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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Influence of Shear and Flexural Hinge Length and Ductility Class on Seismic Performance of Reinforced Concrete Structure.

A Thesis Submitted To The School of Civil And Environmental Engineering For The Degree of Master of Science In Civil Engineering (Structure).

By Abebaw Assefa

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A Thesis

Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science.

Influence of Shear And Flexural Hinges Length And Ductility Class on Seismic Performance of Reinforced Concrete Structure.

The undersigned have examined the thesis entitled **'Influence of Shear and Flexural Hinge Length and Ductility Class on Seismic Performance of Reinforced Concrete Structure'** presented by **ABEBAW ASSEFA**, a candidate for the **Degree of Master of Science** and hereby certify that it is worthy of acceptance.

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Abstract.

Seismic evaluation helps to identify structural and non-structural vulnerabilities in existing buildings. This includes weaknesses in the building's design, construction materials or foundation, which might make it susceptible to earthquake damage. Older buildings were often constructed using old codes that may not be as stringent as modern ones. Evaluating these buildings against current seismic design standards helps to determine if they meet contemporary safety requirements.

The aim of this study is assessing how ductility class, flexural and shear hinge length, impact on the seismic performance of an existing reinforced concrete frame structure in a seismic zone three setting as per EN 1998-3:2004.

The seismic performance evaluation of the proposed structure is carried out by using nonlinear static procedure (NSP) or pushover analysis as per EN1998-3:2004 guidelines. Seismo-structure v-2023 program is used for pushover analysis by providing user-defined nonlinear hinge properties.

The study's findings suggest that the length of flexural and shear hinges and the chosen ductility class are important factors to consider when designing earthquake-resistant structures as they have a direct impact on base shear and inelastic displacement capacity.

Keywords: Nonlinear hinge properties, nonlinear static procedure, Plastic hinge length, Pushover analysis, ductility class, Shear hinge and flexural hinge properties.

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Acronyms

DCM	Ductility class medium/displacement coefficient method.
DCH	Ductility class high.
NSP	Nonlinear static procedure.
FEMA	Federal Emergency Management Agency.
ATC	Applied Technical Council.
ASCE	American Society of Civil Engineers.
IBC	International Building Code.
LPI	Lumped plasticity idealization.
ADRS	Acceleration- Displacement Response Spectrum.
SRSS	Square-Root of Sum of Squares.
CQC	Complete Quadratic Combination.
LS	Life Safety.
IO	Immediate Occupancy.
CP	Collapse Prevention.
DL	Damage Limitation.
SD	Significant Damage.
NC	Near Collapse.
EN	European Norm.

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CHAPTER ONE

Introduction

1.1. General Background.

Seismic performance assessment is an indispensable process in our efforts to secure the safety and functionality of our built environment in the face of seismic events, particularly earthquakes. It serves as a sentinel guardian of human lives and property, and a guarantor of societal resilience in regions prone to seismic activity. By meticulously scrutinizing how structures respond to ground shaking, fault ruptures, and other seismic forces, seismic performance assessment provides us with invaluable insights. These insights guide engineers, architects, and policymakers in making informed decisions that can range from strengthening existing buildings to the design of new, earthquake-resistant structures and the formulation of effective seismic risk reduction strategies. In this exploration, we will embark on a journey to uncover the foundational principles, assessment methodologies, and profound significance of seismic performance assessment within the realm of earthquake engineering and disaster risk reduction.

Seismic performance evaluation is a critical process used to assess how well buildings, infrastructure, and other structures can withstand the forces generated by earthquakes. This evaluation serves several important purposes, including:

Public Safety: Seismic performance evaluations are fundamentally about protecting human lives. Earthquakes can lead to the collapse of buildings and infrastructure, which can result in casualties. By assessing and strengthening structures, the risk to occupants, passers-by, and emergency responders can be significantly reduced.

Property Protection: Earthquakes can result in extensive property damage, leading to substantial economic losses. Seismic performance evaluation helps property owners and insurers understand the potential risks associated with their buildings or infrastructure, enabling them to take proactive measures to protect their investments and reduce financial losses.

Legal compliance: Up-to-date building codes and regulations that incorporate lessons learned from seismic evaluations can significantly reduce the risk to life and property during earthquakes. By setting higher standards for seismic resilience in construction, communities are better prepared to withstand seismic events.

Risk assessment: Seismic performance evaluations help quantify the risk associated with earthquakes in a specific area. By assessing the vulnerability of structures or infrastructure, these evaluations provide a quantitative understanding of the potential consequences of seismic events, such as damage, economic losses, and casualties.

Research and innovation: The data gathered from real-world seismic evaluations are used to validate and refine mathematical models and simulations of structural behaviour. This iterative process enhances the accuracy of predictive models, allowing engineers to better design earthquake-resistant structures.

Disaster preparedness: Seismic evaluations can serve as a basis for educational initiatives within communities. This includes informing residents about building safety, emergency evacuation plans, and disaster supply kits. Community workshops and outreach programs can help individuals and families prepare for earthquake.

Older buildings often lack of adequate reinforcement in their construction. This means they may not withstand the lateral forces generated by earthquakes. Older buildings might have been constructed using materials that do not meet current standards. This can lead to structural weaknesses. Stirrups are important for providing ductility to a structure, without them, the building is less able to absorb and dissipate seismic energy and increase its vulnerability.

Damage in structural engineering can encompass a wide range of conditions, from minor cosmetic issues like surface cracks to severe damage that leads to a total collapse. Earthquakes subject structures to dynamic forces, and how a building performs during an earthquake depends on its design and construction. Structural engineers aim to achieve specific performance objectives for different levels of seismic activity.

Structures subjected to seismic forces often exhibit force redistribution after certain structural components have yielded. This redistribution of forces can lead to increased damage in specific areas of the structure. Current design methodology is a Force-based methods and it doesn't account this phenomenon, which can be problematic in accurately predicting the structural response. Force-based seismic design procedures are primarily concerned with ensuring that the forces generated by seismic events do not cause structural failure. These procedures use factors such as lateral forces or response spectra to design structures to withstand specified levels of ground motion. However, they do not consider what happens to a structure after yielding, which can result in localized damage.

The emergence of ASCE/SEI 41-13 represents a significant milestone in the development of performance-based seismic design and assessment. This set of guidelines provides a framework for engineers and researchers to evaluate and design buildings with a greater emphasis on their actual seismic performance. ASCE/SEI 41-13 promotes the use of nonlinear static analysis, where a building's response to seismic forces is thoroughly evaluated, considering post-yield behaviour, to ensure it can withstand earthquakes. Pushover analysis is a valuable tool for this purpose, allowing engineers to assess a building's seismic performance and make necessary improvements or retrofits to enhance its earthquake resistance.

In the context of pushover analysis for structural engineering, the process of modelling is indeed a crucial step. Pushover analysis is a static, nonlinear analysis method used to assess the performance of structures under lateral loads, such as earthquake forces. When modelling a structure for pushover analysis, it is important to account for nonlinear behaviour, and one common approach is to use the lumped plasticity idealization (Fig. 1.1). Pushover analysis accounts for the nonlinear behaviour of structures under increasing lateral loads. This includes considering both the strength and deformation capacities of structural components.

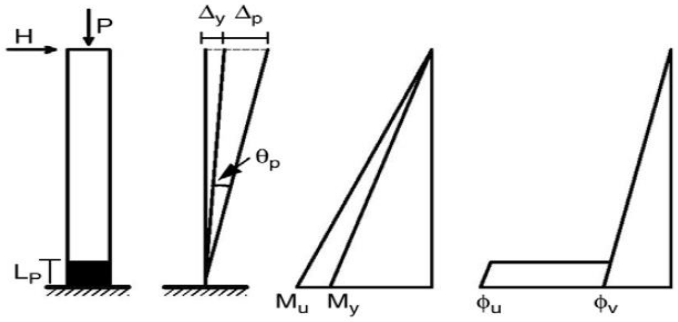


Figure 1.1 Lumped plasticity idealization of a cantilever.

FEMA-356 document is titled "Pre standard and Commentary for the Seismic Rehabilitation of Buildings" and was published by FEMA. It provides guidelines and recommendations for the seismic rehabilitation of existing buildings. FEMA-356 includes information on non-linear static analysis, which is a method used to evaluate the seismic performance of buildings.

In practical engineering applications, default properties provided in documents like FEMA-356, EN1998-3:2004, and ATC-40 are often preferred for their convenience and simplicity. These documents provide standardized guidelines and parameters for seismic analysis and design, which can be easily implemented in widely used structural analysis software. It's common for structural engineering software programs like SEISMOSTRUCTURE, SAP2000, and ETABS to provide default nonlinear properties for various structural elements and materials.

These properties are often based on industry standards and research, and they aim to simplify the modelling process for structural engineers. Default nonlinear properties can include things like material behaviour, element connectivity, and boundary conditions. In some cases, structural engineers may need to perform more detailed and customized nonlinear analyses, which may require overriding or modifying the default properties to accurately represent the behaviour of the structure under various loading conditions. It's also important to consider site-specific factors, local building codes, and other project-specific requirements when using any software tool for structural analysis and design.

The deformation capacity of reinforced concrete components is influenced by various factors, including the assumptions made in their modelling. This includes factors like material properties, detailing of reinforcement, construction techniques, and more. FEMA-356, EN1998-3:2004 and ATC-40 guidelines are specific to the United States and Europe. They are developed based on the typical practices and construction standards in these regions. These guidelines provide information about hinge properties for different ranges of detailing.

1.2. Statement of the Problem.

Ductility and plastic hinge formation, it is essential in the design of structures to ensure that the formation of plastic hinges (localized areas of inelastic deformation) occurs in a controlled and predictable manner. The ductility of a structure determines its ability to absorb energy during an earthquake, and the formation of plastic hinges is a part of this energy dissipation mechanism. Different plastic hinge lengths and ductility classes may be required for various performance levels, as structures designed for higher performance levels need to exhibit greater ductility and energy dissipation capacity.

1.3. General Objectives of the Study.

The main objective of this study is to assess the seismic performance of a 2-D reinforced concrete frame structure by using different Plastic hinge length and ductility class (DCM and DCH):

- To identify Plastic hinge length effects on the displacement capacity of the structure.
- To identify, the base shear capacity dependency on user-defined hinge properties.
- To identify, displacement capacity dependency on ductility class at the potential hinge regions.
- To identify how the shear hinge pattern will affect the overall properties of the structure.

1.4. Significance of the Study.

The primary aim of evaluating the performance of current structures is to inform decisions regarding the necessity for renovating or applying structural improvements to each specific structural elements. However, prior to reaching this point, it is essential to exercise caution and address various aspects.

The followings are the main advantages of this study:

- This assists us in exercising caution when dealing with critical areas, particularly in the plastic hinge region.
- It help us to detail carefully the potential plastic hinge region.
- This enables us to readily recognize the impact of hinge length and ductility classification on the overall performance of the structure.

- This facilitates our ability to readily grasp the impact of shear hinge formation and the measures taken to mitigate it.

1.5. Scope of the Study.

The current research is constrained to the following factors:

- The evaluation will focus solely on a two-dimensional reinforced concrete frame, which means that the study's findings may not apply to different structural configurations or lateral load resistance systems.
- Because the structure is a two-dimensional frame, the assessment will exclusively address horizontal ground motion in the x-direction.
- It is assumed that all base column ends are fixed (with no consideration of soil-structure interaction).

1.6. Thesis Organization.

This thesis comprises five chapters and centres around exploring the impact of shear and flexural length, along with ductility class, on the seismic behaviour of a two-dimensional reinforced concrete structure.

In chapter one, the thesis introduces the overall context and background. Chapter two delves into a comprehensive review of the existing literature related to shear and flexural length, as examined by numerous scholars. Chapter three covers the materials, modelling, analysis, and methodologies employed in this study. Chapter four is dedicated to presenting the study's results and conducting a detailed discussion. Lastly, in chapter five, the thesis concludes and provides recommendations based on the findings.

CHAPTER TWO

Literature Review

2.1 Introduction.

The joint panel zone of existing reinforced concrete frame buildings in seismic-prone areas is highly susceptible to structural vulnerabilities, which can result in brittle failures and significant damage during seismic events. Addressing these issues through proper structural detailing, anchorage, and capacity design principles is essential for improving the seismic resilience of these buildings. The issues in the joint panel zone can have consequences for both local and global damage and failure mechanisms. Local damage pertains to issues in specific areas, while global damage relates to broader structural problems that can compromise the entire building. Investigations revealed a significant vulnerability in the joint panel zone region of these buildings. The joint panel zone is a critical area where the columns and beams of a frame building intersect however Inadequacies in this region can have serious consequences during seismic events.

Assessing the seismic performance of existing buildings that were under-designed or designed only for gravity loads is a critical task, and accurately modelling the inelastic behaviour of the joint panel zone is essential for this evaluation. Several approaches exist in the literature for modelling reinforced concrete (RC) beam-column joints, each with its own level of complexity and applicability. These approaches range from simplified empirical models to more complex finite element models. In a seismic event, the joint panel zone, which connects beams and columns, is subjected to significant forces and deformations. Modelling this inelastic behaviour accurately is crucial because it can affect the overall structural performance.

Older Building codes are generally based on static load assumptions, which means they don't adequately address the dynamic and often unpredictable nature of earthquake forces. Earthquakes exert forces that vary in frequency, amplitude, and direction, making their effects more complex to predict and design. In a powerful earthquake, structures may experience inelastic behaviour, meaning they deform and do not return to their original shape, even after the seismic event has passed. Older Building regulations do not explicitly address inelastic behaviour or the limits of deformation. Some regions prone to earthquakes have started to adopt performance-based design approaches. These approaches consider a structure's expected behaviour under different levels of seismic loading, from elastic to inelastic responses, and aim to ensure that buildings remain functional and safe even after a major earthquake.

Cyclic loading refers to the repeated application of loads, often in a back-and-forth manner, over time. In the context of beam and column connection joints in structural engineering, cyclic loading, particularly from seismic forces, can have several significant effects:

Fatigue: Repeated cyclic loading can lead to fatigue in the joint components, causing them to weaken and potentially fail over time. This fatigue can be particularly detrimental if the connection is not designed to withstand cyclic loading, as it can result in gradual degradation and reduced structural performance.

Loss of Stiffness: Cyclic loading can lead to a loss of stiffness in the connection, making it less effective in resisting lateral or axial loads. This can result in reduced structural performance and a potential increase in the building's lateral sway during subsequent seismic events.

Shear and Bending Stress: Repeated cycles of lateral forces from seismic loading can induce shear and bending stresses in the connection joints. These stresses can accumulate, leading to localized damage or weakening of the joint.

Hysteresis Behaviour: Cyclic loading often results in hysteresis behaviour, where the connection exhibits a "pinching" effect as it cycles back and forth between tension and compression. This hysteresis behaviour can impact the overall response of the structure to seismic forces. And Hysteresis behaviour is associated with energy dissipation. The area enclosed by the hysteresis loop represents the energy absorbed and dissipated by the material or structure during each loading-unloading cycle. This energy dissipation can be crucial in applications like seismic engineering to prevent structural damage.

Nonlinear static analysis, often known as pushover analysis, offers a simplified yet pragmatic alternative to nonlinear time history analysis. It approximates a structure's nonlinear behaviour when subjected to earthquake loads by incrementally applying lateral forces and assessing the structure's response at various displacement levels. This approach is preferred because it strikes a balance between precision and efficiency in forecasting a building's seismic performance. In contrast, nonlinear time history analysis is a highly advanced technique used to predict how a structure will react to seismic forces over a period. It takes into consideration material nonlinearity and the dynamic effects of earthquakes, providing exceptionally accurate results. However, it can demand extensive computational resources and generate a substantial volume of data, rendering it less practical for routine design and evaluation purposes.

2.2. Pushover Analysis.

Federal Emergency Management Agency (FEMA), EN1998-3:2014 and Applied Technical Council (ATC), which formulated and suggested the Non-linear Static Analysis or Pushover Analysis under seismic rehabilitation programs and guidelines. This included documents FEMA-356, FEMA-273 and ATC-40. A static pushover analysis, nonlinear process that gradually increases the structural loading in accordance with a predetermined load pattern. Static pushover analysis, a useful and effective technique for performance-based design, is an effort by the structural engineering profession to evaluate the true strength of the structure.

Pushover analysis modelling parameters, acceptance criteria, and techniques have been created and are described in the ATC-40, FEMA-356, and ASCE 41-13 papers. These documents also detail the steps taken throughout the analysis to determine the degree of frame member failure. The member's inelastic behaviour is regulated by either deformation-controlled (ductile action) or force-controlled (brittle action), during the pushover analysis.

2.3. Types of Pushover Analysis.

There are basically two types of non-linear static analysis procedures available, Displacement Coefficient Method (DCM), documented FEMA-356 and Capacity Spectrum Method (CSM) documented in ATC-40. Both methods depend on lateral load-deformation variation obtained by non-linear static analysis under the gravity loading and idealized lateral loading due to the seismic action. This analysis is called Pushover Analysis.

2.3.1. Capacity Spectrum Method.

The base shear vs. control node displacement curves obtained from pushover analysis can be converted into spectral acceleration and spectral displacement values. Spectral acceleration represents the maximum acceleration response at a specific period, while spectral displacement represents the maximum displacement response at a specific period. These values provide a way to understand the structure's behaviour in terms of acceleration and displacement under seismic loading.

$$Sa,m = \alpha m(Vm/W) \tag{2.1}$$

Where Sa,m is the spectral acceleration for mode ‘m’ (expressed in units of ‘g’), Vm is the base shear for mode ‘m’, W is the seismic weight of the building.

$$\alpha m = \sum_{i=1}^{N} \frac{(Wi\ \phi i,m)^2}{\sum_{i=1}^{N}(Wi\ \phi i,m)^2} \tag{2.2}$$

$$Sd,m = \frac{\Delta c,m}{\beta m\ \phi cm} \tag{2.3}$$

$$\beta m = \frac{\sum_{i=1}^{N}(wi\ \phi i)}{\sum_{i=1}^{N} wi\ \phi i^2} \tag{2.4}$$

Where:

αm = effective mass ratio.

βm = participation factor.

N = number of floors in the building

$S_{a,m}$ = spectral acceleration for mode,m

$S_{d,m}$ = spectral displacement for mode,m

V_m = base shear for mode 'm'

W = seismic weight of building

w_i= seismic weight of floor at level 'i'

$\Phi_{i,m}$ = modal amplitude at level 'i' for mode 'm'

$\Delta_{c,m}$, $\Phi_{c,m}$ = displacement and modal amplitude of control node for mode 'm'

The ADRS format of the response spectrum represents the demand side of the equation. A debated issue in CSM is the representation of damping when developing the demand curve to account for inelastic effects. When the structure is in the inelastic range under the action of seismic forces, much of the dissipated energy is due to yielding of the structure. The net effect of yielding is to increase the overall damping of the system. Hence a series of ADRS curves for different damping values should be generated. The pushover curve (the capacity side of the equation) is then superimposed on these demand curves. The intersection of the pushover curve with one of the demand curves at an appropriate damping value represents the "performance "point).

2.3.2. Displacement Coefficient Method.

The Displacement Coefficient Method (DCM) is indeed a widely recognized approach for determining the expected maximum displacement, often referred to as the target displacement, for the nonlinear static analysis of buildings in seismic design and rehabilitation. The method is commonly used in conjunction with documents like FEMA-356, which provides guidelines for seismic rehabilitation, as well as Euro norm (EN) for European countries. The general idea behind the Displacement Coefficient Method is to estimate the target displacement by modifying the spectral displacement of an equivalent Single Degree of Freedom (SDOF) system.

$$\delta t = \frac{CoC1C2SaTe^2}{4\Pi^2} g \tag{2.5}$$

$$det = Se(T)(T/2\pi)^2 \tag{2.6}$$

Where:

δt = target displacement according to FEMA-356

det = target displacement according to EN1998-3:2014.

The factors C_0, C_1, C_2 and C_3, are modification factors that account for spectral displacement, inelasticity, hysteresis shape, and P-Δ effects, respectively. S_a is spectral acceleration and T_e is the effective fundamental period computed as shown in equation (2.7).

$$Te = Ti\sqrt{\frac{Ki}{Ke}} \tag{2.7}$$

Where Ti is the elastic fundamental period, Ki is the initial elastic stiffness and Ke is the stiffness at a base shear strength equal to 60% of the yield strength of the structure. Since the nonlinear static response of the structure is extremely sensitive to choice of load pattern, FEMA-356 recommends using at least two load patterns that approximately bound the distribution of the inertia forces along the building height in a seismic event. The first is a profile based on lateral forces that are proportional to the total mass at each level called the uniform pattern. The second pattern can be a triangular pattern that is dependent on the fundamental period of the structure in the direction under consideration or a pattern resulting from a modal combination using SRSS (Square-Root of Sum of Squares) or CQC (Complete Quadratic Combination) modal response combination.

2.4. Acceptance Criteria (Performance Level) According To FEMA-356.

The performance standard or acceptance criteria for the plastic hinges that were close to the joints is determined by three points at the ends of columns and beams, Life Safety, Immediate Occupancy, and Collapse Prevention are each abbreviated as LS, IO, and CP, respectively. Several other characteristics specified in the ATC-40 specifications, as well as the type of member, affect the values assigned to each of these locations. The structural performance values of the concrete frames are shown in Table 2.1:

Table 2.1: Description of performance levels of the concrete frame as per FEMA-356

Elements	Type	Structural Performance Levels		
		Collapse Prevention S-5	Life Safety S-3	Immediate Occupancy S-1
Concrete Frames	Primary	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Extensive damage to beams. Spalling of cover and shear cracking (< 1/8" width) for ductile columns. Minor spalling in nonductile columns. Joint cracks < 1/8" wide.	Minor hairline cracking. Limited yielding possible at a few locations. No crushing (strains below 0.003).
	Secondary	Extensive spalling in columns (limited shortening) and beams. Severe joint damage. Some reinforcing buckled.	Extensive cracking and hinge formation in ductile elements. Limited cracking and/or splice failure in some nonductile columns. Severe damage in short columns.	Minor spalling in a few places in ductile columns and beams. Flexural cracking in beams and columns. Shear cracking in joints < 1/16" width.
	Drift[2]	4% transient or permanent	2% transient; 1% permanent	1% transient; negligible permanent

Pushover analysis typically involves assessing the building's performance at different predefined performance levels. These performance levels are used to categorize the behaviour and response of the structure under increasing seismic forces. Commonly used performance levels are described in section 2.4.1 to 2.4.3.

2.4.1. Immediate Occupancy Level (IO).

At this level, the building remains fully operational without any damage, and occupants can continue to use it safely.

2.4.2. Life Safety Level (Ls).

The LS level ensures that the building's structural integrity is maintained, preventing structural collapse. Some non-structural damage may occur, but the building remains safe for evacuation.

2.4.3. Collapse Prevention Level (Cp).

The CP level aims to prevent the collapse of the building. It may allow for significant structural and non-structural damage, but the building should not collapse, ensuring the safety of occupants and emergency response teams.

2.5. Acceptance criteria (performance level) according to EN1998-3:2004.

The essential criteria pertain to the condition of structural damage, which is defined in this context by three Limit States (LS).

2.5.1. Limit State of Damage Limitation (DL).

The structure has experienced some damage, but the main load-bearing components have not significantly deformed or lost their strength and stiffness. This suggests that the primary structure is still capable of supporting its intended loads.

2.5.2. Limit State of Significant Damage (SD).

The structure has suffered significant damage. This likely means that its load-bearing components have been affected, and its overall integrity has been compromised. Although the structure has been significantly damaged, it still retains some degree of lateral (horizontal) strength and stiffness. This implies that it may not be in immediate danger of collapsing but is weakened.

2.5.3. Limit State of Near Collapse (NC).

The structure has experienced severe damage, especially to its lateral (horizontal) load-bearing elements. This means that the primary means of supporting horizontal loads (e.g., wind or seismic forces) has been compromised.

2.6. Nonlinear Hinge Property.

2.6.1. The Interaction Surface between Axial Load and Moment (P-M).

The P-M interaction surface, which is commonly used in structural engineering, represents the relationship between axial load (P) and moment (M) for a specific structural element, such as a column or beam. This surface is determined by various factors, including the section shape, material properties, and the type and quantity of reinforcement.

2.6.2. M- θp (Moment-Plastic Rotation) Relationship.

The plastic rotation, θp, and related moments are expressed as a ratio of the yield moment, My, and this ratio defines the M-θp relationship for a particular member section. This relationship is essential in understanding how a structural member behaves under load and how it can redistribute loads when plastic hinges form. Plastic hinges are locations in a structure where plastic rotation occurs, and they often develop in regions with high bending moments. The EN (European norm) and FEMA (Federal Emergency Management Agency) provide guidelines and recommendations for obtaining the values needed to define M-θp relationships for structural design.

CHAPTER THREE

Structural Modelling and Analysis

3.1 Description of Structures.

In this study, a single structure is examined, which is a typical 2D RC frame structure consisting of beams and columns, located in a medium seismicity region are considered according to EN 1998-3:20004. Material properties are assumed to be C-16/20 for the concrete grade and 500MPa for the characteristics strength for both longitudinal and transverse reinforcements. Two layouts are considered for transverse reinforcement in the potential plastic hinge regions, with DCM and DCH detailing ranges. A 3-story frame having 12 m height are considered (Fig 3.2). Typical floor-to-floor height is 4m. Column dimension, amount and arrangement of longitudinal reinforcement are provided in Fig 3.4 and 3.5. All beams and column are 250mm × 300mm and 300mm x 400mm respectively. The amounts of top and bottom reinforcement are shown in mm2 in the elevation view. The dead and participating live loads (30%) on the frame are 25KN/m and 16KN/m, respectively. All necessary Material and other related parameters used for modelling and analysis are listed in the Table 3.1.

3.2. Linear Static Analysis, Design and Detailing For DCM and DCH Classes.

The analysis and design tasks were executed utilizing SAP2000, a versatile software tool designed for performing both static and dynamic structural analyses. For this research, SAP2000 version 23 was employed. In the software, a two-dimensional structural model was generated to conduct linear static analysis and design. Beam and column elements were represented as linear frame elements within the model.

Table 3.1: Description of the Proposed Structure.

Concrete class	C16/20
Reinforcement	S-500
Beam dimension	250mm X300mm
Column dimension	300 X 400
bay width	4m
Story height	4m
number of story	3
number of bay	2
Ground acceleration	0.1g
Dead load	25kn/m
Live load (30%)	16kn/m
Factored load	57.75kn/m
Ductility class	DCM and DCH
Main bar diameter	14mm
Transverse bar diameter	8mm
Concrete cover	30mm
Elastic response spectra	Type 1
Damping ratio	5%
Ground type	C
behavioural factor	3.3
Fundamental period	0.48sec
P-Δ	Based on nominal curvature
Combination equation	Eqs.6.10
Safety factor for rebar	1.15
Safety factor for concrete	1.50
Knowledge level	3

Equations 3.1, 3.2, and 3.3 illustrate the load combination, structural behaviour factor, and fundamental period of vibration.

Combination equation 6.10 as per EN1990:2004 section 6.4.3.2 equation 6.10.

$$\sum_{j\geq 1} \gamma Gj.Gkj + \gamma Q1.Qk1 + \sum_{i>1.} \gamma Qi.\psi oi.Qki \tag{3.1}$$

Behavioural factors as per EN1998:2004 section 5.2.2.2 equation 5.1.

$$q = qo.Kw \geq 1.5 \tag{3.2}$$

Fundamental period of vibration as per EN1998:2004 section 4.3.3.2.2 equation 4.6.

$$T1 = Ct.H^{3/4} \tag{3.3}$$

Where:

γG = safety factor for dead load.

γQ = safety factor for live load.

Gk = dead load.

Qk1 = basic value of leading variable load.

Qki = basic value of accompanying variable load.

$\Psi 0$ = combination factor

q = behavioural factor.

q_0 = basic value of behavioural factor.

K_W = factor reflecting the prevailing failure mode.

T_1 = Fundamental period of vibration.

C_t = regression coefficient.

H=height of the building in meter from the foundation or from the top of rigid basement.

3.2.1. Stability and Deflection Check.

Performance assessment can be conducted on either newly designed buildings or existing structures. Thus, prior to embarking on a nonlinear pushover analysis, it is imperative to subject the frame to a linear analysis, followed by the design and detailing in accordance with the chosen ductility class.

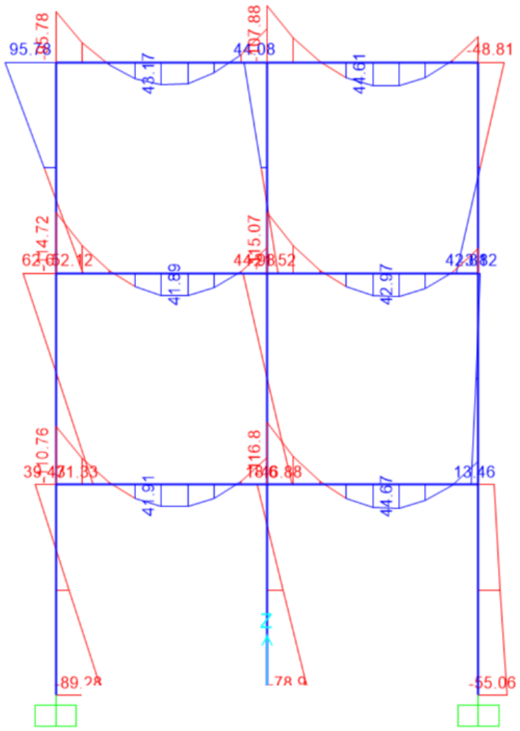


Figure 3.2 analysis result

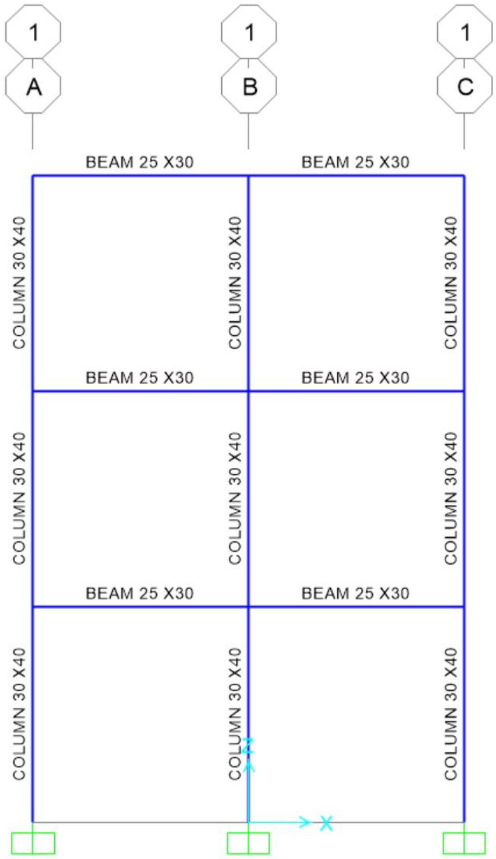


Figure 3.1 Beam and Column Sections.

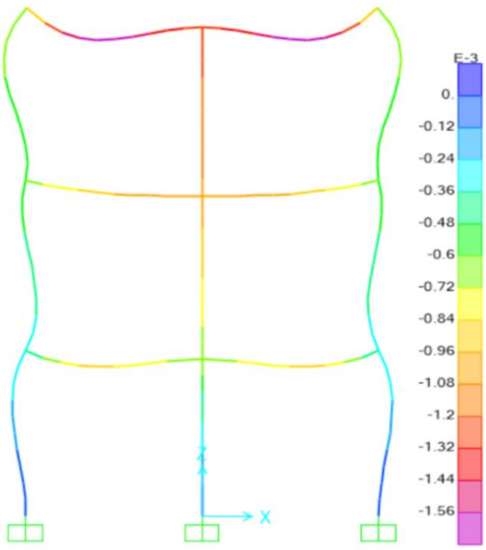


Figure 3.3 Deflection results due to service loads.

An examination of the frame's deflection and stability reveals that it is already stable, and the deflection also conforms to the requirements outlined in the relevant building codes. However, it is important to take into account the P-Δ effect, as indicated in Table 3.2.

Table 3.2 Stability check.

story	P in KN	Displacement in X in mm	Drx	H in m	Vx in KN	Drift ratio	θx *q	Limiting value to ignore P-Δ	Limiting value for stability	P-Δ	stability
3	381	45.78267	0.015324	4	-614.9	0.003831	0.03133	0.1	0.3	consider	stable
2	760	30.4024	0.018916	4	-175.2	0.004728	0.2707	0.1	0.3	Not consider	stable
1	1140	11.4865	0.011487	4	-257.7	0.002871	0.1676	0.1	0.3	Not consider	stable

.

3.2.2. Design and Detailing According To DCM.

After completing the design and conducting a comprehensive verification of the frame, the reinforcement bars required for both flexural and shear applications are visually depicted in figures 3.4 to 3.8.

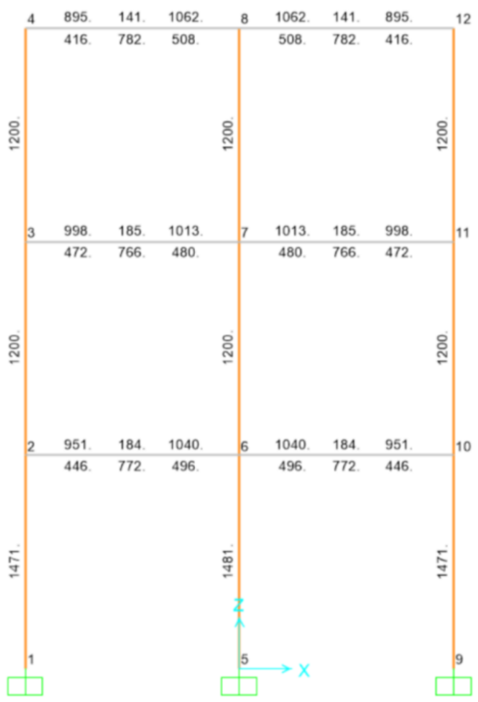


Figure 3.5 Longitudinal Reinforcement Bars.

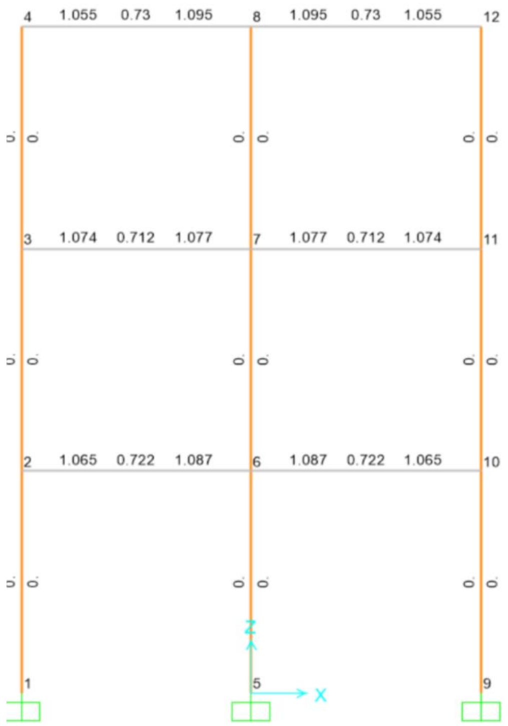


Figure 3.4 Shear Reinforcements bars.

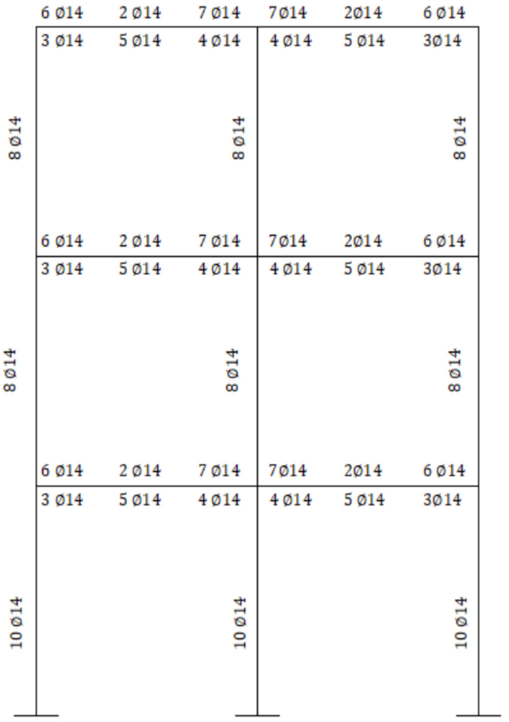


Figure 3.7 longitudinal Bar Detailing according To DCM

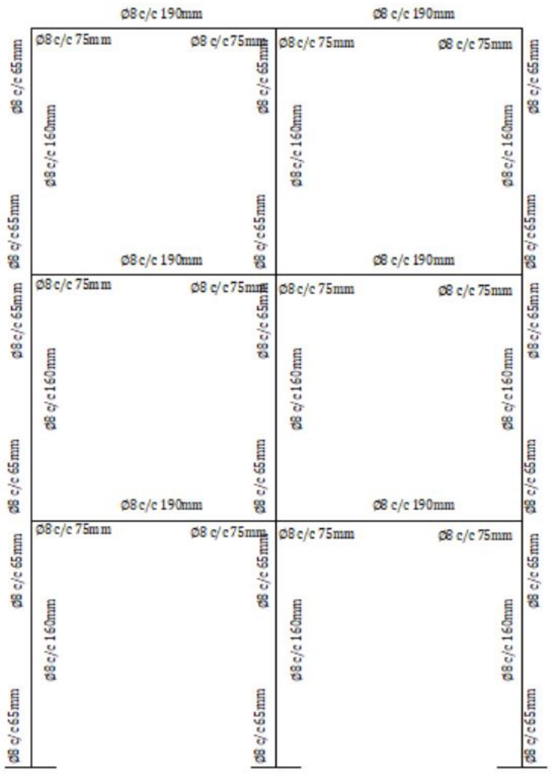


Figure 3.6 Shear Reinforcement Detailing According To DCM

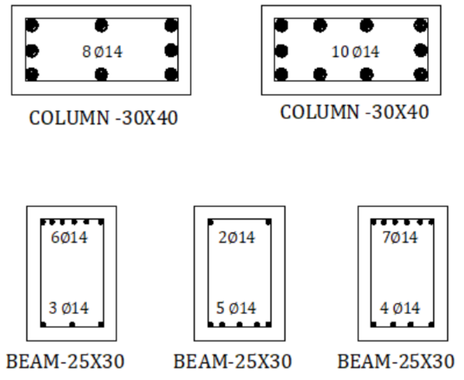


Figure 3.8 Reinforcement Bar For

3.2.3. Design and Detailing According To DCH.

The design and specific arrangement of reinforcement bars for columns and beams, addressing both flexural and shear aspects, are presented in figures 3.9 and 3.10.

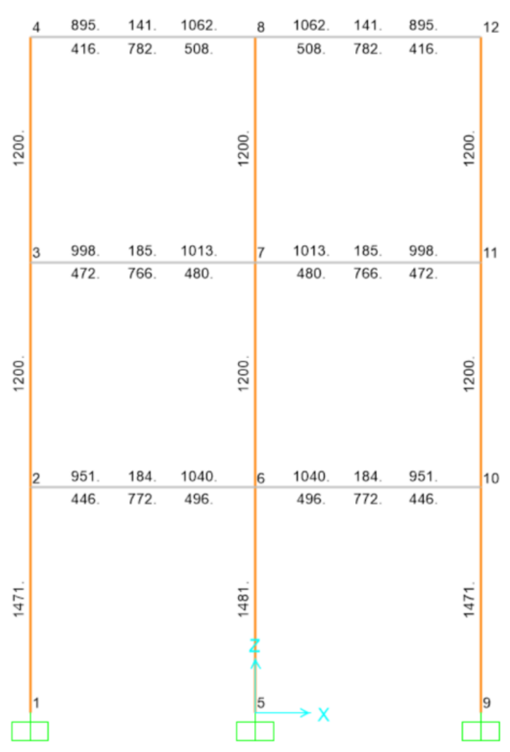


Figure 3.10 Longitudinal Bars

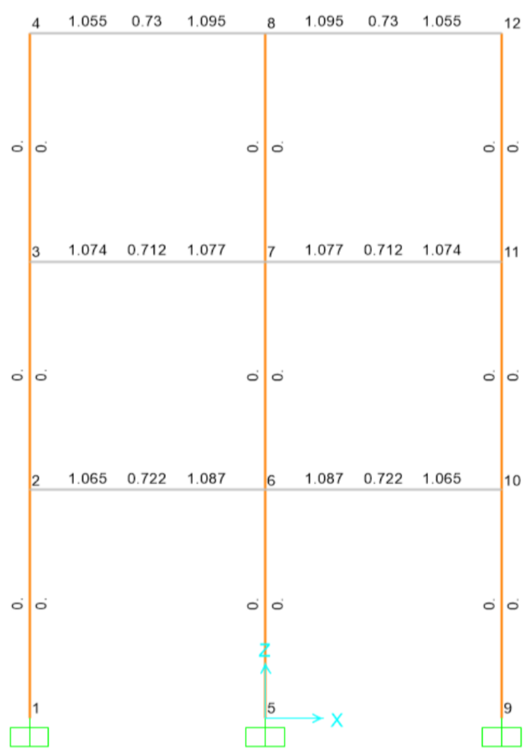


Figure 3.9 Shear Reinforcements

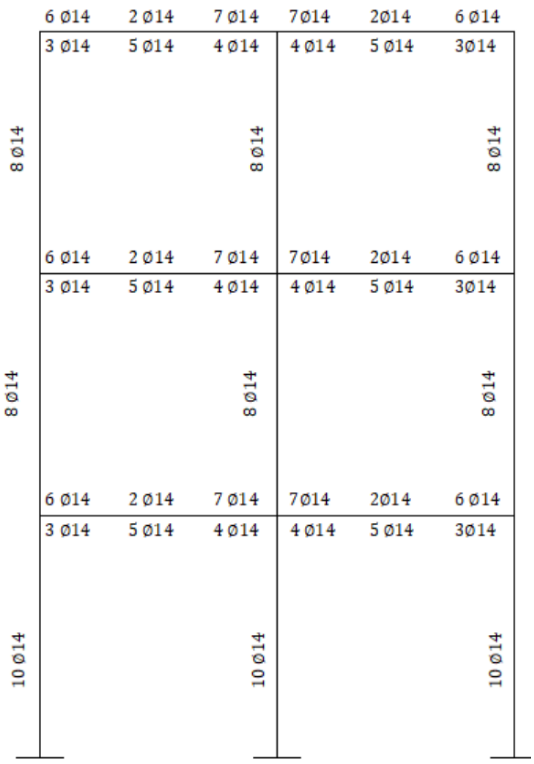


Figure 3.12 Main bar Detailing according To DCH

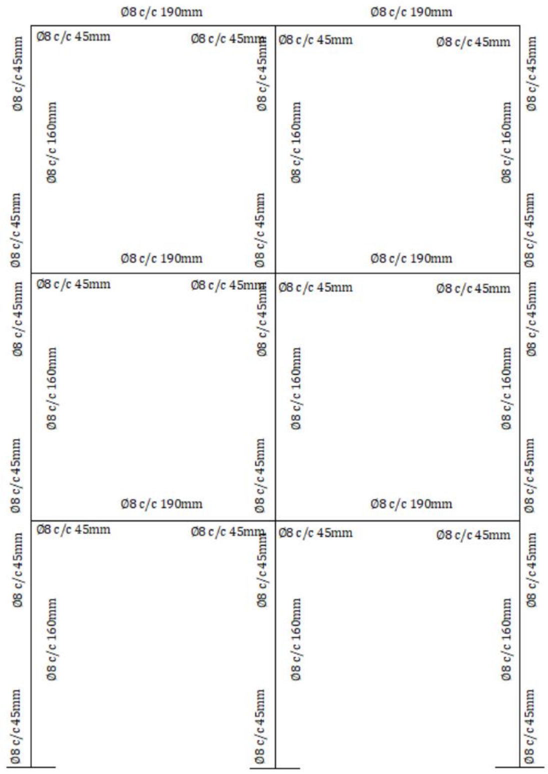


Figure 3.11 Shear Reinforcement Detailing According To DCH

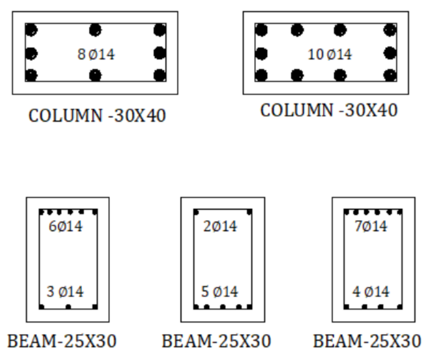


Figure 3.13 beam and column sections.

3.3. Pushover Analysis for Flexure.

Pushover analyses were conducted using the software "seismo-structure v-2023," a versatile tool designed for evaluating the structural performance through both static and dynamic analyses. In this research, version 2023 of seismo-structure was employed. To execute nonlinear static analysis, a two-dimensional model of the structure was established within seismo-structure. In the model, beam and column elements were represented as nonlinear frame elements with localized plasticity, accomplished by specifying the plastic hinge lengths at both ends of the beams and columns. The hinge locations are illustrated in Figure 3.21. Seismo-structure incorporates the plastic hinge properties as outlined in FEMA-356 (or ATC-40). In this scenario, it appears that the default hinge properties were utilized, with the sole adjustment being the modification of hinge lengths for beam and column elements in both shear and flexure.

The literature provides various suggestions for plastic hinge lengths, and the selection of the appropriate hinge length can have a substantial impact on the precision of structural analysis and design. In this study, we aim to employ two distinct hinge length models proposed by Park and Paulay in Equation 3.4 and Priestley in Equation 3.5.

$$Lp1 = 0.5H \tag{3.4}$$

$$Lp2 = 0.08L + 0.022. fye.dbl \geq 0.044.fye.dbl \tag{3.5}$$

$$L_{Pcb} = Lp1, 2 /2 \tag{3.6}$$

$$L_{Pct} = Hbeam - Lp1, 2 /2 \tag{3.7}$$

$$L_{Pb} = Hcol/2 - Lp1, 2 /2 \tag{3.8}$$

Where:

Lp1= plastic hinge length for shear and flexure proposed by park and paulay.

Lp2= plastic hinge length for shear and flexure proposed by Priestley.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth.

fye= expected yield strength

d_{bl} *= diameter of longitudinal reinforcement*

LP_{ct}*= plastic hinge length for shear and flexure at the column top.*

LP_{cb}*= plastic hinge length for shear and flexure at the column bottom.*

$LP_{b=}$ *plastic hinge length for shear and flexure at the two ends of the beam.*

The plastic hinge length in a column is different at the top (LP_{ct}) and bottom ($LP_{cb)}$ due to load distribution, boundary condition, material properties, geometric imperfection and loading condition.

Shear hinge refers to a mechanism used to describe the behaviour of structural elements, specifically in situations where shear forces are predominant. The shear hinge model simplifies the behaviour of a structural element by assuming that it primarily experiences shearing forces and that other forces, such as bending moments. Because of the brittle failure of concrete in shear, no ductility is considered for this type of hinge. Shear hinge properties are defined such that, when the shear force in the member reaches its shear strength, the member fails immediately. The shear strength of each member is calculated according to EN1998-3:2004.

Flexural hinges form when the material within a structural member, such as a reinforced concrete beam and column, undergoes plastic deformation. This occurs when the applied bending moment exceeds the member's capacity to resist further deformation elastically, causing permanent deformation in the form of bending. When a flexural hinge forms, it absorbs and dissipates energy, which is essential for protecting the structural integrity of the building. The energy dissipation helps prevent the sudden collapse of the structure under extreme loading conditions

Seismo-structure offer two types of element modelling approaches this are **force based** and **displacement based** formulations:

3.3.1 Forced-Based Formulation.

In general, forced based formulations are more appropriate than displacement-based formulations due to various limitations of displacement-based models such as the prediction of higher element stiffness and strength. Seismo-Struct categorizes the force-based modelling approach into infrmFB (inelastic force-based frame element type) and infrmFBPH (inelastic force-based plastic hinge frame element type).

3.3.1.1 Inelastic Force-Based Frame Element Type (Infrmfb).

InfrmFB techniques are based on the distributed plasticity modelling approach where the plasticity is distributed along the whole length of the member by dividing elements into different integrated sections from 3 to 1.

3.3.1.2 Inelastic Force-Based Plastic Hinge Frame Element Type (Infrmfbph).

nfrmFBPH feature similar modelling approaches just like infrmFB, but with some advantages such as reduced analysis time and a control/calibration of the plastic hinge length that is spread of inelasticity.

3.3.2. Displacement-Based Formulations.

Similarly, the displacement-based formulations are categorized into infrmDB (inelastic displacement-based frame element type) and infrmDBPH (inelastic displacement-based plastic hinge frame element type).

3.3.2.1 Inelastic Displacement-Based Frame Element Type (Infrmdb).

infrmDB techniques are based on the distributed plasticity modelling approach where the plasticity is distributed along the whole length of the member by defining different nodes for the element, depending upon the accuracy needed, and then connecting those nodes to form the element.(fig.14)

3.3.2.2 Inelastic Displacement-Based Plastic Hinge Frame Element Type (Infrmdbph).

infrmDBPH feature similar modelling approaches just like infrmDB respectively, but with some advantages such as reduced analysis time.

In this study, beams and columns were modelled using the infrmFBPH and Force based approach for shear and flexural plastic hinge length. And the discretization of beams and columns were completed by dividing each sections.

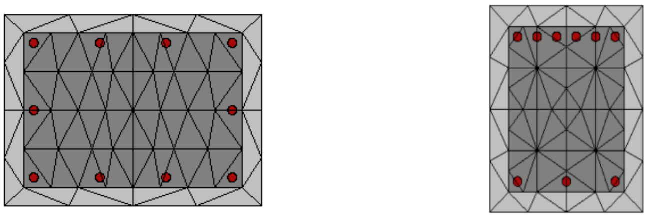


Figure 3.14 Discretization Of Column And Beam Section.

3.3.3. Pushover Analysis and Performance Check Procedures.

Begin by creating a finite element model of the structure in seismo-structure. This involves defining the geometry and properties of the structural elements such as beams, columns, and braces. Assigning material properties to the structural components, Define boundary conditions for the model, perform a nonlinear static pushover analysis using a load pattern that incrementally applies lateral loads to the structure. This analysis considers the nonlinear behaviour of the structure under increasing lateral forces. From now on for all cases the pushover analysis using seismo-structure is performed based on the following typical procedures.

1. Define material properties

- C16/20 concrete grade.
- S 500 steel grade.

The stress-strain relationship of concrete and reinforcement bar are shown in fig 3.15 and 3.16 respectively when subjected to cyclic loading. As cyclic loading continues, the stress-strain responses exhibits a hysteresis loop. The loop is the representation of the material's energy dissipation during loading and unloading cycles and it indicates that energy is absorbed and dissipated during each cycle, leading to a gradual accumulation of deformations.

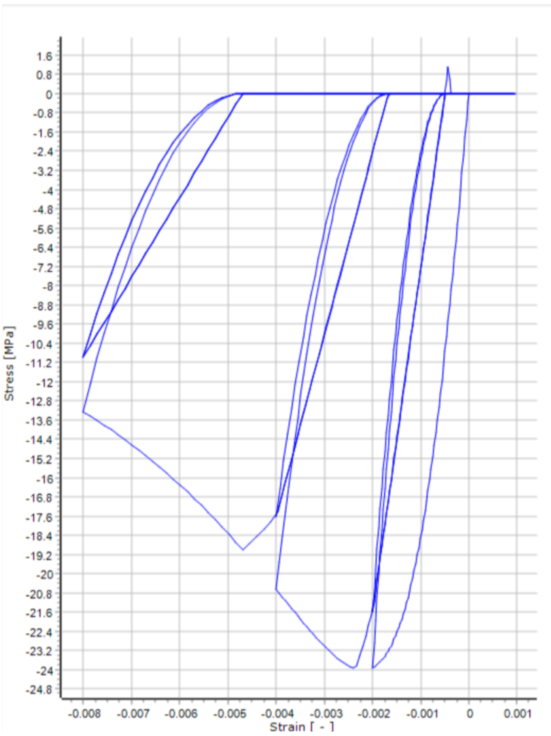


Figure 3.15 Stress Strain Relation Of Concrete For Cyclic Loading.

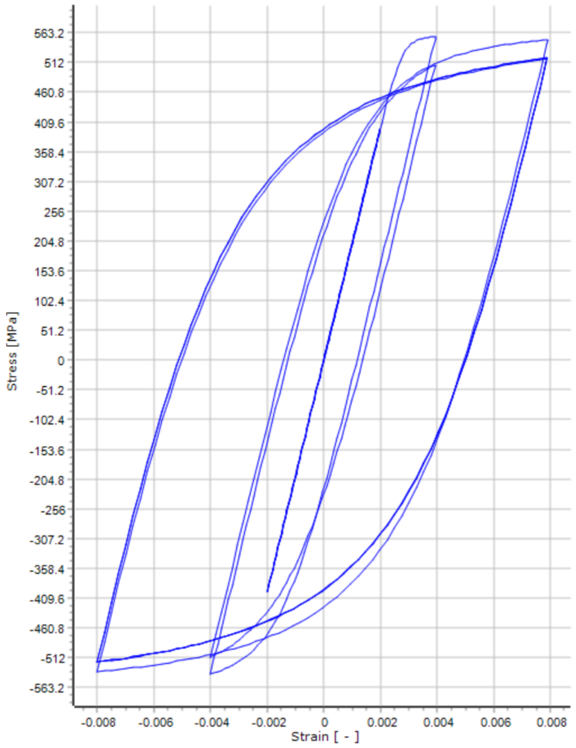


Figure 3.16 Stress Strain Relation Of Steel Reinforcement For Cyclic Loading.

2. Defining section properties.

- Column 300mm X 400mm.
- Beam 250mm X 300mm.

3. Defining Element class.

- In element class definition we usually assign the required plastic hinge length in percent.
- And also assign the amount of section fibres or monitoring points for each frame elements.

4. Application of lateral (nominal shear) and gravitational loads.

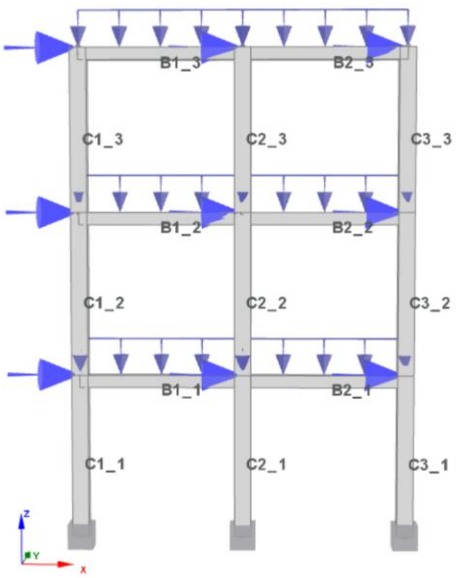


Figure 3.17 lateral and vertical Load Applications.

5. Choosing the nodes for recording displacements.

- Displacement is measured at the designated nodal points located at joint **N-10** as shown in Fig 3.18.

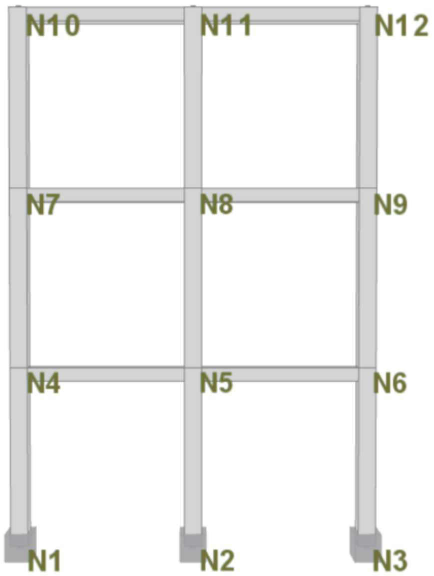


Figure 3.18 Displacement Control Point.

6. Assigning performance criteria.

- Shear and bending moment performance criteria of the frame elements will be assigned as per EN1998-3:2004

7. Pushover analysis.

- The software will determine the shear and bending moment capacity of frame elements in accordance with the EN1998-3:2004.

8. Analysis results.

- Code based checks for flexural and shear hinge damage locations will be assessed and frame element performance will also be assessed.

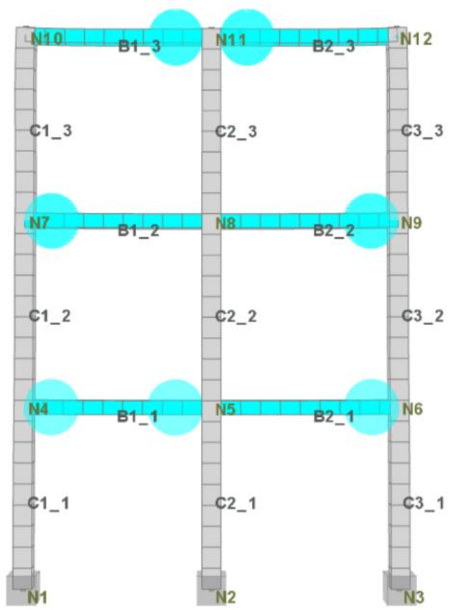


Figure 3.19 Colour Used To Represent Shear Hinge Formation

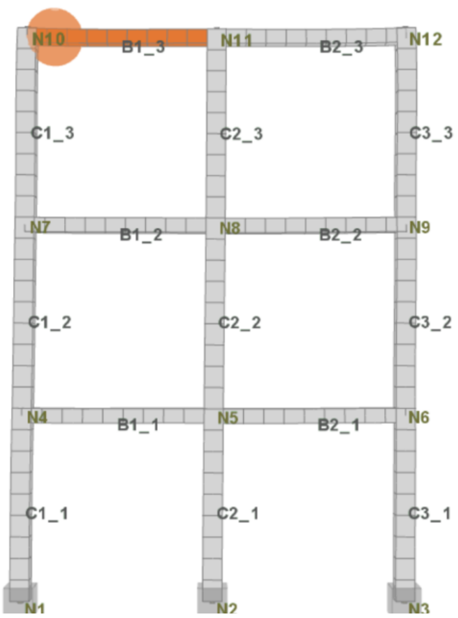


Figure 3.20 Colour Used To Represent Flexural Hinge Formation

3.3.3.1 CASE ONE

3.3.3.1.1 Pushover Analysis for DCM Detailed Flexural Hinge Using Lp-1.

For case one the plastic hinge length for each frame elements will be use the following empirical formula based on Park, Paulay and Priestley.

$$L_{p\text{-}1} = 0.5H$$

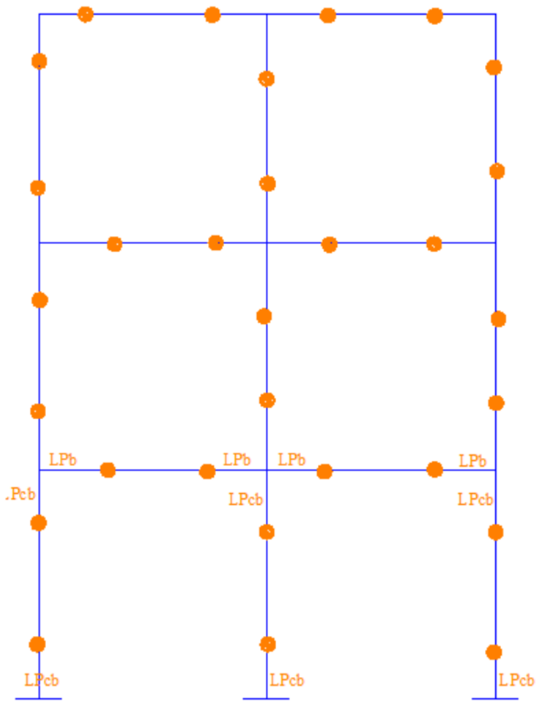
$$L_p \text{ for column} = 0.5 \text{ x } 400\text{mm} = 200\text{mm}$$

$$L_p \text{ for beam} = 0.5 \text{ x } 300\text{mm} = 150\text{mm}$$

$$L_{Pcb} = L_{pc}/2 = 100\text{mm}$$

$$L_{Pct} = \text{Hbeam} – L_{pc}/2 = 200\text{mm}$$

$$L_{Pb} = \text{Hcol}/2 - L_{pb}/2 = 125\text{mm}$$



Lp1= plastic hinge length for shear and flexure proposed by park and paulay.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

d_{bl} = diameter of longitudinal reinforcement

LP_{ct}= plastic hinge length for shear and flexure at the column top.

LP_{cb}= plastic hinge length for shear and flexure at the column bottom.

LP_{b}= plastic hinge length for shear and flexure at the two ends of the beam.

Figure 3.21 Plastic Hinge Locations.

3.3.3.1.2 Capacity check.

Seismo structure gives an idealized linear graphical representation (fig 3.22) of a structure's ability to resist lateral forces (usually plotted as base shear or lateral displacement) as a function of inter-story drift. This curve is typically used in the context of pushover analysis or nonlinear static analysis to assess the seismic performance of a building or structure. It helps us to easily understand the structure's response to increasing lateral loads and the corresponding deformation.

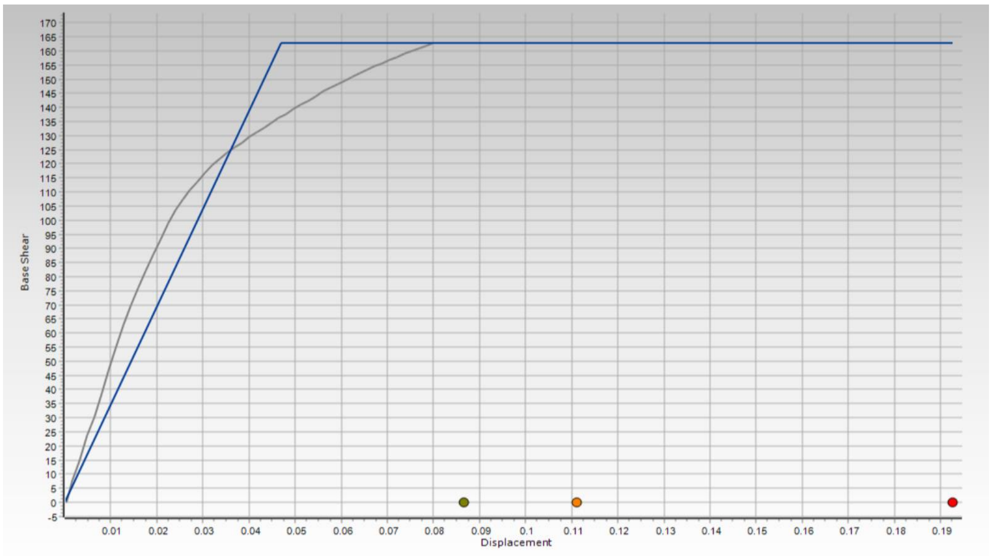


Figure 3.22 Capacity Curve for DCM Flexural Hinge Using Plastic Length -1

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0470	162.67
0.0800	162.67
0.1927	162.67

Table 3.4 Idealized curve for DCM flexural hinge using Lp-1

K-elastic in KN/m	6751.73
K-eff in KN/m	3463.94
a	0.000
Fy in KN	162.67
Dy in meter	0.0470
Un-balanced area	0.01

Table 3.3 Linearization data for DCM flexural hinge using Lp-1

Performance levels	Displacement in meter
Damage limit state(DL)	0.0866452
Significant damage(SD)	0.11115138
Near collapse(NC)	0.1926972

Table 3.5 Displacement capacity for DCM flexural hinge using Lp-1

3.3.3.1.3 Flexural Hinge Formations.

The figure below shows the flexural hinge formations without any un-desirable mechanism.

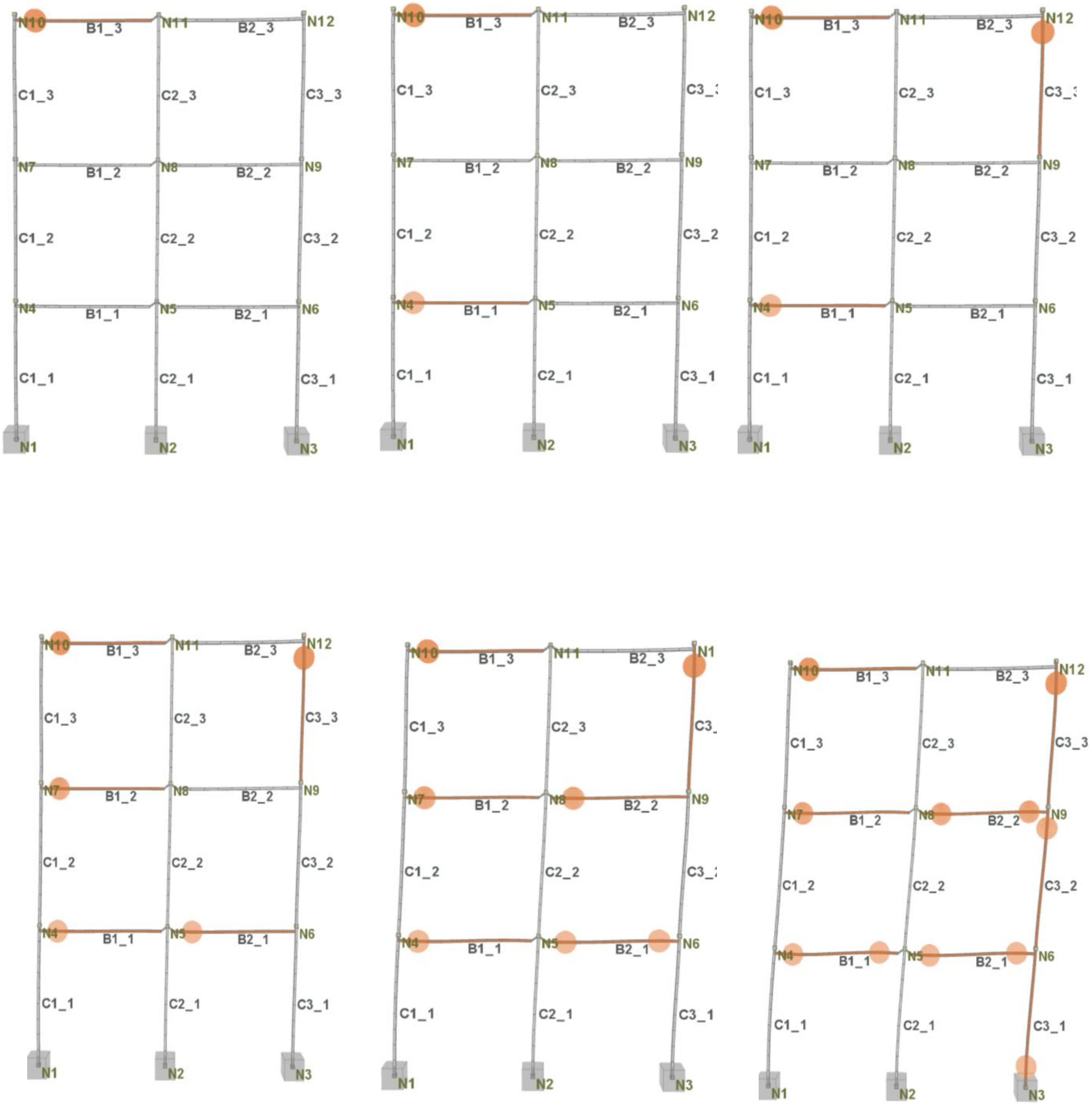


Figure 3.23 Sample Plastic Hinge Formations On Different Load Factors.

3.3.3.2 CASE TWO.

3.3.3.2.1 Pushover Analysis for DCM Detailed Flexural Hinge Using Lp-2.

On this case the same procedure will also be followed but by using different plastic hinge length.

$$L_{p2} = 0.08L + 0.022.\,f_{ye}.d_{bl} \quad \geq \quad 0.044.fye.dbl$$

Where:

Lp2= plastic hinge length for shear and flexure proposed by Priestley.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

dbl = diameter of longitudinal reinforcement

.

Table 3.6 Plastic Hinge Length for Each Structural Elements Using Priestley's Equation.

Distance from section of the plastic hinge to the point of contra flexure.	Calculated Plastic Hinge Length.	Minimum Plastic Hinge length according to Priestley	Remark.
$L_{C1bottom}$ = 1200mm	230mm	260mm	Use 260mm
L_{C1top} = 2500mm	334mm	260mm	Use 334mm
$L_{C2bottom}$ = 1100mm	222mm	260mm	Use 260mm
L_{C2top} = 2540mm	337mm	260mm	Use 337mm
$L_{C3bottom}$ = 1675mm	268mm	260mm	Use 268mm
L_{C3top} = 2048mm	298mm	260mm	Use 298mm
$L_{C4bottom}$ = 1988mm	293mm	260mm	Use 293mm
L_{C4top} = 1795mm	278mm	260mm	Use 278mm
$L_{C5bottom}$ = 1891mm	285mm	260mm	Use 285mm
L_{C5top} = 1903mm	286mm	260mm	Use 286mm
$L_{C6bottom}$ = 2891mm	365mm	260mm	Use 365mm
L_{C6top} = 748mm	183mm	260mm	Use 260mm
$L_{C7bottom}$ = 2578mm	340mm	260mm	Use 340mm
L_{C7top} = 1109mm	223mm	260mm	Use 260mm
$L_{C8bottom}$ = 2963mm	371mm	260mm	Use 371mm
L_{C8top} = 615mm	183mm	260mm	Use 260mm
L_{C9} = 4000mm	454mm	260mm	Use 454mm
$L_{B1-left}$ = 850mm	202mm	260mm	Use 260mm
$L_{B1-right}$ = 690mm	189mm	260mm	Use 260mm
$L_{B2-left}$ = 965mm	211mm	260mm	Use 260mm
$L_{B2-right}$ = 470mm	172mm	260mm	Use 260mm
$L_{B3-left}$ = $L_{B4-left}$ = $L_{B5-left}$ = $L_{B6-left}$ = 980mm	212mm	260mm	Use 260mm
$L_{B3-right}$ = $L_{B4-right}$ = $L_{B5-right}$ = $L_{B6-right}$ = 520mm	176mm	260mm	Use 260mm

3.3.3.2.2 Capacity Check.

In the context of a capacity curve, the dots or broken lines in the curve typically represent the displacement and base shear capacity of the structure at various operating system (performance levels).

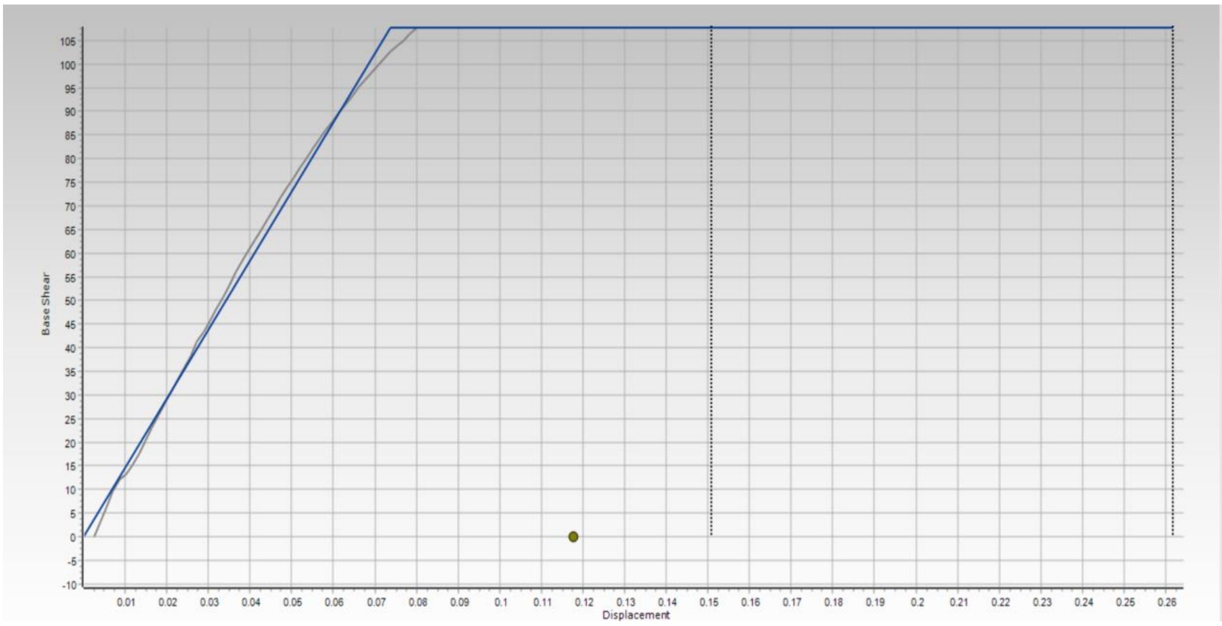


Figure 3.24 Capacity Curve for DCM Flexural Hinge Using Plastic Length -2.

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	107.79
0.0800	107.79
0.2616	107.79

Table 3.8 Idealized curve for DCM flexural hinge using Lp-2

K-elastic in KN/m	2057.87
K-eff in KN/m	1463.59
a	0.000
Fy in KN	107.79
Dy in m	0.0736
Un-balanced area	0.01

Table 3.7 linearization data for DCM flexural hinge using Lp-2

Performance levels	Displacement in meter
Damage limit state(DL)	0.1176
Significant damage(SD)	0.1509
Near collapse(NC)	0.2616

Table 3.9 Displacement capacity for DCM flexural hinge using Lp-2

3.3.3.2.3 Flexural hinge formation.

The diagram below depicts the positions or development of flexural hinges at critical locations within each structural element, without any undesired mechanisms.

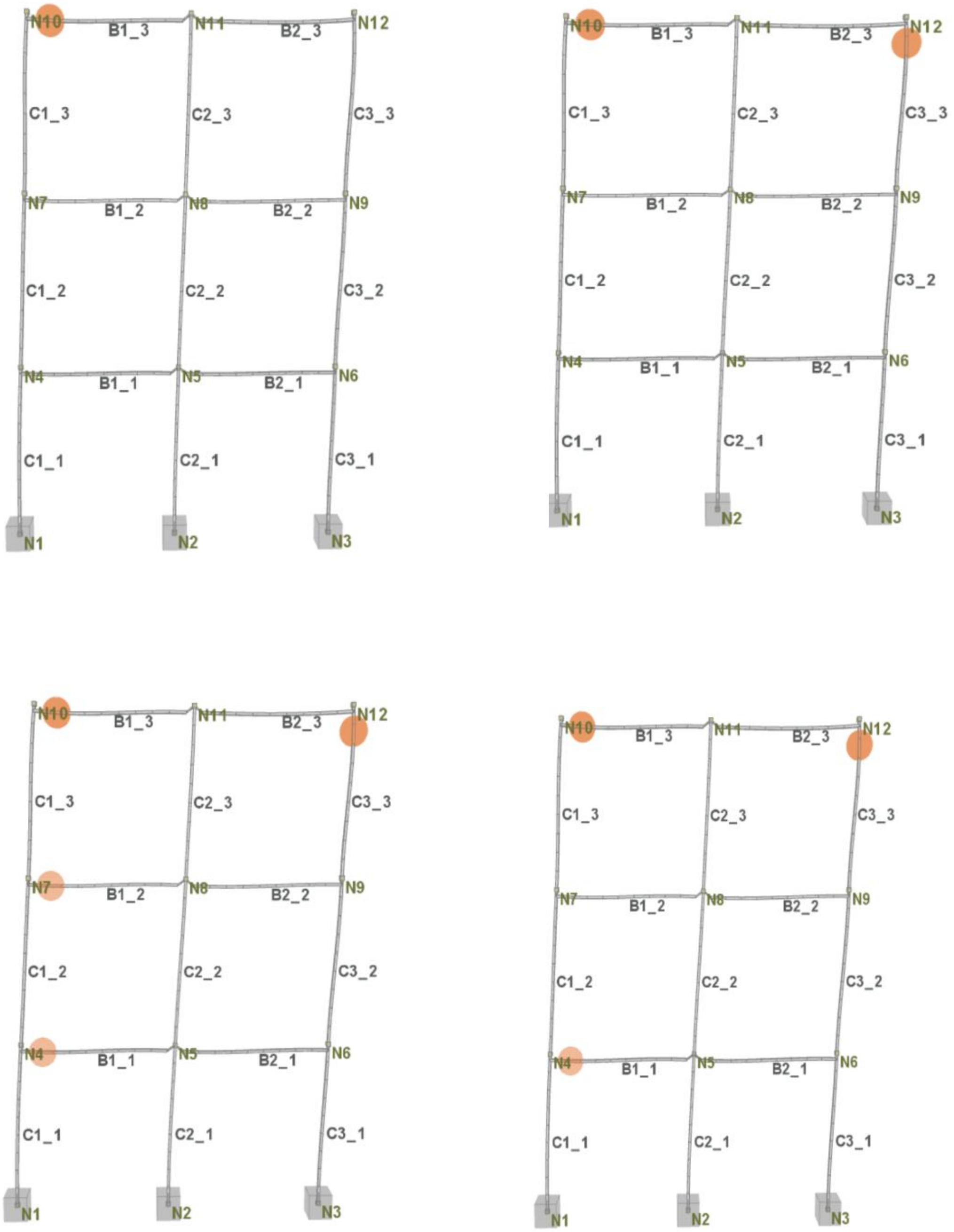


Figure 3.25 Sample Plastic Hinge Formations On Different Load Factors.

3.3.3.3 CASE THREE

3.3.3.3.1 Pushover Analysis for DCH Detailed Flexural Hinge Using Lp-1.

$$L_{p1} = 0.50 \text{ x } H$$

Lp for column = 0.5 x 400mm = 200mm

Lp for beam = 0.5 x 300mm = 150mm

$LP_{cb} = L_{pc} /2 = 100$mm

$LP_{ct} = \text{Hbeam} – L_{pc} /2 = 200$mm

$LP_b = \text{Hcol}/2 - L_{pb} /2 = 125$mm

Lp1= plastic hinge length for shear and flexure proposed by park and paulay.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

d_{bl} = diameter of longitudinal reinforcement

LP_{ct}= plastic hinge length for shear and flexure at the column top.

LP_{cb}= plastic hinge length for shear and flexure at the column bottom.

$LP_{b=}$ plastic hinge length for shear and flexure at the two ends of the beam.

3.3.3.3.2 Capacity Check.

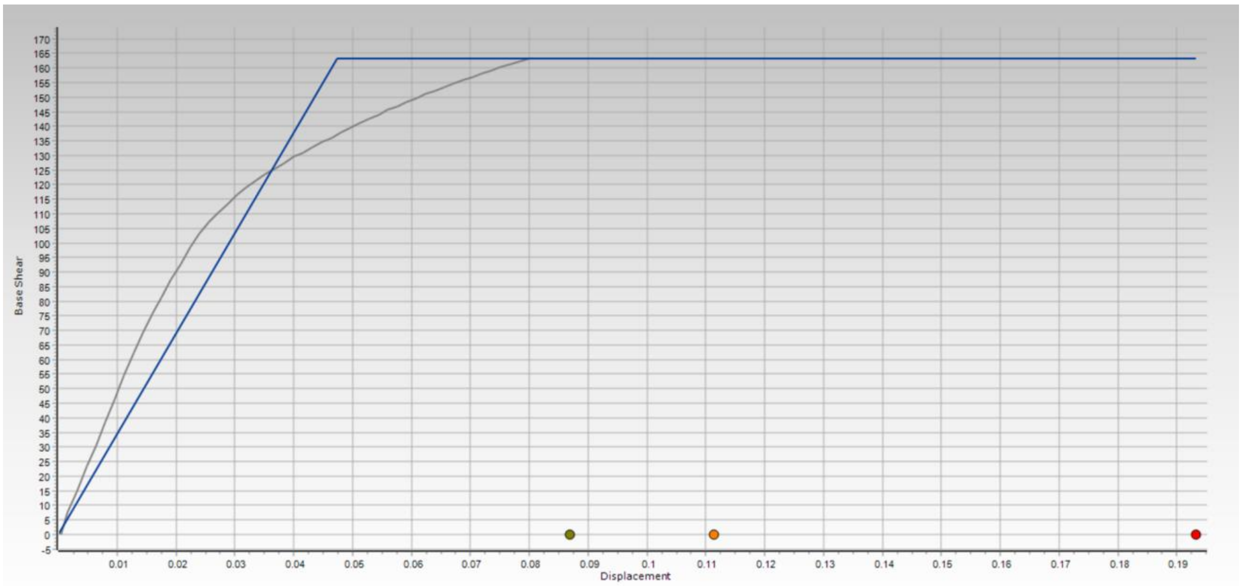


Figure 3.26 Capacity Curve for DCH Flexural Hinge Using Plastic Length -1

Displacement in meter	Base shear in KN
0.000	0.000
0.0736	163.09
0.0800	163.09
0.2616	163.09

Table 3.11 Idealized curve for DCH flexural hinge using Lp-1.

K-elastic in KN/m	6661.61
K-eff in KN/m	3445.78
a	0.000
Fy in KN	163.09
Dy in m	0.0473
Un-balanced area	0.01

Table 3.10 linearization data for DCH flexural hinge using Lp-1.

Performance levels	Displacement in meter
Damage limit state(DL)	0.0868
Significant damage(SD)	0.1114
Near collapse(NC)	0.1932

Table 3.12 Displacement capacity for DCH flexural hinge using Lp-1.

3.3.3.3.3 Flexural Hinge Formation.

The diagram below exhibits representative flexural hinge configurations, all free from any undesirable mechanisms.

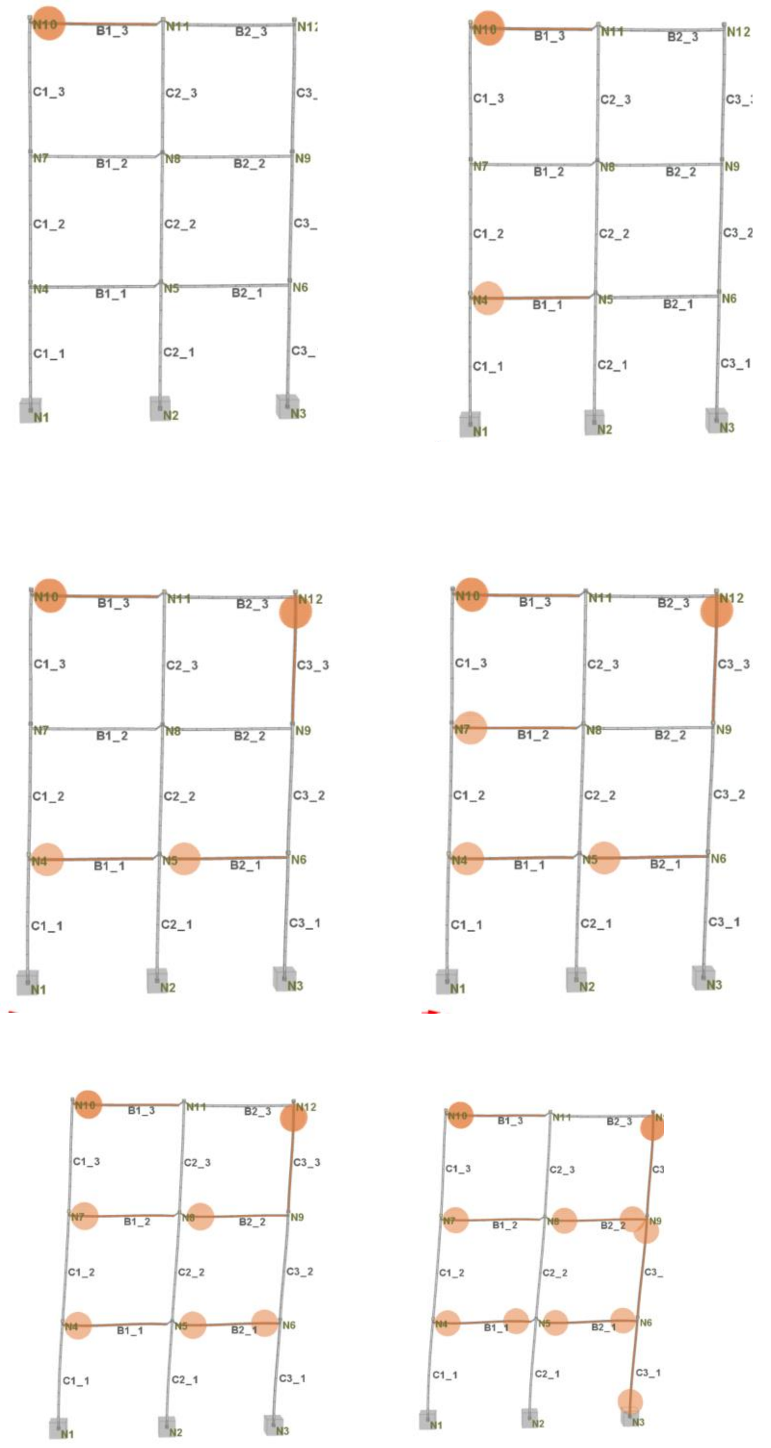


Figure 3.27 Sample Plastic Hinge Formations On Different Load Factors.

3.3.3.4 CASE FOUR

3.3.3.4.1 Pushover Analysis for DCH Detailed Flexural Hinge using Lp-2.

In this scenario, we will employ the identical method, but with the plastic hinge length utilized in the second case.

$$L_{p2} = 0.08L + 0.022.\ f_{ye}.d_{bl} \quad \geq \quad 0.044.fye.dbl$$

Where:

Lp2= plastic hinge length for shear and flexure proposed by Priestley.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

dbl = diameter of longitudinal reinforcement

3.3.3.4.2 Capacity Check.

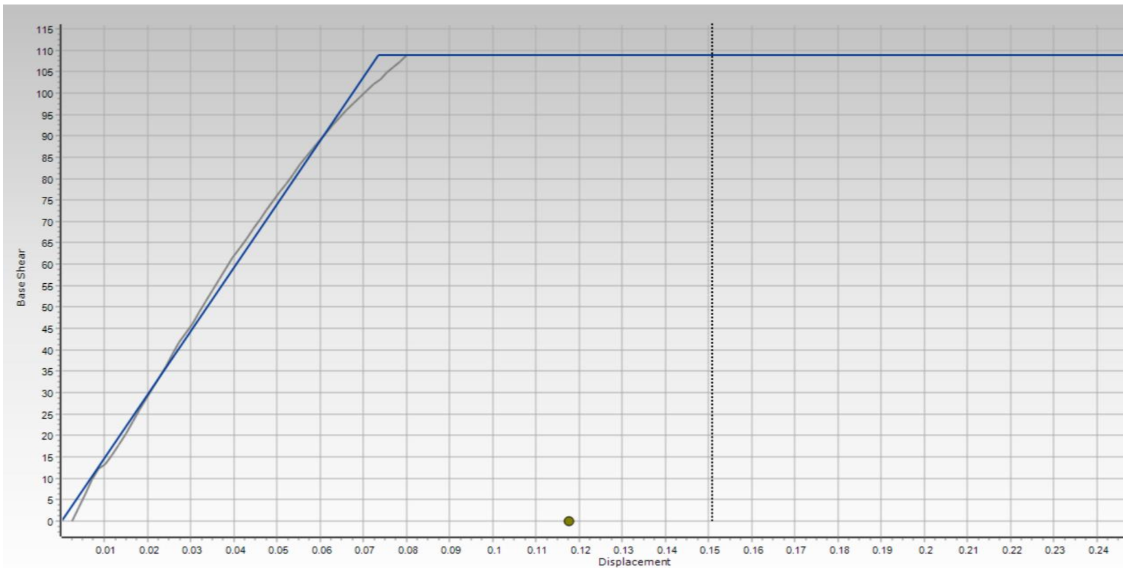


Figure 3.28 Capacity Curve for DCH Flexural Hinge Using Plastic Length -2

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	108.75
0.0800	108.75
0.2616	108.75

Table 3.14 Idealized curve for DCH flexural hinge using Lp-2.

K-elastic in KN/m	2094.75
K-eff in KN/m	1480.36
a	0.000
Fy in KN	108.75
Dy in m	0.0735
Un-balanced area	0.00

Table 3.13 linearization data for DCH flexural hinge using Lp-2.

Performance levels	Displacement in meter
Damage limit state(DL)	0.1176m
Significant damage(SD)	0.1508m
Near collapse(NC)	0.2615m

Table 3.15 Displacement capacity for DCH flexural hinge using Lp-2.

3.3.3.4.3 Flexural Hinge Formation.

The diagram below illustrates the absence of any instable mechanisms in the flexural hinge configurations. These flexural hinges signify areas where yielding and enduring deformation take place as a result of bending moments.

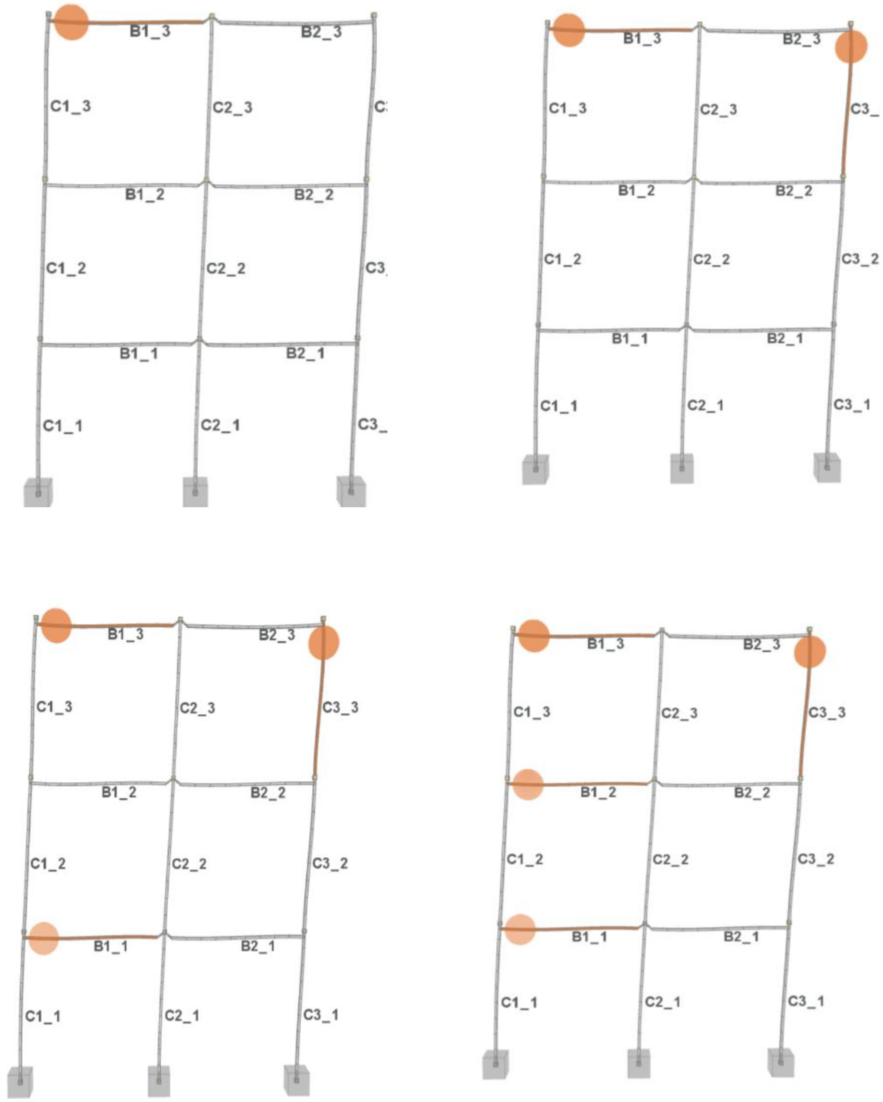


Figure 3.29 Sample Plastic Hinge Formations On Different Load Factors.

3.4 Pushover Analysis for Shear Hinges.

In a standard frame modelling approach, many failure modes are typically considered. However, the specific failure mode related to joints, such as joint shear hinging, is frequently overlooked. In this modelling technique, the joint is usually simplified as being rigid, meaning it behaves in a linearly elastic manner and doesn't contribute to the frame's deformability. This implies that even in the face of significant joint distortion, the members remain perpendicular, and the joint panel remains elastic, even as the beam and column members rotate significantly under lateral cyclic loads.

In the case of a non-ductile reinforced concrete frame with weak joints, shear hinging and brittle shear failure may occur before the beam and column members reach their maximum capacity. Joint shear distortion can have a significant impact on lateral story drift, which, in turn, greatly influences the overall structural performance. Therefore, it is crucial to create numerical models that can accurately simulate joint shear hinging to predict the seismic response of the frame under lateral loads.

3.4.1 CASE ONE

3.4.1.1 Pushover Analysis for DCM Detailed Shear Hinge Lp-1.

$$L_{p-1} = 0.5H$$

L_p *for column = 0.5 x 400mm = 200mm*

L_p *for beam = 0.5 x 300mm = 150mm*

$L_{Pcb} = L_{pc} /2 = 100mm$

$L_{Pct} = Hbeam – L_{pc} /2 = 200mm$

$L_{Pb} = Hcol/2 - L_{pb} /2 = 125mm$

Lp1= plastic hinge length for shear and flexure proposed by park and paulay.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

d_{bl} *= diameter of longitudinal reinforcement*

LP_{ct}*= plastic hinge length for shear and flexure at the column top.*

LP_{cb}*= plastic hinge length for shear and flexure at the column bottom.*

$LP_{b=}$ *plastic hinge length for shear and flexure at the two ends of the beam.*

3.4.1.2 Capacity Check.

The capacity curve in figure 3.30 is related to shear hinge formation to represent the structural response in terms of base shear capacity and lateral deformation. The idealized capacity curve helps us to easily assess the shear capacity of a structure and how it responds under lateral loads.

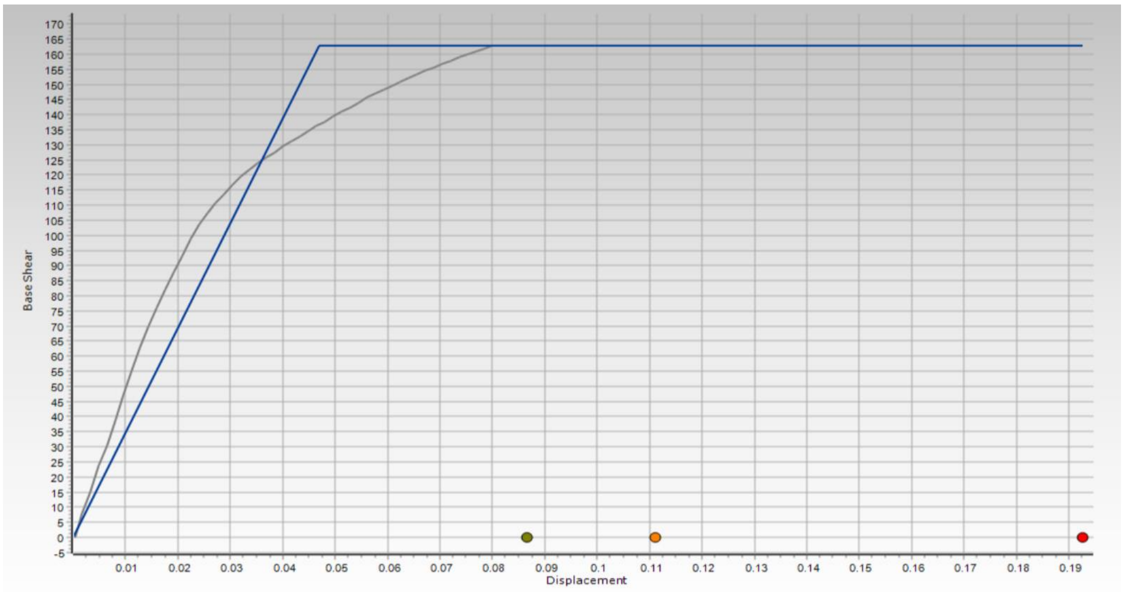


Figure 3.30 Capacity Curve for DCM shear Hinge Using Plastic Length -1

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	162.67
0.0800	162.67
0.2616	162.67

Table 3.17 Idealized curve for DCM shear hinge using Lp-1

K-elastic in KN/m	6751.73
K-eff in KN/m	3463.94
a	0.000
Fy in KN	162.67
Dy in m	0.0470
Un-balanced area	0.01

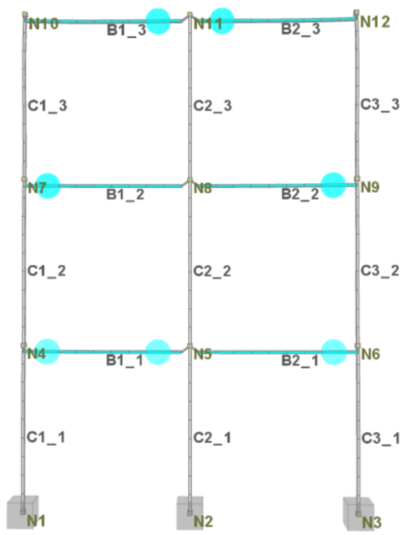
Table 3.16 linearization data for DCM shear hinge using Lp-1

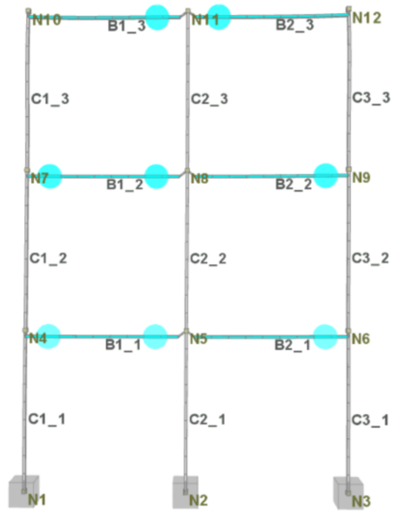
Performance level	Displacement in meter
Damage limit state(DL)	0.0866m
Significant damage(SD)	0.1111m
Near collapse(NC)	0.1926m

Table 3.18 Displacement capacity for DCM shear hinge using Lp-1

3.4.1.3 Shear Hinge Formation.

The Shear hinges shown in fig 3.31 in beams form in a regions where plastic deformation occurs due to excessive shear forces. These shear hinges form where the applied shear force exceeds the shear capacity of the beam's cross-section. When the first shear hinge is formed the member will fail due brittle failure mechanism.





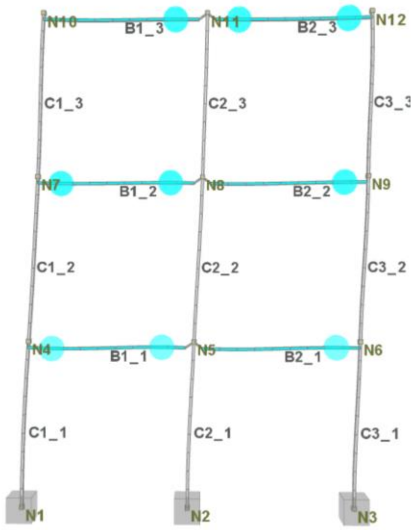


Figure 3.31 shear Hinge Formations on Each Iterations.

3.4.2 CASE TWO

3.4.2.1 Pushover Analysis for DCM Detailed Shear Hinge Using Lp-2.

In this situation, we will employ an identical approach, with the only variation being the use of a different plastic hinge length.

$$L_{p2} = 0.08L + 0.022.\ f_{ye}.d_{bl} \quad \geq \quad 0.044.fye.dbl$$

Where:

Lp2= plastic hinge length for shear and flexure proposed by Priestley.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

dbl = diameter of longitudinal reinforcement

3.4.2.2 Capacity Check.

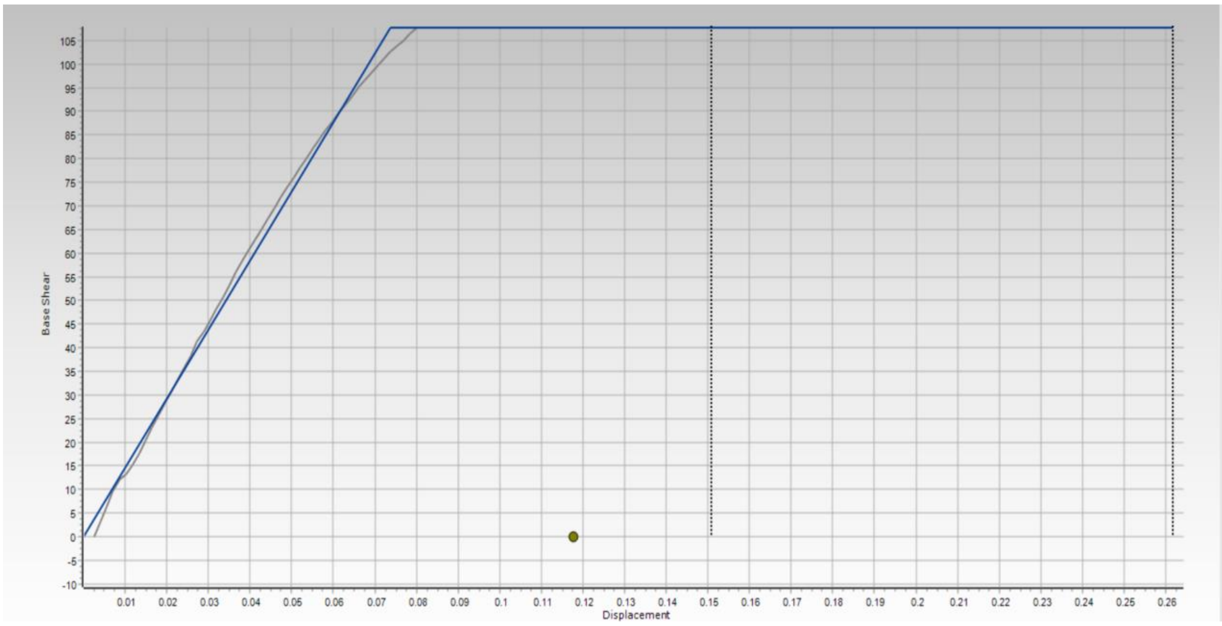


Figure 3.32 Capacity Curve for DCM shear Hinge Using Plastic Length -2.

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	107.79
0.0800	107.79
0.2616	107.79

Table 3.20 Idealized curve for DCM shear hinge using Lp-2

K-elastic in KN/m	2057.87
K-eff in KN/m	1463.59
a	0.000
Fy in KN	107.79
Dy in m	0.0736
Un-balanced area	0.01

Table 3.19 linearization data for DCM shear hinge using Lp-2

Performance level	Displacement in meter
Damage limit state(DL)	0.1176m
Significant damage(SD)	0.1509m
Near collapse(NC)	0.2616m

Table 3.21 Displacement capacity for DCM shear hinge using Lp-2

3.4.3. CASE THREE

3.4.3.1 Pushover Analysis For DCH Detailed Shear Hinge Using Lp-1.

$$L_{p1} = 0.50 \text{ x } H$$

$$Lp \text{ for column} = 0.5 \text{ x } 400mm = 200mm$$

$$Lp \text{ for beam} = 0.5 \text{ x } 300mm = 150mm$$

$$LP_{cb} = L_{pc}/2 = 100mm$$

$$LP_{ct} = Hbeam – L_{pc}/2 = 200mm$$

$$LP_b = Hcol/2 - L_{pb}/2 = 125mm$$

Lp1= plastic hinge length for shear and flexure proposed by park and paulay.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

d_{bl} *= diameter of longitudinal reinforcement*

LP_{ct}*= plastic hinge length for shear and flexure at the column top.*

LP_{cb}*= plastic hinge length for shear and flexure at the column bottom.*

$LP_{b=}$ *plastic hinge length for shear and flexure at the two ends of the beam.*

3.4.3.2 Capacity Check.

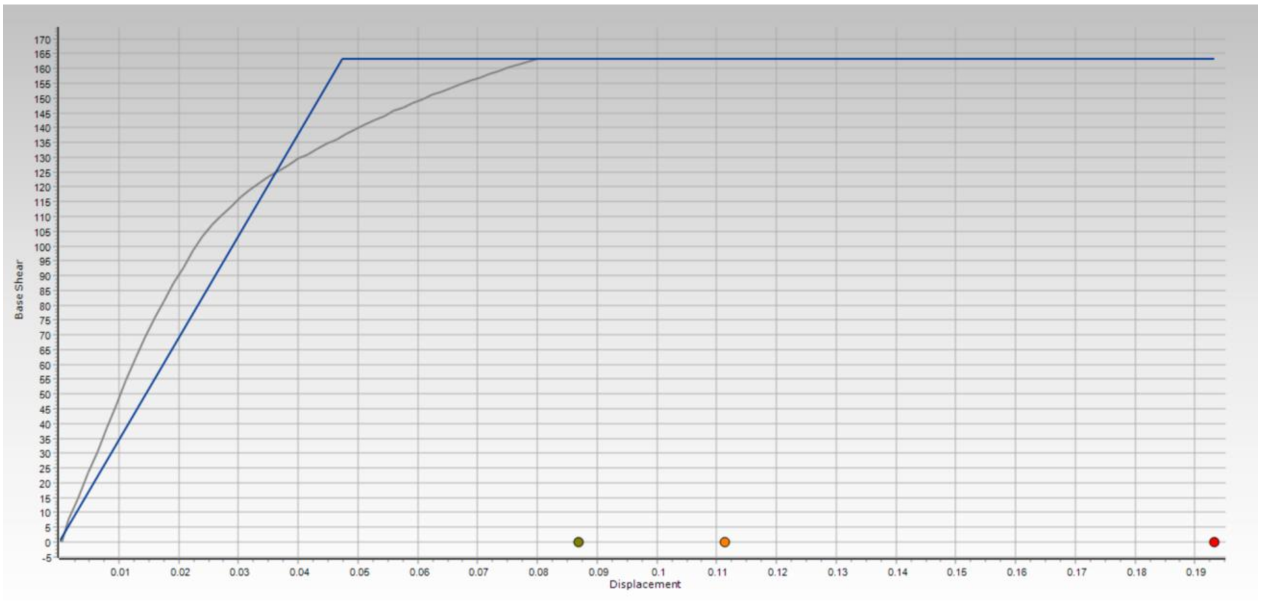


Figure 3.33 Capacity Curve for DCH shear Hinge Using Plastic Length -1.

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	163.09
0.0800	163.09
0.2616	163.09

Table 3.23 Idealized curve for DCH shear hinge using Lp-1

K-elastic in KN/m	6661.61
K-eff in KN/m	3445.78
a	0.000
Fy in KN	163.09
Dy in m	0.0473
Un-balanced area	0.01

Table 3.22 linearization data for DCH shear hinge using Lp-1

Performance level	Displacement in meter
Damage limit state(DL)	0.0868m
Significant damage(SD)	0.1114m
Near collapse(NC)	0.1932m

Table 3.24 Displacement capacity for DCH shear hinge using Lp-1

3.4.4. CASE FOUR

3.4.4.1 Pushover Analysis For DCH Detailed Shear Hinge Using Lp-2.

In this instance, we will proceed with the same method, but this time we will utilize the plastic hinge length that was employed in case two.

$$L_{p2} = 0.08L + 0.022.\ f_{ye}.d_{bl} \quad \geq \quad 0.044.fye.dbl$$

Where:

Lp2= plastic hinge length for shear and flexure proposed by Priestley.

L= critical distance from the critical section of the plastic hinge to the point of contra flexure.

H= the section depth

fye= expected yield strength

dbl = diameter of longitudinal reinforcement

3.4.4.2 Capacity Check.

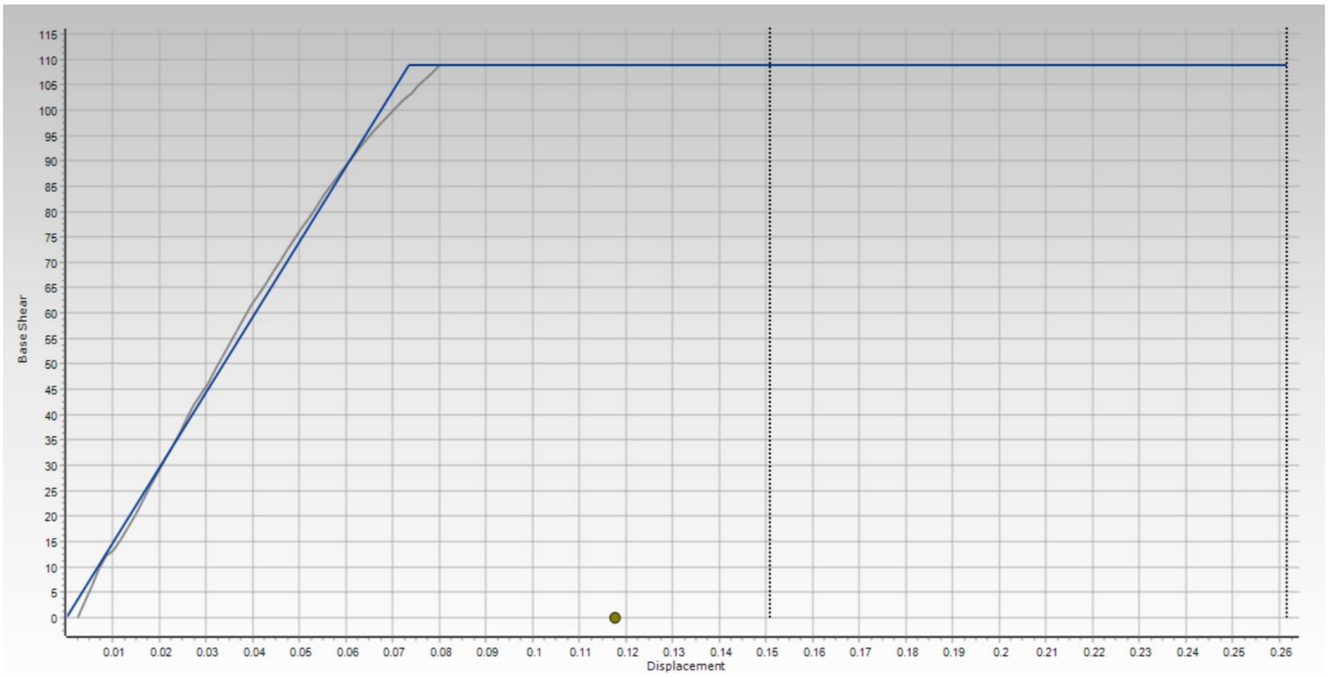


Figure 3.34 Capacity Curve for DCH shear Hinge Using Plastic Length -2.

Displacement(in meter)	Base shear(in KN)
0.000	0.000
0.0736	108.75
0.0800	108.75
0.2616	108.75

Table 3.26 Idealized curve for DCH shear hinge using Lp-2

K-elastic in KN/m	2094.75
K-eff in KN/m	1480.36
a	0.000
Fy in KN	108.75
Dy in m	0.0735
Un-balanced area	0.01

Table 3.25 linearization data for DCH shear hinge using Lp-2

Performance level	Displacement in meter
Damage limit state(DL)	0.1176m
Significant damage(SD)	0.1508m
Near collapse(NC)	0.2615m

Table 3.27 Displacement capacity for DCH shear hinge using Lp-2

CHAPTER FOUR

Result and Discussion.

4.1. Introduction.

In this study eight Model of a two dimensional reinforced concrete frame elements with similar base dimensions, width and number of bays, story height, cross sectional dimensions of structural elements such as columns and beams modelled and analysed for nonlinear static pushover analysis for different ductility classes by using different plastic hinge length using finite element software (seismo-structure version-2023). The results and discussions presented here are focused on performance of the structure and hinge formation. The detail collected result and the outline of the analysis procedure followed in this study are discussed in chapter three.

In this section, we delve into the findings of our numerical study. We examine the hinge formation, base shear, and displacement capacity for each model. Furthermore, we extend our investigation by performing a comparative analysis of the results obtained from nonlinear static pushover analysis for each model. This comparative analysis aims to assess the variations in base shear capacity, plastic hinge length, and the formation of shear and flexural hinges across different ductility classes.

4.2. Result and Discussion.

We conduct pushover analysis on the eight models, taking into account both flexural and shear hinge characteristics, considering two distinct plastic and shear hinge lengths and ductility class for each model.

From this point forward, this chapter will unveil and elucidate the results through the utilization of the chart displayed in Figure 4.1.

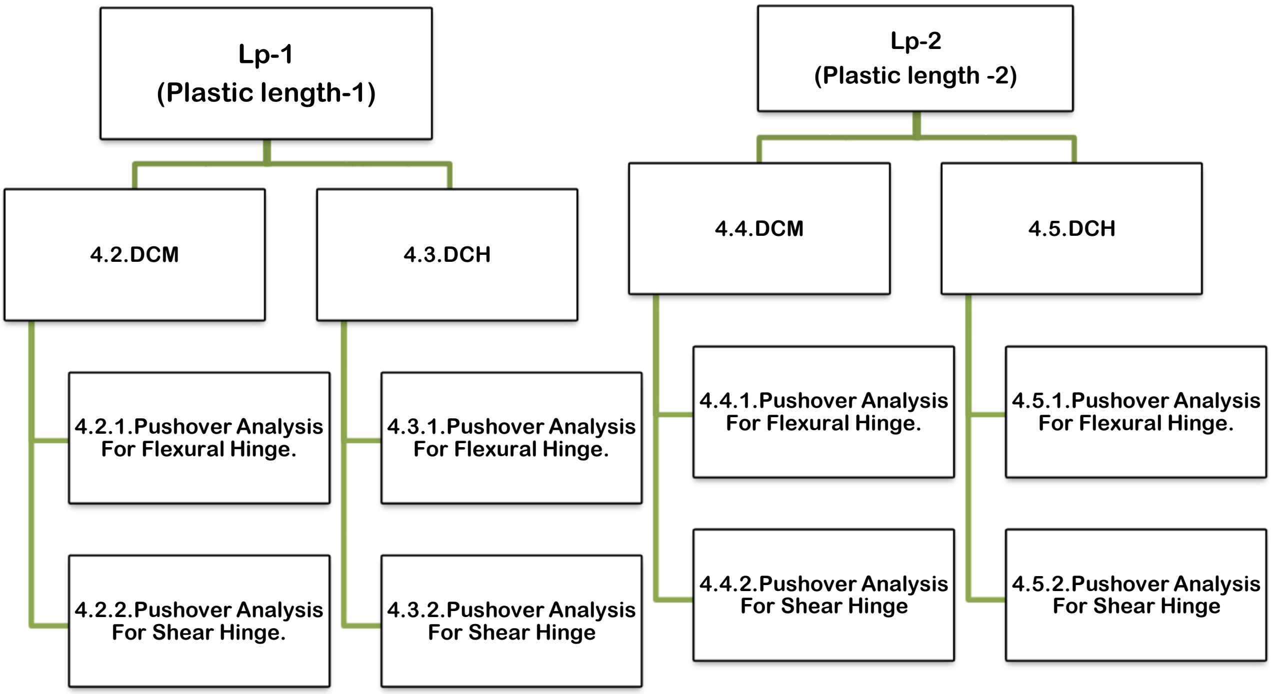


Figure 4.1 Result and Discussion Sequence.

4.2.1. DCM Detailed Flexural Hinge Using Plastic Hinge Length-1.

Employing the first plastic hinge length and a medium ductility class for flexural hinge formations, the following user-defined hinge characteristics and associated parameters are attributed to the proposed structure.

- The plastic hinge length for the top and bottom of the column is 200mm and 100mm, respectively, which accounts for 8.1% of the column's clear height.
- The plastic hinge length at both ends of the beam measures 125mm, representing approximately 3.47% of the beam's clear span.
- Clear height of the beam 3.60m.
- Clear height of the column 3.70m.

4.2.1.1 Results.

Observations on the structure response:

- The **1st** flexural hinge is formed on **B1-3** when the **6th** iteration step is reached, with a load factor of 0.03893.
- The **2nd** flexural hinge is formed on **B1-1** when the **9th** iteration step is reached, with a load factor of 0.06290.
- The **3nd** flexural hinge is formed on **C3-3** when the **12th** iteration step is reached, with a load factor of 0.08228.
- The **4nd** and **5th** flexural hinge is formed on **B1-2** and **B2-1** when the **15th** iteration step is reached, with a load factor of 0.08228.
- The **6th** flexural hinge is formed on **B2-2** when the **20th** iteration step is reached, with a load factor of 0.11662.
- The **7th** flexural hinge is formed on **B2-1** when the **32th** iteration step is reached, with a load factor of 0.13927.
- The **8th** flexural hinge is formed on **B1-1** when the **41th** iteration step is reached, with a load factor of 0.15206.
- The **9th** and **10th** flexural hinge is formed on **B2-2** and **C3-1** when the **45th** iteration step is reached, with a load factor of 0.15675.

- The **11th** flexural hinge is formed on **C3-2** when the **46th** iteration step is reached, with a load factor of 0.15784.
- The structure has a total of 11 plastic flexural hinges.
- There are a total of 8 plastic flexural hinges formed on the beams.
- There are a total of 3 plastic flexural hinges created on the columns
- The base shear capacity is 162.76KN.
- Displacement capacity for damage limitation (DL) is 86.645mm.
- Displacement capacity for significant damage (SD) is 111.151mm.
- Displacement capacity for near collapse damage (NC) is 192.697mm.

4.2.1.2 Discussion.

Following the lateral push in the pushover analysis with the first plastic hinge length (Lp1), the structure ultimately generates 11 flexural hinges, each associated with distinct load factors. Within these 11 flexural hinges, 3 are formed on columns and 8 on beams. Notably, these flexural hinges emerge at the 6th, 9th, 12th, 15th, 20th, 32nd, 41st, 45th, and 46th incremental steps.

We also evaluate the base shear and displacement capacity of the structure according to EN1998-3:2004, considering the three distinct limit states: the limit state for damage, the limit state for significant damage, and the limit state for near collapse. This assessment is detailed in Section 4.2.1.1.

4.2.2. DCM Detailed Shear Hinge Using Plastic Hinge Length-1.

The suggested structure is endowed with shear hinge characteristics, determined by the first plastic hinge length and a medium level of ductility.

- The shear hinge length for the upper and lower parts of the column measures 200mm and 100mm, respectively, equivalent to 8.1% of the column's unobstructed height.
- The shear hinge length at both ends of the beam is 125mm, constituting approximately 3.47% of the beam's clear span.

4.2.2.1 Results.

Observations on the structure response:

- From **1st** up to **7th shear hinge** is formed on **B1-3, B2-3, B1-2, B2-2, B1-1 and B2-1** on the **1th** iteration step, with a load factor of 0.0.
- The structure has a total of 9 shear hinges formed.
- Nine shear hinges have been formed on the beams.
- No shear hinges have been formed on the columns.
- The base shear capacity is 162.37KN.
- Displacement capacity for damage limitation (DL) is 86.645mm.
- Displacement capacity for significant damage (SD) is 111.151mm.
- Displacement capacity for near collapse damage (NC) is 192.697mm.

4.2.2.2 Discussion.

Upon conducting the pushover analysis using the first plastic hinge length (Lp1) and applying lateral force to the frame, the structure ultimately generates nine shear hinges, each associated with distinct load factors. Notably, all these shear hinges form exclusively on the beams. These shear hinges come into existence at the 1st, 8th, and 9th incremental steps.

- ❖ Out of the nine shear hinges, seven are exclusively generated at the very first step, with load factors at zero. This occurrence is attributed to the structural response under lateral and constant vertical loads, which initiate deformation and internal stress even at minimal loads, including zero. This initial deformation, mainly influenced by gravity loads, is typically elastic and can give rise to the formation of shear hinges.

❖ Shear hinges develop before flexural hinges emerge because the sections reach their shear capacity before they reach their yielding moment, as explained in Section 4.2.1.1

4.2.3. DCH Detailed Flexural Hinge Using Plastic Hinge Length-1.

By introducing plastic hinge length one and selecting a high ductility class for the development of flexural hinges at critical locations, we assign distinct hinge properties and associated parameters to the proposed structure

- Flexural hinge length for column top and bottom is 200mm and 100mm respectively or 8.1% of the clear height of the column.
- Flexural hinge length for the ends of the beam is 125mm or 3.47% of the clear length of the beam.

4.2.3.1 Results.

Observations on the structure response:

- The **1st** flexural hinge is formed on **B1-3** when the **6th** iteration step is reached, with a load factor of 0.03860.
- The **2nd** flexural hinge is formed on **B1-1** when the **9th** iteration step is reached, with a load factor of 0.06237.
- The **3rd** flexural hinge is formed on **C3-3** when the **13th** iteration step is reached, with a load factor of 0.08739.
- The **4th** flexural hinge is formed on **B2-1** when the **15th** iteration step is reached, with a load factor of 0.09851.
- The **5th** flexural hinge is formed on **B1-2** when the **16th** iteration step is reached, with a load factor of 0.10335.
- The **6th** flexural hinge is formed on **B2-2** when the **20th** iteration step is reached, with a load factor of 0.11628.
- The **7th** flexural hinge is formed on **B2-1** when the **32th** iteration step is reached, with a load factor of 0.13935.
- The **8th** flexural hinge is formed on **B1-1** when the **41th** iteration step is reached, with a load factor of 0.15225.

- The **9th** and **10th** flexural hinge is formed on **B2-2 and C3-1** when the **45th** iteration step is reached, with a load factor of 0.15698
- The **11th** flexural hinge is formed on **C3-2** when the **46th** iteration step is reached, with a load factor of 0.15811.
- There are a total of 11 plastic flexural hinges formed within the structure.
- The beams in the structure have a total of 8 plastic flexural hinges.
- There are a total of 3 plastic flexural hinges established on the columns
- The base shear capacity is 163.09KN.
- Displacement capacity for damage limitation (DL) is 86.687mm.
- Displacement capacity for significant damage (SD) is 111.443mm.
- Displacement capacity for near collapse damage (NC) is 193.204mm.

4.3.1.2 Discussion.

After conducting a lateral pushover analysis on the structure using the second plastic hinge length (Lp2), it became evident that the structure produced a total of 11 flexural hinges. Each of these flexural hinges displayed unique load factors. Among these hinges, 3 formed on columns, and 8 formed on beams. Notably, these flexural hinges emerged at the 6th, 9th, 13th, 15th, 16th, 20th, 32nd, 41st, 45th, and 46th incremental steps.

As indicated by the findings in Sections 4.2.1, 4.2.2, and 4.2.3, the utilization of higher ductility classes significantly bolsters the structure's capability to dissipate energy. Consequently, the structure becomes more proficient at redistributing and dissipating lateral forces without the formation of concentrated shear hinges

4.2.4. DCH Detailed Shear Hinge Using Plastic Hinge Length-1.

Hinge properties are:

- Plastic hinge length for column top and bottom is 200mm and 100mm respectively or 8.1% of the clear height of the column.
- Plastic hinge length for the left and right side hinge location beam is 125mm or 3.47% of the clear length of the beam.

4.2.4.1 Results.

Observations on the structure response:

- Total number of **shear hinge** formed on the structure is 0.
- Total number of **shear hinge** formed on beams is 0.
- Total number of **shear hinge** formed on columns is 0.
- The base shear capacity is 163.09KN.
- Displacement capacity for damage limitation (DL) is 86.873mm.
- Displacement capacity for significant damage (SD) is 111.443mm.
- Displacement capacity for near collapse damage (NC) is 193.204mm.

4.2.4.2. Discussion.

Drawing from the outcomes presented in Section 4.2.2 alongside Section 4.2.4, applying identical plastic hinge lengths for both shear and flexural components while leveraging higher ductility class specifications augments the structural rotational capacity. This approach achieves this enhancement by eliminating brittle failure mechanisms in critical regions.

4.2.5. DCM detailed flexural hinge using Plastic hinge length-2.

Hinge properties are:

- Plastic hinge length for column C1-1 is 16.05% of the clear height of the column.
- Plastic hinge length for column C2-1 is 16.13% of the clear height of the column.
- Plastic hinge length for column C3-1 is 15.3% of the clear height of the column.
- Plastic hinge length for column C1-2 and C2-2 is 15.43% of the clear height of the column.
- Plastic hinge length for column C3-2 is 16.89% of the clear height of the column.
- Plastic hinge length for column C1-3 is 16.22% of the clear height of the column.
- Plastic hinge length for column C2-3 is 17.05% of the clear height of the column.
- Plastic hinge length for column C3-3 is 24.54% of the clear height of the column.
- Plastic hinge length for beam is 14.44% of the clear length of the beam.

4.2.5.1 Results.

Following the pushover analysis with an emphasis on high ductility class detailing and taking into account the second plastic hinge length, several noteworthy observations come to light:

- The **1st** flexural hinge is formed on **B1-3** when the **26th** iteration step is reached, with a load factor of 0.06289.
- The **2nd** flexural hinge is formed on **C3-3** when the **29th** iteration step is reached, with a load factor of 0.06960.
- The **3rd** flexural hinge is formed on **B1-1** when the **38th** iteration step is reached, with a load factor of 0.08809.
- The **4th** flexural hinge is formed on **B1-1** when the **41th** iteration step is reached, with a load factor of 0.09340.
- Total number of plastic flexural hinge formed on the structure is 4.
- Total number of plastic flexural hinge formed on beams is 4.
- Total number of plastic flexural hinge formed on columns is zero.
- The base shear capacity is 107.79KN.
- Target displacement for damage limitation (DL) is 117.644mm.

- Target displacement for significant damage (SD) is 150.918mm.
- Target displacement for near collapse damage (NC) is 261.639mm.

4.2.5.2. Discussion.

After performing the pushover analysis for the second plastic hinge length (Lp2) by pushing the frame laterally. Then 4 flexural hinges with different load factors formed. All hinges are formed on beams only. And those hinges are formed on 26th, 29th, 38th and 41th incremental steps.

The evaluation of the structure's performance was conducted in accordance with EN1998-3:2004, considering the three defined limit states: the limitation for damage, the limitation for significant damage, and the limitation for near collapse. Notably, the structure did not even reach the damage limitation state. Furthermore, it exhibited a maximum base shear capacity of 107.79KN.

4.2.6. DCM Detailed Shear Hinge Using Plastic Hinge Length-2.

Hinge properties are:

- Plastic hinge length for column C1-1 is 16.05% of the clear height of the column.
- Plastic hinge length for column C2-1 is 16.13% of the clear height of the column.
- Plastic hinge length for column C3-1 is 15.3% of the clear height of the column.
- Plastic hinge length for column C1-2 and C2-2 is 15.43% of the clear height of the column.
- Plastic hinge length for column C3-2 is 16.89% of the clear height of the column.
- Plastic hinge length for column C1-3 is 16.22% of the clear height of the column.
- Plastic hinge length for column C2-3 is 17.05% of the clear height of the column.
- Plastic hinge length for column C3-3 is 24.54% of the clear height of the column.
- Plastic hinge length for beam is 14.44% of the clear length of the beam.

4.2.6.1. Results.

Following the pushover analysis with a focus on medium ductility class detailing and taking into account the second plastic hinge length, several significant observations have come to light:

- From **1st** up to **7th shear hinge** is formed on **B1-3, B2-3, B1-2, B2-2, B1-1 and B2-1** on the **1th** iteration step, with a load factor of 0.0.
- Total number of **shear hinge** formed on beams is 8.
- Total number of **shear hinge** formed on columns is 0.
- The base shear capacity is 107.79KN.
- Displacement capacity for damage limitation (DL) is 117.644mm.
- Displacement capacity for significant damage (SD) is 150.918mm.
- Displacement capacity for near collapse damage (NC) is 261.639mm.

4.2.6.2 Discussion.

❖ Out of the eight shear hinges, seven of them exclusively manifested at the very first step with load factors at zero, as detailed in Section 4.2.2.2.

❖ The formation of these shear hinges occurred during the initial incremental step before the flexural hinges came into existence. This phenomenon is attributed to the dominance of shear forces in critical sections, where shear hinges tend to develop. These particular sections are more prone to shear-related failure mechanisms, often involving diagonal cracking in concrete members, as compared to flexural failure.

4.2.7 DCH Detailed Flexural Hinge Using Plastic Hinge Length-2.

Hinge properties are:

- Plastic hinge length for column C1-1 is 16.05% of the clear height of the column.
- Plastic hinge length for column C2-1 is 16.13% of the clear height of the column.
- Plastic hinge length for column C3-1 is 15.3% of the clear height of the column.
- Plastic hinge length for column C1-2 and C2-2 is 15.43% of the clear height of the column.
- Plastic hinge length for column C3-2 is 16.89% of the clear height of the column.
- Plastic hinge length for column C1-3 is 16.22% of the clear height of the column.
- Plastic hinge length for column C2-3 is 17.05% of the clear height of the column.
- Plastic hinge length for column C3-3 is 24.54% of the clear height of the column.
- Plastic hinge length for beam is 14.44% of the clear length of the beam.

4.2.7.1 Results.

Upon conducting the pushover analysis while focusing on high ductility class detailing and taking into account the second plastic hinge length, the following significant observations have been made:

- The **1st** flexural hinge is formed on **B1-3** when the **26th** iteration step is reached, with a load factor of 0.06382.
- The **2nd** flexural hinge is formed on **C3-3** when the **30th** iteration step is reached, with a load factor of 0.07275.
- The **3rd** flexural hinge is formed on **B1-1** when the **37th** iteration step is reached, with a load factor of 0.08718.
- The **4th** flexural hinge is formed on **B1-2** when the **40th** iteration step is reached, with a load factor of 0.09261.
- Total number of plastic flexural hinge formed on the structure is 4.
- Total number of plastic flexural hinge formed on beams is 3.
- Total number of plastic flexural hinge formed on columns is 1.
- The base shear capacity is 108.75KN.
- Displacement capacity for damage limitation (DL) is 117.616mm.

- Displacement capacity for significant damage (SD) is 150.882mm.
- Displacement capacity for near collapse damage (NC) is 261.576mm.

4.2.7.2 Discussion.

Drawing from the findings presented in sections 4.2.4 and 4.2.7, it's evident that augmenting the plastic hinge length while maintaining the same ductility class has a direct impact on the structure's base shear capacity. This impact is rooted in the plastic hinge length's influence on the structure's capacity to dissipate energy and exhibit ductile behaviour when subjected to lateral loads.

Greater plastic hinge lengths facilitate more extensive plastic deformation and energy absorption prior to structural failure, thereby enhancing the structure's ductility and its resilience in the face of lateral loads. This heightened ductility is often a desirable characteristic in earthquake-resistant design, ensuring that the structure can withstand seismic forces without experiencing sudden and brittle failure

4.2.8. DCH detailed shear hinge using Plastic Hinge Length-2.

Hinge properties are:

- Plastic hinge length for column C1-1 is 16.05% of the clear height of the column.
- Plastic hinge length for column C2-1 is 16.13% of the clear height of the column.
- Plastic hinge length for column C3-1 is 15.3% of the clear height of the column.
- Plastic hinge length for column C1-2 and C2-2 is 15.43% of the clear height of the column.
- Plastic hinge length for column C3-2 is 16.89% of the clear height of the column.
- Plastic hinge length for column C1-3 is 16.22% of the clear height of the column.
- Plastic hinge length for column C2-3 is 17.05% of the clear height of the column.
- Plastic hinge length for column C3-3 is 24.54% of the clear height of the column.
- Plastic hinge length for beam is 14.44% of the clear length of the beam.

4.2.8.1 Results.

After performing the pushover analysis for high ductility class detailing by considering the second plastic hinge length the following important points are observed:

- Total number of **shear hinge** formed on the structure is 0.
- Total number of **shear hinge** formed on beams is 0.
- Total number of **shear hinge** formed on columns is 0.
- The base shear capacity is 108.78KN.
- Displacement capacity for damage limitation (DL) is 117.616mm.
- Displacement capacity for significant damage (SD) is 150.882mm.
- Displacement capacity for near collapse damage (NC) is 261.576mm.

4.2.8.2. Discussion.

As indicated by the findings in Section 4.2.8.1, increasing the plastic hinge length without altering the ductility classes does not yield a significant impact on shear hinge behaviour or the emergence of brittle failure mechanisms. This observation arises from the fact that plastic hinges are primarily linked to ductile behaviour within structural elements. In contrast, shear hinge behaviour, which represents a brittle failure mechanism, is typically influenced by factors such as materials, detailing, and loading conditions, rather than the length of the plastic hinge.

CHAPTER FIVE

Conclusions and Recommendations.

5.1. Conclusion.

Seismic performance is a vital aspect in structural engineering, representing a structures ability to efficiently endure and react to the forces produced during seismic events. In the structural design, two essential parameters, namely the extent of plastic hinge formation and the categorization of ductility class, play a central role in determining how a structure functions when exposed to seismic forces.

Based on the present research study, the following conclusions are drawn:

⇒ when flexural hinge length increases while maintaining the same ductility class, the base shear capacity of the structure will decrease, but it will result in a higher inelastic displacement capacity. Because a longer flexural hinge length allows for more plastic deformation and energy dissipation within the structure. While this can improve a building's ability to absorb seismic energy and undergo ductile behaviour, it often comes at the expense of base shear capacity. This is because some of the lateral force applied during an earthquake is dissipated through plastic deformation rather than being directly resisted by the structural elements, leading to a reduced ability to resist lateral forces.

⇒ If you increase the shear hinge length while maintaining the same ductility class, you'll experience a decrease in the base shear capacity, with only a slight increase in elastic displacement. Because the increase in shear hinge length may lead to a slight increment in elastic displacement, meaning the structure can undergo slightly larger displacements within the elastic range before reaching the yield point. This can be attributed to the increased flexibility provided by longer shear hinges. However, the increase in elastic displacement is generally relatively modest compared to the significant decrease in base shear capacity.

⇒ Changing the ductility class from DCM to DCH maintains the same base shear capacity in flexural elements while making the system more ductile. However, shifting to a higher ductility class significantly diminishes the likelihood of shear hinge formation. Because higher ductility class allow structures to undergo more extensive deformation before experiencing structural failure. As a result, the system can better absorb seismic energy and deform plastically without losing its load-carrying capacity, thus becoming more ductile. So the ductile flexural behaviour reduces the likelihood of brittle shear failures and promotes a more resilient response to seismic loading.

5.2. Recommendations.

The seismic performance of a newly designed and existing structure is influenced by a range of parameters, and it's not limited to the investigation of shear, flexural hinge formation, and ductility classes. I propose the following suggestions for further examination to improve this matter:

⇒ I strongly advise conducting laboratory experiments because of their superior precision when compared to software simulations.

⇒ This paper exclusively examines earthquakes in the horizontal x-direction. Nevertheless, it is crucial to consider shear hinge formation for earthquakes in the y-direction as well when dealing with three-dimensional structures.

⇒ It is essential to model multiple joints in various buildings to obtain valuable insights into the formation of shear and flexural hinges at beam-column connections.

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