku me sugjerime për studime të mëtejshme.

Fjalët kyçe: *Analiza Jolineare, Vlerësimi i Performancës Sizmike, Ndërtesa Betonarme Model në Shqipëri, Zeus-NL, Metoda e Spektrit të Kapacitetit, Dizajnet para Zbatimit të Kodeve Moderne*

Dedicated to: My family

My friends

My country

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

In structural engineering, reinforced concrete (RC) buildings rely heavily on two primary materials: steel and concrete, each well-known for its unique mechanical properties and versatile applications. Concrete, a composite material comprising cement, sand, aggregates, and water, serves as a cornerstone in construction, providing robustness and stability, particularly in load-bearing elements like columns, beams, and foundations. Its versatility enables engineers and architects to craft complex designs, making it indispensable in various construction projects [1].

Conversely, steel, prized for its flexibility, high tensile strength, and resistance to corrosion, complements concrete as a vital structural material. Often used in reinforcement components like rebars or mesh, steel strengthens concrete structures against diverse stresses, enhancing overall stability. Together, concrete and steel form the backbone of strong, enduring buildings [2].

However, over time structures are subject to various internal and external factors that influence their long-term durability. Factors such as temperature fluctuations and external forces can impact structural performance, potentially reducing durability [3]. Among these external threats, earthquakes are particularly significant as they can cause devastating damage to buildings and endanger lives [4].

Predicting and mitigating the effects of seismic ground motion on structures is essential for ensuring safety and minimizing losses [5]. As such, earthquake engineering has emerged as a critical field, focusing on designing structures to withstand strong ground motions and minimize losses [6].

The problem addressed in this thesis is the seismic vulnerability of existing RC buildings in Albania, particularly those constructed before the implementation of modern seismic codes. Many of these buildings lack adequate seismic detailing, making them susceptible to significant damage during earthquakes [7]. This research aims to evaluate the seismic performance of a typical five-story RC building using nonlinear static and dynamic analyses to identify potential weaknesses and suggest necessary retrofitting measures. By employing advanced analysis methods like eigenvalue analysis, static pushover analysis, and the Capacity Spectrum Method (CSM), this study provides a comprehensive assessment of the building's behavior under seismic loads, thereby contributing to improved safety and resilience of RC structures in seismic regions [5].

1.2 Thesis Objective

A considerable number of residential buildings in our country were constructed using standardized project designs. When regulations are updated, these designs are adjusted to meet the new requirements while preserving the original architecture. After the 1989 earthquake regulations were implemented, these standardized designs were revised to comply with the new standards to enhance their earthquake safety. Despite these updates, many pre-1989 residential structures remain, and these older buildings continue to hold significant importance in our current building stock.

This study aims to assess the structural performance of a template RC building in Albania subjected to seismic events through static analyses. Nonlinear static pushover analysis and eigenvalue analysis are employed to understand the building's response to lateral loads, deformations, and vibrations. Additionally, the Capacity Spectrum Method (CSM) is used to calculate seismic demand, providing insights into how the buildings respond to various dynamic excitations.

The selected building, constructed in 1980 holds significant value for Albania due to its widespread presence across the country. Evaluating seismic parameters is crucial for assessing the lifespan and community safety of such structures, especially those built without code provisions.

This research aims to provide a comprehensive evaluation of the seismic performance of older RC buildings, contributing valuable data to the field of earthquake engineering. By highlighting potential vulnerabilities and recommending retrofitting measures, the study seeks to enhance the resilience and safety of Albania's building stock, ultimately protecting lives and property from future seismic events.

1.3 Scope of works

This study involves assessing the seismic performance of a five-story reinforced concrete building using nonlinear analysis tools. To achieve this, eigenvalue analysis, static pushover analysis, and the capacity spectrum method are employed to evaluate the building's structural performance.

The study begins with a comprehensive review of existing literature on seismic performance assessment of reinforced concrete buildings. This review helps identify key parameters and methodologies relevant to the analysis of seismic behavior in buildings. Following the literature review, the building selected for this study, constructed in 1980, is thoroughly examined to gather its architectural and structural details, including blueprints and material properties.

Next, a detailed finite element model of the building is developed using Zeus-NL software. The model incorporates the building's geometrical and material characteristics to accurately simulate its response to seismic loading. Eigenvalue analysis is performed to determine the building's natural frequencies and mode shapes, which are essential for understanding its dynamic behavior. Subsequently, static pushover analysis is conducted to evaluate the building's capacity to withstand increasing lateral loads until failure. The results from these analyses provide a basis for generating capacity curves, which are used in the capacity spectrum method to assess the building's performance under seismic excitation.

Finally, the outcomes of the analyses are interpreted to derive conclusions about the building's seismic performance. Key findings, including the building's expected failure modes and overall resilience, are presented. The study also identifies limitations and areas for further research, particularly concerning the generalization of results to similar structures and the potential need for retrofitting to enhance seismic safety. This research aims to contribute to the body of knowledge in earthquake engineering and provide practical insights for improving the safety and durability of the reinforced concrete building stock in Albania designed with premodern building codes.

1.4 Organization of the thesis

This thesis is structured into seven chapters, each dedicated to exploring different aspects of the seismic performance evaluation of reinforced concrete buildings in Albania through nonlinear analysis.

Chapter 1 introduces the problem statement, thesis objectives, and the scope of the work. It sets the context for the study, explaining the importance of assessing the seismic performance of RC buildings in Albania, especially those constructed before modern seismic codes were implemented.

Chapter 2 provides a comprehensive examination of previous research and methodologies related to seismic performance evaluation. It covers the fundamentals of performance-based earthquake engineering, various seismic analysis methods, and the specific challenges associated with RC buildings in Albania. The chapter also discusses the Capacity Spectrum Method (CSM) and its application in seismic evaluations.

Chapter 3 details the research methodology used in this study. It includes the development of the structural model in Zeus-NL software and the procedures for performing eigenvalue analysis to determine the building's natural frequencies and mode shapes. It also covers the nonlinear static pushover analysis and the application of the Capacity Spectrum Method. The chapter outlines the steps taken to simulate the seismic performance of the selected building and describes the tools and techniques used for analysis.

Chapter 4 provides an overview of the Zeus-NL software and its capabilities for performing nonlinear static and dynamic analyses. It describes the modeling process, including the definition of materials, sections, element classes, and the assignment of loads and restraints. The chapter also explains how the static pushover analysis and eigenvalue analysis were conducted using Zeus-NL.

Chapter 5 presents a detailed description of the 5-story RC building used as the template for this study. It includes architectural and structural details, material specifications, and the design codes applied during its construction. Elevation profiles and plans are provided to illustrate the building's configuration and key structural elements.

Chapter 6 discusses the results of the seismic performance analyses. It includes the findings from the eigenvalue analysis, static pushover analysis, and capacity spectrum method. The chapter interprets the building's dynamic behavior, capacity curves, and performance points, highlighting potential vulnerabilities and areas for improvement.

The final chapter summarizes the key findings of the study, drawing conclusions about the seismic performance of the examined RC building. It offers recommendations for future research and practical measures to enhance the seismic resilience of similar structures in Albania. The chapter also discusses the limitations of the current study and suggests directions for further investigation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The fundamentals of performance-based earthquake engineering (PBEE) involve determining the demand and capacity of structures under seismic loads. This process requires understanding and interpreting limit states, which serve as critical indicators for performance evaluation [5]. Nonlinear analyses are crucial as they allow engineers to assess the performance of structures beyond their elastic range, considering various performance levels such as immediate occupancy, life safety, and collapse prevention.

Earthquake engineering has evolved significantly over the past few decades, with the development of various analysis methods aimed at improving the accuracy of seismic performance evaluations. The transition from linear to nonlinear analysis techniques has been driven by the need to capture the complex inelastic behavior of structures under seismic loading. Linear analysis methods, while simpler, do not account for the inelastic or plastic behavior of materials and components, which are critical for accurate seismic performance assessment. Nonlinear analysis methods, on the other hand, provide a more realistic representation of structural behavior, allowing for a comprehensive evaluation of potential failure mechanisms and overall resilience [1,9].

Several methods have been proposed by researchers for assessing seismic performance in the development of PBEE. Earthquake engineering expresses global instability as the inability of the structural system to carry gravity loads due to seismic excitation. Many studies distinguish between local and global collapse. Local collapse is defined as the failure of specific elements in the structure, such as vertical load-carrying elements (columns or shear walls) due to compression or shear forces, which prevent the transmission of shear forces between members. This localized failure can lead to global instability. Williamson [15] describes how the transmission of local collapse from one element to another, considering the P-Δ effect, can result in the total collapse of the building.

Researchers have focused extensively on developing appropriate analysis methods to evaluate structural performance during earthquakes [16-18]. Over the years, numerous methods have been implemented, including both linear and nonlinear analyses. Advances in technology and the desire to move from linear static methods to nonlinear dynamic analyses have greatly impacted the field of earthquake engineering. The goal of performance-based design is to prevent structural collapse and ensure an acceptable safety margin against global instability due to strong ground motions. Past experiences have identified significant factors influencing global collapse, such as the P-Δ effect and the shear capacity of elements, which are often the initial points of collapse.

Numerous experiments have been conducted to investigate global collapse. Yoshimura [19] found that axial failure of columns occurs when the shear capacity approaches zero. Vian and Bruneau [20] conducted shaking table tests on a single degree of freedom (SDOF) steel structure, gradually increasing intensity until global collapse occurred due to geometric irregularities, concluding that the stability factor has a significant influence. Kanvinde [21] demonstrated that nonlinear dynamic analyses performed with OpenSees software are highly precise in predicting global failure.

The P-Δ effect significantly impacts the seismic performance of structures. According to FEMA 356 [5], elements and components of a building must be designed for nonlinear displacement effects. Analyses are categorized into "second order analyses," which include the P-Δ effect, and "first order analyses," which do not take into account such effects. Wilson [22] explained that lateral stiffness decreases in a long rod subjected to large compressive forces. He noted that in a well-designed structure, the changes in displacement and forces should not exceed 10%. For static analyses, P-Δ increases structural lateral displacement, whereas for dynamic analyses, it depends on the fundamental period of the structure, potentially altering the building's response. When structural response is within the elastic limit, the nonlinear displacement effect remains small, but when it exceeds this limit, significant impacts occur [23].

This chapter reviews the existing literature on methodologies and findings relevant to seismic analysis of RC structures, focusing on nonlinear analysis techniques and the seismic vulnerability of RC buildings in Albania. It also highlights the importance of nonlinear analysis compared to linear methods and discusses the Capacity Spectrum Method, a critical tool for seismic performance evaluation.

2.2 Damage Limit States

Earthquakes can cause various levels of damage to building structures, ranging from minor cracks to complete collapse. Identifying discrete performance levels for structural components is essential for assessing building functionality, property protection, and safety [24]. The standards such as ASCE41 [25] and FEMA356 [5] typically provide guidance on three performance levels (*Figure 1*): Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP).

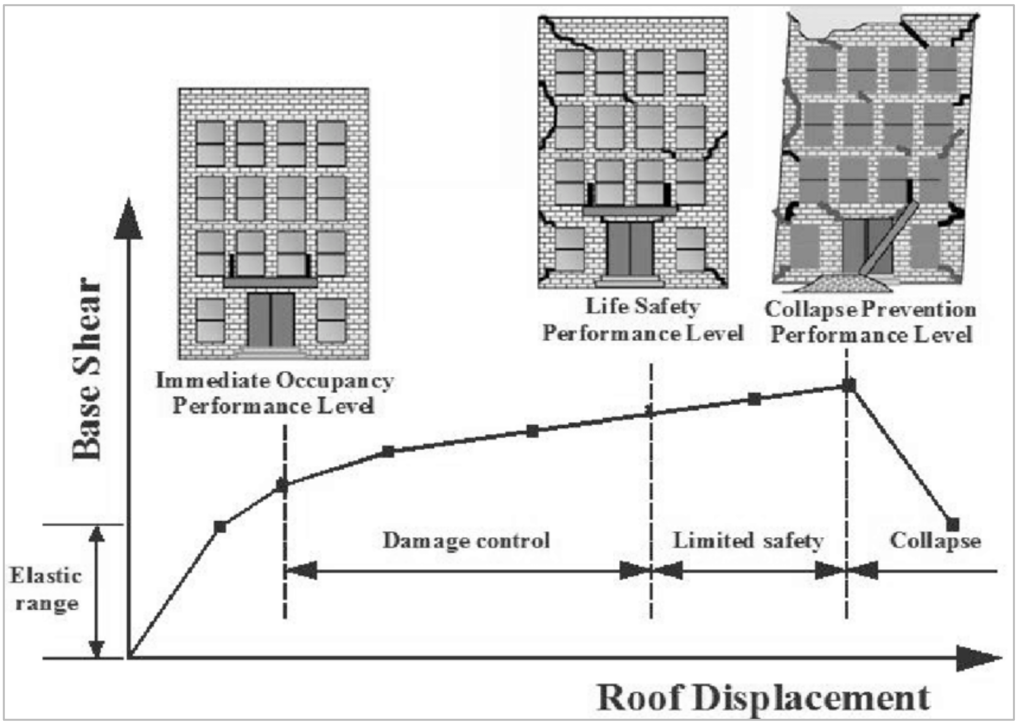


Figure 1. Capacity Curve of Structures with Performance Levels Illustration

2.2.1. Immediate Occupancy (IO)

The immediate occupancy (IO) limit state indicates that the structure remains safe to occupy with minor, easily repairable damages. According to the FEMA 356 guidelines, buildings classified under this limit state will have only minor structural and non-structural damage. The structure's main components, such as beams, columns, and load-bearing walls, retain their strength and stiffness, ensuring the safety and usability of the building immediately after an earthquake. Typical repairs include minor cracks in walls, slight damage to finishes, and minor deformations in non-load-bearing elements. This state is critical for facilities that must remain operational after a seismic event, such as hospitals and emergency response centers [5].

2.2.2. Life Safety (LS)

In the life safety (LS) limit state, the structure sustains significant damage but avoids total or partial collapse. FEMA 356 defines this level as a condition where the structure has significant structural damage and non-structural components are extensively damaged, but the risk of life-threatening injury is low. While the building may be economically repairable, the cost of such repairs is often high, sometimes comparable to complete reconstruction. This limit state ensures that while the building may not be immediately usable, it provides a reasonable margin of safety against collapse, allowing occupants to evacuate safely. Key indicators include large cracks in structural elements, significant spalling of concrete, and partial yielding of steel components [5].

2.2.3. Collapse Prevention (CP)

The collapse prevention (CP) level signifies severe post-earthquake damage that may lead to total or partial collapse. According to FEMA 356, buildings in this state have suffered extensive damage to both structural and non-structural elements, making the structure unrepairable and unsafe for occupancy. The primary goal at this limit state is to prevent loss of life by ensuring that the structure does not collapse, though it may be on the verge of it. Typical characteristics include large, irreparable cracks, significant deformations, and a high likelihood of failure under further loading. Repairing the structure is generally impractical due to the extensive damage, and demolition and reconstruction are usually necessary [5].

2.2.5. Assessing Performance Levels

Nonlinear static pushover analysis is employed to estimate the building's capacity. To calculate the seismic demand, we use the Capacity Spectrum Method (CSM). These results are then compared and interpreted based on the Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) limit states. This comparison allows for a clear understanding of how the building will perform under different seismic conditions [6, 9].

2.3 Seismic Vulnerability of RC Building

Albania's seismic history underscores the significant risk faced by RC buildings, many of which were constructed without modern seismic provisions. This section explores specific buildings, locations, and timeframes, supported by evidence to provide a comprehensive analysis of historical seismic events, construction practices, and the evolution of seismic codes.

Many residential, commercial, and public buildings in Albania, especially those built before the 1990s, were constructed without modern seismic detailing. These include buildings in major cities such as Tirana, Durrës, and Shkodra. For instance, numerous residential buildings constructed in the 1960s and 1970s in Tirana were built according to Soviet-era standards, which did not fully address the seismic risks specific to Albania [26].

2.3.1. Historical Seismicity in Albania

Albania has experienced numerous significant earthquakes, notably impacting cities such as Shkodra, Durrës, and Vlora. Historical records from the III-II century until 1990 indicate that Albania was hit by 89 earthquakes with an intensity above VIII on the MSK-64 scale, 15 of which exceeded IX intensity [27]. Notable seismic events include the 1967 Dibër earthquake, the 1979 Montenegro earthquake, and the most recent 2019 Durrës earthquake, which caused substantial damage and loss of life, emphasizing the need for robust seismic performance evaluations [28].

The 2019 Durrës earthquake, with a magnitude of 6.4 Righter, resulted in significant structural damage and numerous fatalities, particularly affecting RC buildings constructed prior to modern seismic codes. This event highlighted the critical vulnerabilities in older construction practices and underscored the urgent need for reassessment and retrofitting of such buildings to mitigate future risks [29].

2.3.2. Construction Practices and Seismic Codes

During the communist era, construction practices in Albania relied heavily on Soviet design standards, which did not fully account for the region's seismic risks [26]. Many buildings constructed during this period lack adequate seismic detailing and reinforcement, making them vulnerable to seismic events [30]. Despite updates to seismic regulations post 1989, older buildings remain at significant risk and require comprehensive assessments and potential retrofitting [8].

Albania is situated in a seismically active region characterized by significant tectonic activity. The country is influenced by several seismogenic zones, including the Ionian-Adriatic coastal belt, the Drini seismic belt, and the Elbasan-Dibër seismic belt, among others. These zones are responsible for generating frequent and sometimes severe seismic events. Historical records indicate that Albania has experienced numerous earthquakes with magnitudes ranging from moderate to strong, leading to substantial damage and loss of life [8].

2.4 Previous Studies on Zeus-NL Modeling

Several studies have been conducted using Zeus-NL for modeling and analyzing the seismic performance of structures. Elnashai, Papanikolaou, and Lee provided a comprehensive manual for Zeus-NL, detailing its capabilities and applications in inelastic analysis of structures [10]. Mwafy and Elnashai used Zeus-NL to compare static pushover and dynamic collapse analyses of reinforced concrete buildings, demonstrating the tool's effectiveness in evaluating seismic performance [16]. Kanvinde applied nonlinear dynamic analyses with Zeus-NL to predict global failure mechanisms in structures under seismic loading, highlighting the importance of advanced modeling techniques in seismic engineering [21].

Furthermore, research by Bilgin, Hysenlliu, and Leti evaluated the seismic vulnerability and capacity of typical existing reinforced concrete buildings in Albania using Zeus-NL, providing valuable insights into the structural performance and potential retrofitting measures [11]. Their subsequent study continued this line of investigation, confirming the reliability and applicability of Zeus-NL in assessing the seismic performance of Albanian buildings [4].

These studies collectively underscore the robustness and utility of Zeus-NL in seismic performance evaluation and provide a solid foundation for its application in the current research.

2.5 Linear vs. Nonlinear Analysis

Structural analysis can be broadly classified into linear and nonlinear methods. Each has distinct characteristics and applications, which are compared in this section to emphasize the importance of nonlinear analysis in seismic performance evaluation.

2.5.1. Linear Analysis

Linear analysis is the fundamental and initial method for structural analysis, providing basic definitions and parameters. It assumes that the relationship between applied loads and structural response is linear, meaning that deformations are directly proportional to the loads. This method simplifies calculations but does not account for the inelastic behavior of materials and components, making it less accurate for seismic performance evaluations.

Linear static analysis applies gradually increasing loads until they reach their full magnitude, remaining constant over time. This method neglects inertial and damping forces and assumes a linear relationship between loads and responses. Despite its limitations, linear static analysis is still used for preliminary design and assessments [5].

Linear dynamic analysis, such as modal response spectrum analysis, calculates modal shapes and natural frequencies. It provides insights into the dynamic behavior of structures under seismic loads but still assumes a linear response, limiting its accuracy for evaluating inelastic behavior [5, 9].

2.5.2. Nonlinear Analysis

Nonlinear analysis addresses the limitations of linear methods by considering the inelastic behavior of materials and components. This method provides a more realistic representation of structural performance under seismic loads, capturing the complex interactions and failure mechanisms that occur beyond the elastic range.

Nonlinear static analysis, also known as pushover analysis, involves applying gradually increasing lateral loads to a structure until it reaches a target displacement. This method identifies the building's capacity, potential failure mechanisms, and performance levels by plotting pushover curves [13].

Nonlinear dynamic analysis evaluates the response of structures to dynamic loads, capturing the inelastic behavior and complex interactions between structural components. This method provides detailed insights into the building's performance under various seismic scenarios [9].

2.5.3. Comparison and Importance of Nonlinear Analysis

Nonlinear analysis is crucial for accurate seismic performance evaluation as it accounts for the inelastic behavior of structures, which linear methods cannot capture [9]. By providing a realistic representation of structural responses, nonlinear analysis helps identify potential vulnerabilities and design effective retrofitting measures [5], ensuring the safety and resilience of buildings during earthquakes [1].

2.6 Seismic Performance of RC Buildings in Albania

Several studies have focused on evaluating the seismic performance of RC buildings in Albania, particularly those constructed during the 1980s [8, 12].

2.6.1. Studies on Typical Albanian RC Buildings

Bilgin [12] conducted a comprehensive study on the seismic performance of RC buildings in Albania, focusing on a typical 5-story building constructed in 1980. The study employed nonlinear static analysis to evaluate the building's response to seismic loading, highlighting significant vulnerabilities due to inadequate seismic detailing and reinforcement.

Elnashai [10] utilized Zeus-NL software to model and analyze the seismic performance of RC buildings, demonstrating its effectiveness in capturing nonlinear structural behavior and providing insights into potential failure modes.

2.6.2. Evaluation of Seismic Codes and Practices

Aliaj [8] assessed the evolution of seismic codes and construction practices in Albania, emphasizing the importance of updating and enforcing seismic regulations to improve building resilience. The study highlighted the need for systematic retrofitting programs to address the vulnerabilities of older buildings constructed under outdated codes.

2.7 Capacity Spectrum Method (CSM)

2.7.1. Introduction

The Capacity Spectrum Method (CSM) is a seismic performance evaluation technique that combines pushover analysis results with response spectra. Introduced by Freeman [31], CSM has become a widely used method for assessing the seismic performance of structures, providing a graphical representation of both the capacity and demand of a structure under seismic loads. The method involves plotting the capacity curve of a building (obtained from pushover analysis) against the demand spectra (representing seismic demand) to identify performance points and evaluate the building's behavior during an earthquake.

The objectives of the Capacity Spectrum Method are:

- To provide a visual comparison of a structure’s seismic capacity and demand [13].
- To determine performance points, which indicate the expected performance level of the structure during seismic events [13].
- To evaluate the effectiveness of various retrofitting measures by comparing the pre- and post-retrofit capacity spectra [13].

- To facilitate the performance-based design approach by allowing engineers to design structures that meet specific performance objectives under different seismic intensities [13].
- To provide a basis for the development of fragility curves and probabilistic seismic risk assessments [5].

2.7.2. Fundamentals of CSM

CSM integrates the capacity curve, which represents the structural capacity, with the demand spectrum, which represents the seismic demand. The intersection of these curves, known as the performance point, provides a clear indication of how a structure is expected to perform under a given seismic event.

2.7.2.1. Capacity Curve

The capacity curve, derived from nonlinear static pushover analysis. It plots the base shear versus roof displacement (*Figure 2*), illustrating the progression of structural response from elastic behavior to plastic deformation and eventual collapse [9]. This curve is crucial for understanding the strength and ductility of the structure.

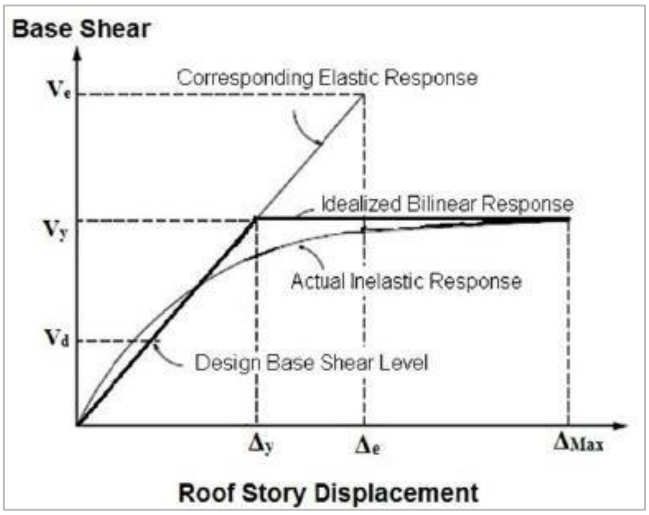


Figure 2. Sample Capacity Curve Illustration for Nonlinear Analysis

2.7.2.2. Demand Spectrum

The demand spectrum is a representation of seismic demand. It is typically presented in Acceleration-Displacement Response Spectrum (ADRS) format (*Figure 3*), where spectral acceleration is plotted against spectral displacement. This transformation allows for a direct comparison with the capacity curve [31].

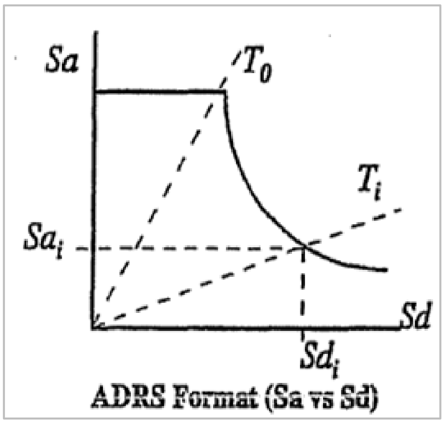


Figure 3. Acceleration-Displacement Response Spectrum

2.7.2.3. Performance Point

The performance point is the intersection of the capacity curve and the demand spectrum. It represents the expected displacement and corresponding base shear for a given seismic event, providing a measure of the structure's performance level. The performance point helps in identifying whether the building meets the desired performance objectives, such as Immediate Occupancy, Life Safety, or Collapse Prevention [13].

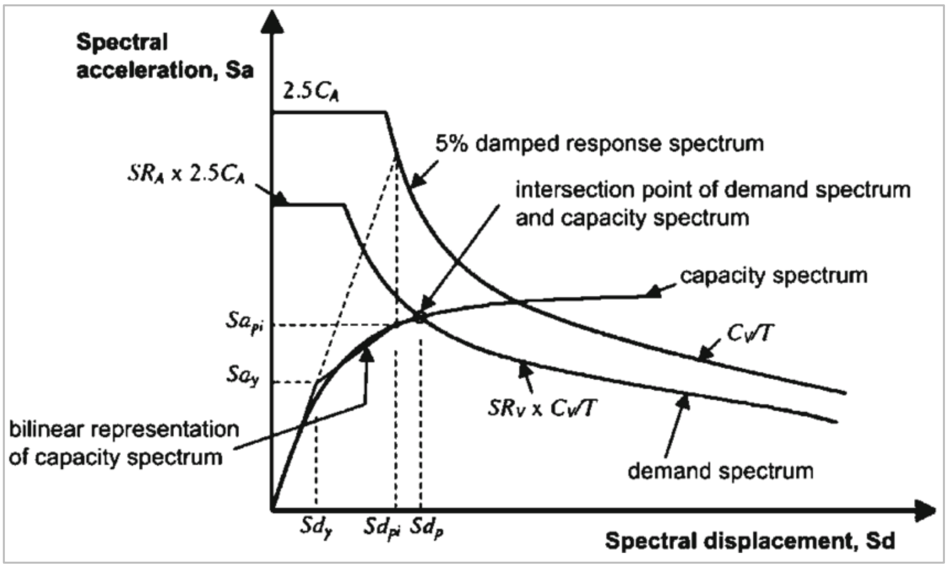


Figure 4. Performance Point According to the Capacity Spectrum Method ***[13]***

2.8 Application of CSM in Seismic Evaluation

CSM is applied by following a systematic procedure to evaluate the seismic performance of structures. The steps involved in applying CSM are [9, 31]:

- Conducting Nonlinear Static Pushover Analysis: Develop a detailed finite element model of the structure and perform a nonlinear static pushover analysis to generate the capacity curve.
- Developing the Demand Spectrum: Transform the seismic demand into ADRS format using site-specific seismic hazard data.
- Superimposing Capacity and Demand Curves: Plot the capacity curve and demand spectrum on the same ADRS graph.
- Identifying the Performance Point: Determine the performance point where the capacity curve intersects the demand spectrum.
- Evaluating Performance Levels: Assess the performance of the structure based on the location of the performance point relative to predefined performance objectives (e.g., Immediate Occupancy, Life Safety, Collapse Prevention).

2.9 Case Studies Using CSM

Several case studies have demonstrated the effectiveness of CSM in evaluating the seismic performance of buildings.

2.9.1. Seismic Retrofit Evaluation

A study by Freeman evaluated the seismic performance of a retrofitted RC building using CSM. The capacity curve was developed from pushover analysis, and the demand spectrum was derived from site-specific seismic hazard data. The performance point indicated significant improvements in seismic performance post-retrofit, validating the effectiveness of the retrofitting measures [31].

2.9.2. Performance-Based Design

Chopra and Goel applied CSM to a newly designed RC building to ensure it met specific performance objectives. The capacity curve and demand spectrum were plotted, and the performance point confirmed that the building would achieve the desired performance level under the design earthquake, demonstrating the utility of CSM in performance-based design [32].

Furthermore, studies by Vian and Bruneau [33] involved shake table tests on RC structures, providing empirical data that supported the theoretical findings of CSM applications. Their research highlighted the method's capability to predict structural performance accurately under seismic conditions, reinforcing its utility in earthquake engineering.

2.10 General Properties of CSM

CSM offers several advantages and characteristics that make it a valuable tool in seismic performance evaluation:

- Graphical Representation: CSM provides a clear and intuitive graphical representation of both structural capacity and seismic demand, facilitating easy interpretation of results.
- Performance-Based Evaluation: By identifying performance points, CSM aligns with performance-based design principles, allowing engineers to design and retrofit structures to meet specific performance objectives.
- Flexibility: CSM can be applied to a wide range of structures and seismic scenarios, making it a versatile tool for seismic performance evaluation.
- Comprehensive Analysis: The integration of pushover analysis and response spectra provides a comprehensive evaluation of structural performance, capturing both the strength and ductility of the structure [9, 31].

2.11 CSM vs. Other Seismic Analysis Methods

Comparing CSM with other seismic analysis methods highlights its unique advantages and limitations:

- CSM vs. Nonlinear Static Pushover Analysis: While both methods use pushover analysis to develop the capacity curve, CSM integrates this with the demand spectrum to provide a more comprehensive evaluation. Pushover analysis alone does not account for varying seismic demands across different ground motions.
- CSM vs. Incremental Dynamic Analysis (IDA): IDA provides detailed insights into structural performance under varying intensity measures through a series of dynamic analyses, but it is computationally intensive. CSM offers a more

straightforward and less resource-intensive approach while still providing valuable performance insights [34].

- CSM vs. Time History Analysis: Time history analysis evaluates the response of structures to specific seismic events in detail, but it requires extensive computational resources and detailed ground motion records. CSM provides a balance between detailed evaluation and practical applicability, making it suitable for a wider range of projects [9].

CHAPTER 3

METHODOLOGY

3.1 Methodology overview

This study employs an analytical approach to evaluate the seismic performance of a typical reinforced concrete (RC) template building. The research design involves conducting nonlinear analyses using a combination of eigenvalue analysis, nonlinear static pushover analysis, and the Capacity Spectrum Method (CSM). The procedures include modeling the RC building in Zeus-NL software, performing eigenvalue analysis to determine the natural frequencies and mode shapes, executing nonlinear static pushover analysis to assess the building's capacity, and applying the CSM to compare the seismic demand with the building's capacity.

The process begins with eigenvalue analysis to determine the natural frequencies and mode shapes of the structure. Understanding these dynamic properties is crucial as they provide the foundation for further seismic performance evaluations and highlight the building's behavior under vibrational loads [9].

Next, the nonlinear static pushover analysis is performed to estimate the seismic capacity of the structure. This method involves applying a gradually increasing lateral load pattern to the building until it reaches a target displacement. By identifying weak points and assessing the overall capacity to withstand seismic forces, this analysis offers a realistic representation of the building's inelastic behavior under lateral loads [5].

Following the static pushover analysis, the Capacity Spectrum Method (CSM) is employed to calculate the seismic demand. The methodology used in this study for the implementation of CSM follows the guidelines of the ATC-40 standard. The CSM involves plotting the structure's capacity against the demand in a graphical format known as the capacity spectrum. This comparison allows for the assessment of performance levels and potential vulnerabilities by evaluating how the actual displacements induced by seismic forces compare with the building's capacity to withstand these displacements [35].

By integrating eigenvalue analysis, nonlinear static pushover analysis, and the Capacity Spectrum Method, this study aims to provide a comprehensive evaluation of the seismic performance of a five-story RC template building in Albania. This approach offers critical insights for improving the resilience of such buildings against earthquakes.

3.2 Development of structural model in Zeus-NL

The selected building is modelled using Zeus-NL, a robust software specifically designed for conducting nonlinear static and dynamic analyses utilizing finite elements [10]. Zeus-NL is highly effective for simulating complex structural behaviors, though it offers limited flexibility in modeling structures that lack symmetry or consist of diverse members. In our case, although the building maintains symmetry across its floor plans, variations in column dimensions and reinforcement occur across different story levels.

The modeling process in Zeus-NL begins by opening a new template, which provides options to develop either a 2D or 3D building model (*Figure 5*). The user selects the desired parameters, such as the number of bays, stories, and frames, specifying their respective dimensions in millimeters. Additionally, the type of analysis to be conducted later can also be specified at this stage, ensuring a tailored approach to the simulation.

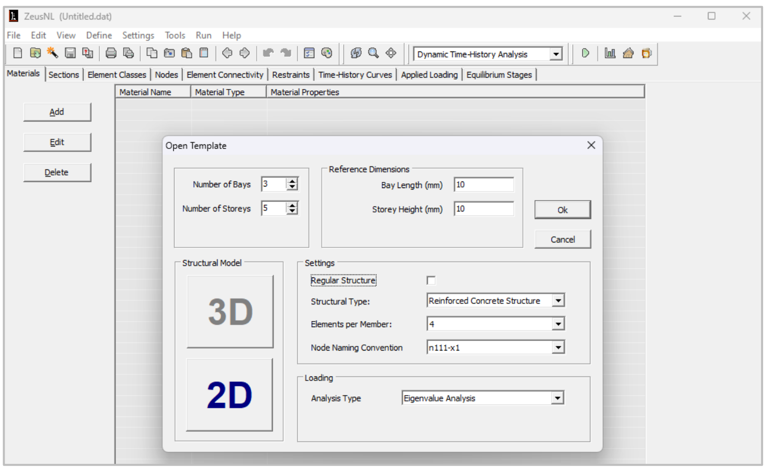


Figure 5. Structural Configuration and Layout of the RC Building

The 2D structure in the x-direction is developed, as visually presented in (*Figure 6*), illustrating the arrangement of nodes and their corresponding coordinates. The materials and their properties are defined according to the specifications outlined in the construction plan. The sections are designed, according to the dimensions and reinforcement requirements provided in the blueprint. Finally, element classes are incorporated with the corresponding sections, facilitating the subsequent connection of elements to their respective sections.

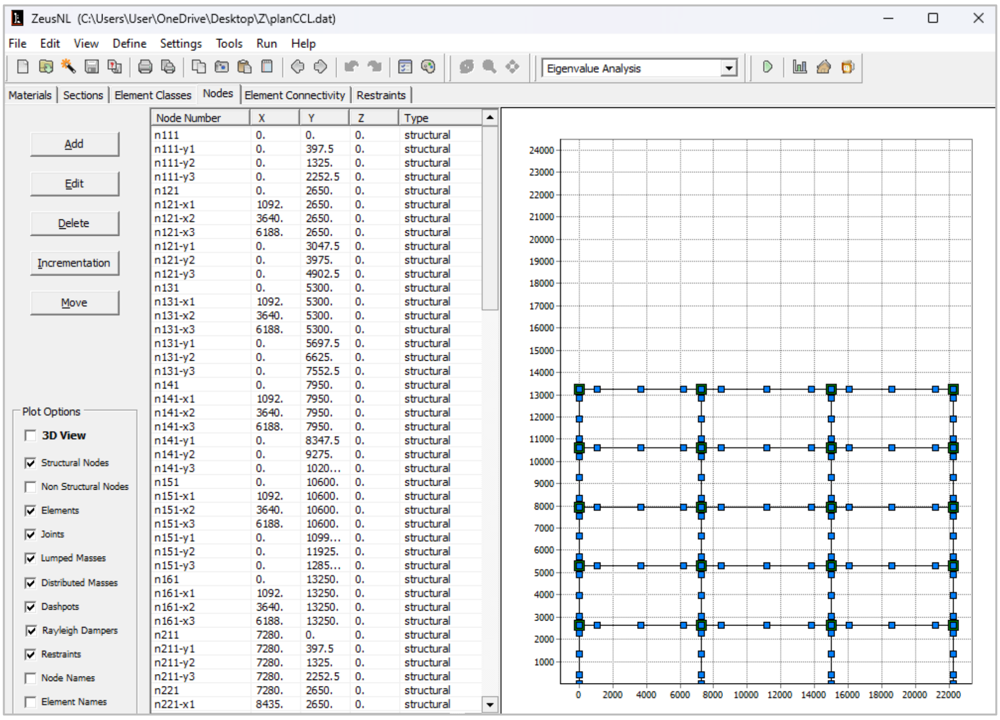


Figure 6. 2D Model in X-Direction Developed in Zeus-NL

Following the completion of section design, the next step involves manually adding the weight of the slabs. Zeus-NL provides the option to incorporate mass either as lumped or distributed. The calculation of slab type and weight is facilitated by utilizing Excel formulas tailored for each specific case, as shown in *Table 1* and *Table 2.* This precise calculation ensures accurate distribution of loads within the structural model.

Table 1. Specifications of Slab Types and Dimensions

SLAB TYPE			
Slab No.	Length [m]	Width [m]	Slab Type
S1	7.20	4.20	Two-way
S2	7.05	4.20	Two-way
S3	7.20	4.20	Two-way
S4	7.20	3.40	One-way
S5	7.05	3.40	One-way
S6	7.20	3.40	One-way
S7	7.20	4.20	Two-way
S8	7.05	4.20	Two-way
S9	7.20	4.20	Two-way

Table 2. Load Calculation for Slabs

LOAD CALCULATION		
Conc. Unit weight	25	[kN/m^3]
Slab thickness	0.1	[m]
Gk =	2.5	unit weight x thickness
Qk =	2	live load
Load [kN/m^2] =	3.1	1.0*Gk+0.3*QK

Once the type of slab and the load per unit area are determined, the loads are efficiently distributed by dividing them into geometric shapes such as rectangles, triangles, and trapezoids. This is accomplished by multiplying the load in kilonewtons per square meter (kN/m^2) by the height of each geometric shape, as illustrated in (*Figure 7*). For 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, providing the load in kilonewtons (kN).

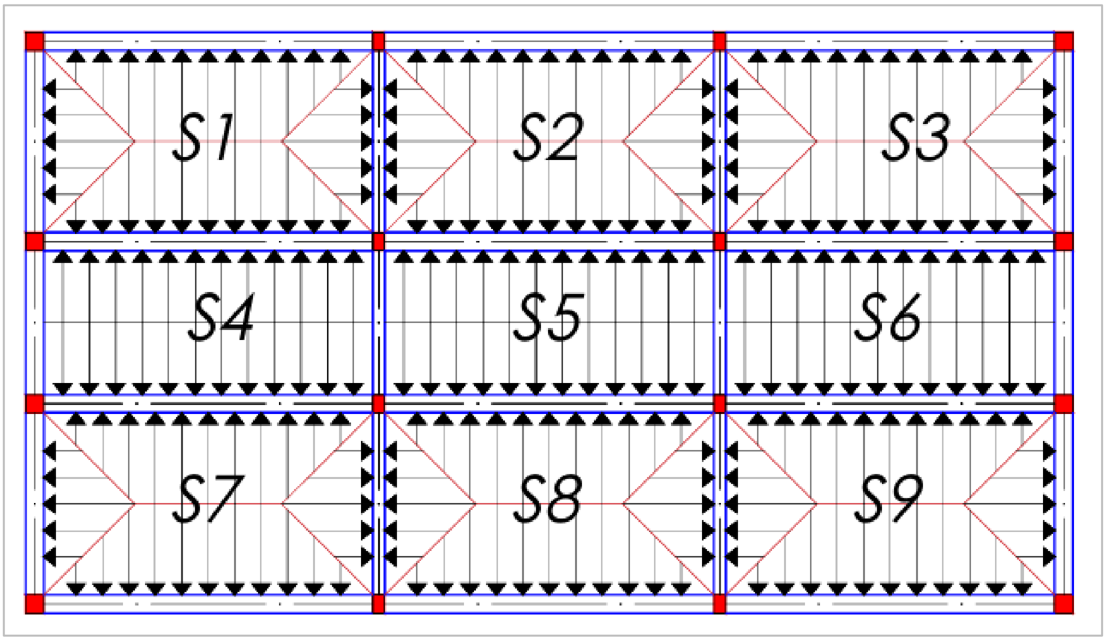


Figure 7. Geometric Load Distribution Method for Slabs

In addition to slab loads, the weights of columns and beams must be considered. The weight of each beam and column section is calculated by finding its volume and multiplying it by the concrete unit weight. These weights are then assigned to their respective frame directions, providing the necessary beam and column loads.

These loads are incorporated into the element classes either as lumped or distributed mass. The next phase involves connecting the elements with their corresponding sections, while also integrating the calculated masses into the respective nodes. It is crucial to verify that restraints have been automatically applied to the bottom nodes in the x-direction, ensuring stability and accuracy in the model. These procedures are systematically implemented for every design conducted in Zeus-NL, providing a comprehensive and detailed structural analysis.

3.3 Procedures for nonlinear analysis

The procedures for nonlinear analysis in this study include eigenvalue analysis, static pushover analysis, and the capacity spectrum method. These analyses are performed using Zeus-NL software to evaluate the seismic performance of a selected five-story reinforced concrete building. Each method provides unique insights into the building's behavior under seismic loading, helping to assess its structural integrity and identify potential areas for improvement.

3.3.1. Eigenvalue Analysis

Eigenvalue analysis is conducted to determine the natural frequencies and mode shapes of the building, which are essential for understanding its dynamic behavior. This analysis helps verify that all modal masses are properly assigned and ensures the accuracy of the finite element model developed in Zeus-NL [10]. The fundamental period of the building is obtained by solving the eigenvalue problem for the system's stiffness and mass matrices (*Figure 8*). This step is crucial for subsequent dynamic analyses as it provides the basis for evaluating the building's response to seismic excitation [9].

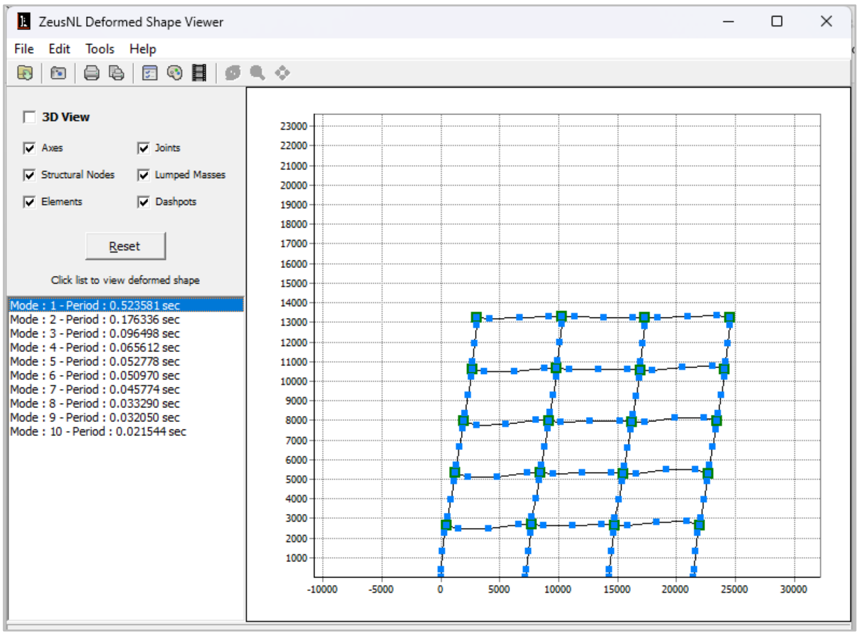


Figure 8. Performing Eigenvalue Analysis in Zeus-NL

The eigenvalue analysis is conducted by considering the self-weight of the building. It is important to note that Zeus-NL does not automatically calculate the mass of the elements. However, it provides the capability to assign masses either as nodal masses or distributed masses over the beams. In this study, the masses of slabs, beams, and columns, along with 0.3 times the live load, are calculated and assigned as lumped masses to the nodes.

3.3.2. Static Pushover Analysis

Static pushover analysis is a simplified nonlinear analysis technique used to estimate the seismic demands of structures [5]. This method involves applying a gradually increasing lateral load pattern to the structure until it reaches a target displacement. The procedure aims to evaluate the building's capacity to withstand increasing lateral loads until failure, identifying weak points and understanding its overall capacity to resist seismic forces. The analysis produces pushover curves, which plot base shear versus roof displacement, providing a graphical representation of the structure's capacity (*Figure 9*).

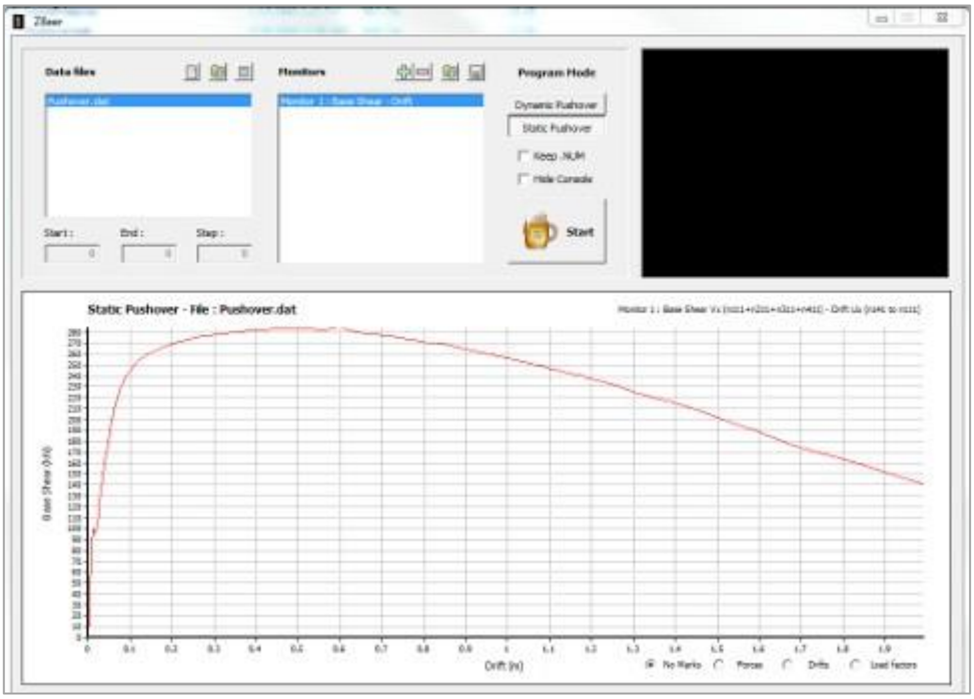


Figure 9. Example of Performing Static Pushover Analysis in Zeus-NL

To generate pushover graphs, employing a method known as modal combinations (MMC) is essential to enhance the accuracy of the structure's response. This involves considering three distinct lateral load patterns: uniform (rectangular distributed load), triangular (upside-down triangular), and modal. The process starts by selecting Static pushover analysis within the Zeus software platform. Subsequently, coefficients derived from the deformed shape of the structure, obtained through earlier Eigenvalue analysis, are utilized to allocate loads in a modal pattern. Upon specifying monitoring points for base shear (along the y-axis) and drift (along the x-axis), the analysis is executed. Following these steps, a static pushover graph is generated for each load pattern. These values are then exported to Excel for further analysis and visualization. The same procedure is repeated for each load pattern, and subsequently, all Excel graphs are merged to facilitate the comparison of drift between load patterns.

3.3.3. Capacity Spectrum Method

The capacity spectrum method is employed to compare the building's capacity to withstand displacements with the actual displacements induced by seismic forces [6, 13]. This method integrates the results from the static pushover analysis to generate capacity curves, which are then superimposed on demand spectra derived from seismic ground motion records. By plotting the capacity curve against the demand spectrum, performance levels and potential vulnerabilities can be assessed. This approach provides valuable insights into the behavior of structures under seismic loading conditions, aiding in the design of resilient buildings.

3.3.3.1. Overview of the KTP-2-78 Seismic Design Code

The introduction of the KTP-2-78 code in 1978 marked a significant evolution in Albania's approach to designing structures for seismic resilience. Based on Russian technical codes, KTP-2-78 emphasized adequate resistance distribution, structural mass and stiffness distribution, and favorable mechanisms during plastic deformations. The code's principles included ensuring stability even after partial structural collapse and addressing seismic actions comprehensively [36].

3.3.3.2. Seismic Load Calculations in KTP-2-78 and KTP-N2-89

KTP-2-78 employs a specific formula for seismic load calculations, incorporating various factors to represent seismic intensity, structural behavior, and dynamic response. The formula is as follows [13, 5]:

$$\boldsymbol{S_k = K_c \cdot \beta \cdot \eta_k \cdot 1.5 \cdot Q_k} \qquad \text{(Equation 1)}$$

Where:

- S_k represents the seismic force,
- Q_k includes loads inducing inertia forces such as self-weight, dead load, live load, and snow load,
- K_c is the seismic coefficient,
- η_k accounts for the mode shape coefficient of the building,
- β is the dynamic coefficient dependent on the structural period.

The most recent Albanian seismic design code, titled "Technical Design Code for Seismic Resistance" [30], was introduced in 1989, representing a significant advancement from previous versions such as KTP-2-78 (*Figure 10*). This code includes comprehensive detailing of reinforced concrete elements with a specific focus on seismic effects. Notably, it incorporates seismic microzonation maps developed between 1984 and 1991, which assess intensity based on these maps and the importance classification of buildings [36].

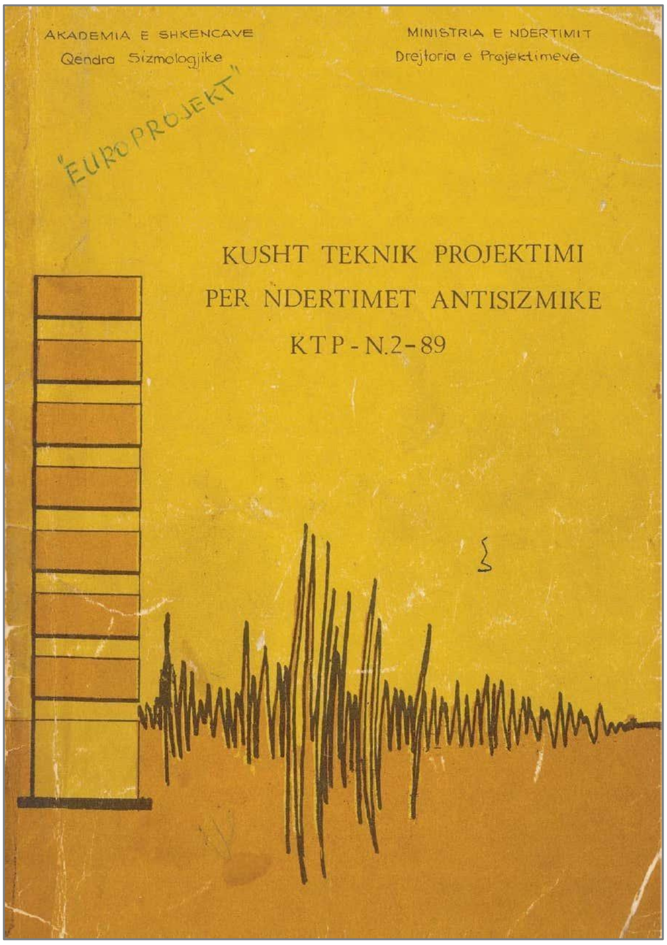


Figure 10. Seismic design code of 1989 ***[30]***

For locations lacking specific microzonation data, the seismic intensity is determined from a general seismic map, taking into account the ground type and the building's importance class. KTP-N.2-89 meticulously describes structural uniformity, considering factors such as the geometrical shape of the building, the description of structural members, construction materials, and plastic hinge mechanisms [36].

The design methodology in KTP-N.2-89 employs spectral analysis using a well-defined design response spectrum. This method includes a simplified analysis utilizing the fundamental period and first mode shape, described by the following empirical formula [13, 5]:

$$\boldsymbol{S_a = k_E \cdot k_r \cdot \psi \cdot \beta \cdot g} \quad \text{(Equation 2)}$$

Where:

- S_a represents the spectral acceleration of the horizontal seismic component,
- k_E is the seismic coefficient,
- k_r is the importance coefficient of the building type,
- ψ is the structural behavior coefficient under seismic loading,
- β is the dynamic coefficient calculated based on the structural period,
- g is the acceleration due to gravity [36].

All the coefficients are found in KTP-N.2-89, *Table 3 & Table 4*.

Table 3. Seismic Coefficient According to Soil Category and Seismic Intensity (MSK-1964)

Soil category	**Seismic coefficient k_E**		
	Intensity VII	**Intensity VIII**	**Intensity IX**
I	0.08	0.16	0.27
II	0.11	0.22	0.36
III	0.14	0.26	0.42

- k_r=1.0 - importance coefficient, Table 4-a in KTP-N.2-89 [30]
- ψ=0.28 - structure coefficient, Table 5 in KTP-N.2-89 [30]

Table 4. Dynamic Coefficient (β_i)

β_i	**Soil category**
$0.65 \leq \beta_i = 0.7/T_i \leq 2.3$	I
$0.65 \leq \beta_i = 0.8/T_i \leq 2.0$	II
$0.65 \leq \beta_i = 1.1/T_i \leq 1.7$	III

Since 1990, there have been no updates to the Albanian seismic design code, and KTP-N2-89 remains in use. However, the adoption of Eurocodes began in 2012, marking a shift towards integrating European standards into Albanian practice [36].

3.3.3.3. Fundamental Concepts of Performance-Based Evaluation

Performance-based assessment employs various nonlinear analysis procedures to determine performance points for reinforced concrete structures. Notable methods in contemporary literature include the Capacity Spectrum Method (CSM) detailed in ATC-40 [13] and the displacement coefficient method [37, 38]. Performance-Based Earthquake Engineering (PBEE) has emerged as a rapidly developing concept aimed at designing buildings to meet performance objectives under severe seismic events through various analysis procedures. The primary goal of PBEE is to ensure that buildings perform adequately during earthquakes by achieving specific performance objectives through detailed and systematic analyses [39].

In this study, the Capacity Spectrum Method (CSM) is employed to conduct the seismic performance assessment of the selected template reinforced concrete building.

3.3.3.4. Performance Level Assessment

Recent codes, including FEMA 356 and Eurocode 8, present three main boundaries regarding structural behavior from the initial stage to collapse, referred to as limit states. These limit states are defined as Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) [5, 37] (*Figure 11*).

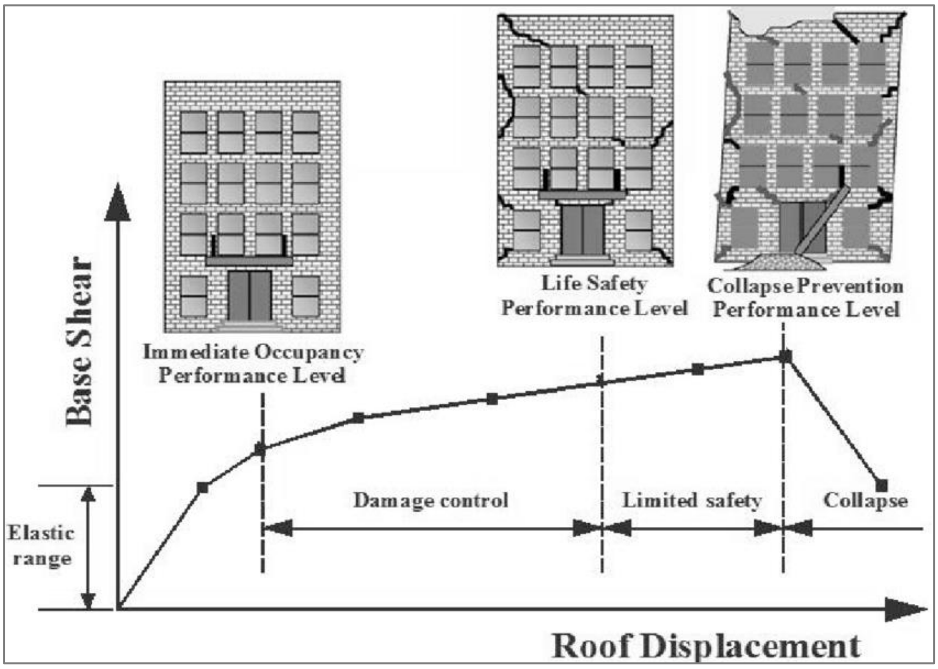


Figure 11. Expected Building Response and Damage Under Seismic Events

The FEMA 356 guidelines provide detailed descriptions of damage control for building performance levels across all structure types. For the selected templates in this study, performance levels will be determined directly in the pushover curve. The software used for the analysis Zeus-NL does not automate the determination of plastic hinge formations in structural elements. Therefore, performance levels will be assigned directly in the pushover curve based on empirical observations and research [40].

The immediate occupancy (IO) level is defined at the end of the elastic curve of the pushover. The life safety (LS) level 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 (*Figure 12*) [5, 13].

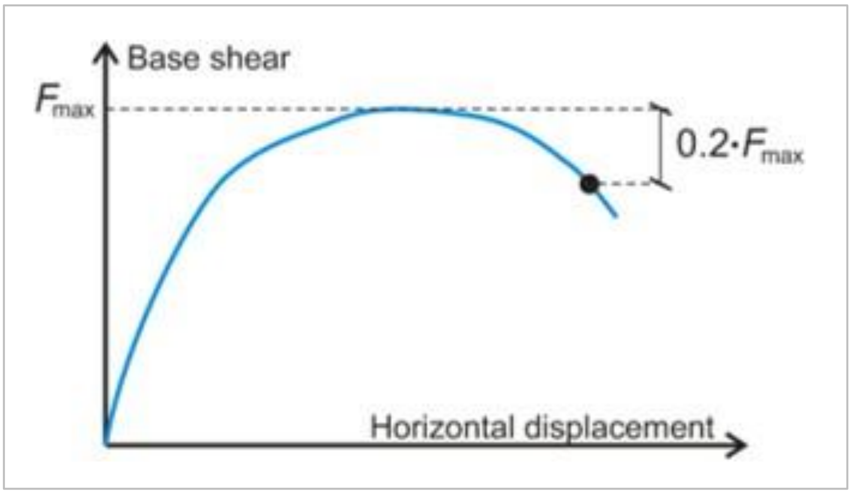


Figure 12. Defining the Collapse Prevention (CP) Limit State at the Structural Level based on previous studies ***[40]***

3.3.3.6. Evaluation of Seismic Capacity and Demand

To apply the Capacity Spectrum Method using the guidelines from KTP-2-78, a systematic procedure is followed. This involves several key steps to transform pushover analysis data into a capacity spectrum and compare it with the demand spectrum.

The assessment of seismic capacity and demand is guided by the ATC-40 standard [13]. To generate capacity curves for the template building selected in this study, a static nonlinear (pushover) analysis is performed. The results are initially plotted on a 2D graph, with base shear on the vertical axis and global drift on the horizontal axis. The procedure followed is illustrated in (*Figure 13*).

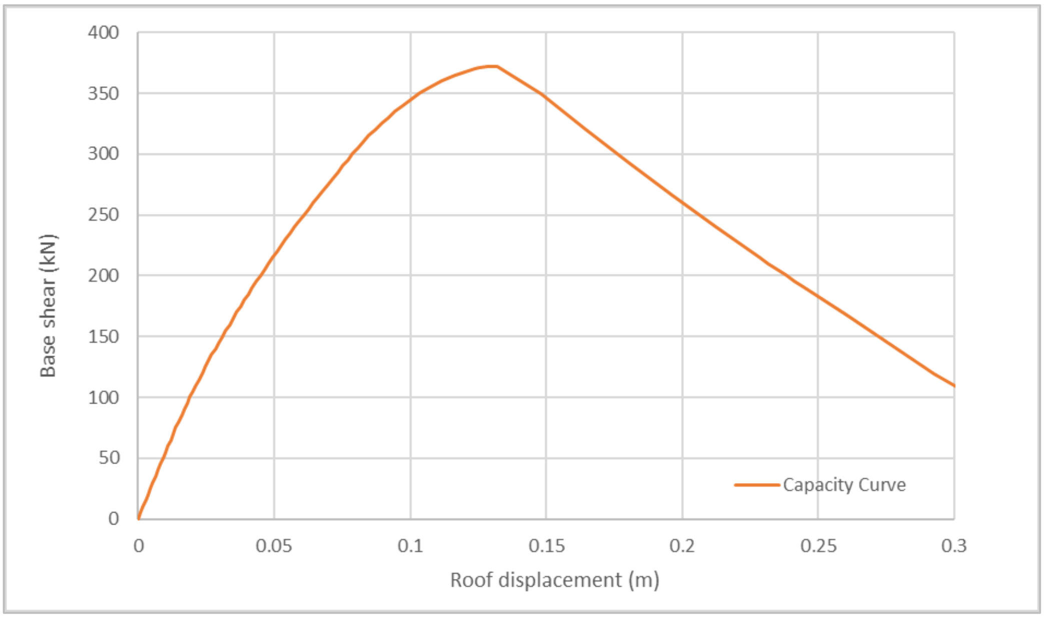


Figure 13. Capacity Curve Example

Following the generation of the capacity curve, a transformation to the Acceleration-Displacement Response Spectrum (ADRS) format is necessary. This conversion is performed using specific equations to convert base shear and roof displacement into spectral acceleration and spectral displacement. The equations utilized are as follows [5, 13]:

$$s_{ai} = \frac{v_i/w}{a1} \quad \text{(Equation 3)}$$

$$s_{di} = \mu \frac{\Delta roof/w}{\text{PF1} * \phi 1, roof} \quad \text{(Equation 4)}$$

$$PF_1 = \frac{\sum_{i=1}^{N}(w_i \phi_i)/g}{\sum_{i=1}^{N}(w_i \phi i^2)/g} \quad \text{(Equation 5)}$$

$$\alpha 1 = \frac{[\sum_{i=1}^{N}(w_i \phi_i)/g]}{[\sum_{i=1}^{N} w_i/g]\,[\sum_{i=1}^{N}(w_i \phi i^2)/g]} \quad \text{(Equation 6)}$$

Where:

- V_i represents the base shear at any point on the capacity curve,
- W is the weight of the structure,
- Δ_{roof} is the roof displacement,
- α_1 is the modal mass coefficient,
- PF_1 is the modal mass participation factor,
- $\Phi_{1,roof}$ is the roof level amplitude in the first mode.

Additionally, bilinearization calculations are performed for each pushover curve. Bilinearization is necessary to effectively evaluate the damping and reduce the spectral demand. Developing bilinear lines requires determining the points a_{pi} and d_{pi} shown in (*Figure 14*), known in ATC-40 as the "trial performance point" used to develop a reduced scale of the response spectrum demand.

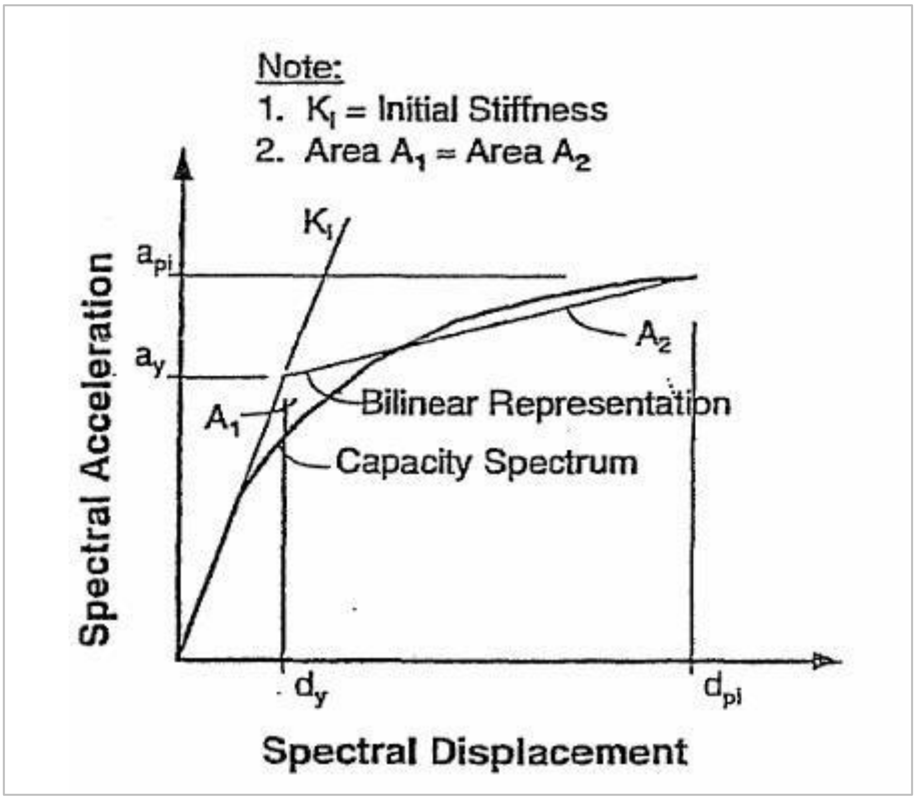


Figure 14. Conversion from Pushover Curve to Seismic Capacity Curve with Bilinearization ***[13]***

Subsequently, the development of the demand spectrum involves converting the standard seismic response spectrum to the ADRS format (*Figure 15*). This conversion is performed using the equation:

$$s_{di} = \frac{T_i^2}{4\pi^2} s_{ai} g \qquad \text{(Equation 3)}$$

Where:

- Ti is the structural period,
- g is the acceleration due to gravity.

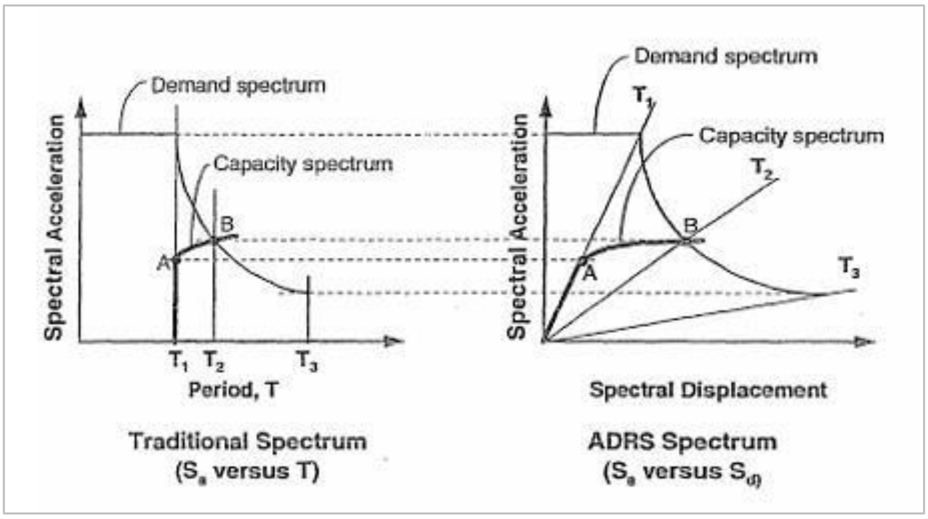


Figure 15. Transformation from Standard Format to ADRS Format ***[13]***

3.3.3.7. Modal Displacement Demand and Performance Point Determination

ATC-40 provides three procedures for determining modal displacement demand: Procedure A, Procedure B, and Procedure C. For this study, Procedure A is used as it offers a straightforward method for calculation and is suitable for programming automation [13].

After bilinearization of each pushover curve are performed, two values must be specified: a_y, d_y and a_{pi}, d_{pi}. The first value represents the end of the elastic segment of the bilinear line, while a_{pi}, d_{pi} represents the far end of the bilinear lines (*Figure 14*). These points are based on the equal displacement approximation using the elastic region of the curve. After properly locating both points on the graph, the equivalent viscous damping (5% damped) is calculated using the formula below:

$$\beta_{eff} = \frac{63.7k(a_y d_{pi} - d_y a_{pi})}{a_{pi} d_{pi}} + 5 \qquad \text{(Equation 3)}$$

Where k is the damping modification factor, taken as 0.33 for structural behavior type C, which represents poor hysteretic behavior [13].

The spectral reduction factor is then derived using:

$$S_{RA} = \frac{3.21 - 0.68 ln(\beta_{eff})}{2.12} + 5 \qquad \text{(Equation 3)}$$

The values from the elastic response spectrum (5% damped) are reduced using the formula: $2.5*CA*SR_A$, where CA is taken as 0.4 for building behavior types A, B, and C [13].

The final step requires extending the equally displaced linear segment from the bilinear lines and finding the intersection with the reduced response spectrum. This intersection point is then compared with the intersection between the reduced response spectrum and the seismic capacity curve ($a_{pi_{new}}$, $d_{pi_{new}}$) as shown in (*Figure 16*).

The distance between a_{pi}, d_{pi} and $a_{pi_{new}}$, $d_{pi_{new}}$ must satisfy the ATC-40 condition: $0.95d_{pi} \leq d_{pi_{new}} \leq 1.05d_{pi}$

If this condition is satisfied, the performance point determination is correct. If not, the new point $a_{pi_{new}}$, $d_{pi_{new}}$ becomes a_{pi}, d_{pi} and the process repeats. This iterative process can be time consuming, thus an automation procedure was prepared using Python V.3.3 to expedite the process [41].

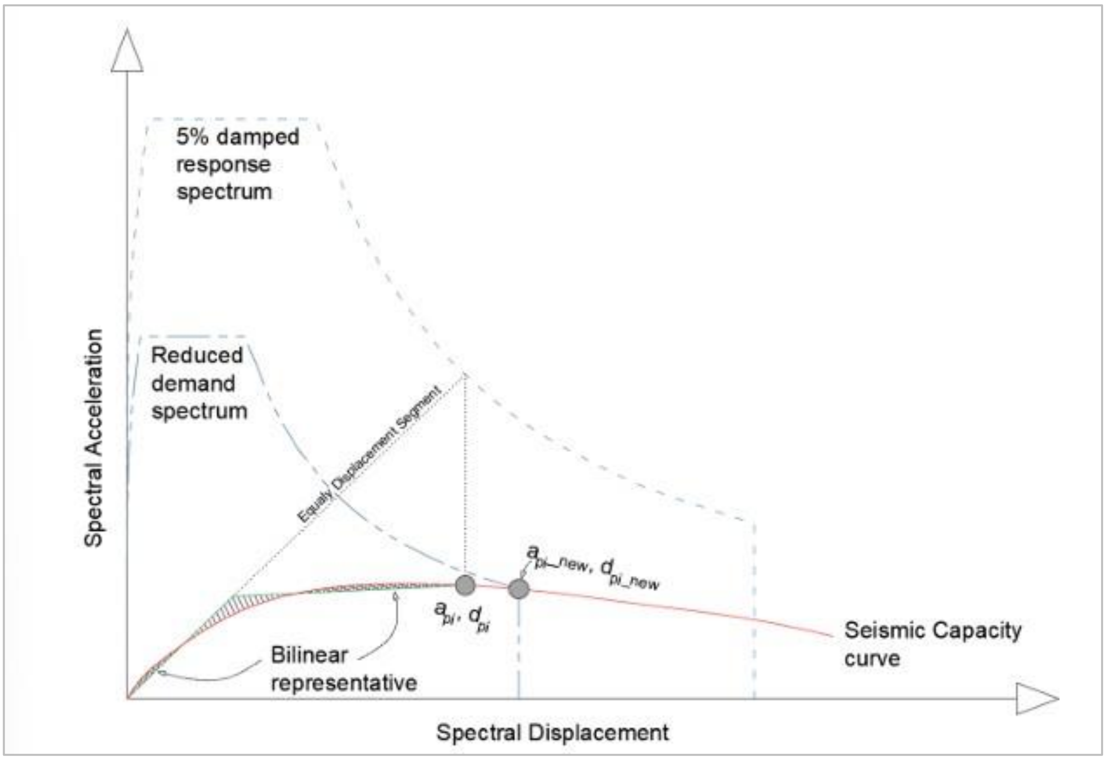


Figure 16. Calculating the Performance Point Using Procedure A ***[42]***

CHAPTER 4

MODELLING IN ZEUS-NL

4.1 Software Overview

The main analyses conducted in this study utilize Zeus-NL [10], a powerful software tool capable of performing both static and dynamic assessments. Zeus-NL was selected for its proficiency in executing nonlinear dynamic time-history, conventional and adaptive pushover, and eigenvalue analyses. This program offers a wide range of materials to choose from, such as concrete, steel, and composite sections, while employing finite elements from its extensive library to accurately simulate structural models. It handles both constant and variable loads, encompassing various factors like forces, displacements, and acceleration. Distinguishing itself from similar software packages, Zeus-NL simplifies dynamic analysis through intuitive, user-friendly steps, employing a fully visual interface. This section provides a concise overview of relevant information.

4.2 Performing Analysis in Zeus-NL

This section provides an in-depth look into the advanced functionalities of Zeus-NL, facilitating a comprehensive exploration of the program's capabilities. Additionally, it assists in developing a deeper understanding of the procedures involved in modeling and conducting analyses, thereby enhancing proficiency in effectively utilizing the software.

4.2.1. Analysis Type

In Zeus-NL six types of analyses can be conducted as listed below and shown in (*Figure 17*):

- Dynamic time-history analyses
- Static time-history analyses
- Conventional pushover
- Adaptive pushover
- Eigenvalue analyses

When switching analyses type, cubic and joint elements are versatile, while mass elements like dmass and lmass are only necessary in dynamic, eigenvalue, and adaptive pushover analyses, not in static analyses. Similarly, damping elements such as ddamp and rdamp are specifically required for dynamic analysis. Additionally, in dynamic analysis, support degrees of freedom (DOF) need to be released in the direction of earthquake motion to apply acceleration input effectively. For instance, if a node is fully supported and subjected to earthquake motion in the x-direction, the x-restraint should be released. If earthquake motion occurs in both x- and y-directions, the supported DOF are adjusted accordingly. Furthermore, whenever the user switches the analysis type, the program prompts them about necessary adjustments, like removing mass and damping elements and modifying boundary conditions, to ensure accuracy and consistency in the analysis.

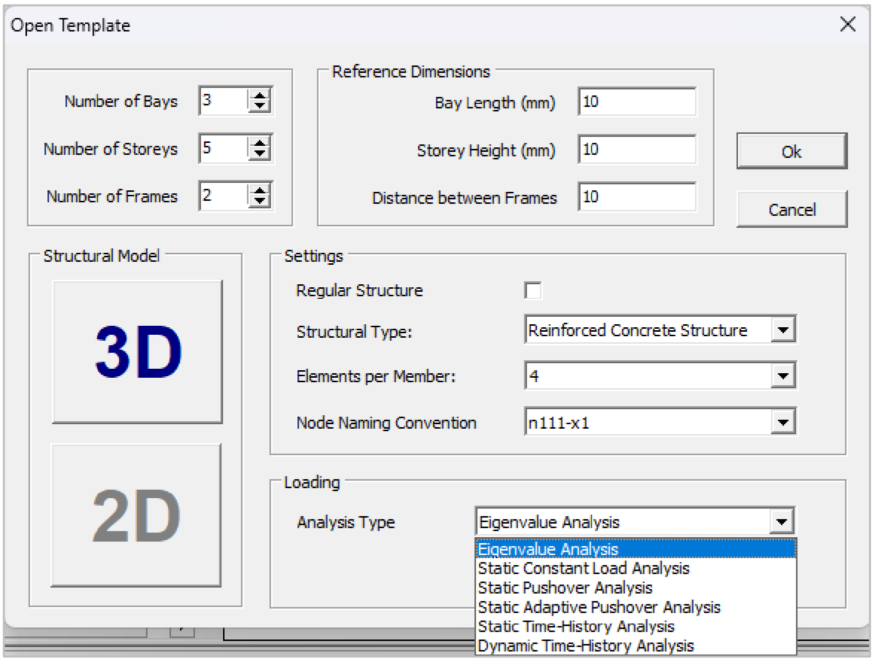


Figure 17. Create from Template Window in Zeus-NL

4.2.2. Materials

Zeus-NL offers a range of material types for defining sections. Since all modules are interconnected, it's crucial to be cautious when defining or altering inputs. Users can create various materials based on these types. The available material types include linear elastic, bilinear elasto-plastic and Ramberg-Osgood model, for mild steel. Trilinear concrete, nonlinear concrete with constant confinement, and nonlinear concrete with variable confinement. Additionally, there's the Sheikh-Uzumeri nonlinear concrete model and the uniaxial constant fiber-reinforced plastic confined concrete model. Each material type requires different parameters, such as Young's Modulus, yield strength, strain-hardening, compressive strength, tensile strength, and confinement factor, among others. These parameters help in accurately modeling different materials and behaviors, ensuring precise analysis outcomes for engineering applications. It's crucial to note that the names of materials should not be confused with those used in the section's module, as this could lead to software errors preventing analyses from running. The same guidelines apply when saving the file. If materials, sections, or other inputs are deleted, the Zeus software offers an undo/redo feature.

Users can modify material properties for project-specific purposes by selecting different materials from the library.

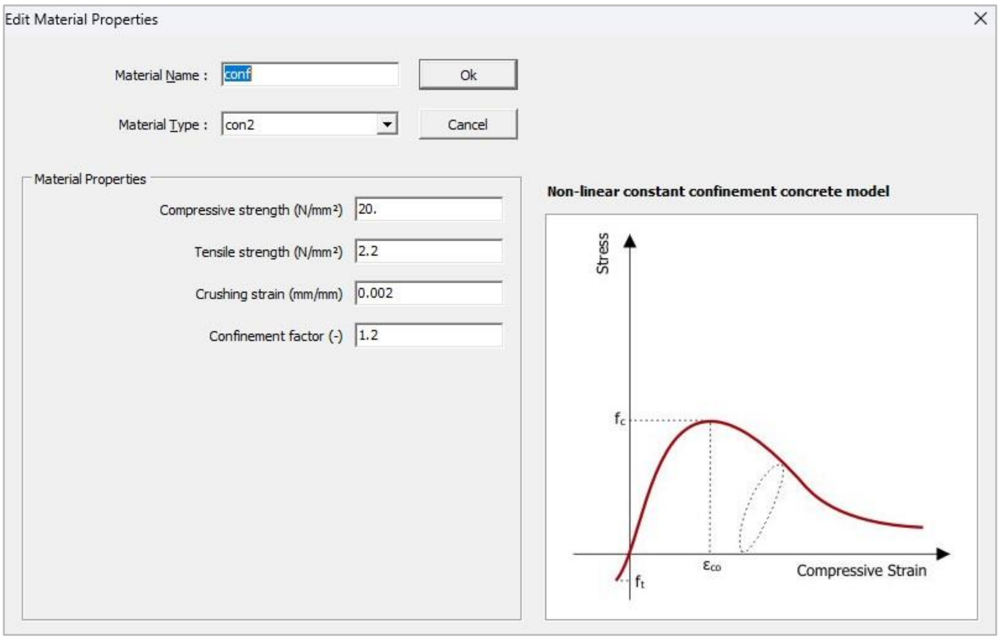


Figure 18. Material Properties Window in Zeus-NL

4.2.3. Sections

In Zeus-NL libraries, there are various steel, reinforced concrete (RC), and composite section types available for use. These include rectangular solid sections, circular solid sections, circular hollow sections, symmetric and asymmetric I- or T-sections, partially and fully encased composite I-sections, and various types of RC sections. Each section is defined by specific dimensional parameters and materials selected from the Materials module. Users can create numerous sections for defining element classes, each with its unique name and editable properties. Reinforcing bars can be added to RC sections and positioned within the confined region of the section. These bars are specified in groups of three (area, depth, and distance from the section centroid). Since sections are symmetrical, only bars in one quadrant need to be specified, with the program generating the rest automatically.

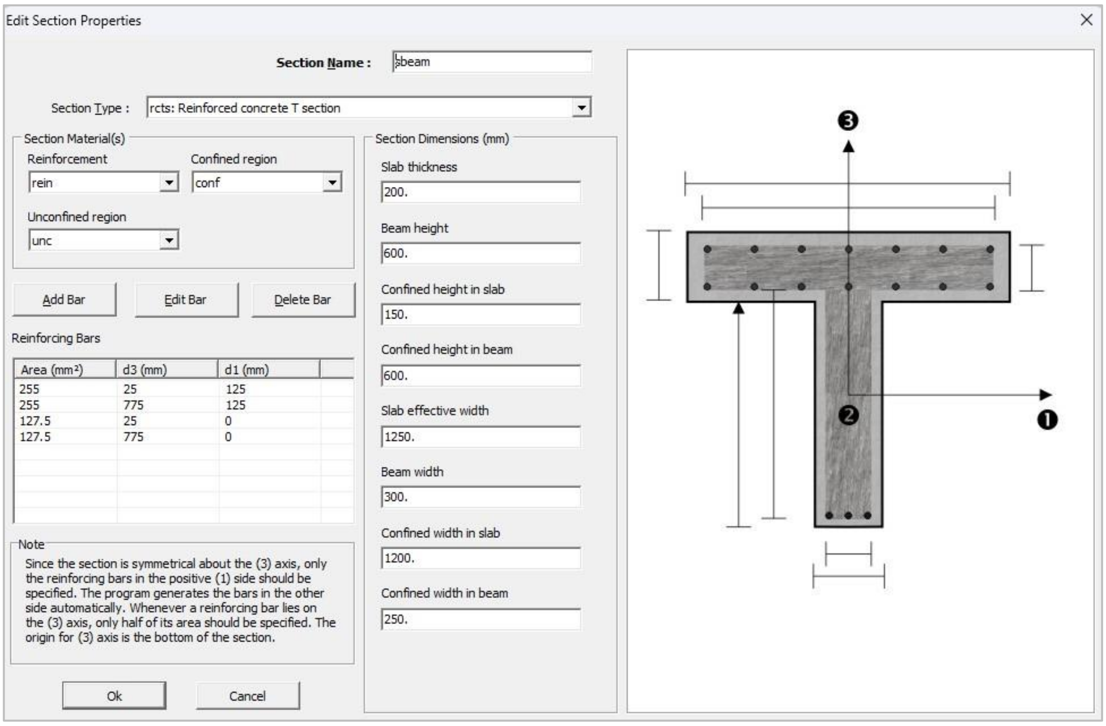


Figure 19. Section Properties Window in Zeus-NL

4.2.4. Element Classes

The Zeus-NL element library contains various types of elements used for modeling structural components (such as beams and columns), non-structural elements (including mass and damping), and boundary conditions (like supports and joints). These include the Cubic element, which is a 3D beam-column element with elasto-plastic properties, ideal for detailed inelastic modeling. The Joint element is a 3D component used for modeling pin joints, inclined supports, and elasto-plastic joint behavior, among other applications. Other elements include Lmass for lumped mass, Dmass for distributed mass, Ddamp for dashpot damping, and Rdamp for Rayleigh damping. Adding an element class involves specifying properties unique to each element type, such as section details for cubic elements and mass values for mass elements. The process is slightly more complex than adding a section and requires input through a dialog box. Certain element types may not be available for specific analysis types. Selection of an element type prompts the user to input relevant properties, ensuring accurate modeling of structural behavior.

The primary elements utilized in this study are the Cubic 3D beam-column elements, chosen due to the three-dimensional structural modeling employed, which eliminates the necessity for joint elements. Additionally, the presence of the Lmass element, representing lumped mass, serves to simulate the self-weight of modeled elements and unmodeled mass from components such as slabs and walls. Lumped mass assumes a critical role in eigenvalue analyses, assisting in determining the structure's period.

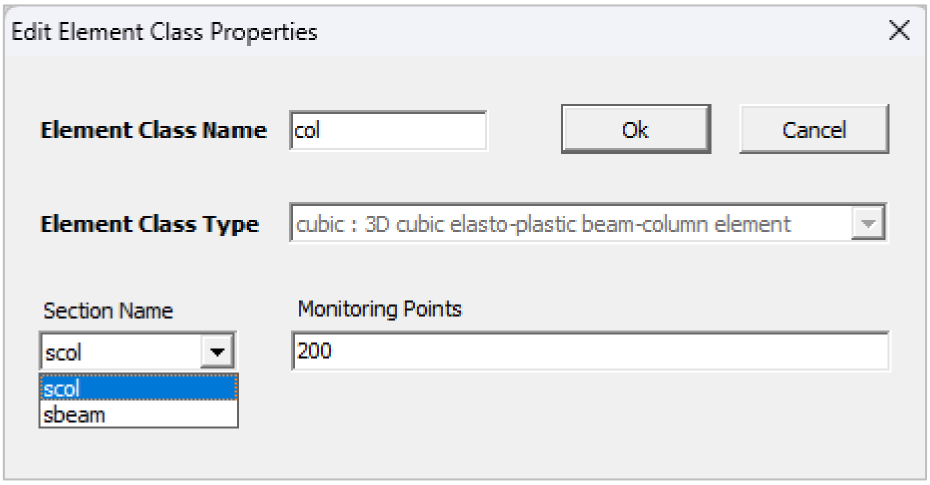


Figure 20. Element Class Properties Window in Zeus-NL

4.2.5. Nodes

In Zeus-NL, nodes serve as intermediaries in modeling. Two types of nodes, structural and non-structural, play key roles in this process. Structural nodes connect element sections, while non-structural nodes define local axis orientation. To make non-structural nodes visible, users can enable the option in the Nodes module settings. The 3D plot offers various customization options, including color, line thickness, and node size. The Nodes Incrementation feature allows users to generate new nodes systematically. For instance, selecting nodes and specifying increments generates new nodes accordingly. This facilitates detailed modeling and analysis of structures within Zeus-NL.

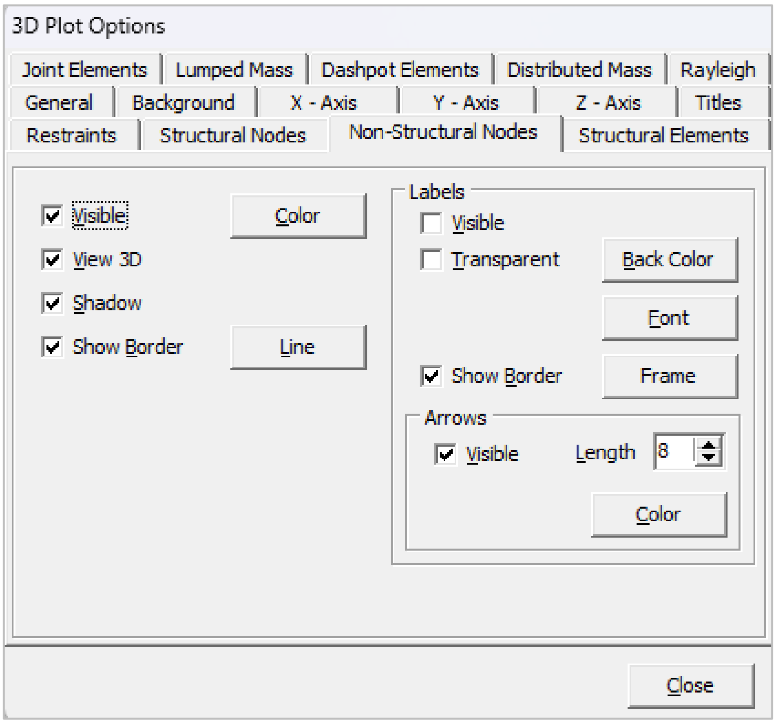


Figure 21. 3D Plot Options Window in Zeus-NL

4.2.6. Element Connectivity

In this module, all components of the structure are defined. Nodes, sections, and materials are combined to form complete structural members. Typically, each element requires three nodes for connection, along with an element name. By default, element numbers follow a specific format, such as 'col111' for columns and 'bmx121' for beams. The prefix 'col' denotes columns and 'bm' denotes 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. The elevation number determines the location of columns, whereas beams are positioned one story above ground level. The presence of non-structural nodes aids in visualizing element locations in the 3D view. For lumped mass elements, only the node where the mass is applied is required.

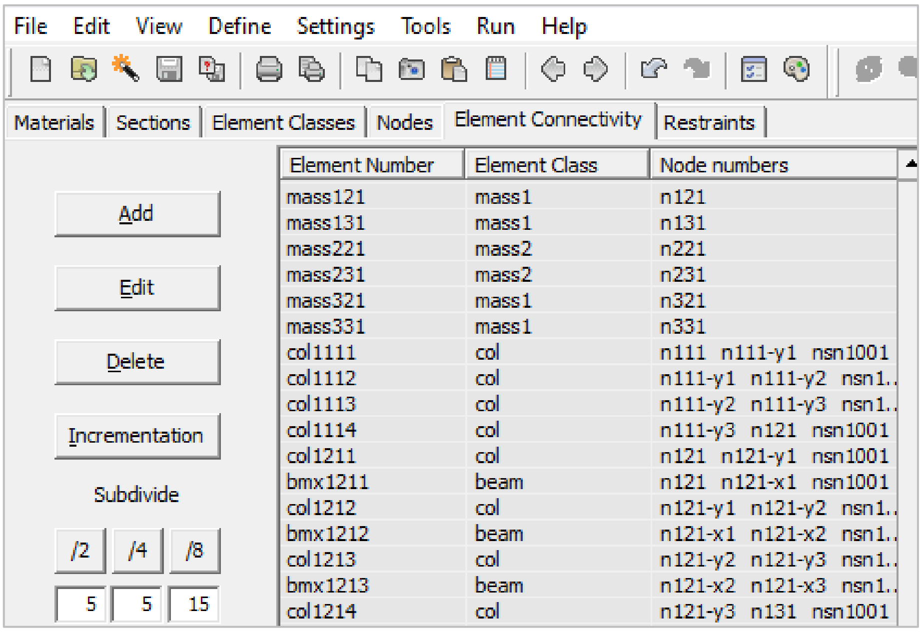


Figure 22. Element Connectivity Section in Zeus-NL

4.2.7. Restraints

Users have the option to design restrained nodes with ease by simply selecting them and utilizing the Edit button. While the process itself is simple, it's crucial to pay attention to a key aspect regarding restraints: In dynamic analysis, the degrees of freedom (DOF) that are restrained at the supports, specifically in the direction of the earthquake, need to be released. Therefore, the restrained DOF at the supports in the model encompass y, z, rx, ry, and rz, excluding x (which denotes the direction of the earthquake).

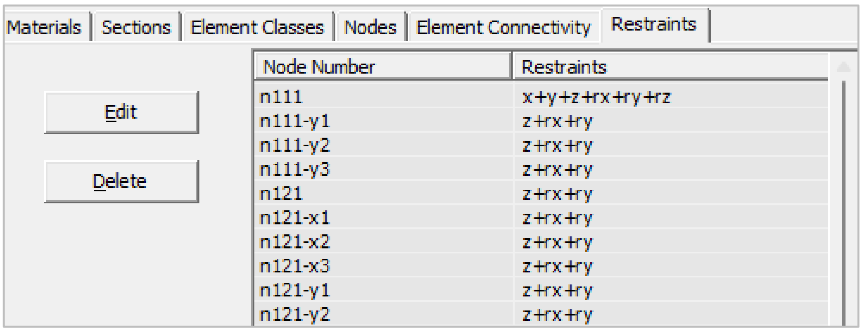


Figure 23. Restraints Section in Zeus-NL

CHAPTER 5

DESCRIPTION OF TEMPLATE BUILDING

5.1 General

In this chapter, an overview of the building chosen for our study is presented. The detailed information provided includes key aspects such as structural design, architectural features, and material specifications. All data utilized in this analysis is sourced directly from the blueprints provided by the Arkivi Qendror Teknik i Ndertimit (AQTN) [43]. Our focus is on a 5-story structure representative of the template building constructed in 1980 This building does not contain plan irregularities and incorporates seismic detailing engineered to withstand seismic events of magnitudes VII to VIII on the MSK-64 scale, making it an ideal sample for our analysis. All findings and observations are organized into tables and accompanied by visual representations, facilitating a comprehensive understanding of the data presented.

5.2 Seismic Design Codes and Scale Used in 1982

During the 1980s, Albania's design codes were based on a combination of Soviet seismic design standards and local practices. The seismic scale used for design purposes was the MSK-64 scale (Medvedev-Sponheuer-Karnik scale), which was prevalent in Eastern European countries and used to assess seismic intensity and the associated damage potential [44].

The MSK-64 scale categorizes seismic intensity on a 12-degree scale, where:

- Intensity VII indicates buildings may suffer minor damage, with non-structural elements such as plaster and chimneys experiencing cracks.

- Intensity VIII suggests moderate damage to structures, including slight structural damage and significant non-structural damage.
- Intensity IX and above implies severe damage, including structural damage that can compromise the building's integrity.

Albanian design codes of that time required buildings to be designed to withstand seismic intensities of at least VII to VIII on the MSK-64 scale, ensuring a reasonable degree of resilience against moderate to strong earthquakes. This aligns with the design of the chosen template building, which was engineered to endure seismic events of magnitudes 7 or 8.

The seismic detailing included in the building's design aimed to enhance its ductility and energy dissipation capabilities, critical for maintaining structural integrity during and after seismic events. Reinforcements and joint details were designed to meet these requirements, following the standards specified in the codes of that era [45].

5.3 Building Description

The template building used in this study is a 5-story, symmetrical, reinforced concrete building. Each floor maintains identical dimensions, with a height of 2.80 meters, resulting in an overall building height of 14.00 meters. The design of the building sections follows the regulations set by the Council of Ministers in 1977, incorporating specific provisions for both cold and warm climates, depending on the geographical location within Albania [46]. The terrace remains unused, making it an inactive component of the structure. As seen in (*Figure 24*), which presents the top view of the fifth floor with dimensions specified in centimeters (cm), the structure's simplicity and symmetry become evident. For analytical purposes, the building is assessed along two primary directions, identified as x-direction and y-direction.

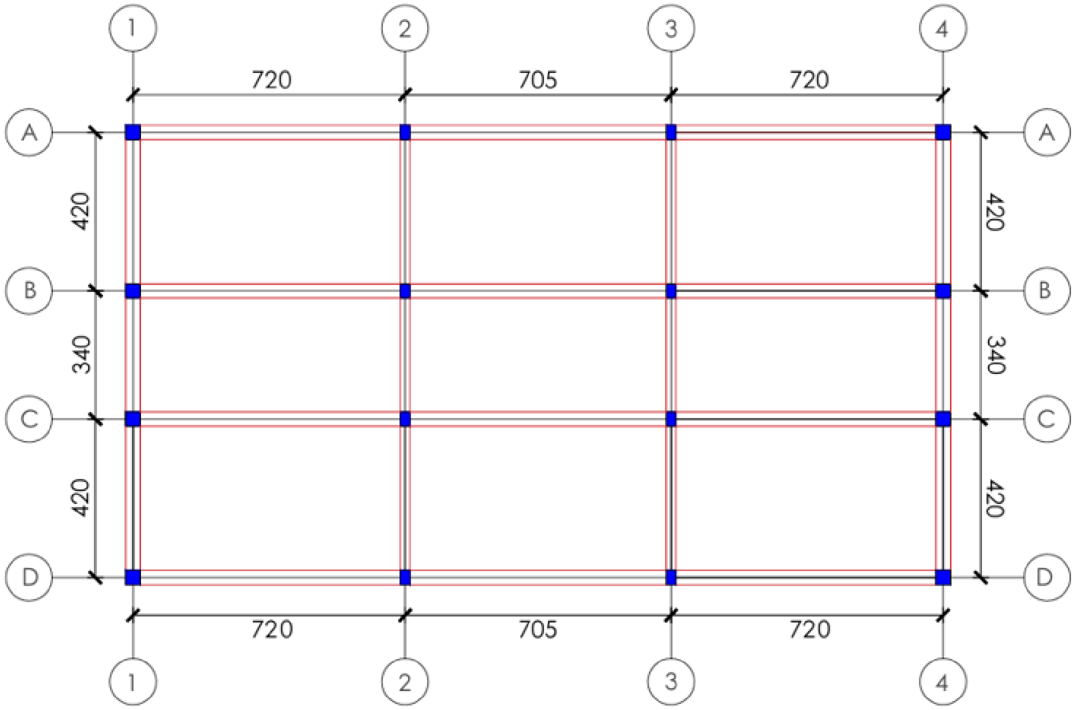


Figure 24. Plan View of the Building (dimensions are given in cm)

Elevation profiles for both directions with dimensions specified in centimeters (cm) are provided in (*Figure 25*), offering a visual representation of the building. Additionally, comprehensive details will be presented concerning the various element types, materials, column and beam cross-sections, and the reinforcement employed to model the building. This information aims to provide a thorough understanding of the structural components and their configurations for the intended analyses.

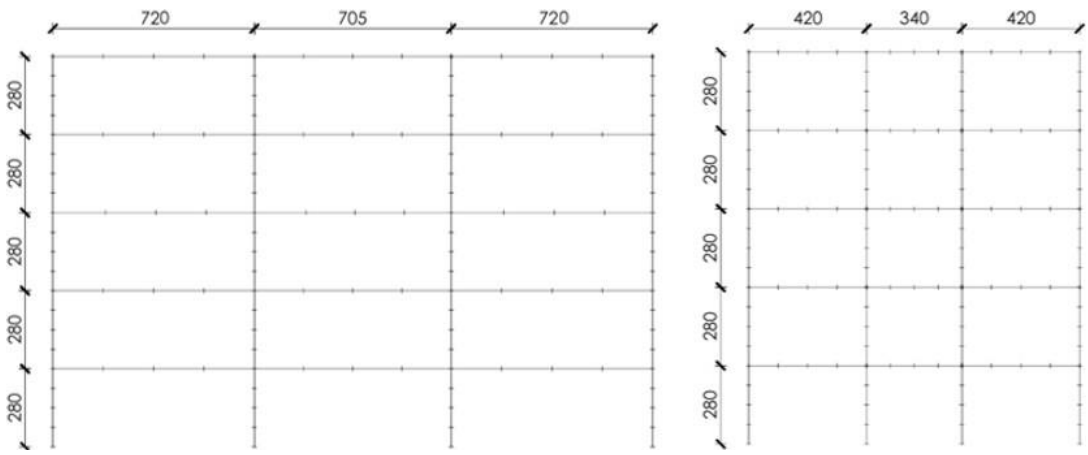


Figure 25. Representative Frames used for Mathematical Model, X-Direction Left and Y-Direction Right (dimensions are given in cm)

5.4 Material Classes

The specifications detailing the material properties are provided in the initial sections of the structure's blueprints. These documents indicate the utilization of two distinct concrete classes within different structural elements: Concrete M-200 for columns and beams, and Concrete M-150 for slabs. However, due to their comparable mechanical characteristics, a decision was made to utilize Concrete M-200 uniformly across all structural elements, including columns, beams, and slabs. The letter "M" was integrated into the pattern of concrete material during the Union of Soviet Socialist Republics (USSR) era in the construction industry. This letter is used to describe the compressive strength of concrete in cubic tests. A summary of the "M" type concrete with its respective compressive strength in MPa is provided in *Table 5*. According to the table below, the type of concrete used for this template building corresponds to C16/20.

Table 5. Corresponding MPa Values for Old Concrete Grades Used in this Study

No.	*Concrete Grade*	Characteristic cube Compressive Strength *in MPa (N/mm^2)*
1	M-100	10
2	M-150	15
3	M-200	20
4	M-250	25
5	M-300	30
6	M-350	35
7	M-400	40
8	M-450	45
9	M-550	50
10	M-600	55

The blueprints characterize the steel material as 2100 Kg/cm^2 (Ç3) used in the project as the reinforcement of the structural elements. Material properties for both concrete and steel are based on the original blueprint of the building project taken from AQTN [43].

These properties reflect the mechanical behavior of the materials used in the structure. The concrete C16/20 is chosen for its adequate compressive strength and durability, while the steel Ç-3 provides the necessary tensile strength and ductility required for reinforcing concrete structures.

5.5 Structural Members

In engineering structure, common components include beams, columns, slabs, and partition walls. However, for our current research, we are excluding partition walls from consideration. Our primary focus is on understanding how the weight is distributed from the slabs to the beams and columns. This decision arises from the limitations of Zeus, a powerful yet simplified software that lacks detailed building modeling capabilities. As a result, our modeling in Zeus-NL primarily revolves around columns and beams to evaluate the structure's seismic performance. Calculations are conducted using Microsoft Excel, taking into account factors like dead and live loads, as well as the self-weight of the slab.

5.5.1. Columns

A column serves as a vertical structural support, responsible for carrying loads and transmitting them to the building's foundation or other structural parts like beams or slabs. Its role is vital for ensuring the stability and robustness of the building. In this examination, columns are rectangular in shape and are built using reinforced concrete. The structure incorporates four distinct types of columns, each varying in cross-sectional dimensions and reinforcement configurations. These attributes remain consistent not only across different frames but also vary between floors within the building.

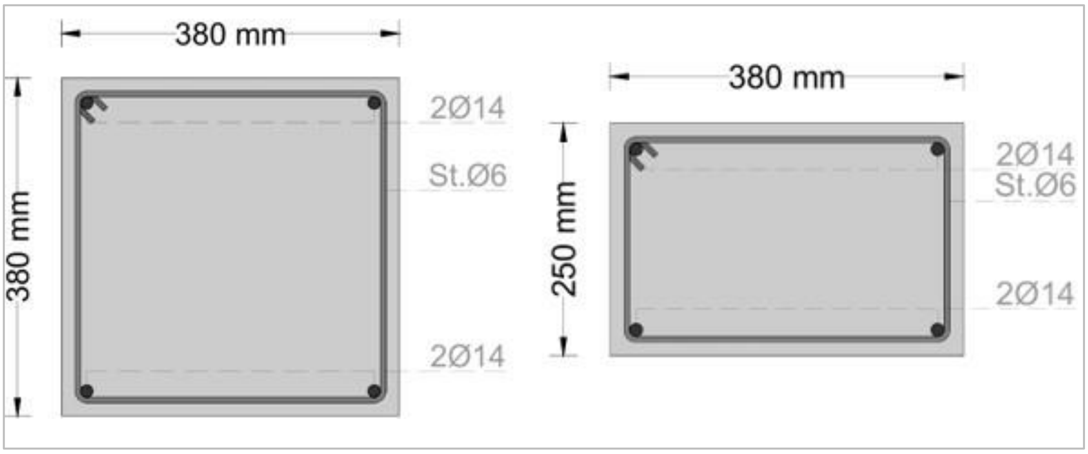


Figure 26. Column Sections of Story 1, 2 and 3

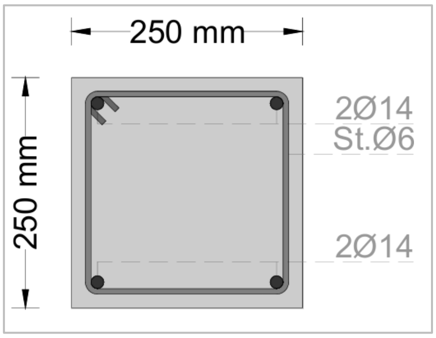


Figure 27. Reduced Column Section of Story 4 and 5

The building consists of three columns, each with different sizes and reinforcement layouts. The first column, measuring 38 cm x 38 cm (*Figure 26*), uses 4 Ø14 steel bars and extends through the initial three levels. The second column, sized at 38 cm x 25 cm (*Figure 26*), is reinforced with 4 Ø14 bars and supports the following two floors of the mid-rise structure. The third column, with dimensions of 25 cm x 25 cm (*Figure 27*), also includes 4 Ø14 reinforcement bars and serves as a reduced column section for upper levels. Details of these columns are presented in *Table 6* and illustrated graphically, with measurements given in centimeters (cm).

Table 6. Detailed Column Specifications and Reinforcement

Column Type	***Column Size***	***Longitudinal reinforcement (No. of bars/ Bar size)***	***Transverse reinforcement (Bar size/Spacing)***	***Floor***
Col38x38	38*38 cm	4 Ø14	Ø6 at 20 cm	1, 2, 3
Col38x25	38*25 cm	4 Ø14	Ø6 at 20 cm	1, 2, 3
Col25x25	25*25 cm	4 Ø14	Ø6 at 20 cm	4, 5

5.5.2. Beams

Beams are the horizontal components of structures, crucial for bearing loads and transferring them to columns or walls. They ensure even distribution of weight across a building. In this context, the beams are rectangular and made of reinforced concrete. Unlike columns, beam sizes and reinforcement differ depending on the structural frames they support. The structure has two distinct types of beams. The initial beam, measuring 50 cm x 38 cm, is fortified with 8 Ø10 steel bars. The second beam, measuring 50 cm x 25 cm, integrates 8 Ø10 reinforcement bars.

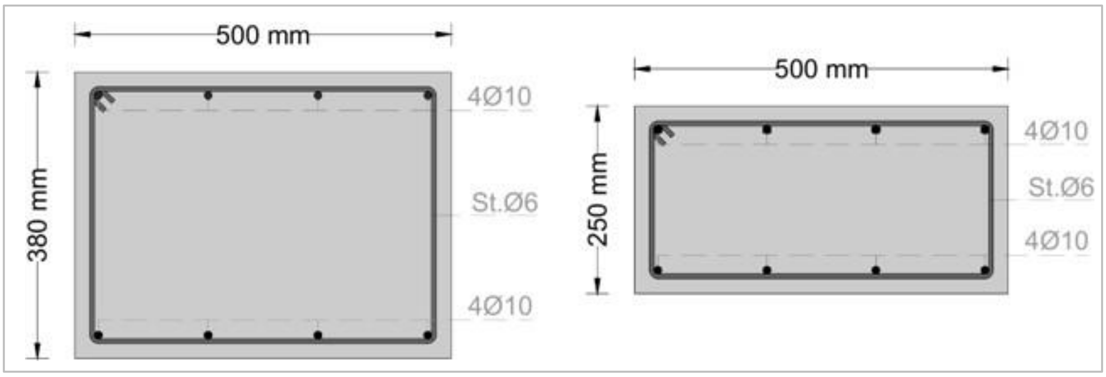


Figure 28. Beam Sections

In *Table 7* the dimensions and reinforcement of these beam elements are detailed.

Table 7. Detailed Beam Specifications and Reinforcement

Beam Type	*Beam Size*	*Longitudinal reinforcement (No. of bars/ Bar size)*	*Transverse reinforcement (Bar size/Spacing)*
BM50X38	50*38 cm	8 Ø10	Ø6 at 20 cm
BM50X25	50*25 cm	8 Ø10	Ø6 at 20 cm

5.5.3. Slabs

The software selected for analysis, Zeus-NL, lacks the capability to model slab elements due to its focus on moment frame structures. However, it's vital not to overlook slabs, particularly in eigenvalue and other dynamic analyses, given the building's considerable mass. Therefore, it's necessary to calculate the self-weight of the elements. Depending on the slab types, whether one-way or two-way, their weight is computed and uniformly distributed onto the beam elements. In both models, slabs are treated as having a 10 cm thick concrete layer. In (*Figure 29*) is provided a breakdown of the slab weight distribution across beams.

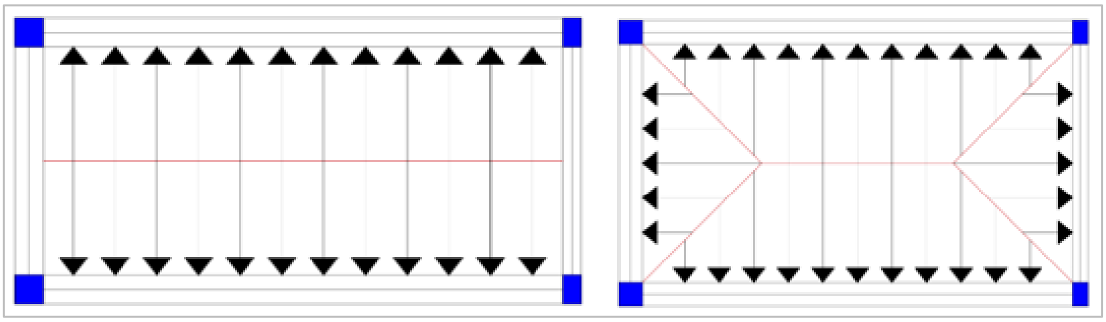


Figure 29. Load Distribution in One-Way (Left) and Two-Way (Right) Slabs

CHAPTER 6

INTERPRETATION OF RESULTS

6.1 General

This chapter explains all the analyses done on the 5-story RC template building, separated in different sections. The results will be interpreted to understand the building's performance based on these methods.

6.1.1. Eigenvalue Analyses

While dealing with the mathematical model, it is crucial to verify the building's natural periods to ensure accurate mass assignment. For this study, eigenvalue analysis was selected as the initial method to determine these periods and mode shapes. This analysis is fundamental in understanding the dynamic characteristics of the structure, which are critical for predicting its seismic response.

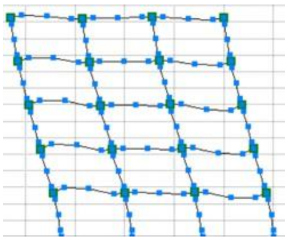
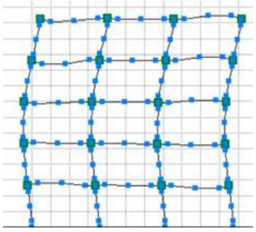
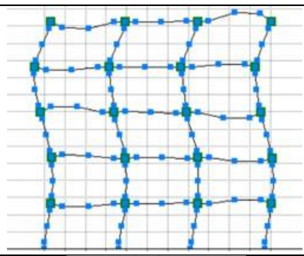
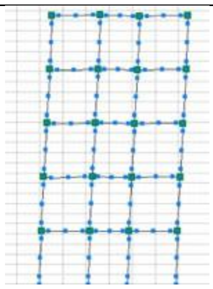
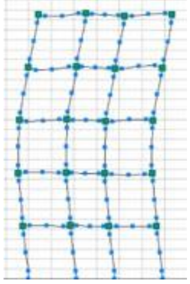
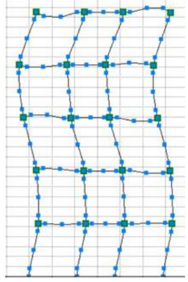
Eigenvalue analysis was performed using Zeus-NL software, defining all relevant geometric and material properties accurately. The analysis provided the first ten natural periods and corresponding mode shapes.

Table 8. Fundamental Period of Vibration Comparison Across Different Structural Models (in seconds)

Mode	X-Frames	Y-Frames	3D Models
1	0.531694	0.506003	0.548295
2	0.179067	0.180626	0.467269
3	0.097966	0.107117	0.509726

Table 8 shows the fundamental periods of vibration for the X-Frame and Y-Frame. The fundamental period is a key parameter in understanding the dynamic behavior of a structure under seismic loads.

Table 9. Deformed Shapes for X-Frame and Y-Frame Across the First Three Modes

	Mode 1	Mode 2	Mode 3
X-Frame			
Y-Frame			

The mode shapes showed in *Table 9* illustrate the dynamic behavior of the structure in the first three modes, providing a visual understanding to the fundamental period data.

In both the X-Frame and Y-Frame, Mode 1 exhibits lateral displacement primarily along the respective frame's direction. Mode 2 shows more complex deformation with lateral displacement. Mode 3 includes significant torsion and higher-order deformations, indicating dynamic response to higher frequency excitations. The similarities in the mode shapes for both frames suggest that they exhibit comparable dynamic behavior under seismic loads, with minor differences in flexibility and deformation patterns.

6.1.2. Interpretation of Static Pushover Analysis Results

Pushover analyses were conducted to estimate the capacity of both structures represented by four frames in the x and y directions. The frames were analyzed using Zeus-NL software [49], employing the "Static Pushover Analyses" procedure.

For the pushover analyses, three lateral load distributions were utilized: a uniform loading pattern, which represents a rectangular load pattern; inverted triangular load pattern; and a modal load pattern, which aligns with the building's first mode shape and represents the most realistic scenario considering the building's dynamic properties [9]. Zeus-NL software allows for the assignment of these rectangular, triangular, or modal patterns as point loads at the nodes. Initially, the program uses a load control phase to incrementally apply the load until global failure occurs. Additionally, the software records the structure's response at each load increment, tracking the progressive deformation and damage until the analysis can no longer converge, indicating structural failure or the maximum capacity of the model has been reached. Consequently, the software is capable of plotting the pushover curve until it can no longer converge the analyses.

The pushover curves were developed using data representing the x and y values in the graph. The user can choose the required parameters. For the purposes of this study, static pushover curves were plotted using the maximum base-shear ratio versus the maximum global drift ratio. The maximum base-shear ratio is calculated as the maximum base shear divided by the weight of the building, specifically the weight of the frame in this case. The maximum global drift ratio is calculated as the ratio of the maximum roof drift over the height of the building. To plot the pushover curve, base shear values are presented on the vertical axis, while drift values are displayed on the horizontal axis of the graph.

Figure 30 & *Figure 31* illustrate the pushover graphs plotted from the extracted results, providing a visual representation of the structural capacity under uniform, inverted triangle and modal loading patterns. The modal distribution provides additional insights by reflecting the building's natural frequencies and mode shapes, thus offering a comprehensive understanding of the structural response under seismic loads [2].

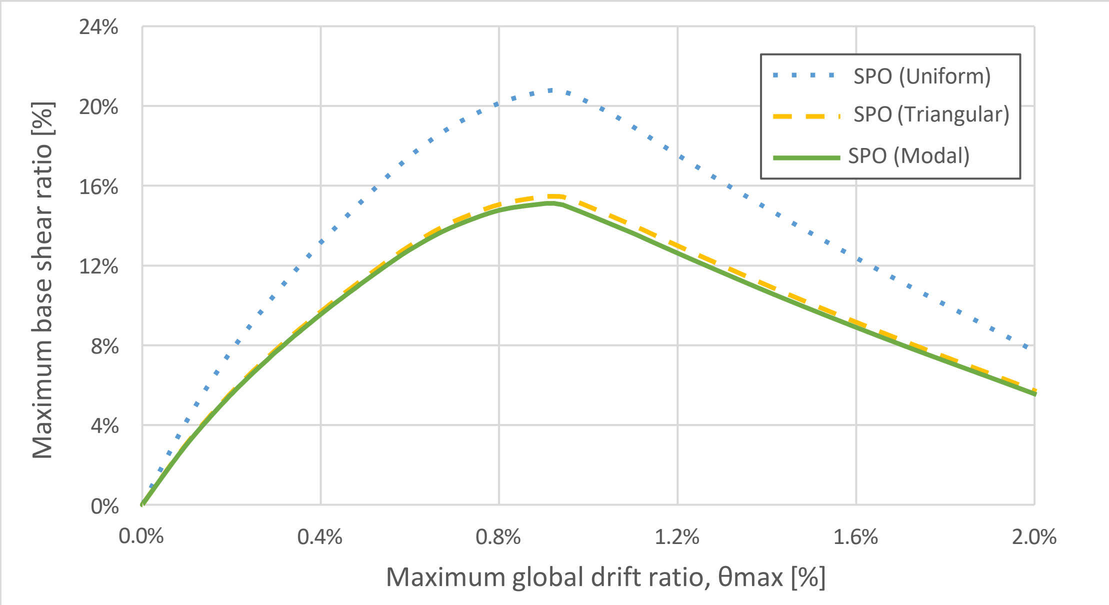


Figure 30. Pushover Analysis Results for the X-Direction Presenting Uniform, Inverted Triangle and Modal Loading Patterns

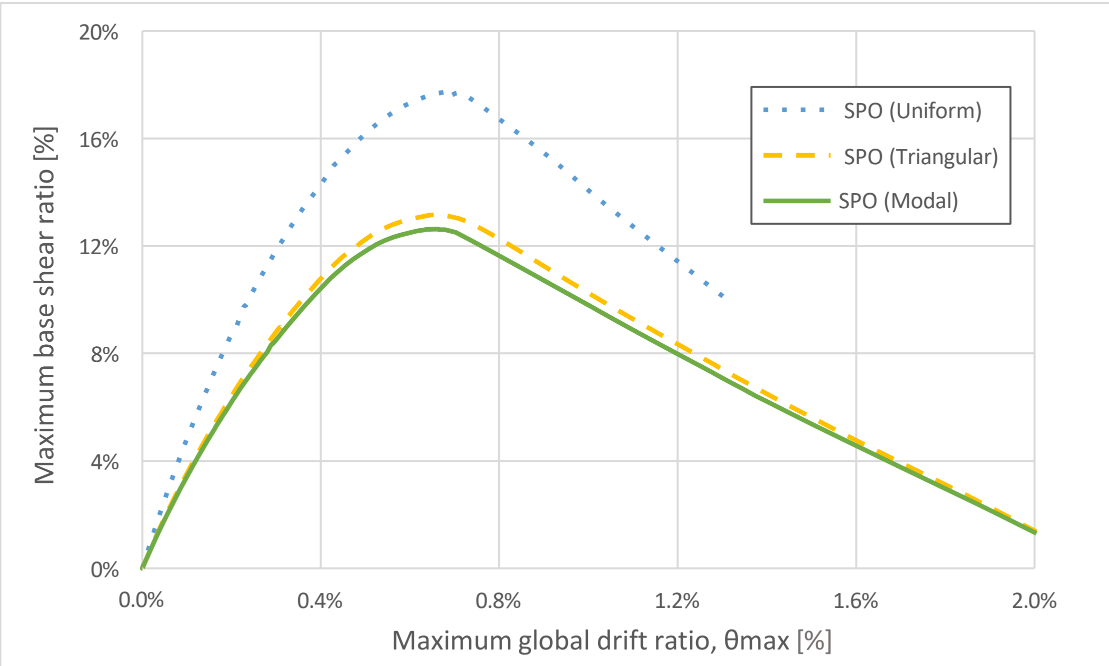


Figure 31. Pushover Analysis Results for the Y-Direction Presenting Uniform, Inverted Triangle and Modal Loading Patterns

As shown from the figures, the pushover curves with modal and triangular lateral loading patterns show very good correlation in building capacity results. These patterns accurately reflect the building's dynamic properties and provide reliable assessments of maximum base shear and global drift ratios.

In contrast, the uniform loading pattern overestimates the structural load-bearing capacity, as it assumes an equal distribution of seismic forces across the building's height, which is less realistic. These findings are consistent with previous research, which has similarly reported that uniform loading patterns tend to overestimate structural capacities [50, 51].

6.1.3. Capacity Curve Analyses

In this section, we delve into the capacity curve analyses for both Frame-X and Frame-Y, examining their seismic performance characteristics and comparing their behaviors. The capacity curves, derived from pushover analyses, illustrate the relationship between base shear and roof drift, providing insights into the structural performance under increasing lateral loads until failure.

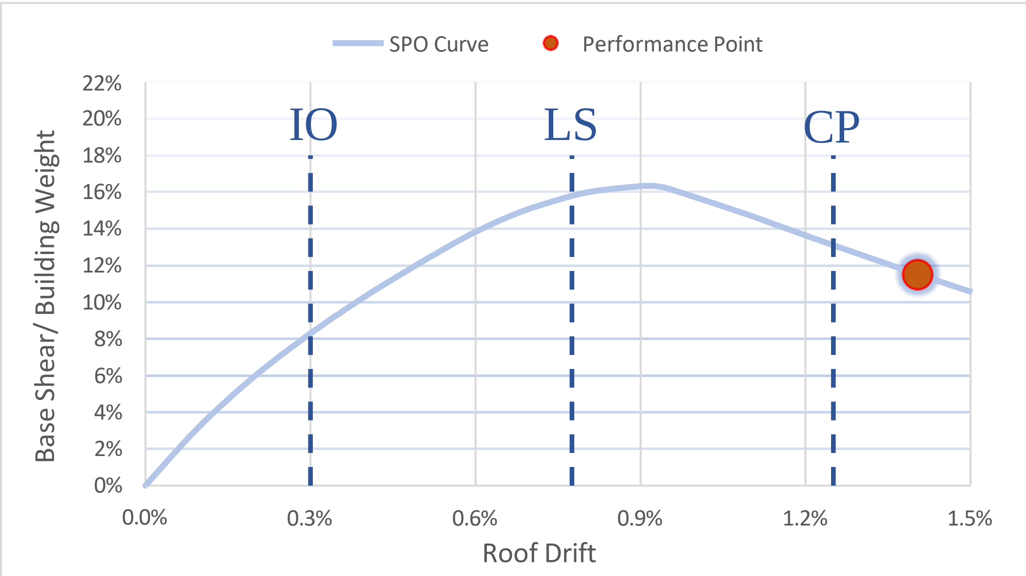


Figure 32. Capacity Curve for Frame-X with Limit States (IO, LS, CP) and Performance Point

The capacity curve for Frame-X (*Figure 32*) demonstrates the relationship between the base shear, normalized by the building weight, and the roof drift in percentage. The limit states are plotted in the graph: Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP).

Immediate Occupancy (IO) is at approximately 0.3% roof drift, the base shear reaches about 12% of the building's weight. This point marks the transition from elastic to inelastic behavior, where minor nonstructural damage might occur, but the building remains safe to occupy.

The LS point is at a roof drift of around 0.8%, with the base shear peaking at about 14%. This phase indicates significant damage to the structure, but it retains its overall stability and strength. Nonstructural components may be heavily damaged, and some structural elements might experience yielding.

Collapse Prevention is at roughly 1.2% roof drift, the base shear drops to about 10%. The CP point signifies severe damage to the structure, nearing failure, but the building avoids total collapse. This stage indicates the maximum deformation the structure can withstand before failure.

The performance point, marked on the graph, exceeds the Collapse Prevention (CP) limit state. This indicates that under the design seismic event, the building experiences demand values that surpass the CP threshold, suggesting that the structure is at risk of collapse.

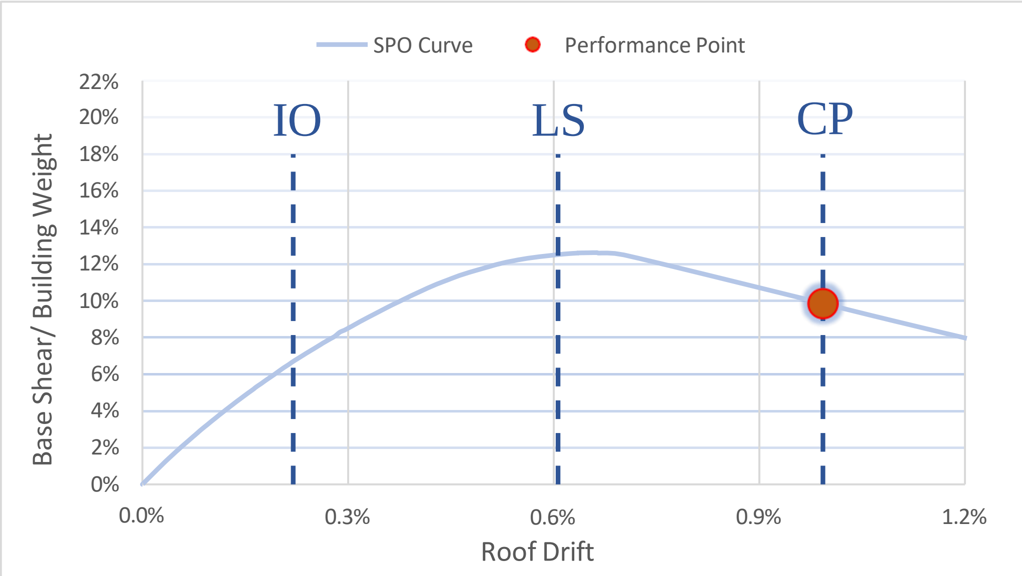


Figure 33. Capacity Curve for Frame-Y with Limit States (IO, LS, CP) and Performance Point

The capacity curve for Frame-Y (*Figure 33*) shows a similar pattern to that of Frame-X but with notable differences in the magnitudes of base shear and roof drift at various performance levels.

Immediate Occupancy (IO) occurring at a roof drift of about 0.3%, the base shear reaches approximately 10% of the building's weight. This indicates that Frame-Y enters inelastic behavior at a slightly lower base shear compared to Frame-X.

Life Safety is at a roof drift of approximately 0.6%, the base shear peaks around 12%. This level of drift indicates considerable structural damage, yet the building retains its integrity. Frame-Y shows lower peak base shear at the LS stage compared to Frame-X, suggesting a lower lateral load capacity.

The CP point is observed at about 1% roof drift, with the base shear dropping to nearly 8%. This signifies a severe level of damage where the structure is close to failure. The drift at CP is slightly lower than in Frame-X, indicating less flexibility before failure.

The performance point, marked on the graph, exceeds the Life Safety (LS) limit state and is within the Collapse Prevention (CP) region. This indicates that under the design seismic event, the building experiences demand values that surpass the LS threshold, suggesting significant structural damage. The close proximity of the performance point to the CP limit state further implies that the building is on the verge of collapse prevention evaluation.

As interpreted, the global performance of the selected template building, which was designed using premodern building codes, is not satisfactory.

CHAPTER 7

CONCLUSIONS AND RECOMANDATIONS

7.1 General

This chapter highlights the findings from the seismic performance evaluation of a five-story reinforced concrete (RC) template building in Albania. Eigenvalue analysis, static pushover analysis, and the Capacity Spectrum Method (CSM) are used, to assess the structural resilience and identify potential vulnerabilities of the building. This chapter provides a summary of the key conclusions drawn from the study, offers practical recommendations for improving the seismic performance of similar structures, and suggests areas for future research.

7.2 Conclusions

The primary objective of this study was to evaluate the seismic performance of an RC building constructed during the 1980s in Albania. The findings of this research can be summarized as follows:

- The eigenvalue analysis revealed the similarities in mode shapes between the X-Frame and Y-Frame suggesting comparable dynamic behavior under seismic loads, with minor differences in flexibility and deformation patterns. These findings are within the boundaries of a proper modeling stage prepared in the environments of Zeus-NL software.
- The static pushover analysis evaluates the building's capacity under uniform, triangular and modal loading patterns. The triangular and modal load distributions show closer results to each other compared to the uniform pattern. The uniform load pattern overestimates the lateral load-bearing capacity of the building, while the triangular pattern shows good correlation with the modal

pattern, providing a more realistic assessment of the building's capacity [50, 51].

- From the pushover analysis, it is shown that the base shear and global drift in the X direction are generally higher than in the Y direction across all loading scenarios.
- Residential buildings must maintain the Life Safety (LS) performance level. However, the results from the comparison between the static pushover analysis (SPO) and the Capacity Spectrum Method (CSM) show that the demand violates the life safety limit state in Frame-Y and exceeds the collapse prevention limit state in Frame-X, indicating a need for significant retrofitting to meet the required safety standards [13].
- The study highlighted the insufficiencies in construction practices and seismic codes prevalent during the building's construction period. Many of these structures lack modern seismic detailing, making them vulnerable to seismic events.

7.3 Recommendations for future research

This study has provided valuable insights into the seismic performance of the five story RC template building in Albania using nonlinear analysis techniques and Capacity Spectrum Method (CSM). However, there are several areas where future research could build upon these findings to enhance our understanding and improve seismic safety further. The following recommendations are proposed:

- Future research should include a broader range of case studies involving different types of reinforced concrete buildings across various regions in Albania. This will help generalize the findings and provide a more comprehensive understanding of the seismic performance of different structural configurations and construction practices.
- Incorporating more advanced simulation techniques, such as Incremental Dynamic Analysis (IDA) and Time History Analysis, could provide deeper insights into the nonlinear dynamic behavior of buildings under seismic

loading. These methods can help capture the complex interactions and potential failure mechanisms that simpler analyses may overlook [52].

- Investigating various retrofitting strategies for existing buildings, particularly those constructed before the implementation of modern seismic codes, is essential. Studies should focus on cost-effective and efficient retrofitting techniques that can be widely applied in Albania to enhance the seismic resilience of older buildings [31].
- Research into the aging and deterioration of construction materials over time, 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 [7].
- 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 [53].
- Further exploration into performance-based design optimization can help in developing design guidelines that ensure new buildings not only meet but exceed current seismic safety standards. This includes optimizing design parameters to achieve the best possible performance within practical and economic constraints [32].
- By addressing these areas, future research can significantly contribute to the field of earthquake engineering and help in developing more resilient infrastructure in Albania and similar seismic regions worldwide.

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APPENDIX

Illustration of the elevation profile of the 5-story reinforced concrete (RC) building examined in this thesis. The cross-sectional view displays the structural framework, including columns, beams, and staircases, providing a clear depiction of the building's vertical organization. Each floor is consistently designed with a height of 2.80 meters, and the thickness of the floor slabs is specified as 10 cm.

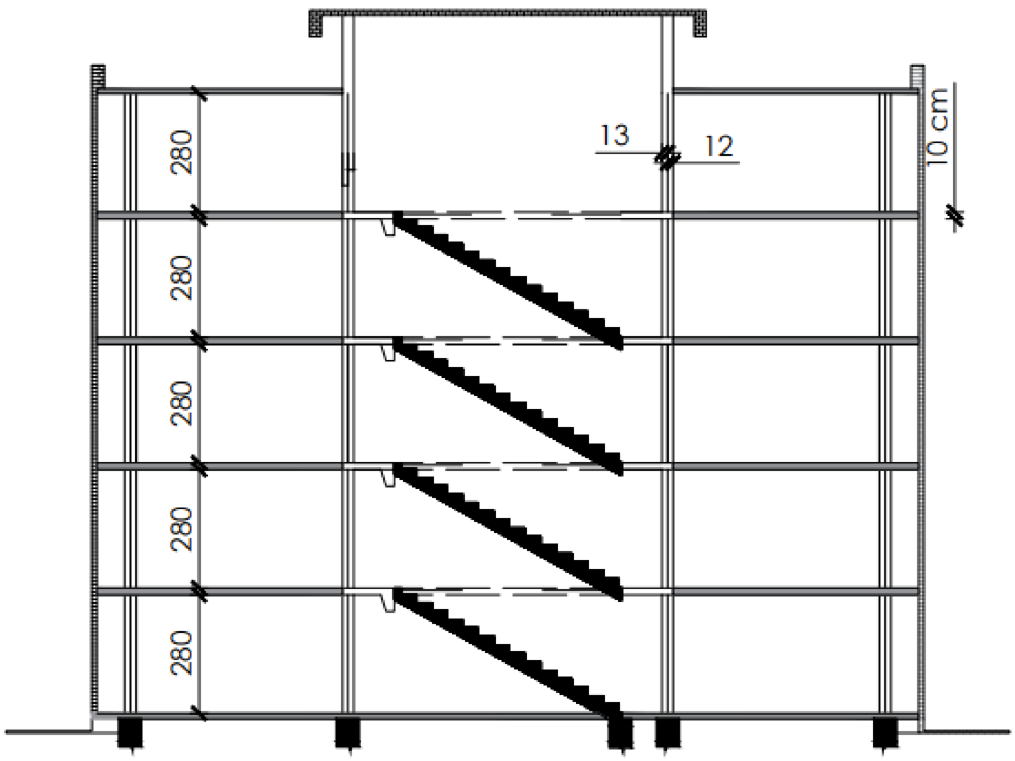

Figure 34. Elevation Profile of the 5-story RC Building (dimensions are given in cm)