

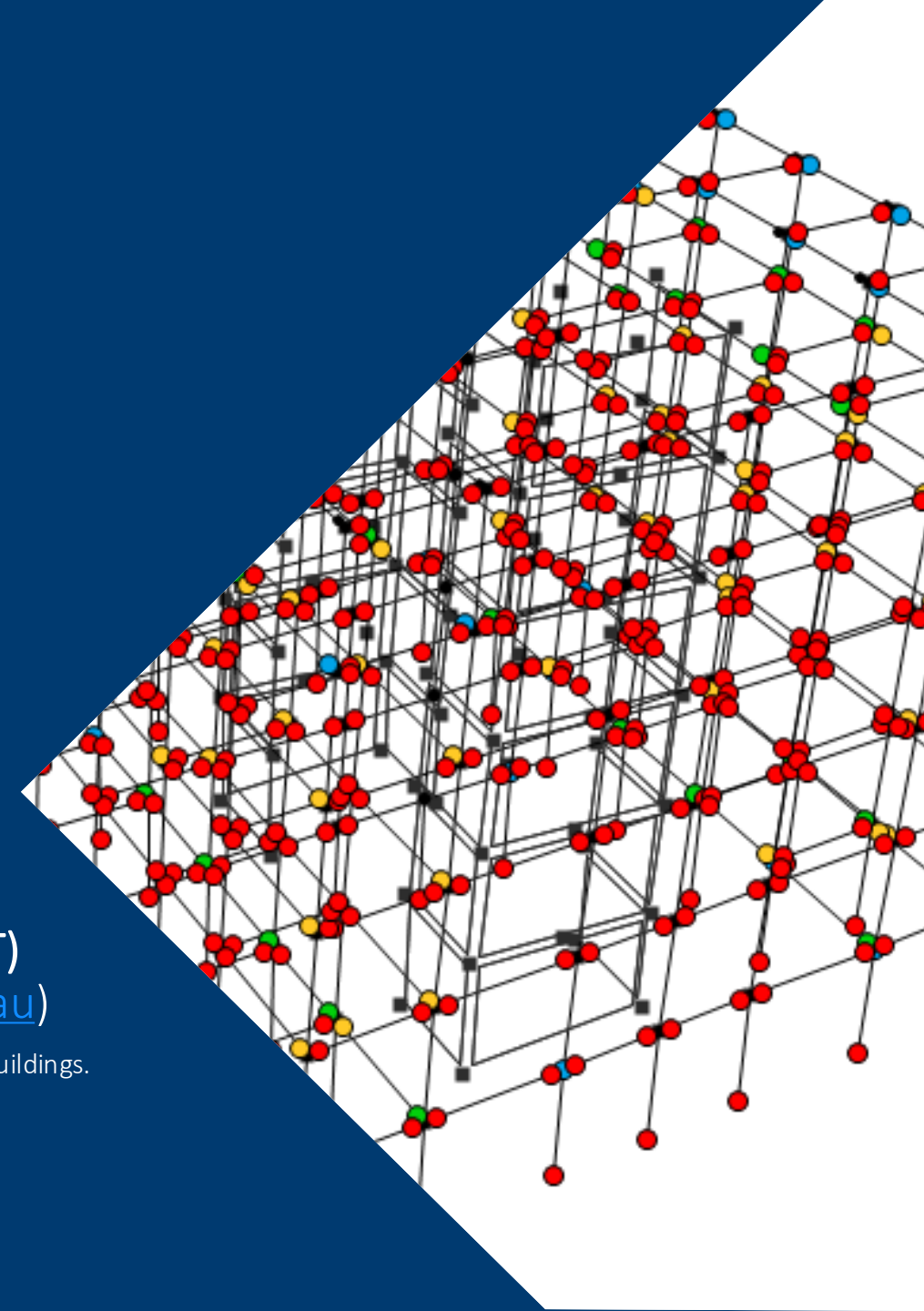
Performance-Based Seismic Design of a G+5 Reinforced Concrete Building Using ETABS and Perform-3D

[Watch Webinar Recording Here](#)

1st October , 2026

Dr. Mistreselasie Sentayehu Abate, (DENG, PMP, M.Sc., MBA, PPST)
Structural Engineer | EIT Lecturer (mistreselasie.abate@eit.edu.au)

Performance-based seismic design (PBSD) is a framework (set of rules and procedures) for designing new buildings. The goal is to get useful information for design , not to calculate “exact” response



About ECT



We are dedicated to ensuring that you receive a world-class education and gain skills that you can immediately apply in the workforce.



Engineering Specialists

ECT - affiliated to the well-established Engineering Institute of Technology (EIT) - is an engineering education specialist. ECT delivers bachelor's and master's degrees.



Industry-Driven programmes

Our programmes are designed by industry experts, ensuring you graduate with cutting-edge skills that are valued by employers. Our programme content remains current with rapidly changing technology and industry developments.



UK Recognised Education

ECT is OfS registered, meeting the Office for Students' requirements for course quality, academic standards, student support and student protection.



Lecturers and Instructors

Our teachers are subject specialists with industry experience and the requisite academic qualifications. They bring extensive expertise from across the engineering sector, ensuring students learn from experienced professionals with both academic and real-world knowledge.



Unique Delivery Model

We deliver our programmes via a unique delivery methodology that makes use of live and interactive tutorials, an international pool of expert lecturers, dedicated learning support officers, hands-on workshops and state-of-the-art remote labs connected to real equipment, and simulation software.

Introduction – Presenter

Dr. Mistreselasie S. Abate, (DENG, PMP, M.Sc., MBA, PPST)

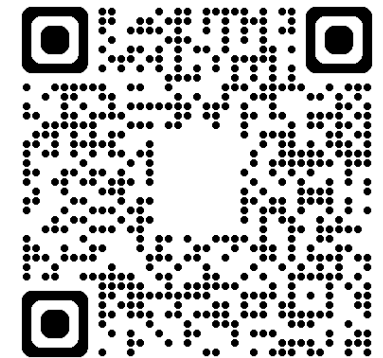
EIT Lecturer[<https://www.adscientificindex.com/scientist/mistreselasie-sabate/4327142>]

Dr. Abate is proficient in utilizing industry-leading software tools such as ETABS, SAP2000, MS-Project, Eagle Point, AutoCAD Civil 3D, ArchiCAD, WaterCAD, Epanet, Inroads, Microsoft Office, Primavera, SAFE, PROKON, GEO5, ELPLA, RSTAB, ADAPT-PT, REWARD, and ADAPT Builder, among others, for structural analysis and design. Specialized in PT (Post-Tensioned) design and implementation, with extensive training in prestressed concrete design from PTI. Skilled in conducting research in performance-based design, with a focus on seismic performance evaluation of high-rise structures. Currently obtain a Doctor of Engineering degree at the Engineering Institute of Technology (EIT), demonstrating a keen interest in advancing structural engineering methodologies for enhanced safety and resilience.

In his research pursuits, Dr. Mistreselasie primarily focuses on evaluating the performance of built structures under extreme conditions, such as severe earthquakes and high winds. His expertise spans seismic resilience, innovative structural systems, site-specific seismic hazard analysis, vulnerability assessments, nonlinear modeling of structures, and studying the dynamic behavior of complex systems during seismic events. With a wealth of experience in structural modeling, analysis, and design of buildings, bridges, and various structures, Abate has made significant contributions to academia-industry collaborations.

Education

1. Doctor of Engineering (DEng) from Engineering Institute of Technology (EIT) [Graduated 2025](#)
2. M.Sc. in Civil Structural Design from Atlantic International University [Graduated 2021](#)
3. Master of Business Administration – MBA From European International University- (EIU - PARIS) [Graduated 2019](#)
4. B.Sc. in Civil Engineering from Addis Ababa University Faculty of Technology [Graduated 2011](#)
5. Advanced Diploma in civil Engineering from Addis Ababa University Faculty of Technology [Graduated 2004](#)
6. Associate Degree Computer Science from University of the People, California, USA [Graduated 2023](#)
7. BSc. Computer Science Student (120 credit hours completed CGPA 3.66) from University of the People, California, USA [Graduated 2024](#)



Agenda

1	Structural modeling for PBD, including material properties and section definitions
2	Load patterns and performance objectives based on FEMA 356 and ASCE 41-17
3	Pushover analysis: step-by-step implementation and interpretation of results
4	Evaluating structural performance and retrofitting strategies
5	Overview of performance-based design principles using PERFORM 3D
6	Focusing on structural behavior, nonlinear analysis techniques, and performance objectives.
7	PBD differs from traditional prescriptive methods and why it is essential for designing structures that can withstand seismic forces effectively.



WEBINAR OUTLINE

Module 1 – Foundations of Performance-Based Seismic Design (PBSD)

- What is PBSD?
- Why code-based design is insufficient
- Performance levels (IO, LS, CP)
- Earthquake hazard levels (SLE, DBE, MCE)

Module 2 – Modeling & Linear Analysis

- Initial code-based design
- ETABS / SAP → PERFORM-3D transfer
- Material definitions
- Sections, diaphragms, and load cases

Module 3 – Nonlinear Methods

- Plastic hinge vs fiber modeling
- Pushover analysis
- Nonlinear time-history analysis (NLTHA)
- Performance point
- Acceptance criteria

Module 4 – Case Study: G+4 RC Building

- Geometry, materials, and loads
- Linear vs nonlinear results
- Drift, D/C ratios, and hinges
- Performance evaluation vs objectives

Module 5 – Research & Practice

- ACI 318-19 Appendix A
- FEMA 356, ATC-40, ASCE 41-17
- EIT published research on PBD
- Practical takeaways

NRHA – is used in the performance based design method for verification in a final stage of a design projects

PBSD –Performance-based seismic design (PBSD) is a framework (set of rules and procedures) for designing new building.

ADDITIONAL TECHNICAL POINTS TO BE DISCUSSED

• Load Cases Considered

- Response Spectrum
- Linear Time History Load Cases
- Nonlinear Time History Load Cases
- Pushover Load Cases

• Model Transfer for Performance Evaluation

- How to transfer the G+4 RC model from ETABS and SAP2000 to PERFORM-3D

- Common issues and best practices during model conversion

• Performance Evaluation Tools in PERFORM-3D

- Usage ratio graphs
- Demand/Capacity (D/C) ratios
- Result combinations and envelopes

• Performance Point Determination

- How to find the performance point on a pushover curve PERFORM 3D
- Drawing and interpreting the capacity curve in PERFORM-3D

• ACI 318-19 Appendix A

- Design verification using nonlinear analysis
- In-depth discussion on the overall performance-based design procedures and process

Why Performance-Based Design & Evaluation Matters??

Sample papers published as part of PBD research at EIT

1. Advanced Seismic Analysis of a 44-Story Reinforced Concrete Building: A Comparison of Code-Based and Performance Based Design Approaches
<https://doi.org/10.3390/infrastructures10040093>
2. Global Research Trends in Performance-Based Structural Design: A Comprehensive Bibliometric Analysis
<https://doi.org/10.3390/buildings15030363>
3. A Comparison Analysis of Buildings as per Norwegian and Ethiopia ES-EN1998-1 Seismic Code
<https://doi.org/10.3390/buildings15030363>
4. Comparative Response Spectrum Analysis on 15- and 50-Story Reinforced Concrete Buildings Having Shear Walls with and without Openings as per EN1998-1 Seismic Code
<https://doi.org/10.3390/buildings13051303>
5. PART -1 WEBINAR Complete Analysis and Design of G+2 RC Building Using Euro Code 2–2004 for Beginners
<https://www.eit.edu.au/event/complete-analysis-and-design-of-g2-rc-building-using-euro-code-2-2004-for-beginners/>
6. PART 2- Performance-Based Design for Beginners: Basic Concepts and Applications
<https://www.ect.ac.uk/event/performance-based-design-for-beginners-basic-concepts-and-applications/>
7. PART 3 - Performance-Based Design in Practice: A Step-by-Step Guide Using a G+4 RC Frame Structure
<https://www.eit.edu.au/event/performance-based-design-in-practice-a-step-by-step-guide-using-a-g4-rc-frame-structure/>

Why Performance-Based Design & Evaluation Matters??

Sample Books published as part of PBD research at EIT

1. Practical Reinforced Concrete Building Design to Eurocode: **Volume 1A**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings <https://www.amazon.com/dp/B0HH43VJX1>
2. Practical Reinforced Concrete Building Design to Eurocode: **Volume 1B**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings. <https://www.amazon.com/dp/B0HH3RND4V>
3. Practical Reinforced Concrete Building Design to Eurocode: **Volume 2**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings. <https://www.amazon.ie/dp/B0HGRL1RMG>
4. Practical Reinforced Concrete Building Design to Eurocode: **Volume 3**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings. <https://www.amazon.com/dp/B0HGR31W3I>
5. Practical Reinforced Concrete Building Design to Eurocode: **Volume 4**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings. <https://www.amazon.com/dp/B0HGQXZF33>
6. Practical Reinforced Concrete Building Design to Eurocode: **Volume 1-4**: Linear Analysis and Code-Based Design - A Complete Step-by-Step Guide to the Low to Mid-Rise Reinforced Concrete Buildings. [E- Book]. <https://www.amazon.com/dp/B0HGHGZ5MQ>
7. PART -1 WEBINAR Complete Analysis and Design of G+2 RC Building Using Euro Code 2–2004 for Beginners. <https://www.eit.edu.au/event/complete-analysis-and-design-of-g2-rc-building-using-euro-code-2-2004-for-beginners/>
8. PART 2- Performance-Based Design for Beginners: Basic Concepts and Applications <https://www.ect.ac.uk/event/performance-based-design-for-beginners-basic-concepts-and-applications/>
9. PART 3 - Performance-Based Design in Practice: A Step-by-Step Guide Using a G+4 RC Frame Structure <https://www.eit.edu.au/event/performance-based-design-in-practice-a-step-by-step-guide-using-a-g4-rc-frame-structure/>

EIT - Performance Based Design Research Team

My Perspective on Linear vs Nonlinear Analysis

Dr. Mistreselasie S. Abate (EIT-Lecturer)



- **Nonlinear analysis** is essential for understanding real structural behavior, damage mechanisms, and performance under extreme loading.
- However, **linear analysis remains indispensable**, especially for:
 - Gravity load design
 - Preliminary sizing and proportioning
 - Serviceability checks
 - Load path verification
 - Code compliance and design iteration efficiency
- In practice, **nonlinear models are built on linear results** — gravity effects, stiffness distribution, load combinations, and initial member design all originate from linear analysis.
- While nonlinear analysis provides **deeper insight**, it **does not eliminate the need for linear analysis**; instead, it refines and validates it.
- A well-calibrated linear model often gives **robust, conservative, and interpretable results**, particularly in early and intermediate design stages.
- Nonlinear analysis should be used **strategically, not linear analysis**, but to **integrate both intelligently** within a performance-based design framework.
- Final principle. *“Nonlinear analysis enhances design — it does not replace sound linear analysis.”*

Engineering reality:

- Linear analysis
efficiency, clarity,
code compliance
- Nonlinear analysis
realism,
performance insight,
damage prediction

Performance-Based Design Philosophy — Dr. Mistreselasie S. Abate

EIT Lecturer Interview: Dr. Ana Evangelista

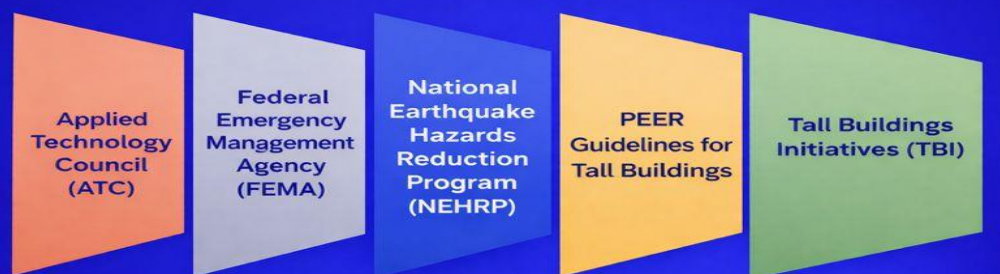
Civil and Structural Engineering
Lecturer, Course Coordinator
and Work-Integrated Learning
Course Coordinator



Professor Vivian W. Y. Tam

Special Purposes Guidelines for PBD

Dr. Mistreselasie S. Abate



Applied Technology Council (ATC)

Federal Emergency Management Agency (FEMA)

National Earthquake Hazards Reduction Program (NEHRP)

PEER Guidelines for Tall Buildings

Tall Buildings Initiatives (TBI)



TBI 2010, 2017 (PBSD)

LATBSDC 2011, 2014, 2017, 2020, 2023 (PBSD)

ACI 318-19 (Appendix A: NRHA)

Dr. Mistreselasie S. Abate



TBI Tall Buildings Initiative Guidelines for Performance-Based Seismic Design of Tall Buildings (Version 3.03, May 2017)

AN ALTERNATIVE PROCEDURE FOR SEISMIC ANALYSIS AND DESIGN OF TALL BUILDINGS LOCATED IN THE LOS ANGELES REGION (2017 Edition with 2024 Supplements)

Seismic Evaluation and Retrofit of Existing Buildings (ASCE 41-17)

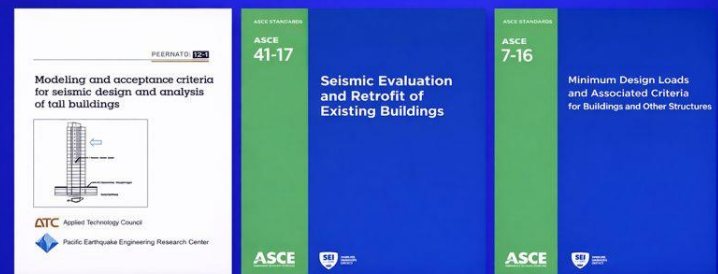
Nonlinear Structural Analysis for Seismic Design (NIST GCR 12-617-46M)

Soil-Structure Interaction for Building Structures (NIST GCR 12-617-21)

Modeling and acceptance criteria for seismic design and analysis of tall buildings (ATC Applied Technology Council)

Guidelines for Nonlinear Structural Analysis for Design of Buildings Part I - General (NIST GCR 12-617-46M)

Other Codes & Standards



ATC 72-1 Modeling

ASCE 41-17 Modeling & Acceptance Criteria

ASCE 7-16 Seismic Design Force

<https://www.csiamerica.com/products>

The US offices of Computers and Structures, Inc. will be closed on Monday, January 19th, 2026 in observance of Martin Luther King Day.

 **COMPUTERS & STRUCTURES, INC.**
STRUCTURAL AND EARTHQUAKE ENGINEERING SOFTWARE

HOME PRODUCTS SALES SUPPORT DEVELOPER NEWS CONTACT

 **SAP2000**
STRUCTURAL ANALYSIS AND DESIGN

 **CsiBridge**
BRIDGE ANALYSIS, DESIGN AND RATING

 **ETABS**
BUILDING ANALYSIS AND DESIGN

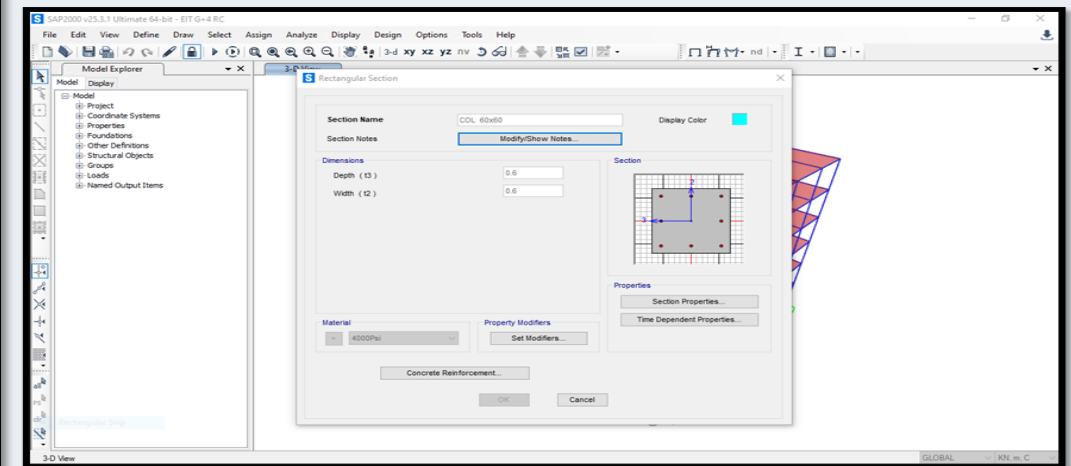
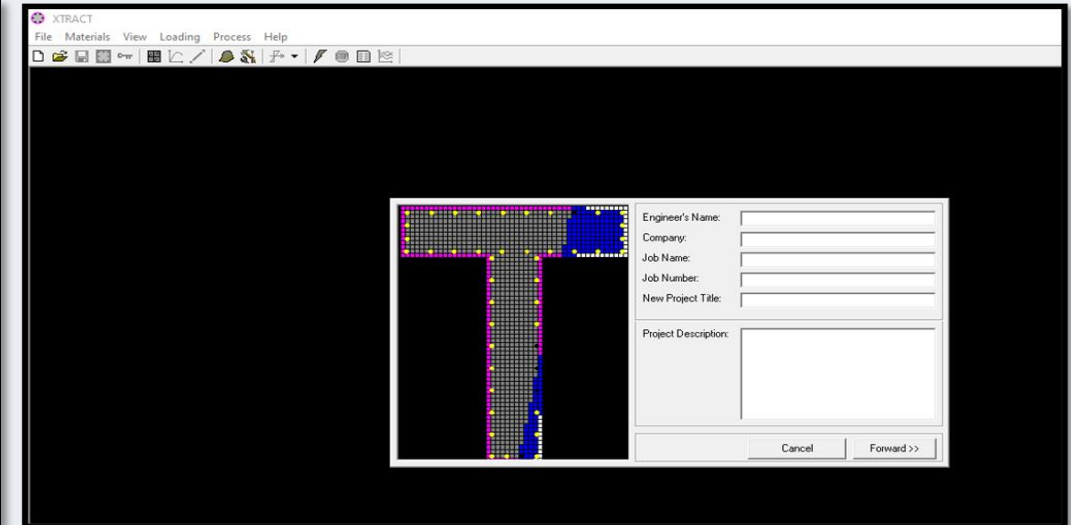
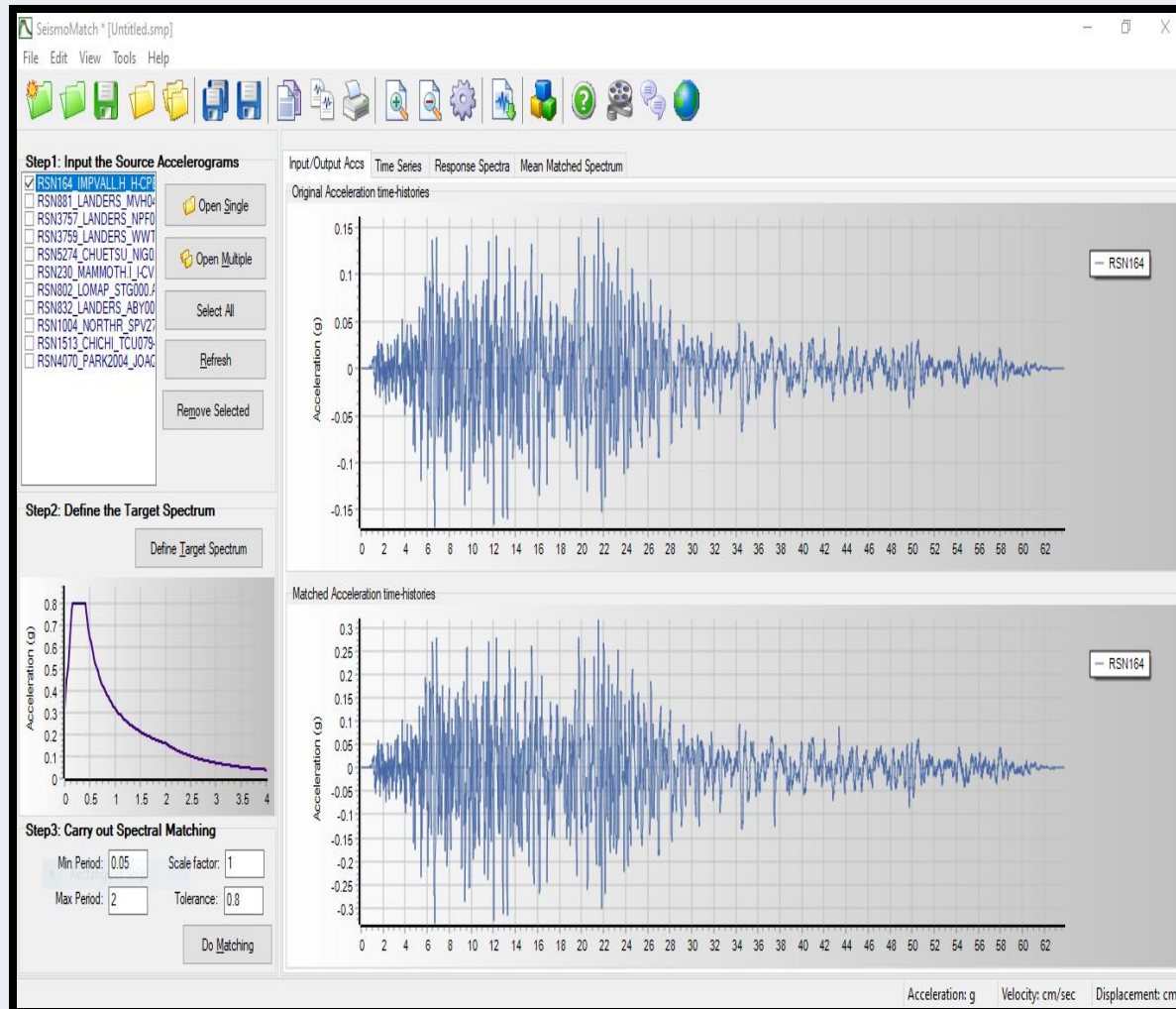
 **SAFE**
ANALYSIS AND DESIGN OF FLOOR SYSTEMS

 **Perform 3D**
PERFORMANCE-BASED DESIGN OF 3D STRUCTURES

 **CsiPlant**
PIPE STRESS ANALYSIS AND DESIGN

 **CsiCol**
DESIGN OF REINFORCED CONCRETE COLUMNS

Matching and scaling of EQ data, XTRACT, SAP2000

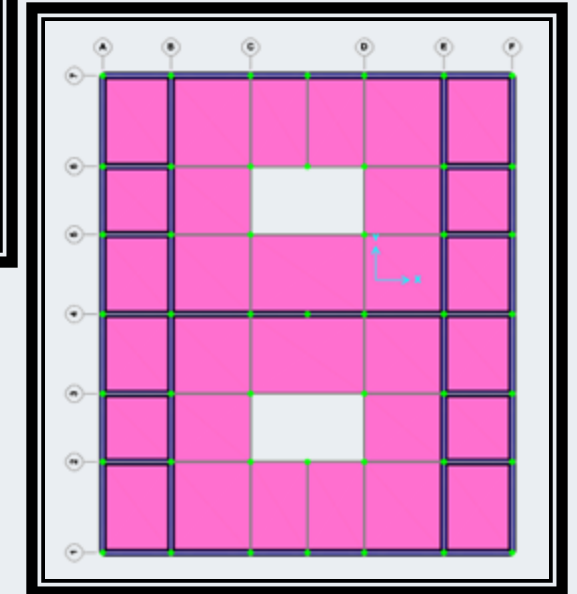
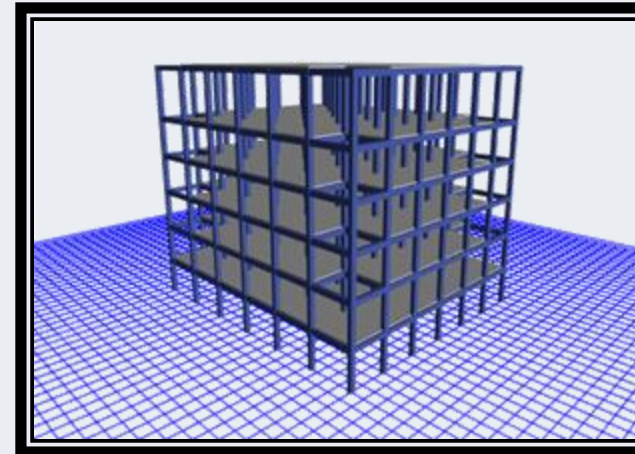


Project Description

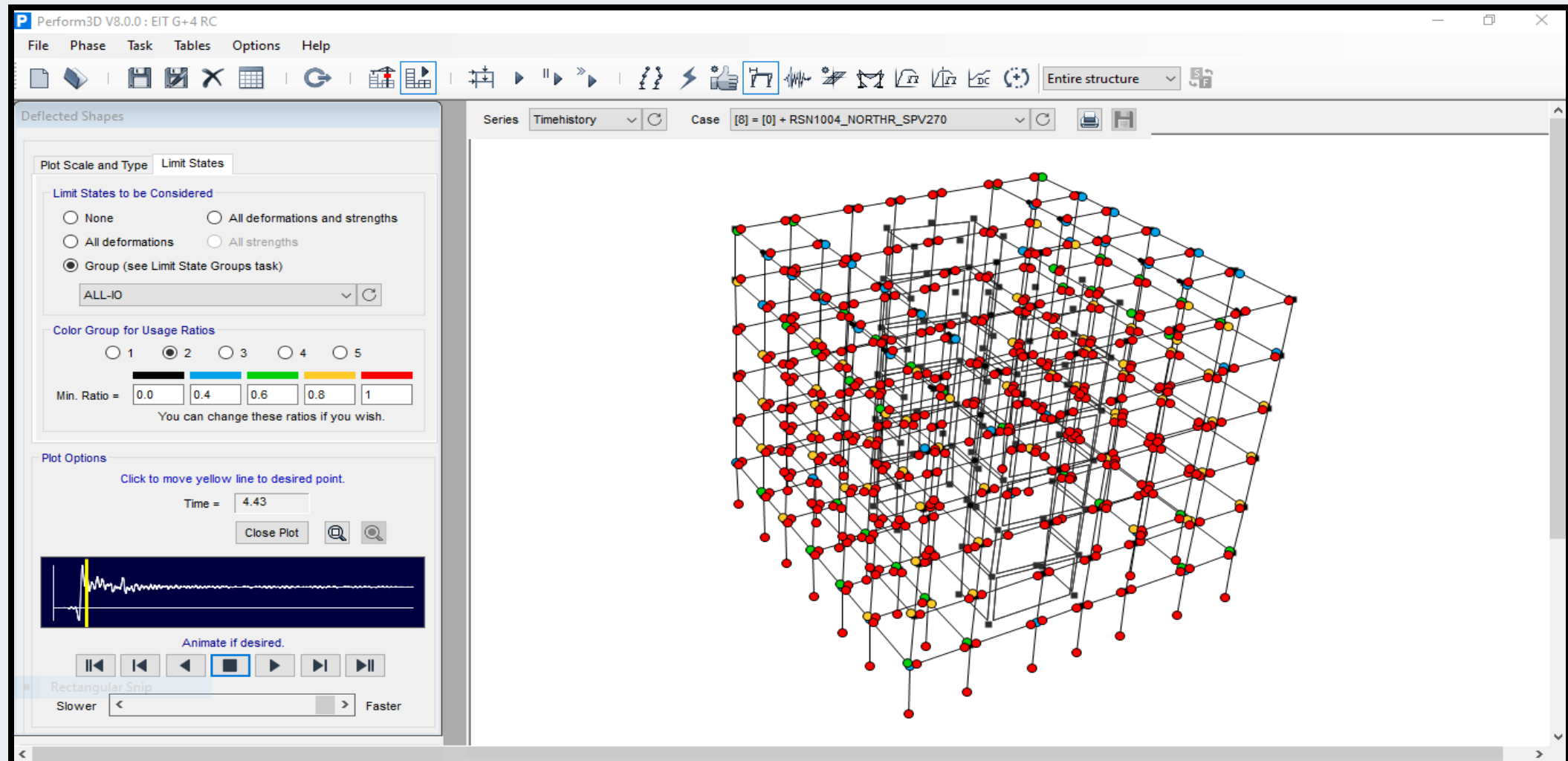
In this in-depth webinar where we will walk you through the complete analysis and design of a G+4 Reinforced Concrete (RC) building, utilizing ACI/ Euro Code 2–2004 / and other International standards. This session is ideal for beginners who want to gain a solid understanding of structural design principles and their practical application in real-world projects.

Project Overview:

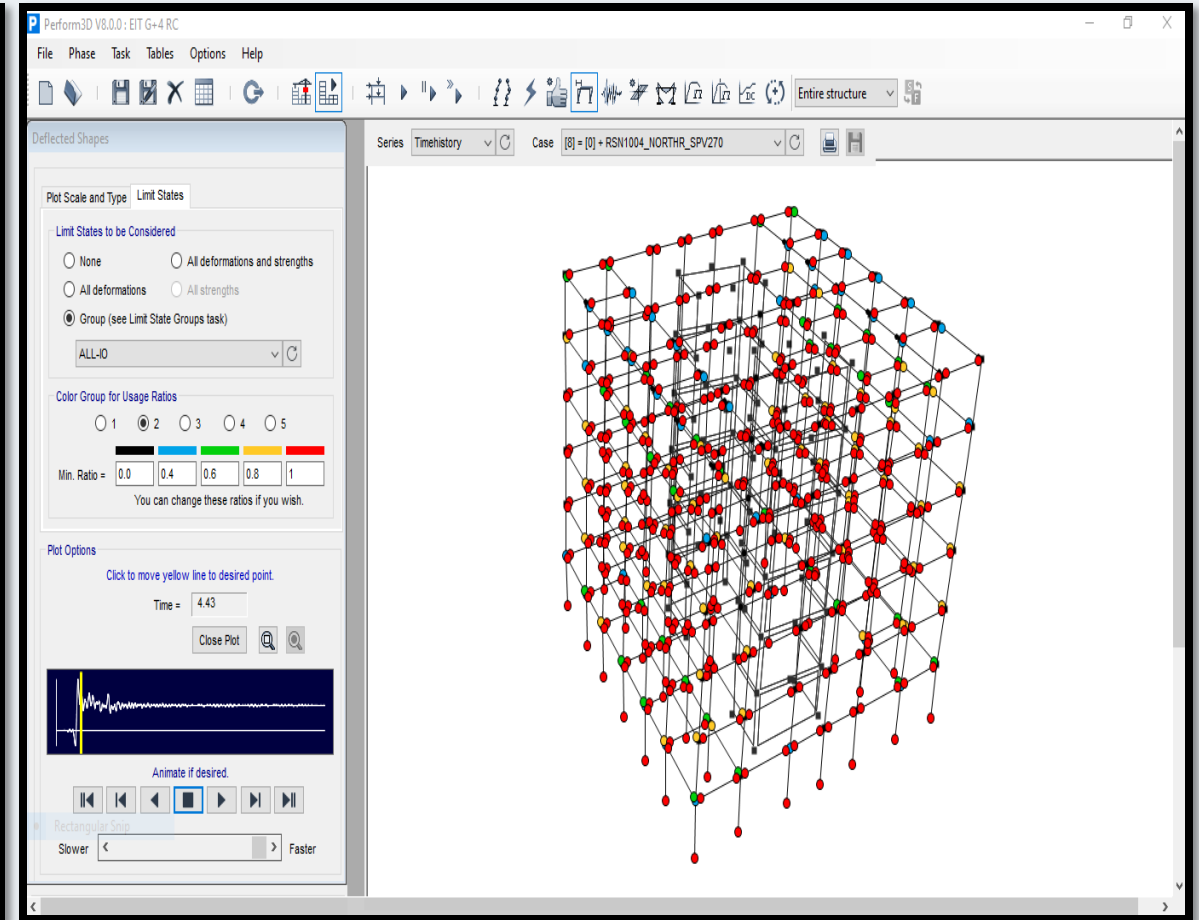
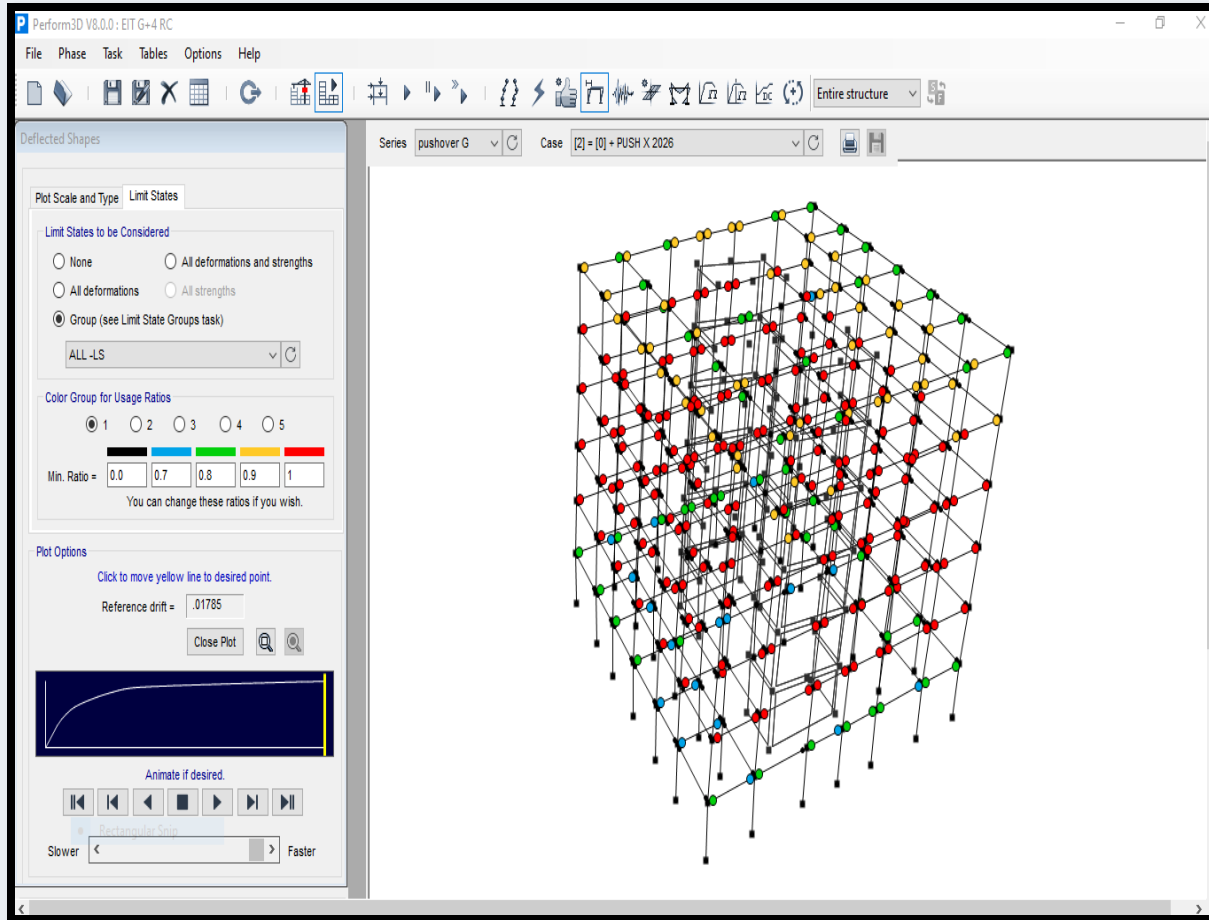
- **Building Type:** G+4 RC Building
- **Concrete Grade:** C-25/30 and 4000 psi
- **Steel Grade:** S-450
- **Structural Elements:**
 - **Beam Sizes:**
 - Ground Floor Beam (GB): 600x250 mm
 - First Floor Beam (FF BM): 600 x250 mm
 - Second Floor Beam (SF BM): 600x 250 mm
 - Third Floor Beam (THF BM) 600 X 250 mm
 - Fourth Floor Beam (4th FL BM 600x250 mm)
 - Roof Beam: RF BM 600x 250 mm
 - **Column Sizes:** 600x600 mm
 - **Slab Thickness:** 250 mm
 - **Wall Thickness :** 300 mm



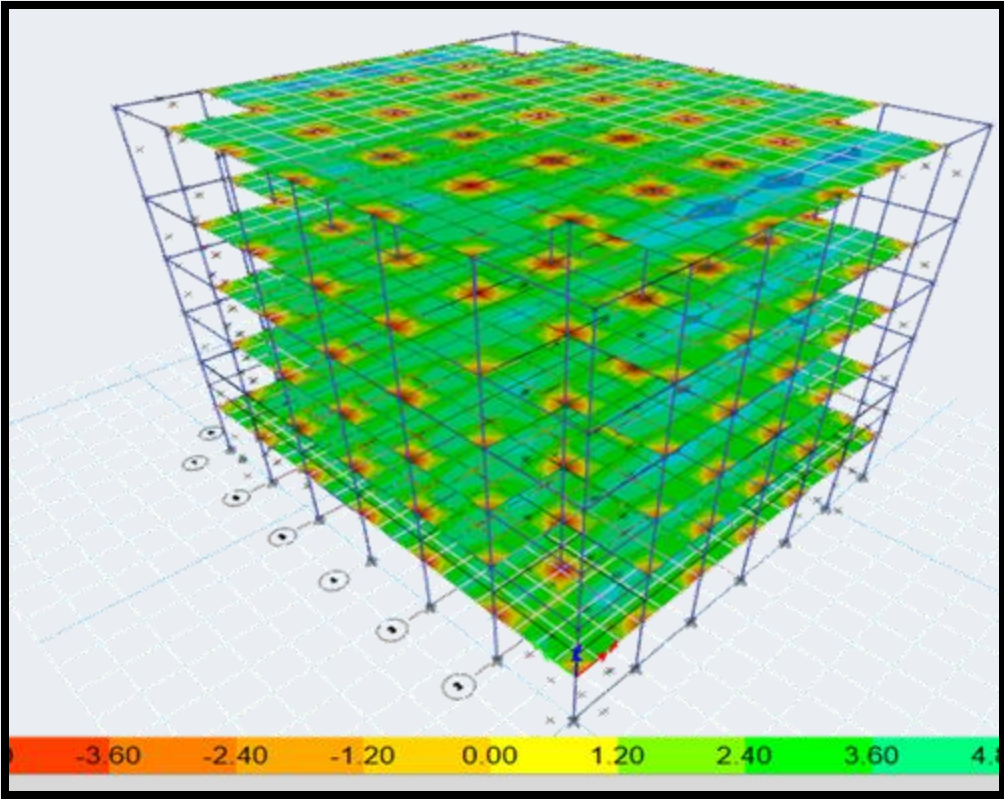
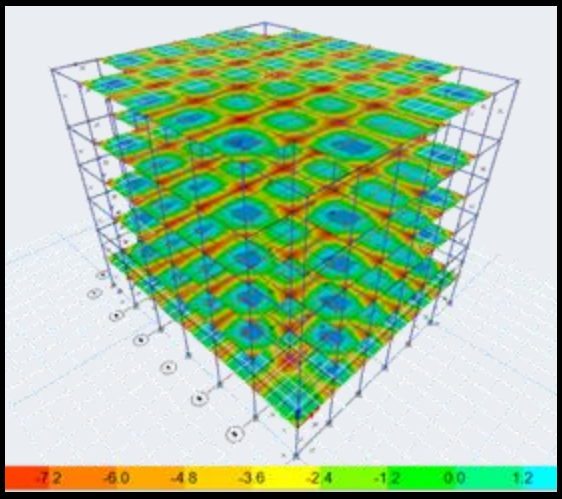
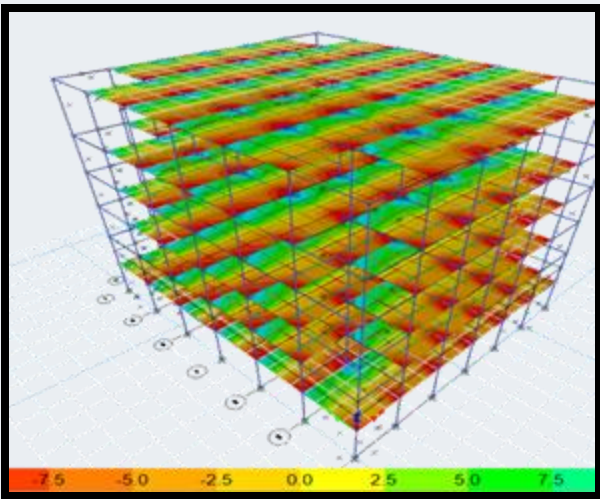
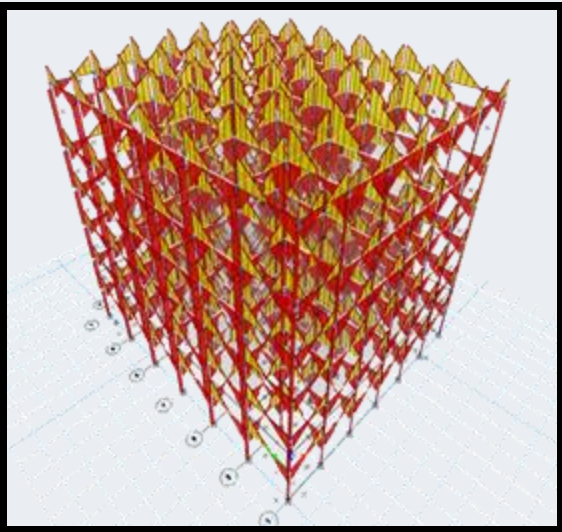
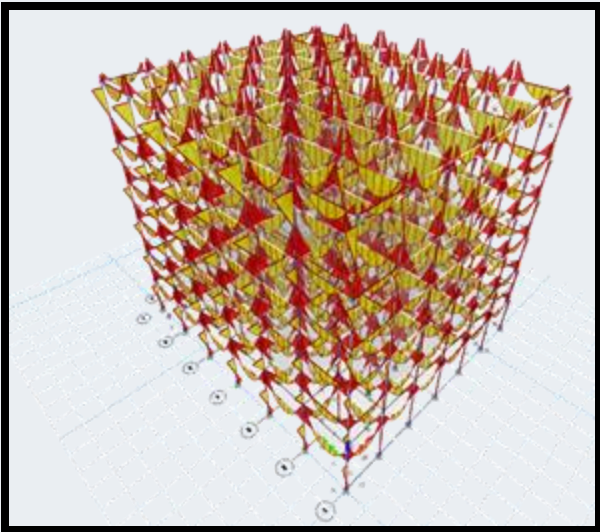
SAMPLE PERFORM - 3D TIME-HISTORY RESULT



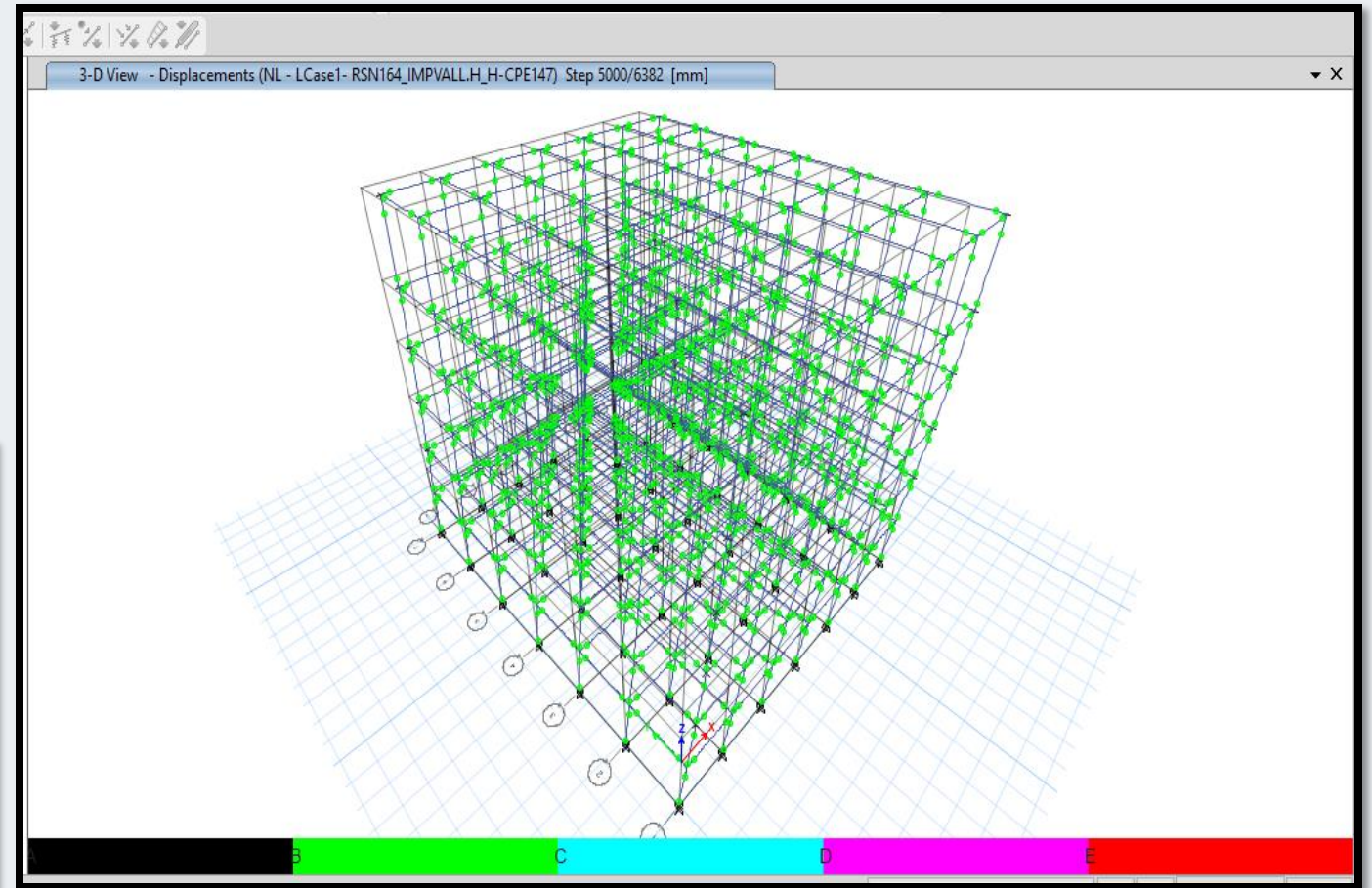
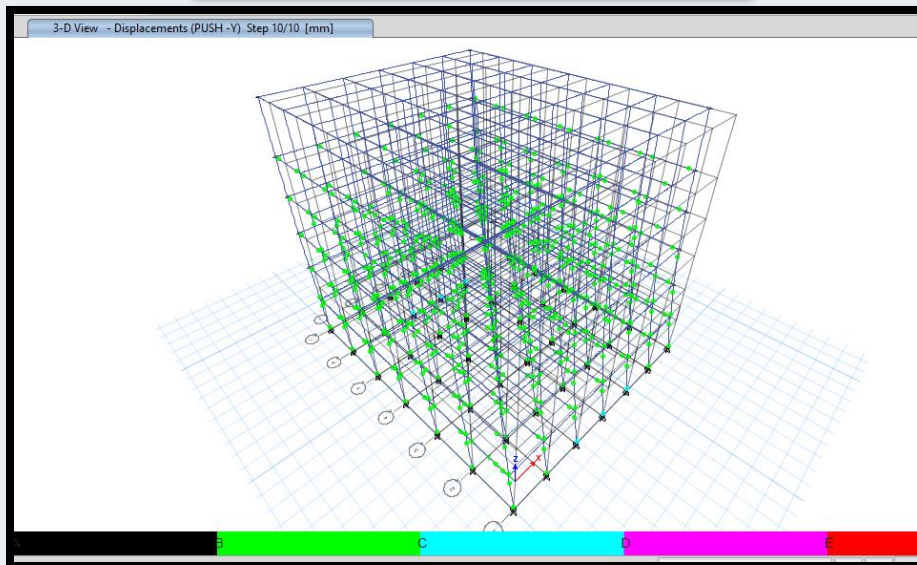
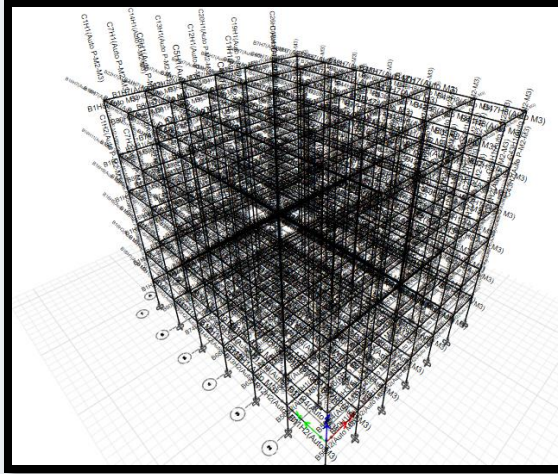
PUSHOVER AND TIMEHISTORY RESULT IN PERFORM-3D



SAMPLE RESULTS



PLASTIC HING MODELING



INTRODUCTION – HOW A CHILLER, COOLING TOWER AND AIR HANDLING UNIT WORK TOGETHER – BASICS

Chilled Water HVAC System for a Multi-Storey Building

Chiller – Cooling Tower – Air Handling Units (AHU) – Complete System Overview

How It Works (Process Flow)

- Chiller:** Produces chilled water (6–8 °C) in the evaporator using the refrigeration cycle.
- Chilled Water Pumps:** Circulate chilled water to AHUs.
- AHU:** Chilled water flows through cooling coils, cools and dehumidifies the supply air.
- Return Chilled Water:** Warmer water (12–14 °C) returns to chiller.
- Condenser Heat Rejection:** Refrigerant heat is rejected to condenser water (≈35 °C).
- Cooling Tower:** Rejects heat to atmosphere and cools water to ≈28 °C, which returns to the chiller.

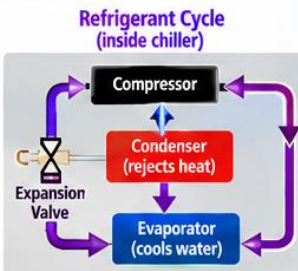
Typical Floor (AHU Level)

- AHU draws return air from rooms.
- Air is cooled and dehumidified in the cooling coil (6–8 °C CHW).
- Cooled supply air is delivered to the building.
- Chilled water leaves AHU at 12–14 °C.

1 Chiller (Vapour Compression)

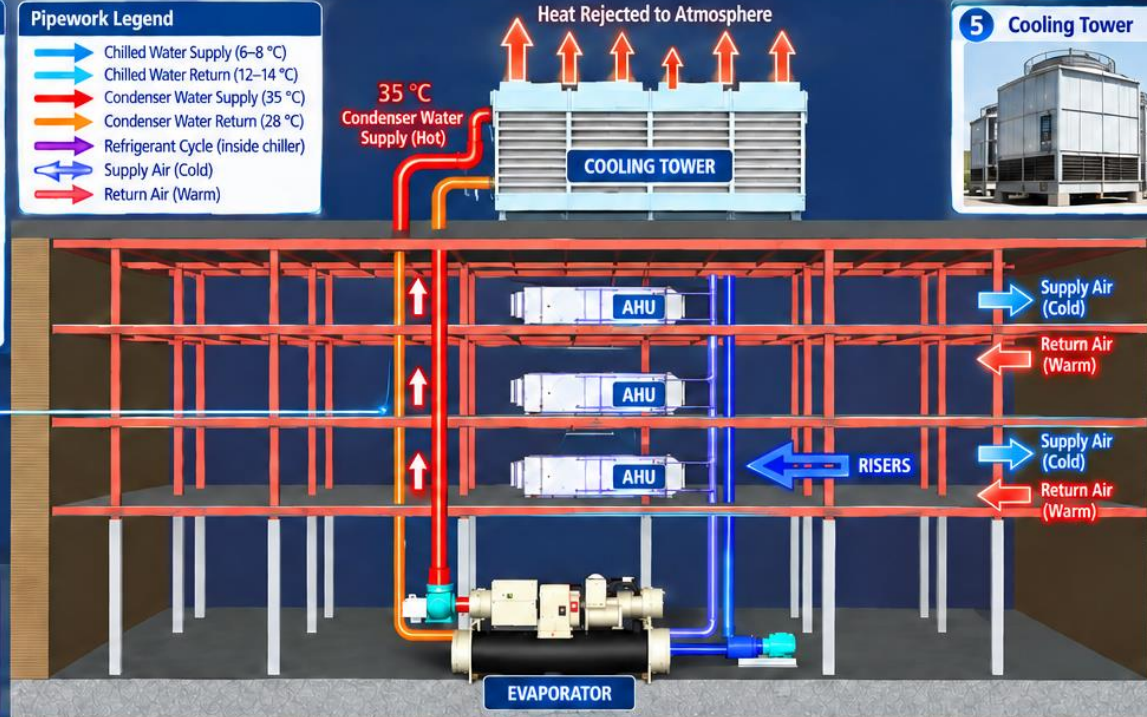


- Evaporator cools water to 6–8 °C.
- Compressor increases refrigerant pressure and temperature.
- Condenser rejects heat to condenser water (≈35 °C).
- Expansion valve reduces refrigerant pressure.
- Refrigerant circulates in a closed loop.



Pipework Legend

- Chilled Water Supply (6–8 °C)
- Chilled Water Return (12–14 °C)
- Condenser Water Supply (35 °C)
- Condenser Water Return (28 °C)
- Refrigerant Cycle (inside chiller)
- Supply Air (Cold)
- Return Air (Warm)



5 Cooling Tower



- Receives hot condenser water (≈35 °C).
- Rejects heat to atmosphere by evaporation (and sensible heat).
- Cooled water returns at ≈28 °C (temperature drop ≈7 °C).
- Fans draw air through the tower.

Air Distribution (Typical AHU)



- Supply Air: Cooled (≈14–16 °C).
- Return Air: Warm (≈24–26 °C).
- Ducts distribute air to rooms.

Benefits

- ✓ Efficient cooling for multi-storey buildings
- ✓ Improved indoor air quality
- ✓ Dehumidification
- ✓ Reliable and scalable system
- ✓ Widely used in commercial, residential and institutional buildings

2 Condenser Water Pump



- Circulates condenser water between chiller and cooling tower.
- Typical temperature: 28–35 °C.
- Maintains constant flow.

3 Chilled Water Pump



- Circulates chilled water to AHUs.
- Typical supply temperature: 6–8 °C.
- Typical return temperature: 12–14 °C.
- Maintains constant flow.

4 Air Handling Unit (AHU)



- Chilled water (6–8 °C) enters cooling coil.
- Leaves at 12–14 °C.
- Cools and dehumidifies air.
- Supplies conditioned air to building.

Typical Temperatures

Chilled water supply	6 – 8 °C
Chilled water return	12 – 14 °C
Condenser water (in)	35 °C
Condenser water (out)	28 °C
Condenser water ΔT	≈ 7 °C
Chilled water ΔT	≈ 6 – 8 °C

Chilled Water HVAC System for a Multi-Storey Building

Chiller – Cooling Tower – Air Handling Units (AHU) – Complete System Overview

How It Works (Process Flow)

- Chiller:** Produces chilled water (6–8 °C) in the evaporator using the refrigeration cycle.
- Chilled Water Pumps:** Circulate chilled water to AHUs.
- AHU:** Chilled water flows through cooling coils, cools and dehumidifies the supply air.
- Return Chilled Water:** Warmer water (12–14 °C) returns to chiller.
- Condenser Heat Rejection:** Refrigerant heat is rejected to condenser water (≈35 °C).
- Cooling Tower:** Rejects heat to atmosphere and cools water to ≈28 °C, which returns to the chiller.

Typical Floor (AHU Level)

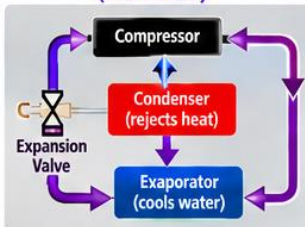
- AHU draws return air from rooms.
- Air is cooled and dehumidified in the cooling coil (6–8 °C CHW).
- Cooled supply air is delivered to the building.
- Chilled water leaves AHU at 12–14 °C.

1 Chiller (Vapour Compression)



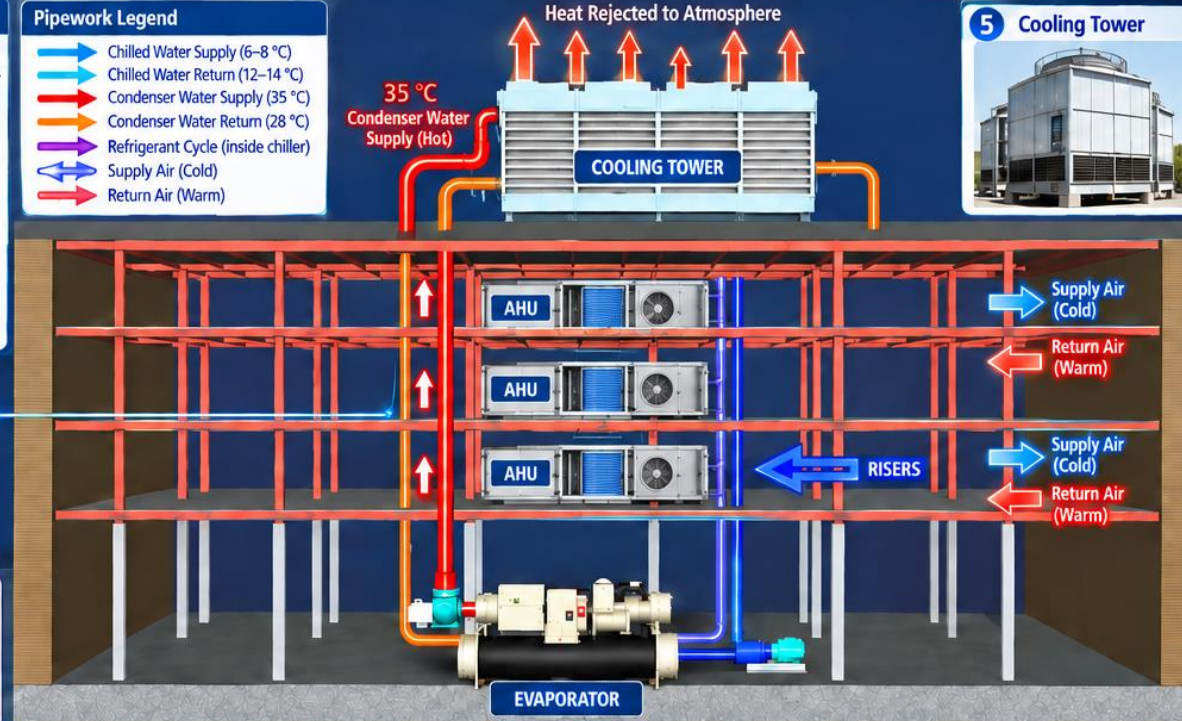
- Evaporator cools water to 6–8 °C.
- Compressor increases refrigerant pressure and temperature.
- Condenser rejects heat to condenser water (≈35 °C).
- Expansion valve reduces refrigerant pressure.
- Refrigerant circulates in a closed loop.

Refrigerant Cycle (inside chiller)



Pipework Legend

- Chilled Water Supply (6–8 °C)
- Chilled Water Return (12–14 °C)
- Condenser Water Supply (35 °C)
- Condenser Water Return (28 °C)
- Refrigerant Cycle (inside chiller)
- Supply Air (Cold)
- Return Air (Warm)



5 Cooling Tower



- Receives hot condenser water (≈35 °C).
- Rejects heat to atmosphere by evaporation (and sensible heat).
- Cooled water returns at ≈28 °C (temperature drop ≈ 7 °C).
- Fans draw air through the tower.

Air Distribution (Typical AHU)



- Supply Air: Cooled (≈14–16 °C).
- Return Air: Warm (≈24–26 °C).
- Ducts distribute air to rooms.

Benefits

- ✓ Efficient cooling for multi-storey buildings
- ✓ Improved indoor air quality
- ✓ Dehumidification
- ✓ Reliable and scalable system
- ✓ Widely used in commercial, residential and institutional buildings

2 Condenser Water Pump



- Circulates condenser water between chiller and cooling tower.
- Typical temperature: 28–35 °C.
- Maintains constant flow.

3 Chilled Water Pump



- Circulates chilled water to AHUs.
- Typical supply temperature: 6–8 °C.
- Typical return temperature: 12–14 °C.
- Maintains constant flow.

4 Air Handling Unit (AHU)



- Chilled water (6–8 °C) enters cooling coil.
- Leaves at 12–14 °C.
- Cools and dehumidifies air.
- Supplies conditioned air to building.

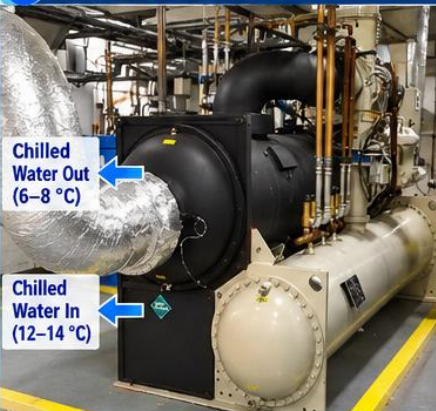
Typical Temperatures

Chilled water supply	6 – 8 °C
Chilled water return	12 – 14 °C
Condenser water (in)	35 °C
Condenser water (out)	28 °C
Condenser water ΔT	≈ 7 °C
Chilled water ΔT	≈ 6 – 8 °C

Real Components of a Chilled Water HVAC System

Pictures from Actual Equipment – For Student Reference

1 Chiller (Actual Unit)



Chiller: Removes heat from the building by cooling water to 6–8 °C using the refrigeration cycle.

2 Inside a Chiller (Tube Bundle View)



Refrigerant Side (evaporator) – absorbs heat from chilled water

Refrigerant Side (condenser) – rejects heat to condenser water

Inside Chiller: Tube bundles for evaporator and condenser heat exchangers (refrigerant side).

3 Chilled Water Pump (Actual Unit)



Chilled Water Pump: Circulates chilled water between the chiller and AHUs.

4 Pipe Identification (Chilled Water)



Chilled Water Pipe Label: Shows flow direction for chilled water (CHW).

5 Pipe Identification (Return)



Chilled Water Return Pipe Label: Shows flow direction for chilled water return.

6 Cooling Coil (Actual Coil)



Cooling Coil: Heat exchanger inside the AHU that cools and dehumidifies the supply air.

7 Air Handling Unit (Actual Unit)



Air Handling Unit (AHU): Contains filters, cooling coil, fans and other components to condition and supply air to the building.

8 Cooling Tower (Actual Unit)



Cooling Tower: Rejects heat from condenser water to the atmosphere by evaporation (and sensible heat).

These are actual pictures of the main components used in a chilled water HVAC system.
They help students understand what the equipment looks like in real buildings and how each component fits into the system.

PART I – CODE BASED DESIGN BASICS

Why Performance-Based Design & Evaluation Matters??

Literature Review / Comprehensive Bibliometric Analysis

- It was examined 3,469 PBD-related publications spanning from 1983 to 2024 using VOSviewer version 1.6.19, a bibliometric mapping and visualization software tool.
- The results of the search cover all studies related to PBD available on Scopus by restricting the search of TITLE-ABS-KEY ("performance based design*.") AND (LIMIT-TO (LANGUAGE, "English")).
- Preferred Journals ,Leading Countries, Leading Organizations and International institutions identified Utilizing the Scopus database.
- Our analysis of co-citations revealed that performance-based design serves as the primary theoretical foundation for structural design and analysis. Furthermore, through a co-word analysis, we tracked the evolution of research topics within the PBD domain over time.

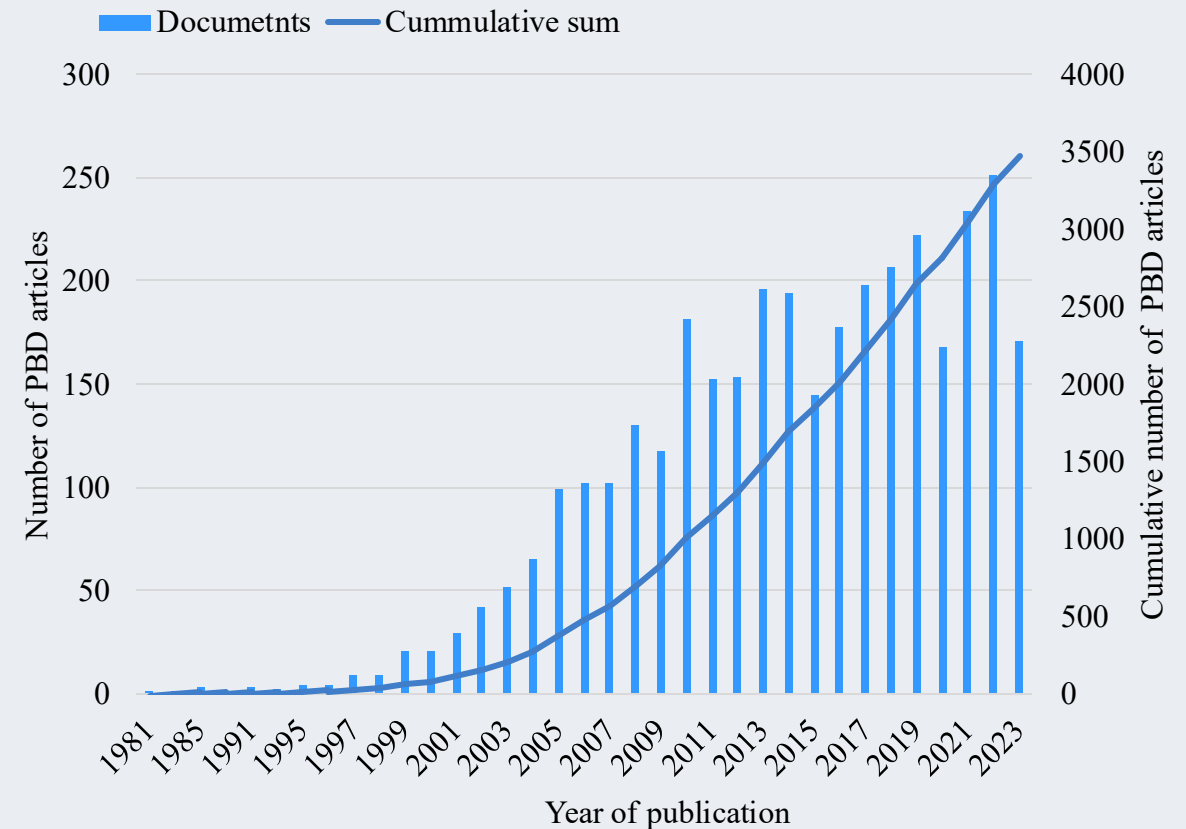


Fig 1. The annual and cumulative numbers of research articles on PBD indexed in Scopus Before 1981 until 2023

-

A network visualization showing the relationships between various countries. The United States is the central node, connected to a large number of other countries. Other prominent nodes include the United Kingdom, Canada, Japan, India, and the Netherlands. The network is dense with many smaller nodes and edges, representing a complex web of international connections.

24

Literature Review / Comprehensive Bibliometric Analysis Results

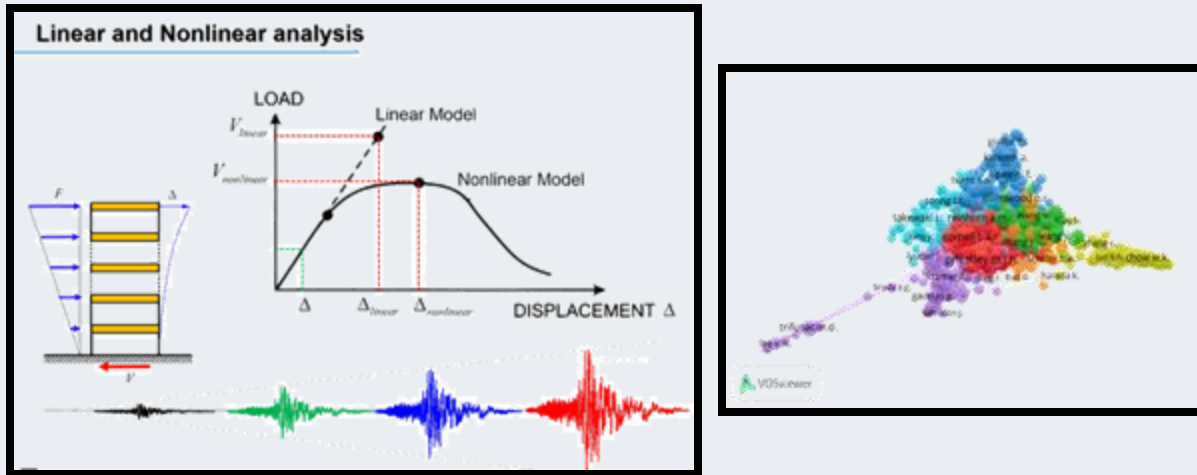


Fig 6. Visualization of Co-citation –cited author

Hypothesis:

"The challenge of adopting seismic design codes without necessary adjustments, accompanied by the absence of reliable seismic maps in countries without earthquake recording stations, may lead to structural failure. In such contexts, Performance-Based Design emerges as a viable and crucial solution for ensuring the structural integrity and safety of both existing and newly constructed tall buildings."

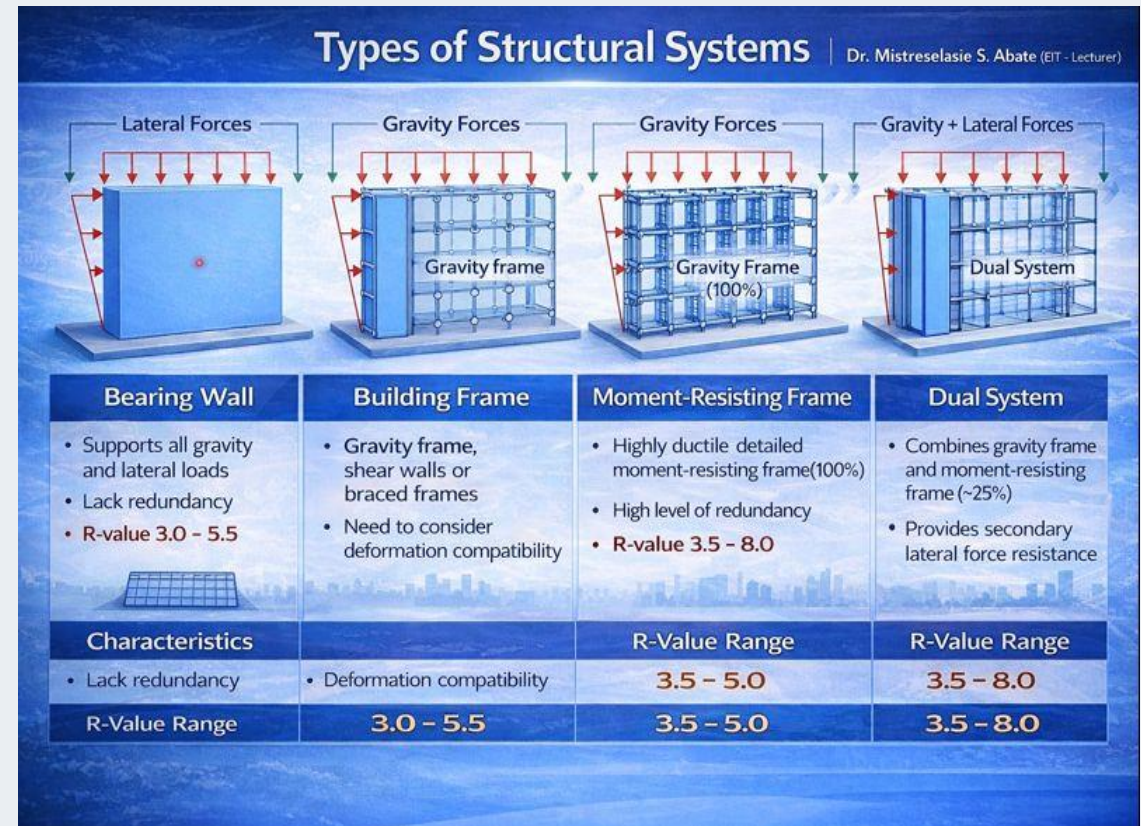
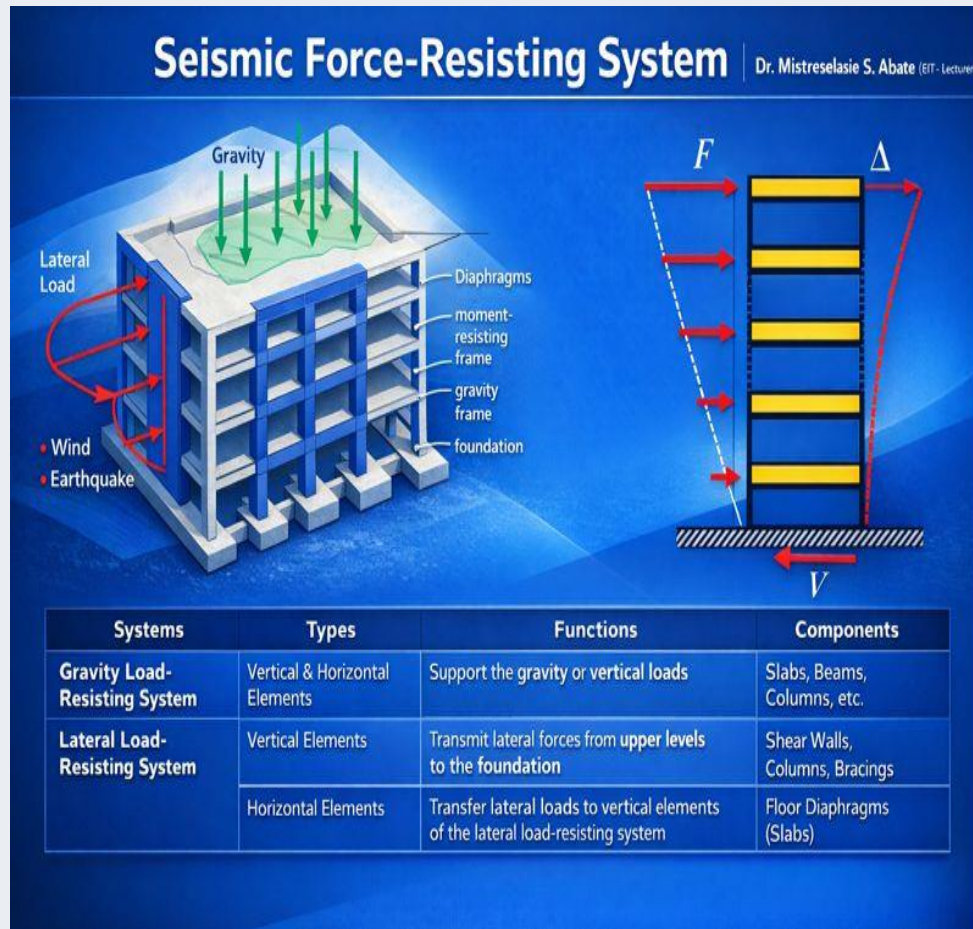
Summary

1. Code-based design can not address earthquake design issues
2. PBD is cutting-edge seismic design techniques
3. The effect of using the prescribed adopted code without amendment.
4. Design approaches focused on forces are not adequate.
5. The shortcomings of the Ethiopian Seismic hazard map.
6. PBD was introduced in the United States.
7. How the Earthquake in East Japan alerts Koreans to assess their building code.
8. Still in Korea the use of PBD is at its infant level.
9. Why do different country codes differ from each other? Their assumptions.
10. Lack of expertise and unawareness of the critical need of PBD.
11. Intensive Comparison of various design building code .

- *Overall, this study provides a comprehensive overview of the research on performance based design and identifies the key research topics and future directions for further exploration in PBD research area*

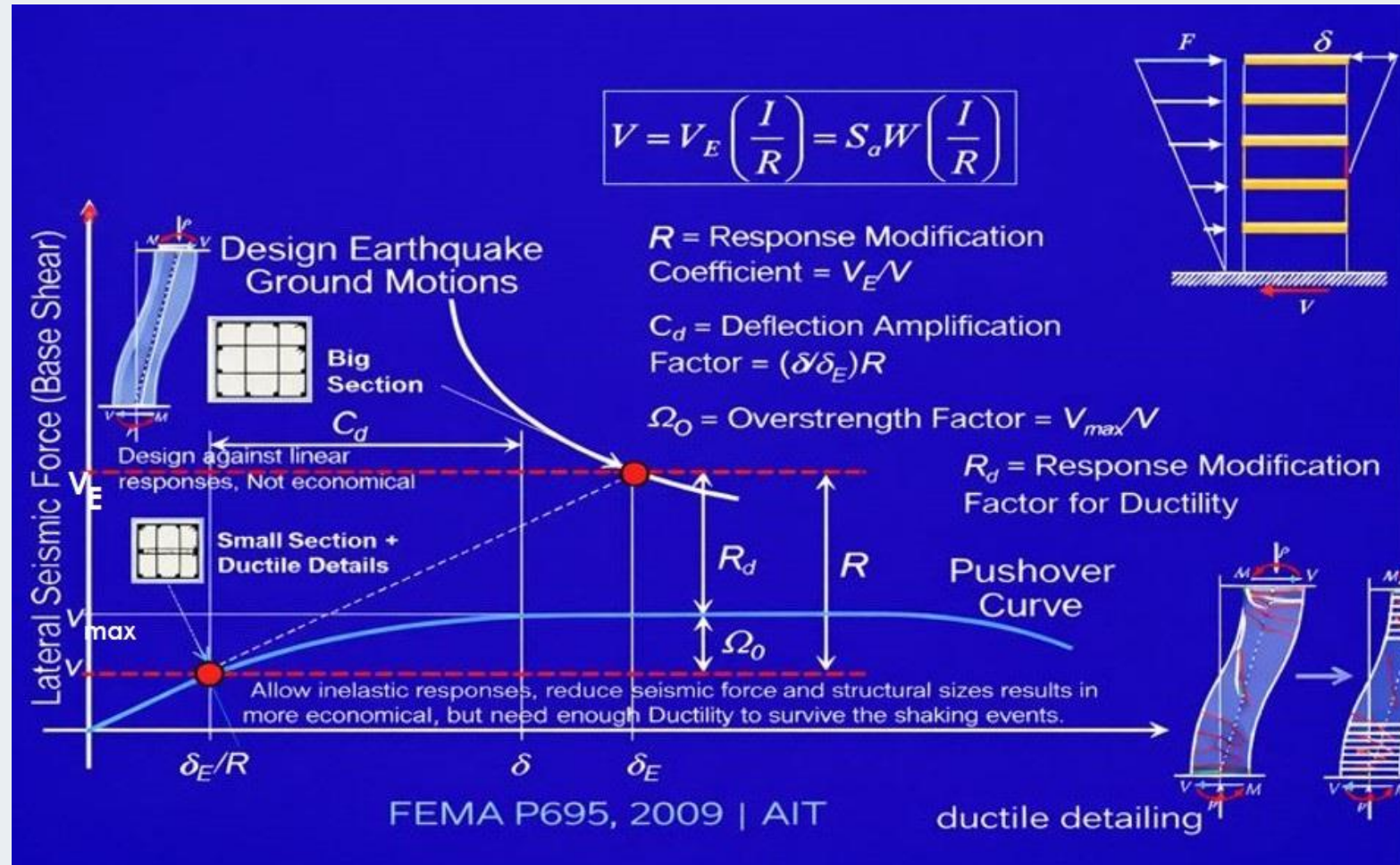
General Concept

The Common Structural Systems Used Frequently



Reference: ASCE 41-17; FEMA 356; ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

General Design Concept



Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

The Evolution of Building Design

There are many ways to hold up a tall building. Over the last 100 years, structural styles have come and gone, depending on the availability of materials and the building's needs. While Los Angeles may not be known for its high-rise culture, the city has a diversity of styles.

Tall Buildings are defined as those with the height, h , greater than 160 feet (48 m = 16 stories) above average adjacent ground surface, LATBSDC 2022.



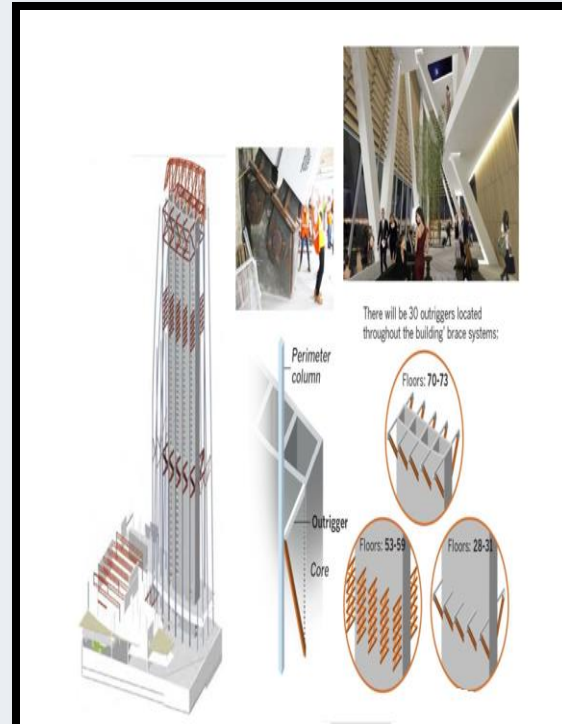
Different Structural Systems Sample Around the World

*One Rincon Hill (Tower 1)
San Francisco, US*



*SOURCE : Performance –Based Seismic Design:
Best Practices, Ron klemencic , MKA*

*Wilshire Grand Center , Los
Angeles , US*



*SOURCE :Performance –Based Seismic Design
for Tall Buildings, CTBUH, Thornton Tomasetti*

*Irregular
Structures*



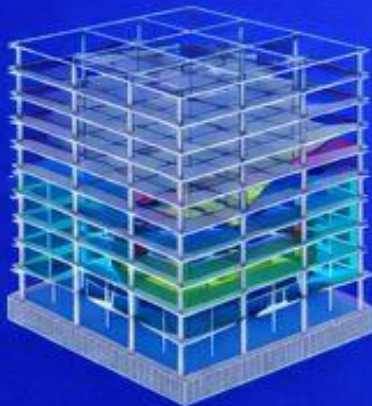
SOURCE :Performance –Based Seismic Design for Tall Buildings, CTBUH, Thornton Tomasetti

*Hybrid (Precast & RC)
Building)*

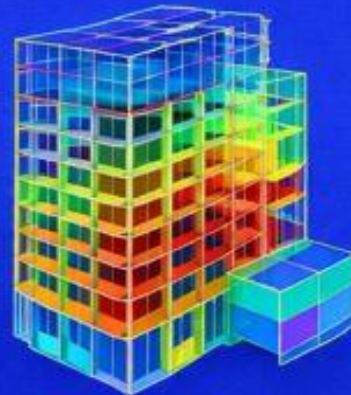


Dr. Mistreselasie S. Abate (EIT-Lecturer)

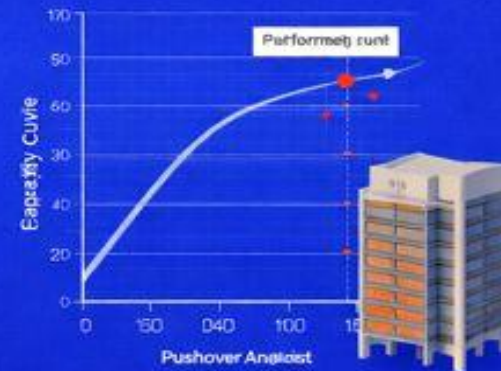
Is my structure safe?



ETABS



SAP2000



PERFORM-3D



NLTHA

Performance-Based Seismic Design (PBSD) of Tall Buildings

Dr. Mistreselasie S.Abate (EIT - Lecturer)



Key Points of PBSD

- Code provisions provide a **minimum level of safety for all building types**, from small dwellings to tall structures.
- Many code requirements are **not tailored for tall buildings**, leading to less optimal designs.
- **Performance-based seismic design** is a **framework** for designing new buildings.
- PBSD offers an **alternative design** with **predictable and safe performance** under earthquake conditions, requiring **more effort** in analysis and design.



Goals of PBSD

(For Developers & Structural Engineers)

- **Make exceptions** to specific code limits for **seismic force-resisting systems**.
- Utilize advanced seismic systems not in the code, like **outriggers**.
- Use **high-strength materials & devices**:
- **Base isolation,**
- **Tuned mass dampers.**



[Source: AIT; ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

How Building Design Codes Ensure Safety?



Dr. Mistreselaisie S. Abate

Prescriptive Codes — Protection with Practical Limits

Public Perspective (Life Safety Focus)

- Will this building protect occupants during an earthquake?
- Is collapse prevention adequately addressed?

Owner Perspective (Functionality & Loss Control)

- Will the structure remain standing after strong shaking?
- Can the building be occupied again immediately?
- How severe will the damage be?
- What level of repair cost should be expected?
- How long will recovery take?

Engineer Perspective (Code Reality Check)

- The structure satisfies code-requirements, but post-earthquake performance is uncertain.
- "The building meets the code, yet serviceability and usability are not guaranteed."

- Prescriptive codes are primarily intended to prevent collapse and protect lives, not to ensure minimal damage, immediate occupancy, or rapid recovery.

Understanding Safety Measures in Design Codes

Strength > Demand

$$\phi M_n > M_u \quad (\text{Safety Factor included})$$



[Source: AIT; ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

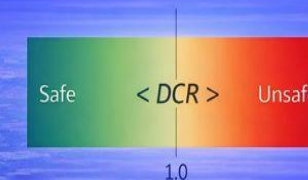
Dr. Mistreselaisie S. Abate (EIT - Lecturer)

Understanding Safety Measures in Design Codes

Strength > Demand

$$\phi M_n > M_u \quad (\text{Safety Factor included})$$

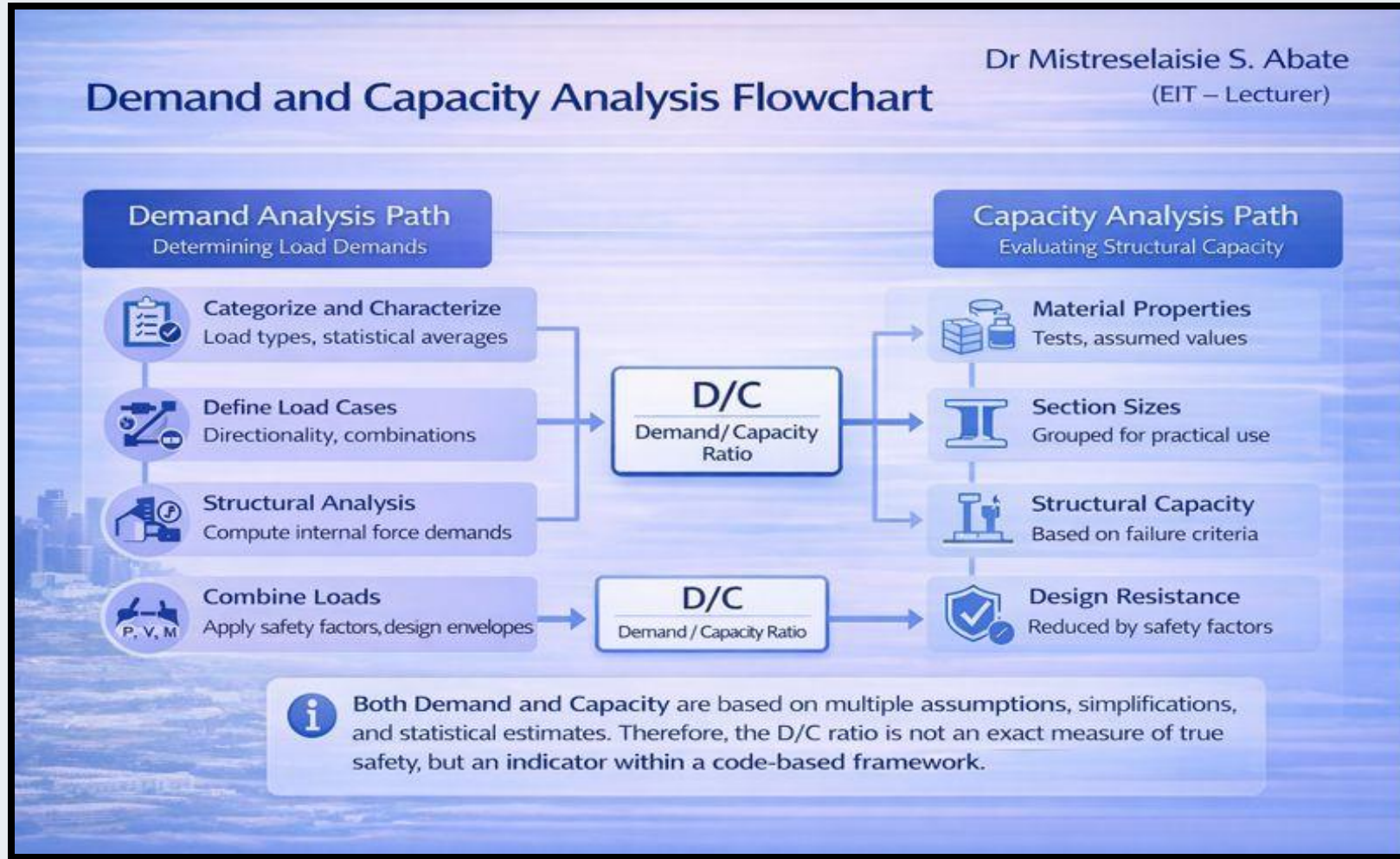
$$DCR = \frac{M_u}{\phi M_n}$$



[Source: AIT; ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

Demand and Capacity Analysis Flowchart

Dr Mistreselaisie S. Abate
(EIT – Lecturer)



[Source: AIT , ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, 1996]

PART – 2

PERFORMANCE BASED DESIGN BASICS

Design for Safety Against Seismic Effects (ASCE and ACI Approach)

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Structural Analysis Methods for Seismic Design (Linear vs Nonlinear Modeling Framework)

Structural Analysis	Linear Procedures E, A, I, G etc = Constant, K = Constant	Nonlinear Procedures E ≠ Constant, E/I ≠ Constant, K ≠ Constant
Seismic Loading	Linear Procedures	Nonlinear Procedures
Static	1. Equivalent Lateral Force (ELF) Procedure • Simplified static force-based approach	5. Several Pushover Analysis Methods • Incremental loading to capture inelastic capacity
Dynamic	2. Response Spectrum Analysis (RSA) • Modal-based elastic dynamic method	6. Nonlinear Modal Response History (NMA) • Fast Nonlinear Analysis (FNA)
	3. Linear Response History / Time History • Analysis Procedure (Modal RHA/LTHA)	7. Nonlinear Response History (or Time History) • Full nonlinear dynamic simulation (BNWLTHA)
	4. Direct Integration Linear RHA/LTHA	• Full nonlinear dynamic simulation (BNWLTHA)

Linear Procedures	Nonlinear Analysis
 Material stiffness and properties remain constant.  No yielding or damage is modeled. • System stiffness (K) does not change.	 Material stiffness changes with deformation.  Cracking, yielding, and damage are explicitly modeled. • Nonlinear stiffness varies.

Key Teaching Message

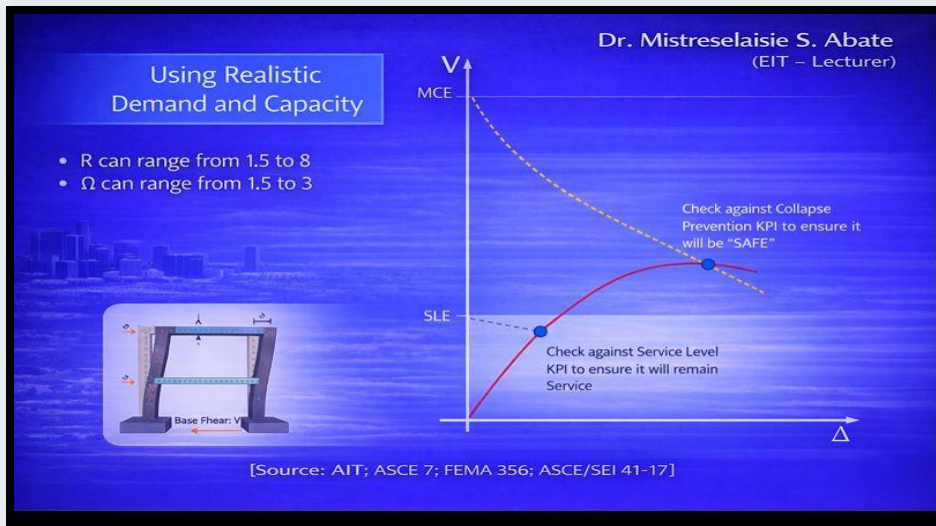
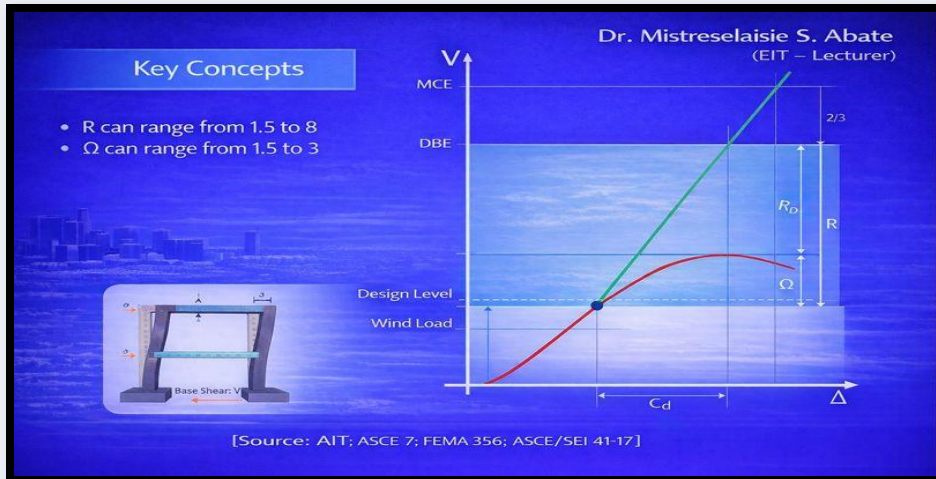
Linear analysis assumes constant stiffness and purely elastic behavior, while nonlinear analysis captures actual inelastic response, damage, and stiffness degradation. Therefore, nonlinear analysis provides a more realistic measure of structural performance under earthquakes.

[Source: AIT, ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, 1996]

Important Point which leads to PBD.

1. Does the absence of earthquake recording stations and reliable seismic data pose a significant challenge for countries without the means to generate accurate seismic hazard maps?
2. If we cannot trust our current seismic hazard map, can we rely on structures designed using it? The answer is evidently no. This raises the question: How can we design structures that perform well in future unexpected earthquakes without a reliable seismic hazard map?
3. Considering the absence of reliable seismic maps in certain countries, could Performance-Based Design be a viable solution?"
4. The seismic performance of reinforced concrete structures designed according to Ethiopian ES8-15 corresponds to Eurocode 8-2004 standards (based on EN1998-1) seismic code recommendations is effective or not?
5. Is there a Consistency Between Non-Linear Time History Analysis (NLTHA) and Pushover Analysis, Compared to Traditional Linear Analysis Methods such as Classical Modal Analysis, Response Spectrum Analysis (RSA), and Linear Dynamic Time History Analysis (LDTHA) in Accordance with the Current Ethiopian Building Codes?

Why Performance-Based Design Required?



Limitations of Code-Based Seismic Design

- ❑ Code factors R and Ω (omega) have wide ranges:
 - ❑ R: Can vary from <1 to 8+
 - ❑ Ω : Can range from 1.5 to 3
- ❑ These large ranges make nonlinear behavior highly approximate
- ❑ The design curve (red line) could fall anywhere in the shaded zone between:
 - ❑ Design-level forces
 - ❑ DBE (Design Basis Earthquake) elastic forces
- ❑ Code values for R and Ω are arbitrary and often do not account for:
 - ❑ Higher mode effects
 - ❑ True nonlinear response
- ❑ Even though tables are provided in the code, these are still approximations

Performance-Based Approach: A Better Alternative

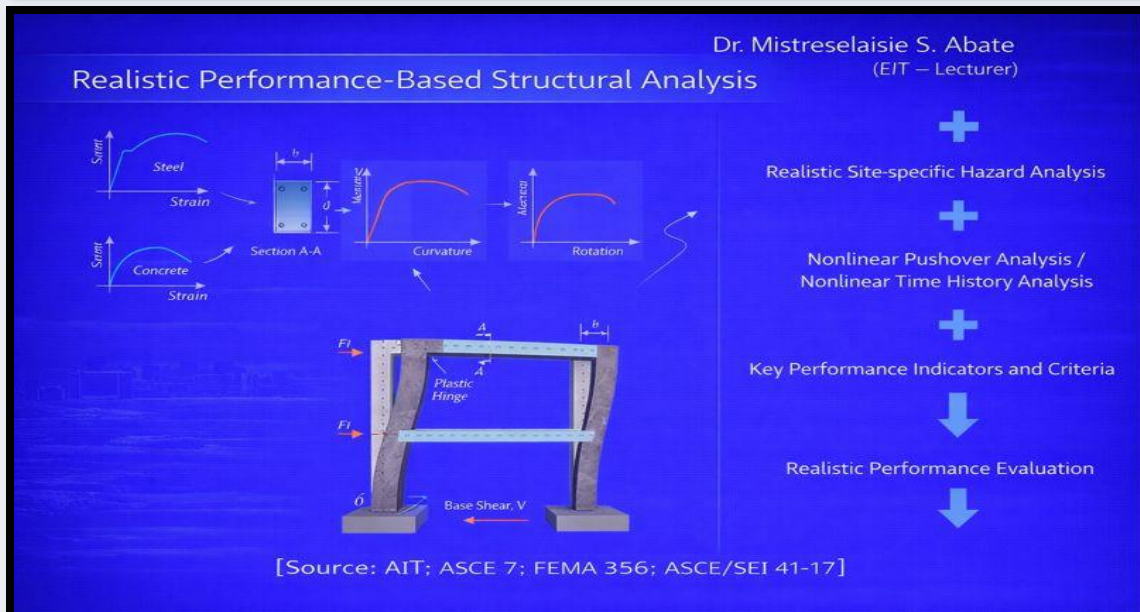
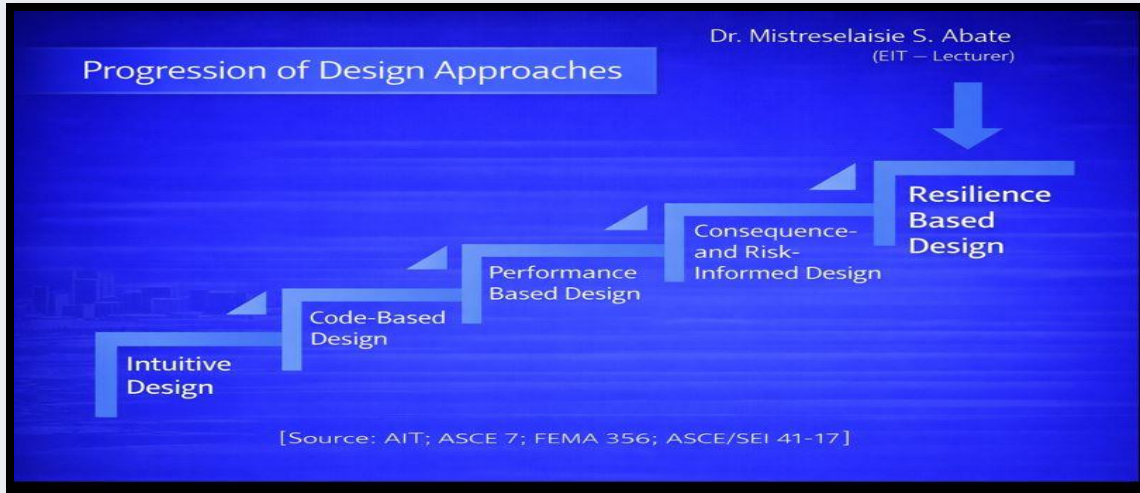
- ❑ Remove assumptions about R and Ω — get the actual nonlinear response of the structure
- ❑ Determine the true capacity curve based on real material behavior

Two Key Performance Levels

- ❑ MCE (Maximum Considered Earthquake) level analysis:
 - ❑ Check Collapse Prevention (CP) KPI
 - ❑ Ensure structure will not collapse under extreme, rare earthquake
- ❑ SLE (Service Level Earthquake) level analysis:
 - ❑ Check Serviceability KPI
 - ❑ Ensure structure will remain functional and undamaged under frequent earthquakes

Conclusion: Why Performance-Based Design?

- Explicitly checks both:
 - o Ultimate limit state (MCE)
 - o Serviceability limit state (SLE)
- Leads to a realistic, capacity-based, and risk-informed design
- Moves beyond approximation — aligns design with actual performance expectations



Reference: ASCE 41-17; FEMA 356; FEMA P695, 2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Dr. Mistreselaisie S. Abate
(EIT-Lecturer)

What is Performance-Based Design (PBD)?

PBD uses real material properties and expected values in the structural model:

- Expected strengths are typically 1–3× the nominal:
 - Concrete compressive strength
 - Rebar tensile strength
- Reinforcement detailing (longitudinal & shear) must be defined before nonlinear analysis:
 - Requires initial linear code-based design
 - Provides cross-section geometry and rebar layout

Transitioning to Nonlinear Modeling

- Convert the model to nonlinear:
 - Use plastic hinge modeling or fiber modeling
- Assign appropriate hinges to:
 - Beams, columns, shear walls
- Define moment-curvature or moment-rotation capacities based on:
 - Section properties
 - Material stress-strain behavior

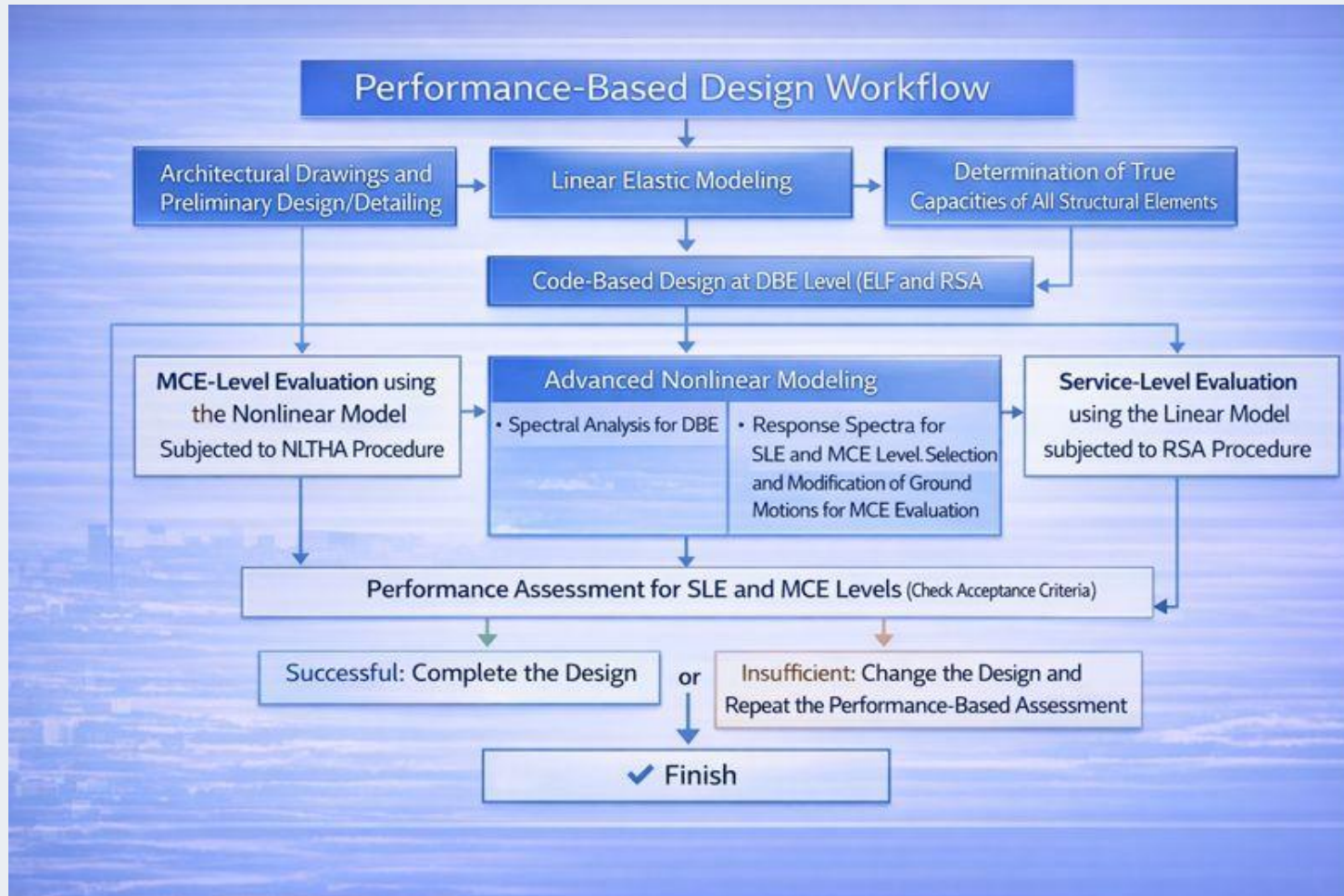
Why Nonlinear Modeling?

- Captures both local (member-level) and global (structure-level) behavior
- Represents the structure as close to reality as possible (as-built conditions)
- Enables realistic simulation of:
 - Moments, shear forces,
 - Drift, displacement, etc.

Design and Evaluation Capabilities

- PBD is applicable to both:
 - New designs
 - Assessment of existing structures
- Allows for:
 - Site-specific hazard input
 - Nonlinear pushover and time history analyses

Performance Based Design Process



Main Considerations -Which Items to Check for Performance?

- Modal analysis results
- Base shear and Base Moment comparisons
- Story Shear and Story Moment comparison
- Building sway and displacement
- Story drift
- Shear wall axial strains
- Shear wall shear capacity
- Frame member rotations, D/C ratios
- Frame member shear strength and D/C ratios
- Coupling beams, in detail
- Slab diaphragm
- Damage overview, weak points etc.

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Define Performance Levels

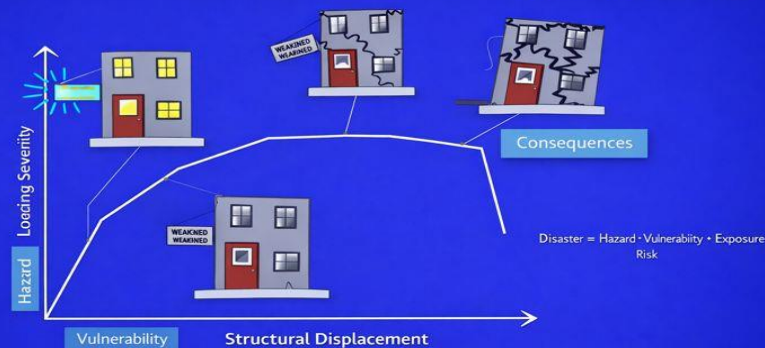
Dr. Mistreselasie S. Abate
(EIT - Lecturer)



[Source: AIT, ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, 1996]

Link the Hazard to Structural Response Performance Levels

Dr. Mistreselasie S. Abate (EIT - Lecturer)

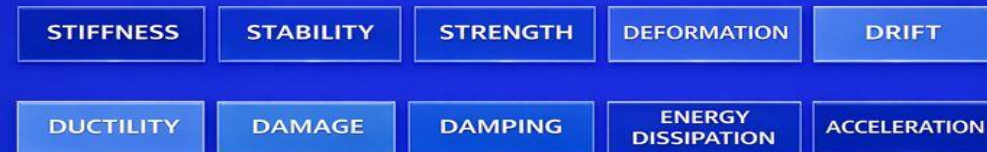


[Source: AIT, ATC-40, Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, 1996]

Reference: ASCE 41-17; FEMA 356; FEMA P695, 2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok

Key Structural Performance Indicators (KPIs)

Dr. Mistreselasie S. Abate (EIT - Lecturer)



[Source: AIT, ATC-40: Seismic Evaluation and Retrofit of Concrete Buildings, Applied Technology Council, 1996]

These key performance indicators can be evaluated based on the nonlinear analysis we perform. This means we have explicit performance limits that clients or governing bodies can adjust or agree upon, depending on the type and importance of the structure. (The PBD board typically defines the required performance levels and associated limits.)

[Source: Paulay, T., & Priestley, M. J. N. (1992). Seismic Design of Reinforced Concrete and Masonry Buildings. Wiley]

PBD Methodology

Part-I Classical Modal Analysis

- ✓ A-Classical Modal Analysis For 44 Story RC Linear Sample Model
- ✓ B- Classical Modal Analysis for 100 Story RC Linear Sample Model

Part -II Response Spectrum Analysis

- ✓ A-RSA for 44 -Story RC Sample Building
- ✓ B- RSA for 100 -Story RC Sample Building

Part III- Linear Dynamic Time History Analysis

- ✓ A-LDTHA for 44 Story Sample RC Building
- ✓ B- LDTHA for 100 Story Sample RC Building

Part IV- Discussion and Findings, Topic; FEMA 356 and ATC 40 requirements are then used to assess their seismic performance.

- ✓ Part -I Nonlinear Static Analysis (Push Over Analysis)
- ✓ Part -II Nonlinear Time History Analysis (NLTHA)

- › Instead of solely relying on Ethiopia's current seismic hazard map or global hazard maps, why not consider a performance-based approach? A performance-based approach allows engineers to design buildings to specified performance levels (IO, LS, CP) even without a reliable seismic hazard map. This approach is akin to a miracle for countries like Ethiopia.
- › This study presents an evaluation of the seismic performance of 3D-modeled reinforced concrete (RC) structures designed in compliance with Ethiopian ES8-15 standards, complied with seismic code recommendations outlined in Eurocode 8-2004 (based on EN1998-1)
- › This analysis results then shall give us that whether our buildings met the required performance levels or not.
- › In this research, linear and nonlinear models of two samples, specifically 44-story and 100-story buildings, were employed. These models are situated in Addis Ababa, the capital city of Ethiopia.

Results and Discussion

ES8-15 standards, complied with seismic code recommendations outlined in Eurocode 8-2004 (based on EN1998-1).

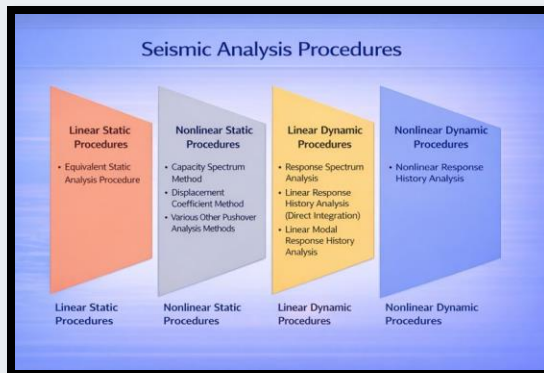


Fig 6- Sample 100 and 44 Story Analysis Procedure

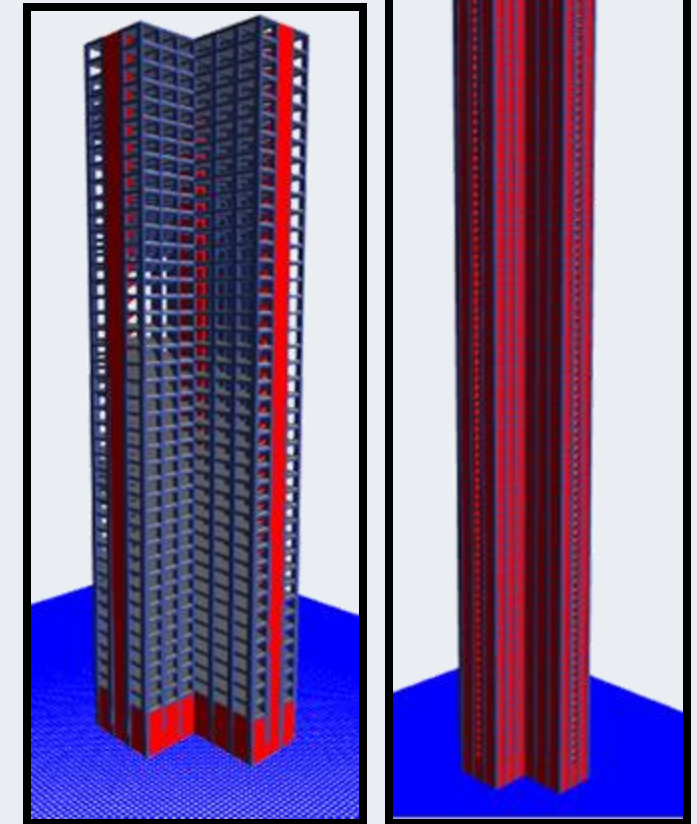
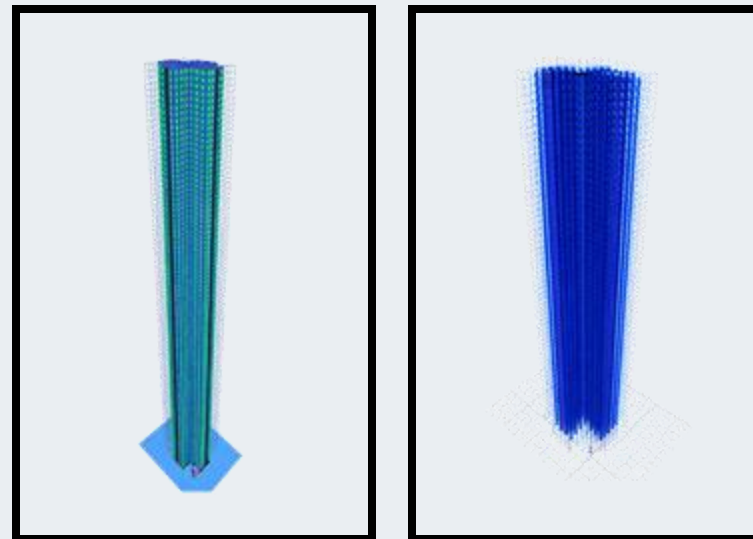
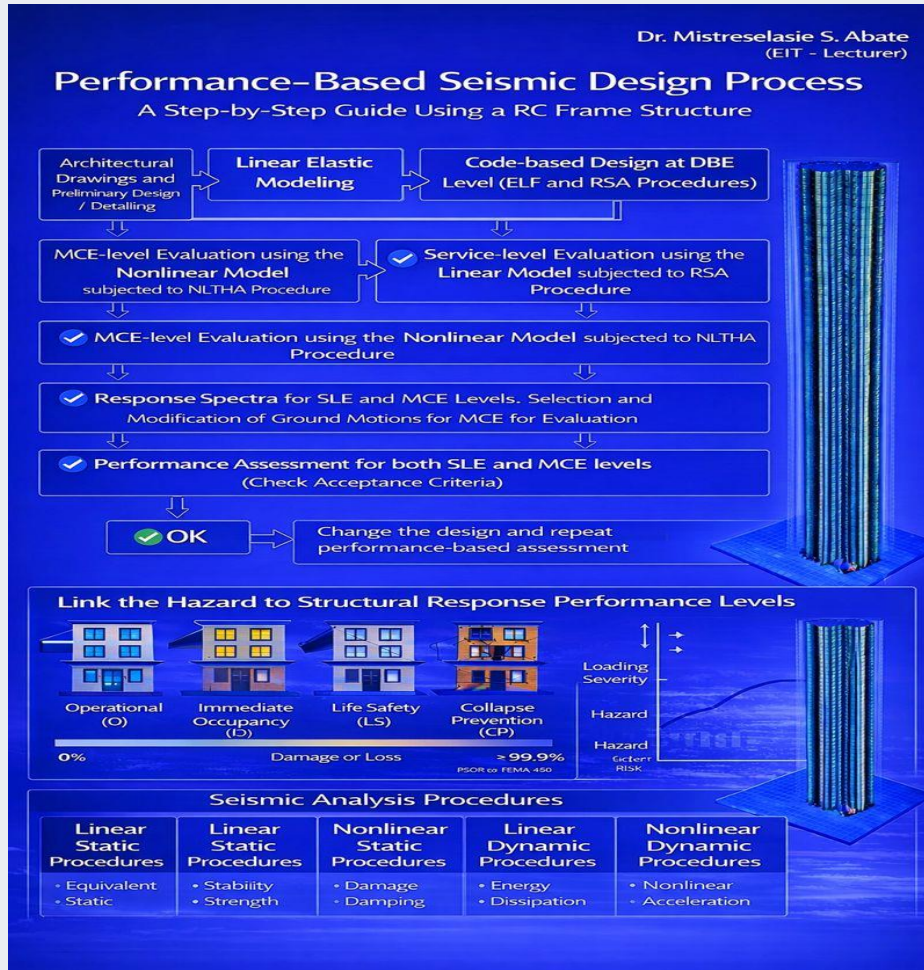


Fig 7- Sample 100 and 44 Story Linear & Non-Linear 3D Modelling

Remark : The result of analysis and design of Sample G+ 44 and G+100 Linear & Nonlinear Structure modeled as per ES EN 2015 code shall be compared with our new PBD proposed analysis and design method.

PEER GROUND Motion Data NGA West-2.



No	EQ	Year	Recording Station No.(RSN)	Mag	Vs30(m/s)	PGA(g)	Mechanism	Spectral Ordinate
1	"Imperial Valley-06"-US	1979	164	6.53	471.53	0.21	strike slip	SRSS
2	"Landers"-US	1992	881	7.28	396.41	0.21	strike slip	SRSS
3	"Mammoth Lakes-01"-US	1980	230	6.06	382.12	0.42	Normal Oblique	SRSS
4	"Landers"-US	1992	3757	7.28	367.84	0.13	strike slip	SRSS
5	"Loma Prieta"-US	1989	802	6.93	380.89	0.51	Reverse Oblique	SRSS
6	"Landers"-US	1992	3759	7.28	425.02	0.12	strike slip	SRSS
7	"Landers"-US	1992	832	7.28	382.93	0.089	strike slip	SRSS
8	"Chuetsu-oki_Japan"	2007	5274	6.8	430.71	0.13	Reverse	SRSS
9	"Northridge-01"-US	1994	1004	6.69	380.06	0.75	Reverse	SRSS
10	"Chi-Chi_Taiwan"	1999	1513	7.62	363.99	0.59	Reverse Oblique	SRSS
11	"Parkfield-02_CA"	2004	4070	6	378.99	0.62	strike slip	SRSS

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Scaling and Matching process of the extracted EQ data as per target response spectrum

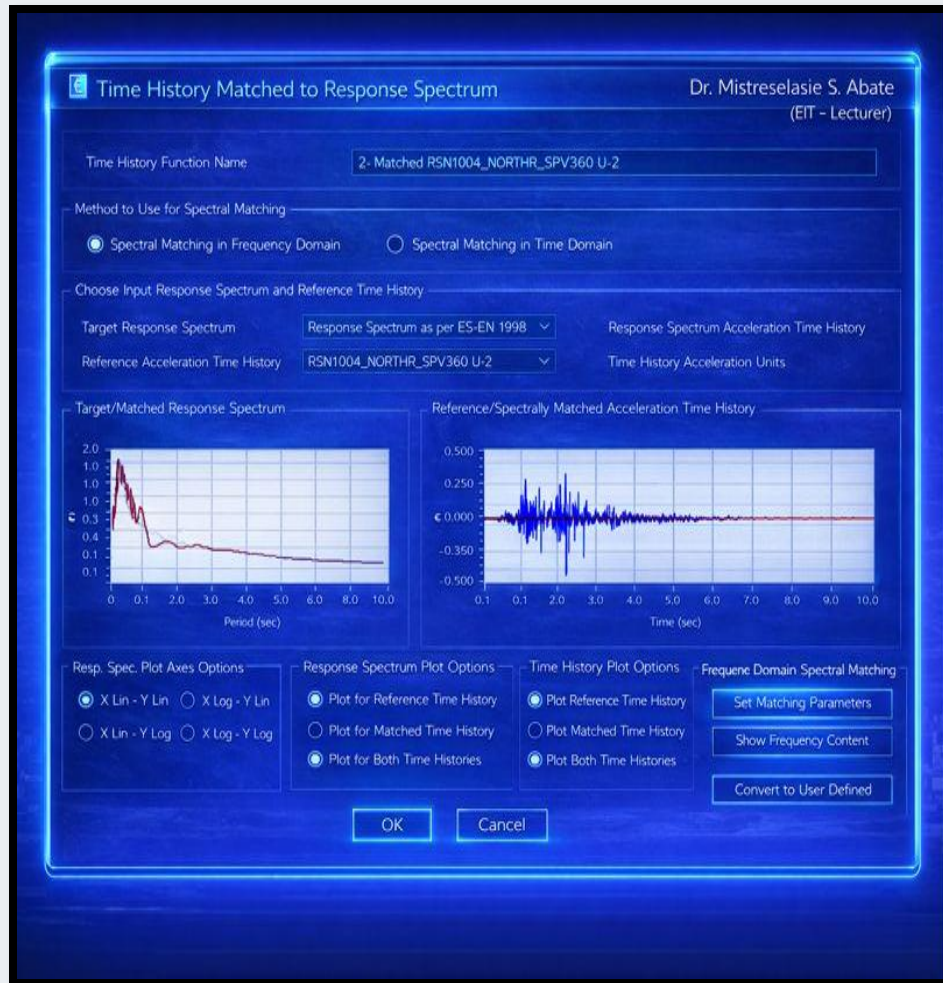


Figure 10 - Matched RSN1004_NORTHR_SPV360 U-2

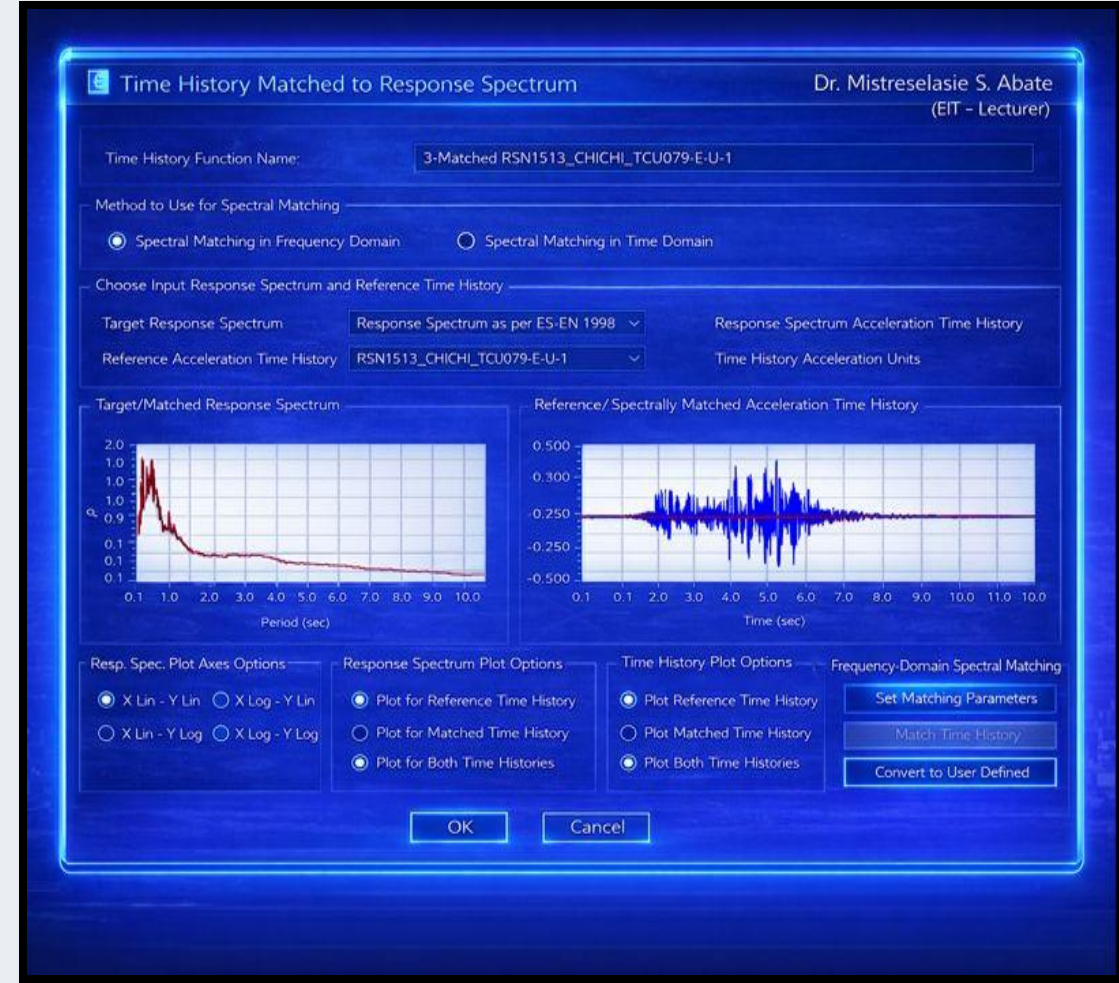


Figure 11 - Matched RSN1513_CHICHI_TCU079-E-U-1

PBD VS BUILDING CODES

Performance-Based Seismic Design

Dr. Mistreselasie S. Abate
(EIT : Lecturer)

Building Codes | Prescriptive

- Specify fixed criteria and procedures that construction must adhere to.
- Engineers don't explicitly assess the structure's real performance under seismic forces, only its compliance with the building code.
- Restricts the use of advanced structural systems.
- Leads engineers to assume competence based solely on code compliance.

PBD | Flexibility & Innovation

- Addresses the limitations of prescriptive codes by making seismic performance objectives **explicit**.
- Ensures greater **building safety** through detailed evaluation of structural performance across various earthquake intensities.
- Allows **exceptions** to standard code requirements based on thorough performance analysis.
- Encourages the use of innovative and cost-effective seismic and structural systems.

Objectives of Performance-Based Design (PBD)

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Enhance Structural Performance

- Improved serviceability, safety and reliability
- Explicit check on various performance indicators

Improve Cost Effectiveness

- Achieve efficient use of materials, resources and time
- Direct reduction cost through reduction of structural material quantities

Objectives to be achieved through

- Better structural system selection and its proportions
- Use of advanced design methodologies and tools

Performance-Based Seismic Design Analysis Workflow

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Analyzing Linear Elastic Model for Code Based Design Loading

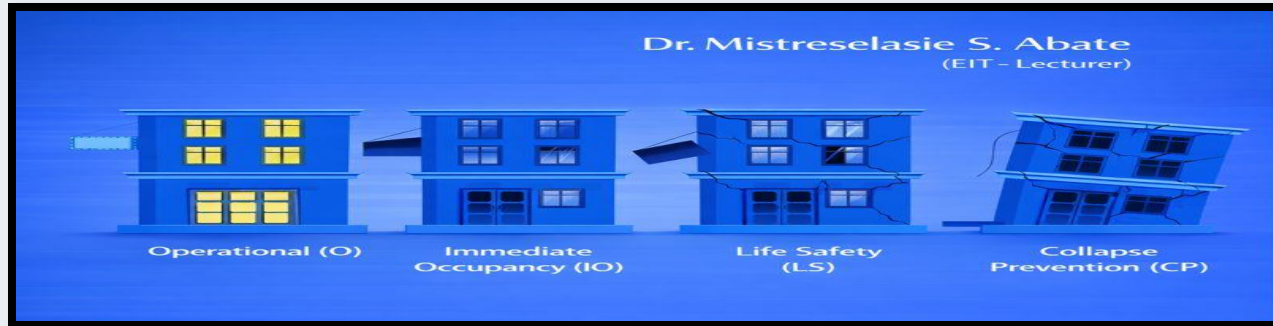
Formulation & Analysis of Nonlinear Model of Real Building

Results Extractions and Processing

Interpretation of Results for Decision Making

[Source: Moehle, J. P. (2014). Seismic Design of Reinforced Concrete Buildings. McGraw-Hill]

Nonlinear Dynamic Modelling Background Knowledge



Collapse Prevention Level

- Extensive (near complete) structural and non-structural damage
- Significant potential for injury but not wide scale loss of life
- Extended loss of use
- Repair may not be practical
- Loss >> 30%

Performance
levels Based on
FEMA 451 B

Operational Level

- Negligible structural and non-structural damage
- Occupants are safe during event
- Utilities are available
- acility is available for immediate re-use (some cleanup required)
- Loss < 5% of replacement value

Immediate Occupancy Level

- Negligible structural damage
- Occupants safe during event
- Minor non-structural damage
- Building is safe to occupy but may not function
- Limited interruption of operations
- Losses < 15%

Life Safety Level

- Significant structural damage
- Some injuries may occur
- Extensive non-structural damage
- Building not safe for re-occupancy until repaired
- Losses < 30%



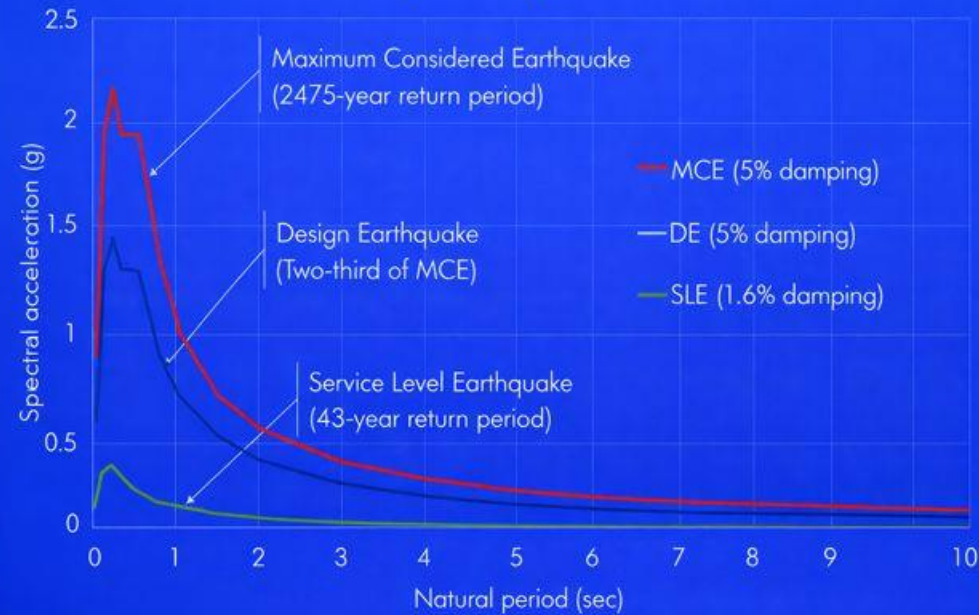
Level of Earthquake	Seismic Performance Objective
Frequent/Service (SLE): 50% probability of exceedance in 30 years (43-year return period)	Serviceability: Structure to remain essentially elastic with minor damage to structural and non-structural elements
Design Basis Earthquake (DBE): 10% probability of exceedance in 50 years (475-year return period)	Code Level: Moderate structural damage; extensive repairs may be required
Maximum Considered Earthquake (MCE): 2% probability of exceedance in 50 years (2475 year return period)	Collapse Prevention: Extensive structural damage; repairs are required and may not be economically feasible.

Figure 15 -Performance levels O, IO, LS, CP

[Source: PEER (2010). Guidelines for Performance-Based Seismic Design of Tall Buildings]

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Response spectra



Dr. Mistreselasie S. Abate
(EIT - Lecturer)

The Relationship Between Return Period and Probability

The return period T is calculated using the following formula:

$$P = 1 - e^{-t/T}$$

Example: Find Return Period for 50% in 30 Years

Given:

- $P = 0.50$,
- $t = 30$ years.

Use the formula:

$$0.5 = 1 - e^{-30/T}$$

Solve:

$$e^{-30/T} = 0.5 \rightarrow -\frac{30}{T} = \ln(0.5) \rightarrow T = \frac{30}{-\ln(0.5)} \approx 43.3 \text{ years}$$

✓ So a 50% chance in 30 years $\approx$ 43-year return period.

Figure 16 – RS at Performance levels MCE, DBE & SLE

[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]

Dr. Mistreselasie S. Abate
Seismic Performance (EIT - Lecturer)

Level of Earthquake

Service Level Earthquake (SLE)

- 50% probability of exceedance in 30 years
- 43-year return period
- Generally, 1.5% to 2.5% of structural damping

Maximum Considered Earthquake (MCE)

- 2% probability of exceedance in 50
- 2475-year return period

Serviceability

- Structure to remain essentially elastic with minor yielding of structural elements, minor cracking of concrete, and minor damage to non-structural elements.
- **Collapse Prevention:** Structure has a low probability of collapse which will be stable, predictable response to MCER shaking at response levels which do not result in loss of gravity load carrying capacity or substantial degradation of lateral resistance. Extensive structural damage may occur; repairs to structural and non-structural systems are required and may not be economically feasible.

Summary Table

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Term	Full Name	Purpose	Return Period (approx.)	Performance Target
SLE	Service Level Earthquake	Functionality	43 years	Immediate Occupancy
DBE	Design Basis Earthquake	Life Safety	475 years	No Collapse, Limited Damage
MCE	Maximum Considered Earthquake	Collapse Prevention	2,475 years	Prevent Total Collapse

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

1. MCE – Maximum Considered Earthquake

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

- **Definition:** The most severe earthquake effects considered by building codes for design purposes.
- **Purpose:** To prevent collapse of structures during the worst credible earthquake.
- **Performance Goal:** Collapse prevention.
- **Return Period:** Usually corresponds to an event with a return period of 2,475 years (probability of 2% in 50 years).
- **Remark:** Think of MCE as the upper limit earthquake the building must survive without collapsing.

2. DBE – Design Basis Earthquake

- **Definition:** The earthquake level for which a building is designed under regular code-based procedures.
- **Purpose:** To ensure life safety.
- **Performance Goal:** The building may be damaged, but should not cause loss of life.
- **Return Period:** Typically 475 years (probability of exceedance = 10% in 50 years).

3. SLE – Serviceability Limit State (or Service Level Earthquake)

- **Definition:** A smaller, more frequent earthquake.
- **Purpose:** To ensure the building remains fully functional with minimal damage.
- **Performance Goal:** Immediate occupancy or continued use.
- **Remark:** SLE is used when the goal is no disruption of services, especially for hospitals, emergency centers, etc.

[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]

PBD Procedure

Dr. Mistreselasie S. Abate
(EIT - Lecturer)



SLE Evaluation

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

Modeling and Analysis

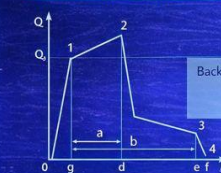
- Use linear model and response spectrum analysis.
- Accidental eccentricities are not considered in serviceability evaluation.
- Critical damping (Generally 1.5 – 2.5%)
- Load combinations
 - $1.0D + 1.0L_{exp} = 1.0ESLEX \pm 0.3ESLEY$
 - $1.0D + 1.0L_{exp} \pm 0.3ESLEX = 1.0ESLEY$
 - L_{exp} = Expected service live load which is 25% of unreduced live load.
- R, Ω, ρ , and C_d are all taken as unity.

Acceptance Criteria

- Member strength
 - $D/C \leq 1.5$ (Deformation-controlled)
 - $D/C \leq 0.7$ (Force-controlled)
- Strength calculation
 - Use expected material properties
 - Strength reduction factor = 1
- Story drift $\leq 0.5\%$

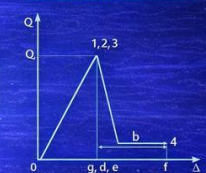
Classification of Components

Deformation-controlled actions



- Reliable inelastic deformation capacity with gradual strength decay
- Model with nonlinear elements

Force-controlled actions



- Concerns for either sudden failure modes and/or inelastic response that cannot be modeled reliably; or
- Conscious design decision motivated by concerns for structural safety or other reasons
- Model with elastic elements

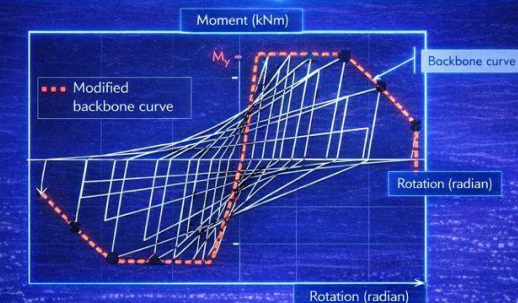
MCE Evaluation

Dr. Mistreselasie S. Abate
(EIT - Lecturer)

- Use nonlinear model and nonlinear response history analysis.
- Eleven pairs of site-specific ground motions are used.
- Generally, 2.4% of constant modal damping is used with small fraction of Rayleigh damping for un-modeled energy dissipation.
- Average of demands from eleven ground motions approach is used.

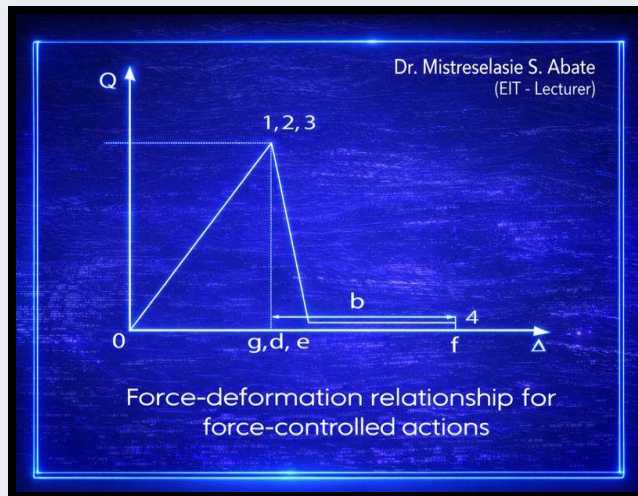
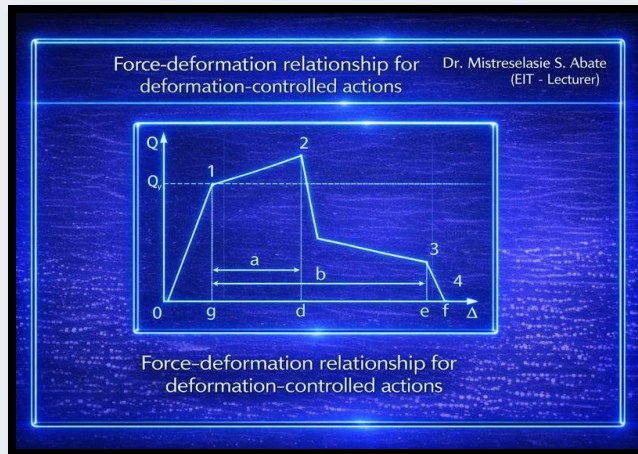
Nonlinear Response and Modeling

Dr. Mistreselasie S. Abate
(EIT - Lecturer)



[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]

Deformation controlled Actions & Force controlled Actions



- Behavior is ductile and reliable inelastic deformations can be reached with no substantial strength loss.
- Results are checked for mean value of demand from eleven sets of ground motion records.
- Behavior is more brittle and reliable inelastic deformations cannot be reached.
- Critical action
- Failure of which is likely to lead to partial or total structural collapse.
- Ordinary action
- Failure of which is either unlikely to lead to structural collapse or might lead to local collapse comprising not more than one bay in a single story.

Main Considerations on which Items to Check for Performance?

- Modal analysis results
- Base shear and Base Moment comparisons
- Story Shear and Story Moment comparison
- Building sway and displacement
- Story drift
- Shear wall axial strains
- Shear wall shear capacity
- Frame member rotations, D/C ratios
- Frame member shear strength and D/C ratios
- Coupling beams, in detail
- Slab diaphragm
- Damage overview, weak points etc.

Figure 17 - Deformation controlled Actions & Force controlled Actions

[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]

Typical PBD Review Objectives

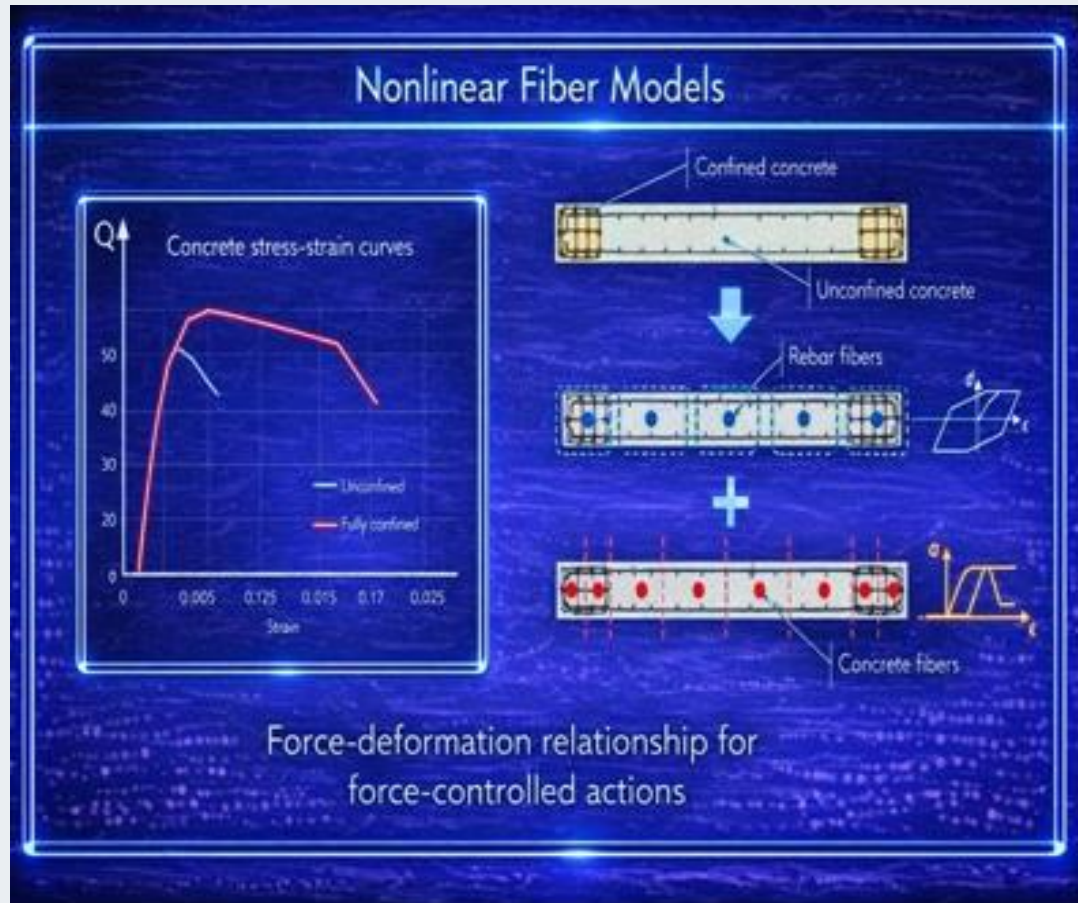
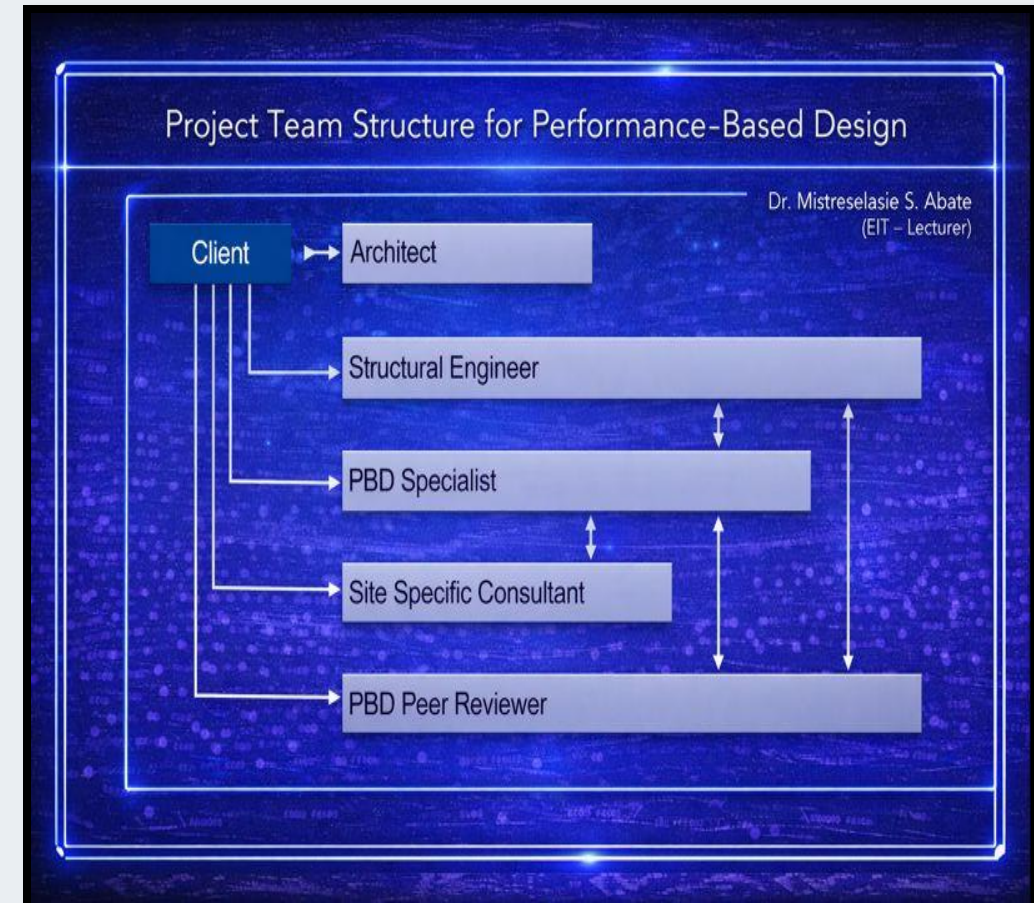


Figure 18 - Deformation controlled Actions & Force controlled Actions

[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]



Performance Based Design Process & Objectives

[Source: ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

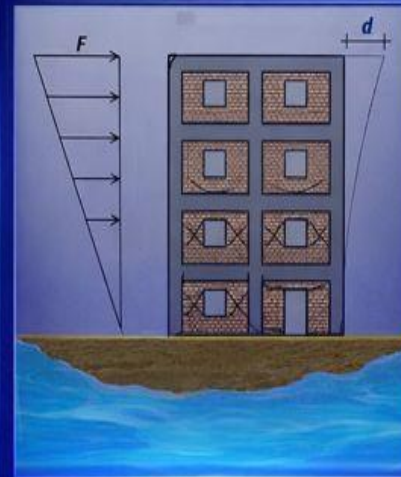
MCE Performance Criteria (ASCE 41-17) Dr. Mistreselasie S. Abate (EIT - Lecturer)

Item	Value
Peak transient drift	Maximum of mean values shall not exceed 3%.
Residual drift	Maximum drift shall not exceed 4.5%. Maximum of mean values shall not exceed 1%.
Coupling beam inelastic rotation	≤ASCE 41-17 limits
Column (Axial-flexural interaction and shear)	Flexural rotation ≤ASCE 41-17 limits Remain elastic for shear response.
Shear wall reinforcement axial strain	≤0.05 in tension and ≤0.02 in compression
Shear wall concrete axial compressive strain	Unconfined concrete ≤ 0.003. Intermediately confined concrete ≤ 0.004 + 0.1 ρ f _l Fully confined concrete ≤ 0.015
Shear wall shear	Remain elastic.
Girder inelastic rotation	≤ASCE 41-17 limits
Girders shear	Remain elastic.
Mat foundation (Flexure and shear)	Remain elastic.
Diaphragm (In-plane response)	Remain elastic.
Piles (Axial-flexural interaction and shear)	Remain elastic.

PROBABILISTIC ASSESSEMENT FRAMEWORK

Dr. Mistreselasie S. Abate
(EIT-Lecturer)

STEP - 3 DAMAGE ANALYSIS



Performance Level		DESCRIPTION OF DAMAGE STATE		
		Slight	Moderate	Extensive
		Immediate Occupancy	Life Safety (LS)	Collapse Prevention (CP)
Curtailed Frames	Primary	Minor hairline cracking; limited yielding possible at a few locations; no crushing (strains below 0.003)	Extensive damage to beams; hinge formation in shear cracking (<1/8" width) for ductile columns; minor spalling in columns; joint cracks < 1/8" wide.	Extensive cracking and hinge formation in ductile elements; limited concrete and splice failure in some nonductile elements; severe damage in short columns.
	Secondary	Minor spalling in a few places in ductile columns and beams; flexural cracking in joints. < 1/16" width*	Extensive cracking and hinge formation in ductile elements; limited cracking and or spalling in columns; severe damage in short columns.	Extensive cracking and hinge formation in ductile elements; limited concrete and splice failure in some nonductile elements; severe damage in short columns.
Unreinforced Masonry Infill	Primary	Minor (<1/16" width) cracking of masonry infills and veneers,	Extensive cracking and some crushing but wall remains standing; extensive spalling crushing of veneer at corners of openings.	Extensive cracking and crushing; some walls dislodge.
	Secondary	minor spalling in veneers at a few corner openings.		Extensive cracking and crushing; some walls dislodge.
	Secondary	Same as primary.	Same as primary.	Same as primary.

References: ASCE 41-06; ASCE 41-13; FEMA 356; ATC40

[Source: Chopra, A. K. (2023). Dynamics of Structures. Pearson]

PROBABILISTIC ASSESSEMENT FRAMEWORK

Dr. Mistreselasie S. Abate
(EIT-Lecturer)

STEP - 3 DAMAGE QUANTIFICATION

DAMAGE QUANTIFICATION					
Damage State		Slight	Moderate	Extensive	Complete
		Slight	Moderate	Extensive	Complete
Vision 2000 (SEAOC 1995); ATC-58-2 (ATC 2003)	Overall Building Damage	ID < 0.5%	0.5% < ID < 1.5%	1.5% < ID < 2.5%	ID > 2.5%
		Transient	ID < 0.5%	ID < 0.5%	ID > 2.5%
FEMA-356 (ASCE 2000); ASCE/SEI 41-06 (ASCE 2007); ATC-58-2 (ATC 2003);	Concrete Frame Elements	Transient	ID = 1%	ID = 2%	ID > 25%
		Transient	ID = 1%	ID = 2%	ID > 4%
		Permanent	ID = 1%	ID = 2%	ID > 25%
FEMA-356 (ASCE 2000); ASCE/SEI 41-06 (ASCE 2007); ATC-58-2 (ATC 2003);	Concrete Frame Elements	Transient	ID = 1%	ID = 2%	ID > 2.5%
		Transient	ID = 1%	ID = 1%	ID > 2.5%
	Unreinforced Masonry Infill Wall Elements	Transient	ID = 0.1%	ID = 0.5%	ID > 0.6%
		Permanent	ID = 0.3%	ID = 0.4%	ID = 0.6%

Vision 2000 (SEAOC 1995); ATC-58-2 (ATC 2003)
FEMA-356 (ASCE 2000); ASCE/SEI 41-06 (ASCE 2007); ATC-58-2 (ATC 2003)

ASCE/SEI 41-17, Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures-Reinforced Concrete Beams.

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

Conditions	Modeling Parameters ^a			Acceptance Criteria ^a		
	Plastic Rotation Angle (radians)		Residual Strength Ratio	Plastic Rotation Angle (radians)		
				Performance Level		
	<i>a</i>	<i>b</i>	<i>c</i>	IO	LS	CP
Condition i. Beams controlled by flexure ^b						
$\frac{V - V'}{V_{bal}}$	Transverse reinforcement ^c	$\frac{V'}{b_w d \sqrt{F_{cE}}}$				
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010
≤0.0	C	≥6 (0.5)	0.02	0.04	0.2	0.005
≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005
≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005
≥0.5	NC	≥6 (0.5)	0.005	0.01	0.2	0.0015
Condition ii. Beams controlled by shear ^b						
Stirrup spacing ≤ <i>d</i> /2			0.0030	0.02	0.2	0.0015
Stirrup spacing > <i>d</i> /2			0.0030	0.01	0.2	0.0015
Condition iii. Beams controlled by inadequate development or splicing along the span ^b						
Stirrup spacing ≤ <i>d</i> /2			0.0030	0.02	0.0	0.0015
Stirrup spacing > <i>d</i> /2			0.0030	0.01	0.0	0.0015
Condition iv. Beams controlled by inadequate embedment into beam–column joint ^b						
			0.015	0.03	0.2	0.01

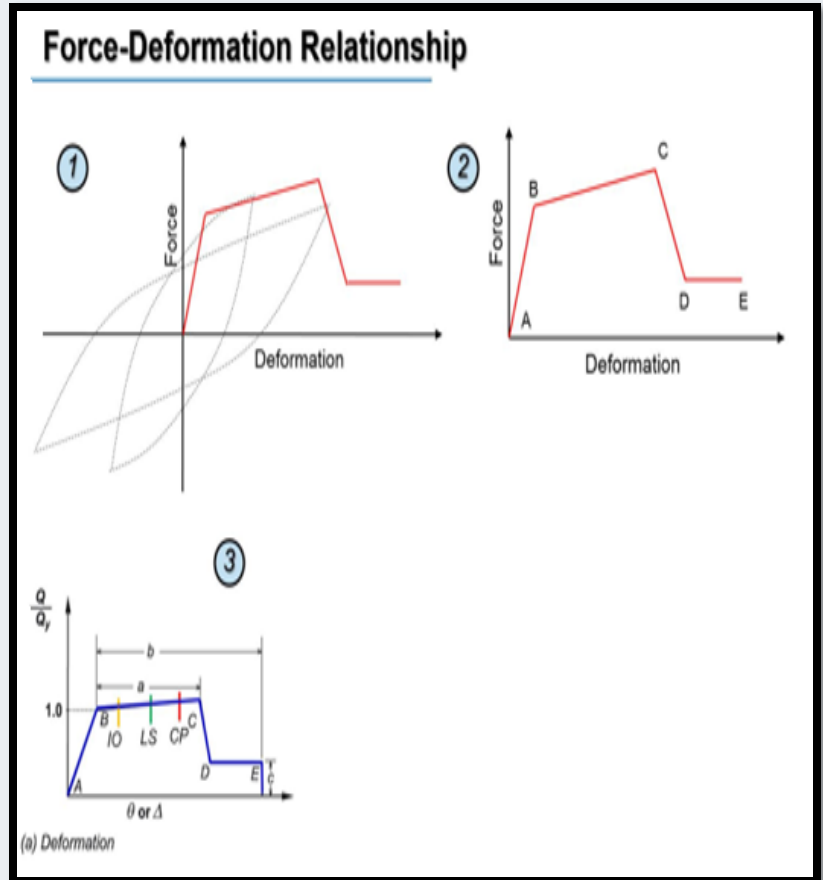
Note: f'_{CE} in lb/in.² (MPa) units.

^a Values between those listed in the table should be determined by linear interpolation.

^b Where more than one of conditions i, ii, iii, and iv occur for a given component, use the minimum appropriate numerical value from the table.

^c "C" and "NC" are abbreviations for conforming and nonconforming transverse reinforcement, respectively. Transverse reinforcement is conforming if, within the flexural plastic hinge region, hoops are spaced at $\leq d/3$, and if, for components of moderate and high ductility demand, the strength provided by the hoops (V_s) is at least 3/4 of the design shear. Otherwise, the transverse reinforcement is considered nonconforming.

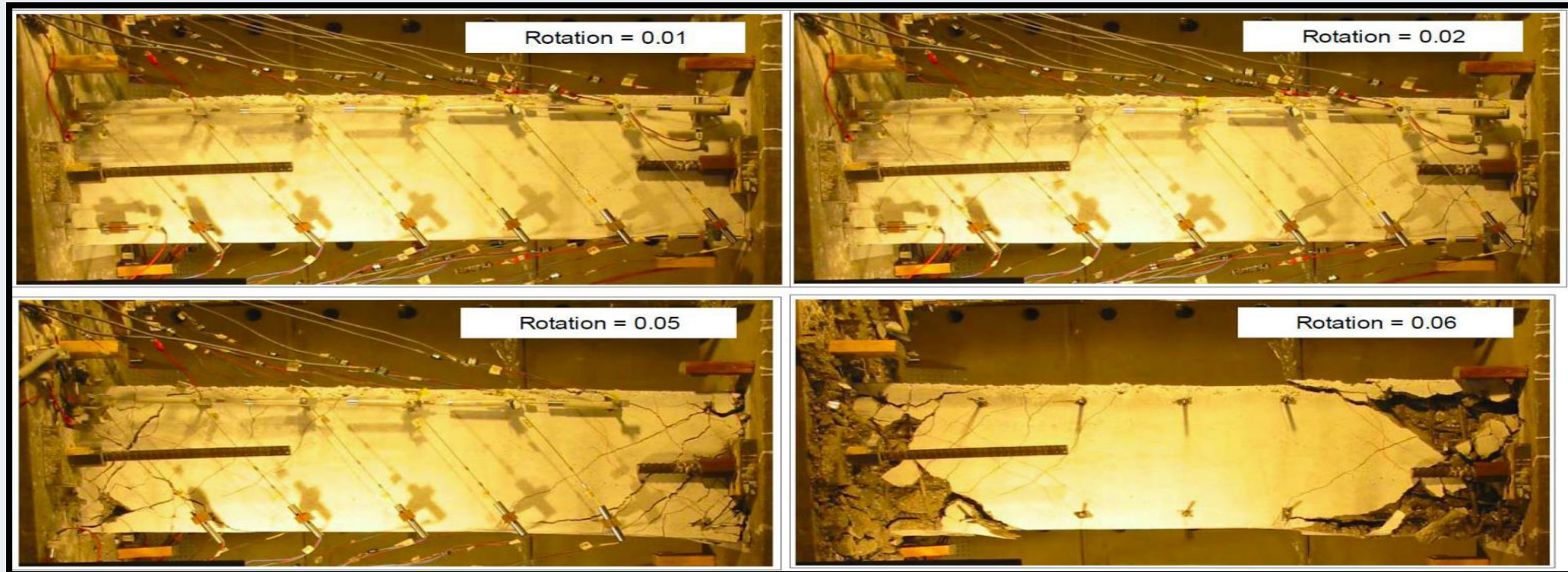
^d V is the design shear force from NSP or NDP.



[Source: ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

Hing performance level lab report Source: UCLA-SGEL Report 2009/06

PRACTICAL HING ROTATION LEVEL VS DAMAGE VISUALIZATION.



The methodology and objectives of Pushover Analysis in nonlinear mode.

- ✓ The Capacity Spectrum Method (ATC 40, FEMA 356)
- ✓ The Displacement Coefficient Method (ATC 40, FEMA 356)
- ✓ The FEMA 440 Improved NSPs (FEMA 440, ASCE 41 06/13)
- ✓ The Modal Pushover Analysis (MPA) Procedure
- ✓ The Uncoupled Modal Response History Analysis (UMRHA) Procedure

Figure 19-Hing performance level lab report Source: UCLA-SGEL Report 2009/06

[Source: ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

Hinge Assignment

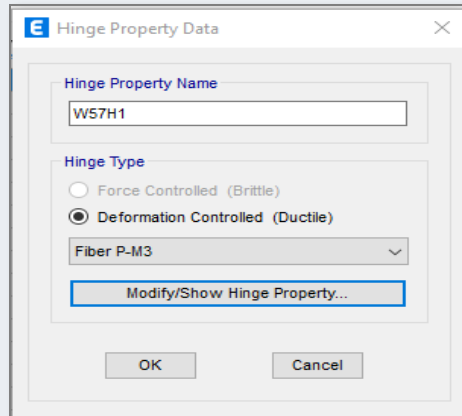


Figure 22-Fiber P-M3 Hinge for Wall Property Data

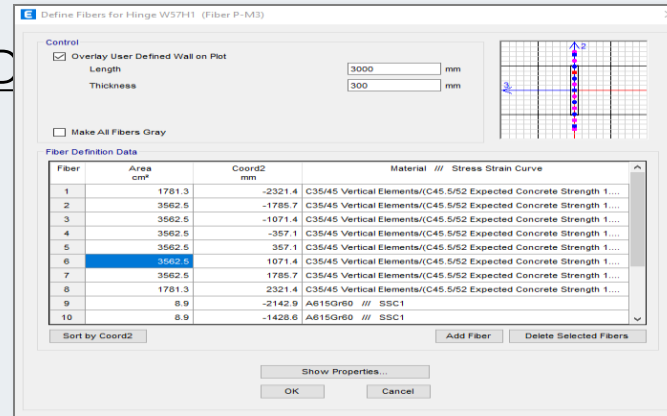


Figure 24-Fiber P-M3 Hinge for Wall Property Data

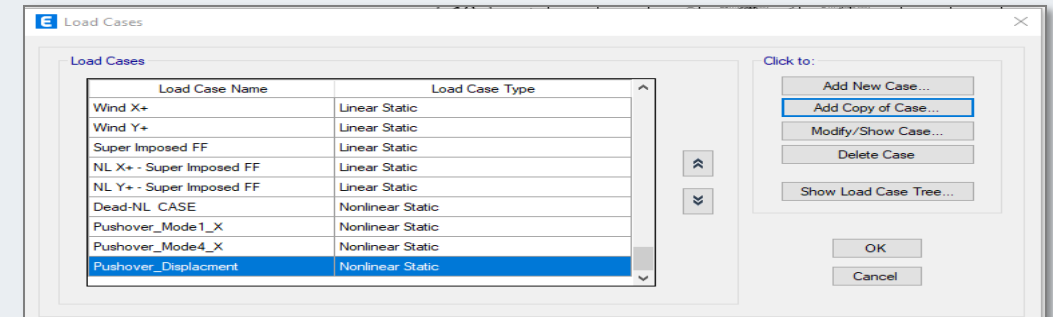


Figure 28-Pushover load case definition

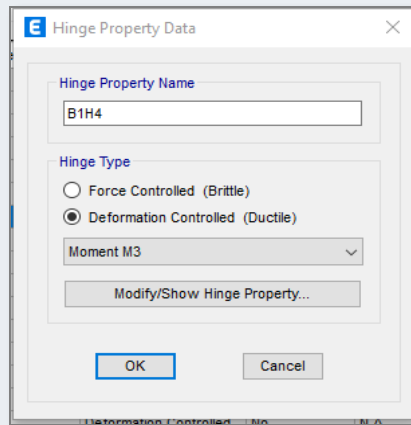


Figure 23-Concentrated plastic M3 hinges for Beam definition

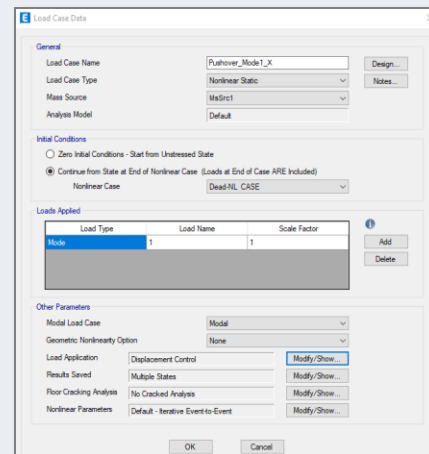


Figure 25-Load Case Pushover_Model1_X (1st Mode Shape)

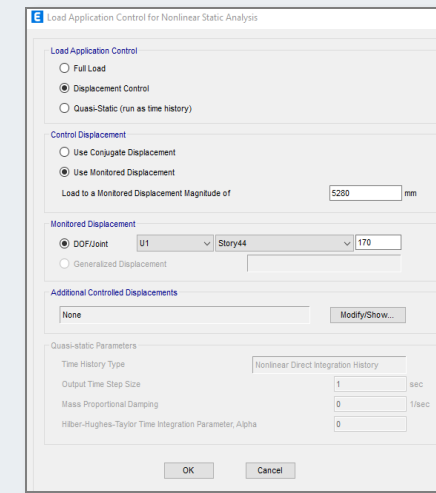


Figure 26-Monitored Displacement Magnitude of 4% of the Height of the building

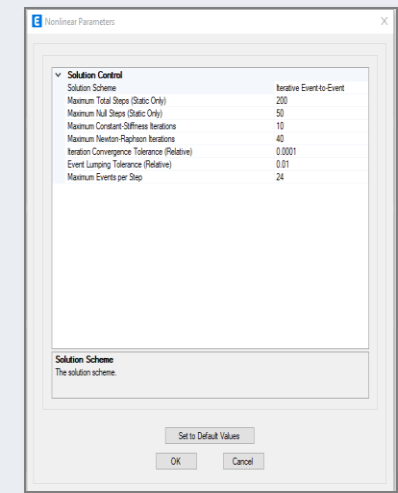


Figure 27-Nonlinear Parameters

Hinge Assignment

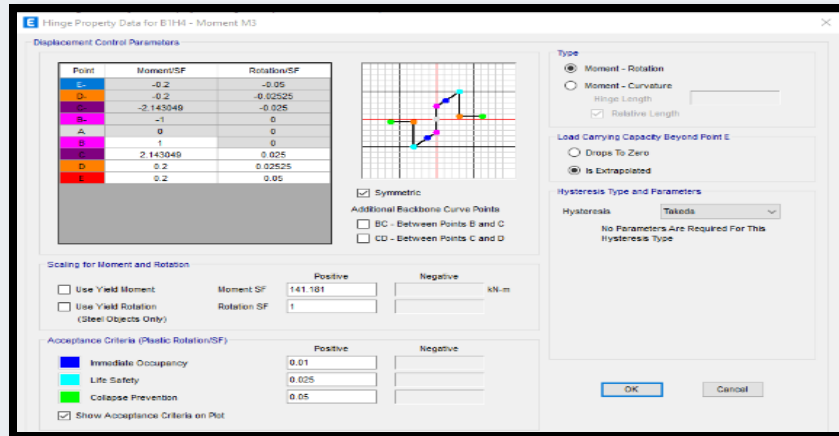


Figure 29-Concentrated plastic M3 hinges for Beam definition and acceptance criteria IO, LS, and CP levels as per ASCE 41-17.

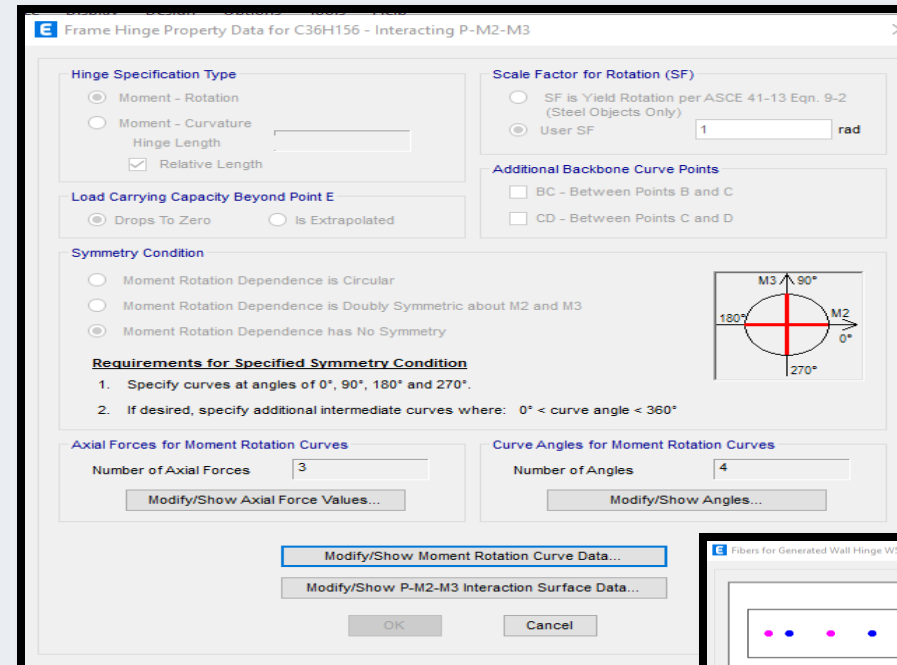


Figure 31-Concentrated plastic P-M2-M3 hinges for column definition and acceptance criteria IO, LS, and CP levels as per ASCE 41-17.

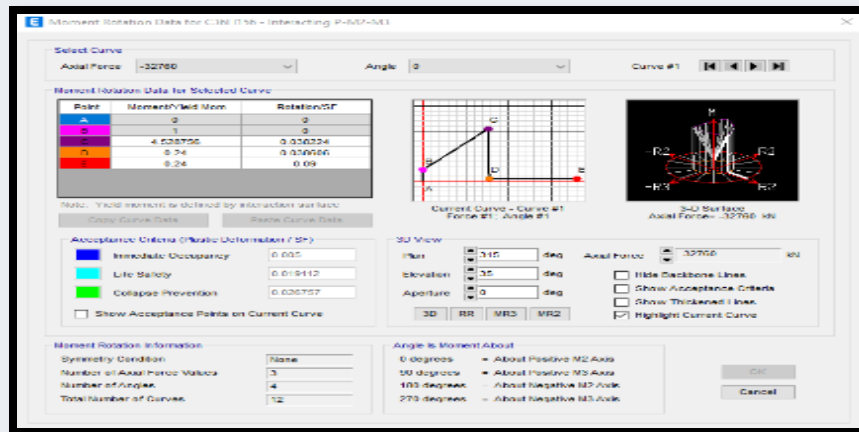


Figure 30--Concentrated plastic P-M2-M3 hinges for column definition and acceptance criteria IO, LS, and CP levels as per ASCE 41-17.

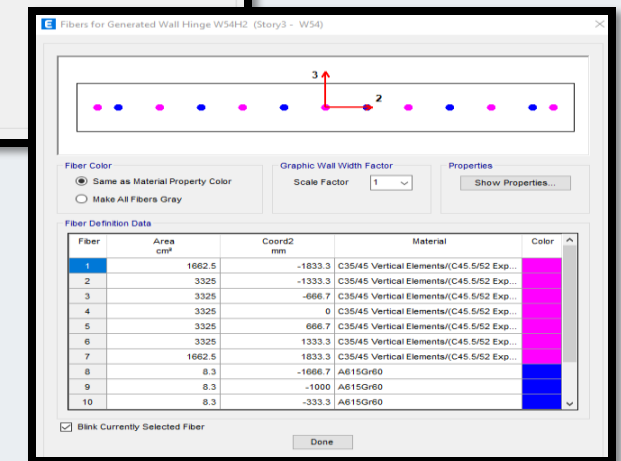
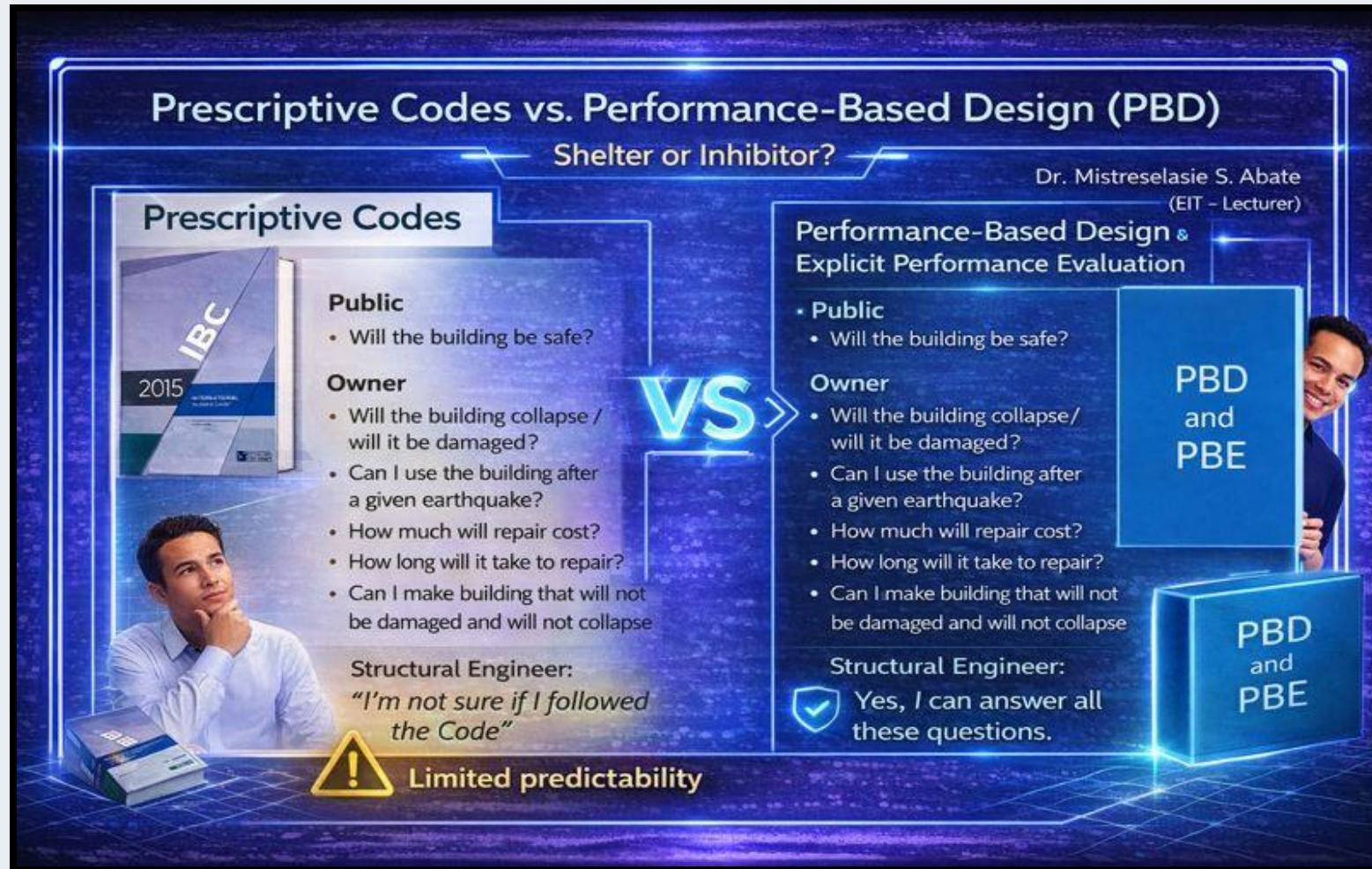


Figure 32- Fibers for Generated wall Hinges P-M3

This is the main reason why PBD and similar techniques are so important.

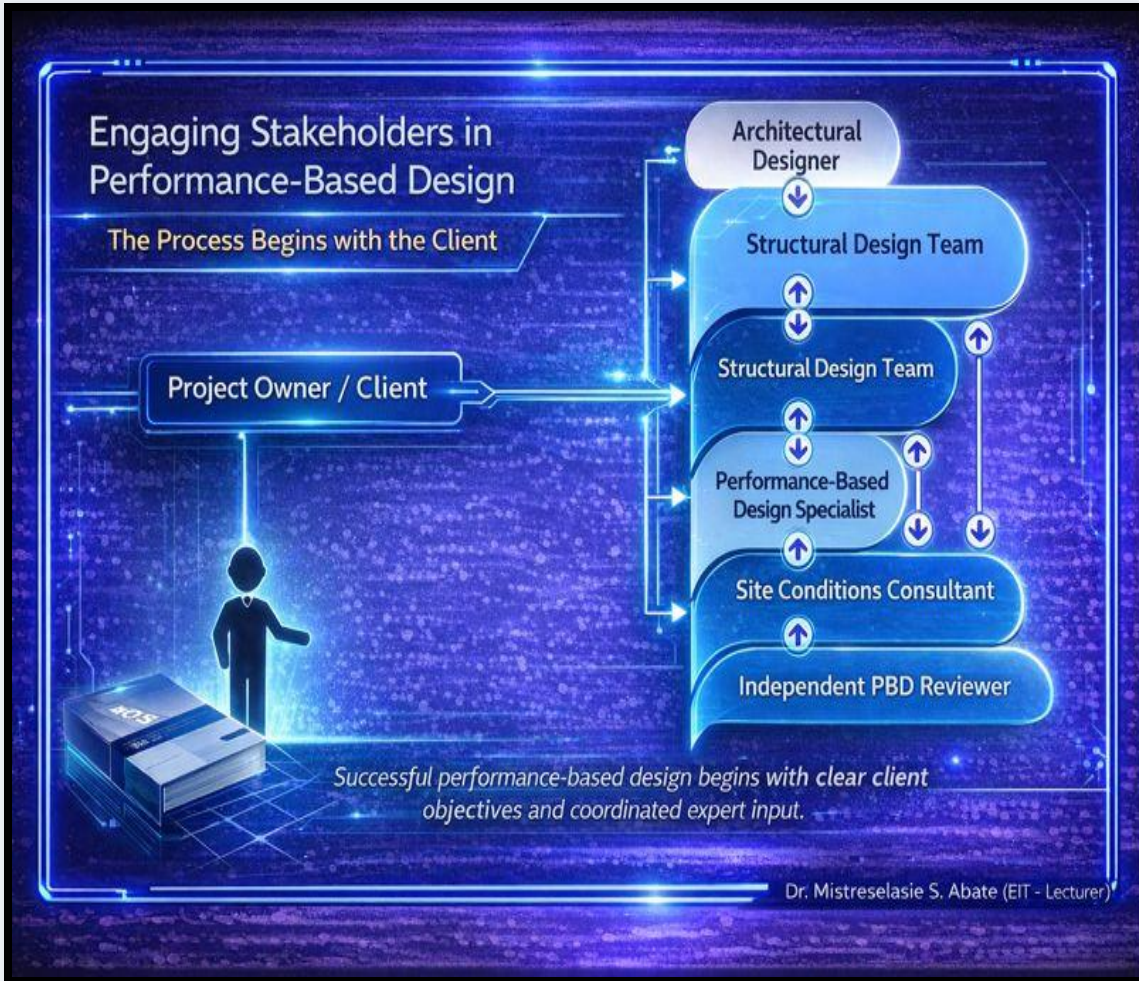


By shifting our paradigm from prescriptive code-based design to performance-based design and explicit performance evaluation, we can now answer all the critical questions. We now have clear, detailed knowledge and the necessary tools to address public concerns—questions that could not be fully answered under traditional code-based approaches.

This is the main reason why PBD and similar techniques are so important.

[Source: AIT, ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

*Now the problem is how to convince other people once we the engineers are convinced
how to convince the General public ?*

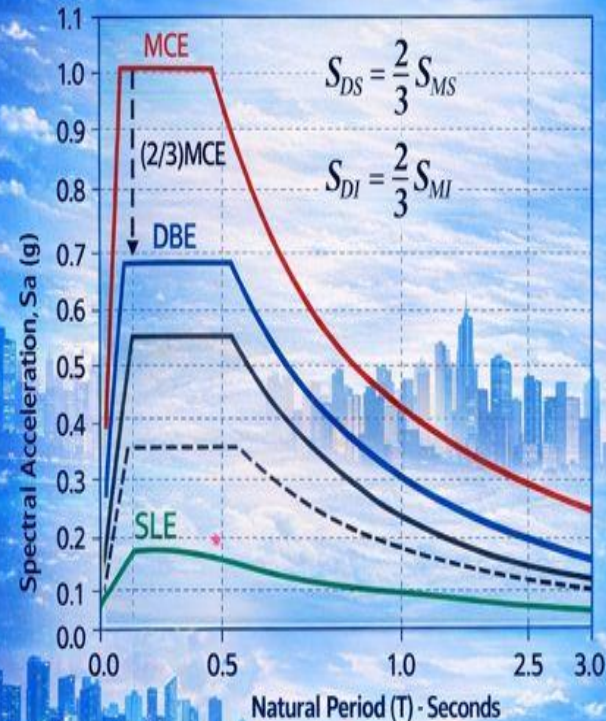


[Source: AIT, ASCE/SEI 41-17: Seismic Evaluation and Retrofit of Existing Buildings, 2017]

Sample Earthquake Levels

If a structure experiences a level of ground motion (MCE) 1.5 times the design level (DBE), the structure should have a low likelihood of collapse."

Response Spectra



— MCE-2500 — DBE-475 ---- BSE-2500
— BSE-475 - - - - SLE-43 - - - - SLE-43

Earthquake Levels

Maximum Considered Earthquake (MCE)

2% probability of exceedance in 50 years
~2,250-year return period

Design Basis Earthquake (DBE)

10% probability in 50 years
~475-year return period

Basic Safety Earthquake (BSE)

20% probability of exceedance in 50 years
~2,500-year return period

Service Level Earthquake (SLE)

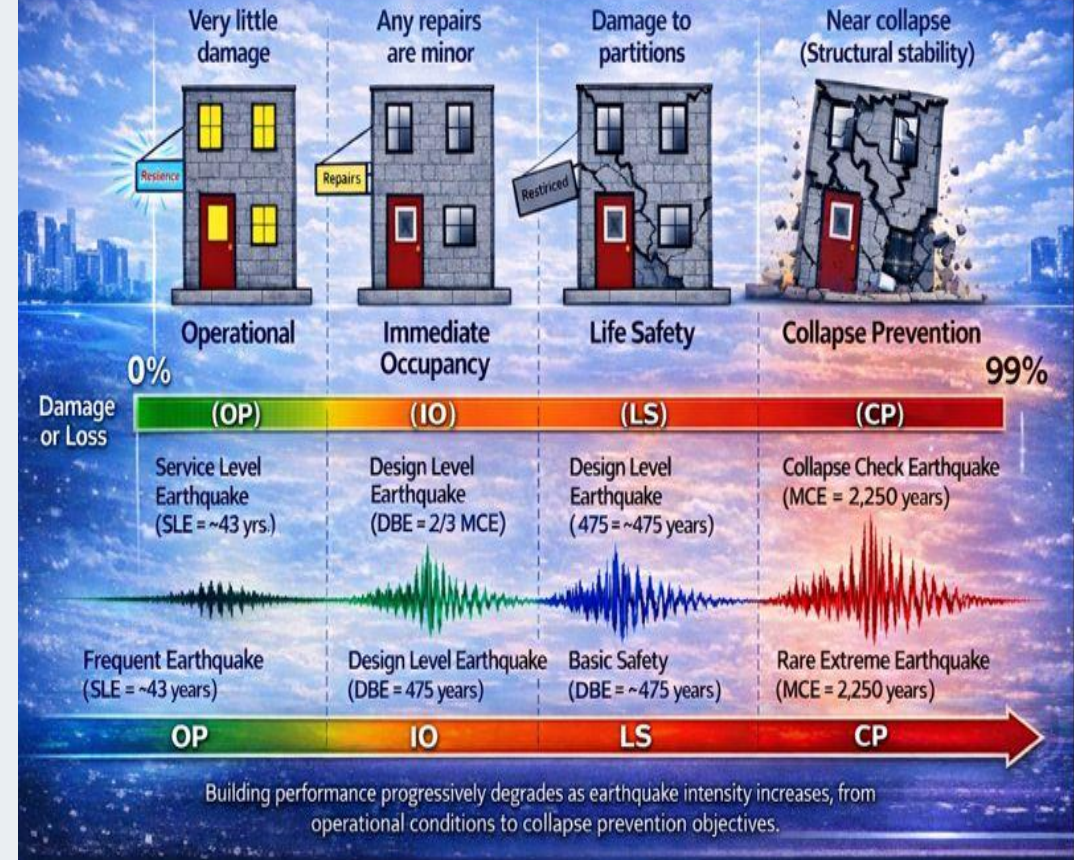
50% probability of exceedance in 30 years
~43-year return period

Why 2/3, 2,500 Years and not 10,000 years?

- An upper limit that would significantly increase construction costs without proportionate benefits.
- Economics: Considerations to balance between safety and cost.
- Ground motions with very high return periods have much greater uncertainty, making them unreliable for practical design.

Structural Performance Levels

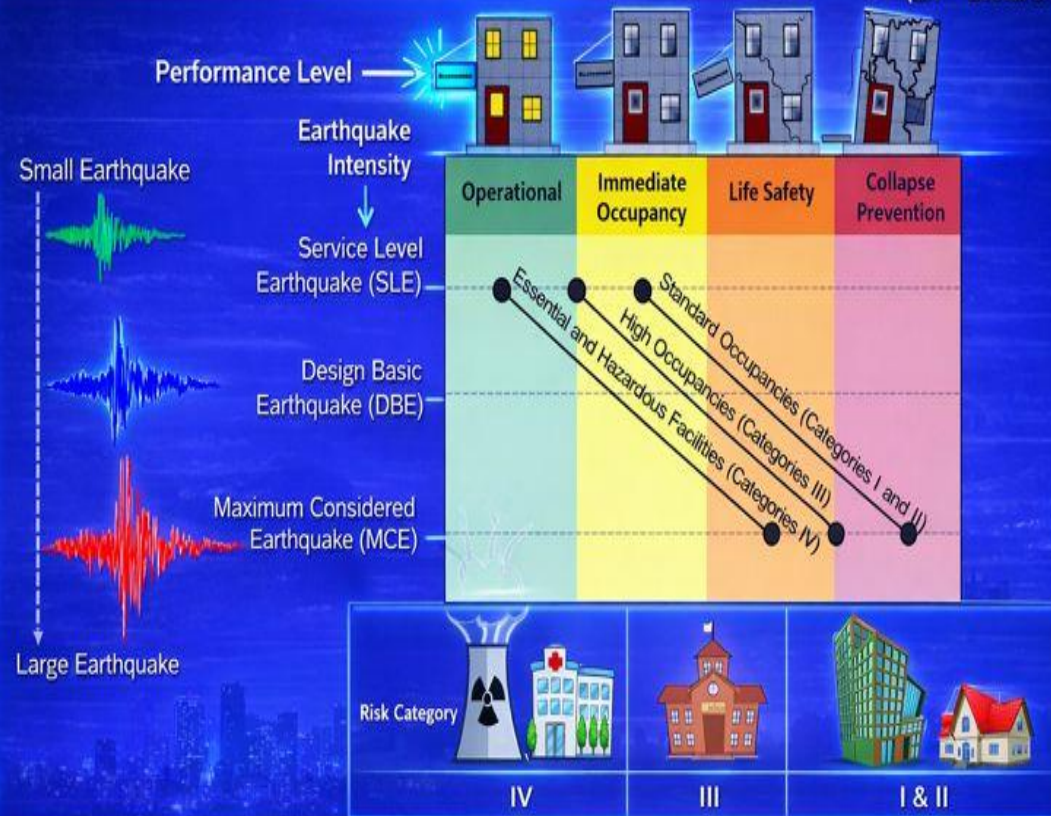
Dr. Mistreselias S. Abate (EIT - Lecturer)



Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Performance Level Concepts

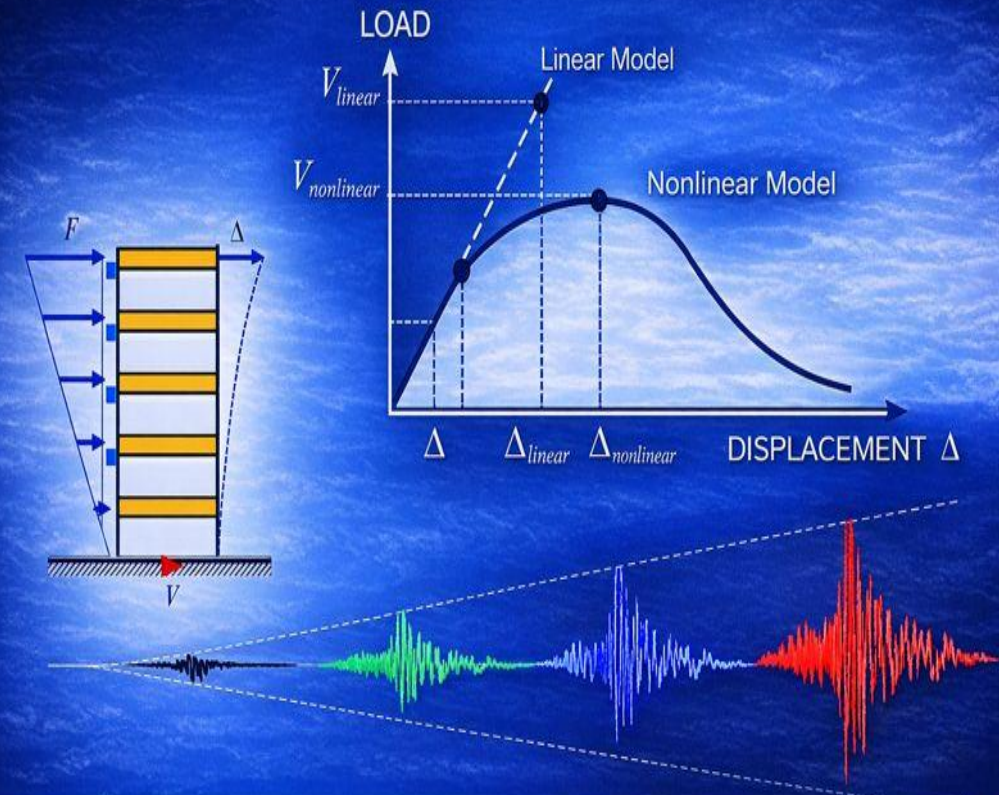
Dr. Mistreselasie S. Abate
(EIT – Lecturer)



Reference: ASCE 41-17; FEMA 356; ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT (Asian Institute of Technology).

Linear and Nonlinear analysis

Dr. Mistreselasie S. Abate (EIT -Lecturer)

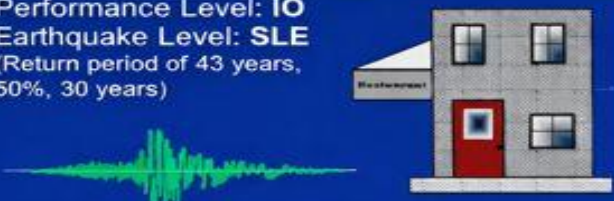


Dr. Mistreselasie S. Abate (EIT - Lecturer)

17

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

General Guidance on SLE and MCE Evaluation

Steps	Items	Serviceability Evaluation	Dr. Mistreselasie S. Abate (EIT-Lecturer)
Design Criteria (LATBSDC 2020)	Performance objective	Performance Level: IO Earthquake Level: SLE (Return period of 43 years, 50%, 30 years) 	Performance Level: CP Earthquake Level: MCE (Return period of 2,475 years, 2%, 50 years) 
Modeling	Material	Expected strengths	Expected strengths
	Model	Linear or Nonlinear	Nonlinear
	Damping	$\zeta = 0.36/\sqrt{H} \leq 0.05$ (5.0%), H in ft	2.5 - 5.0%
Analysis	Analysis & Load combinations	(a) Response spectrum $1.0DL + 0.25 LL + 1.0 E_x + 0.3 E_y$ $1.0DL + 0.25 LL + 0.3 E_x + 1.0 E_y$	Nonlinear time-history analysis $1.0DL + 0.25 LL \pm 1.0 E$ - 11 pairs of ground motions (Mean value)
		(b) Linear or Nonlinear time-history analysis $1.0DL + 0.25 LL \pm 1.0 E$ - 3 pairs of ground motions (LHA, Max) - 7 pairs of ground motions (NRHA, Mean)	
Design (Evaluation)	Load & Reduction factors	$F_u = 1.0 \times F$ $\phi = 1.0$	Force controlled action: $F_u = (1.3-1.5) \times F$ Deformation controlled action: $F_u = 1.0 \times F$ $\phi = \text{ACI 318}$
	Evaluation, DCR = D/C	(a) Response spectrum - Deformation-controlled action: $DCR \leq 1.5$ - Force-controlled action: $DCR \leq 0.7$	Nonlinear time-history analysis - Deformation-controlled action: $DCR \leq 1.0$ - Force-controlled action: $DCR \leq 1.0$
		(b) Nonlinear time-history analysis - Deformation-controlled action: $DCR \leq 1.0$ - Force-controlled action: $DCR \leq 0.7$	

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Load Combinations According to EN 1990

Prepared by:
Dr. Mishra S. Abale
EIT - Lecturer

LOAD COMBINATIONS ACCORDING TO EN 1990 DETAILED EXPLANATION FOR TEACHING

Safe Structures
for a Safer Society

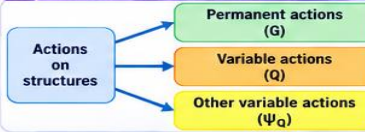
1. WHAT IS EN 1990?

- EN 1990 provides the basis of structural design and is used with other Eurocodes (EN 1991, EN 1992, etc.).
- It gives safety factors and load combination rules for both ULS and SLS verifications.
- The main objective is to ensure: Safety, Serviceability and Durability.

2. LIMIT STATES (WHY COMBINATIONS?)

- Ultimate Limit State (ULS)**
Loss of equilibrium, internal failure, excessive deformation.
- Serviceability Limit State (SLS)**
Excessive deflection, cracking, vibration, comfort.
- Main limit states considered in EN 1990:**
 - EQU** – Loss of static equilibrium
 - STR** – Internal failure or excessive deformation of the structure
 - GEO** – Failure or excessive deformation of the ground (foundation)

3. ACTIONS ON STRUCTURES



4. SYMBOLS AND DEFINITIONS

Symbol	Meaning
$G_{k,j}$	Characteristic value of permanent action j
$Q_{k,1}$	Characteristic value of leading variable action
$Q_{k,i}$	Characteristic value of accompanying variable action
$\Psi_{0,i}$	Combination factor for accompanying variable action
γ_G	Partial factor for permanent action
γ_Q	Partial factor for variable action
ξ	Reduction factor for unfavourable permanent action (used in Eq. 6.10b)

11. STEP-BY-STEP PROCEDURE TO APPLY LOAD COMBINATIONS



5. MAIN LOAD COMBINATION EQUATIONS (EN 1990 Section 6.4)

Equation 6.10 – General form (ULS)

$$\sum \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1} + \sum \gamma_{Q,i} \Psi_{0,i} Q_{k,i}$$

Permanent action
Leading variable actions
Other variable actions

Equation 6.10 a – Alternative form (ULS)

$$\sum \gamma_{G,j} G_{k,j} + \gamma_{Q,1} \Psi_{0,1} Q_{k,1} + \sum \gamma_{Q,i} \Psi_{0,i} Q_{k,i}$$

Equation 6.10 b – For uplift and other unfavourable permanent actions

$$0.925 \sum \xi \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1} + \sum \gamma_{Q,i} \Psi_{0,i} Q_{k,i}$$

7. NATIONAL ANNEX (UK) RECOMMENDED VALUES (Table NA.A1.1)

Action	Ψ_0	Ψ_1	Ψ_2
Imposed loads in buildings, general	-	-	-
Category A : domestic, residential	0.7	0.5	0.3
Category B : office areas	0.7	0.5	0.3
Category C : congregation areas	0.7	0.7	0.6
Category D : shopping areas	0.7	0.7	0.6
Category E : storage areas	1.0	0.9	0.8
Category F : traffic area, ≤ 30 kN	0.7	0.7	0.6
Category G : traffic area, 30–160 kN	0.7	0.5	0.3
Category H : roofs	0.7	0	0
Snow load : H ≤ 1000 m a.s.l.	0.5	0.2	0
Wind loads on buildings	0.5	0.2	0

10. DETAILED EXPLANATION OF KEY VALUES

Why $\gamma_Q = 1.5$ for imposed loads?

- Imposed loads have high variability in magnitude, location and duration.
- Therefore, a higher partial factor (1.5) is used for safety in ULS design.
- This applies to most imposed loads (categories A to H) as per NA. (Table NA.A1.1).

Why $\gamma_Q = 0.5$ for wind loads?

- Wind actions can be favourable (suction) or unfavourable (pressure).
- To avoid over-conservatism, a lower partial factor of 0.5 is used for wind in ULS combinations.
- This is specified in the UK National Annex to EN 1990.

About Ψ_0, Ψ_1, Ψ_2

- Ψ_0 : Used to reduce accompanying variable actions in ULS.
- Ψ_1 : Used for frequent SLS checks (e.g. vibration, comfort).
- Ψ_2 : Used for quasi-permanent SLS checks (e.g. long-term deflection, cracking).

6. MEANING OF EACH SYMBOL AND PARAMETER

Symbol	Name	Explanation
$G_{k,j}$	Characteristic permanent load	Representative value of dead load (material self-weight, finishes, etc.)
$Q_{k,1}$	Characteristic leading variable load	The main variable load that is most unfavourable for the considered effect
$Q_{k,i}$	Characteristic accompanying variable load	Other variable loads acting simultaneously with reduced value
$\Psi_{0,i}$	Combination factor	Factor to reduce accompanying variable actions in ULS combinations
γ_G	Partial factor for permanent action	Accounts for uncertainties in G (favourable/unfavourable effects)
γ_Q	Partial factor for variable action	Accounts for uncertainties in Q
ξ	Reduction factor	0.925 for generally unfavourable permanent actions in Eq. 6.10 b

8. PARTIAL SAFETY FACTORS (γ VALUES)

Action type	Unfavourable	Favourable	Why this value?
Permanent action (γ_G)	1.35	1.00	Accounts for uncertainty in dead loads
Variable action (γ_Q)	1.50	0	Ensures adequate safety for variable loads

9. COMBINATION FACTORS (ψ VALUES)

- Ψ_0 – combination value (used in ULS) → reduces accompanying variable actions.
- Ψ_1 – frequent value (used in SLS) → accounts for frequent occurrence.
- Ψ_2 – quasi-permanent value (used in SLS) → accounts for long-term effect.

Note:
For most imposed loads use $\gamma_Q = 1.5$
For wind actions use $\gamma_Q = 0.5$

12. PRACTICAL EXAMPLES

Example 1: Using Eq. 6.10 (Standard ULS)

Floor imposed load as leading variable:
 $1.35 G_k + 1.5 Q_k + 1.5 \times 0.5 Q_k$
 $= 1.35 G_k + 1.5 Q_k + 0.75 Q_k$

Wind load as leading variable:
 $1.35 G_k + 1.5 Q_k + 1.5 \times 0.7 Q_k$
 $= 1.35 G_k + 1.5 Q_k + 1.05 Q_k$

Example 2: Using Eq. 6.10 a

Floor imposed load as leading variable:
 $1.35 G_k + 1.5 \times 0.7 Q_k + 1.5 \times 0.5 Q_k$
 $= 1.35 G_k + 1.05 Q_k + 0.75 Q_k$

Example 3: Using Eq. 6.10 b ($\xi = 0.925$)

Floor imposed load as leading variable:
 $0.925 \times 1.35 G_k + 1.5 Q_k + 1.5 \times 0.5 Q_k$
 $= 1.25 G_k + 1.5 Q_k + 0.75 Q_k$

Wind load as leading variable:
 $0.925 \times 1.35 G_k + 1.5 Q_k + 1.5 \times 0.7 Q_k$
 $= 1.25 G_k + 1.5 Q_k + 1.05 Q_k$

No leading variable (all with Ψ_0):
 $0.925 \times 1.35 G_k + 1.5 \times 0.7 Q_k + 1.5 \times 0.5 Q_k$
 $= 1.25 G_k + 1.05 Q_k + 0.75 Q_k$

13. KEY TAKEAWAYS

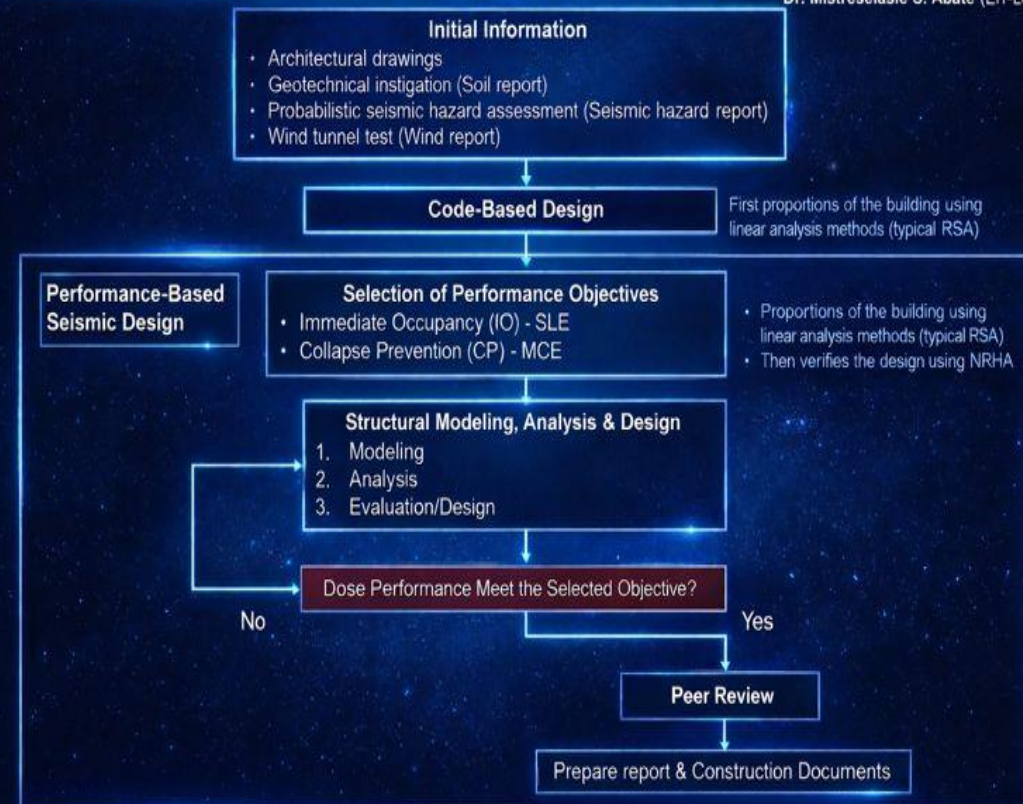
- EN 1990 provides consistent and reliable rules for load combinations.
- Understand the meaning of each symbol and factor.
- Use National Annex values for γ and ψ factors.
- Wind uses $\gamma_Q = 0.5$, most imposed loads use $\gamma_Q = 1.5$.
- Correct load combinations ensure safe, economical and durable structures.

Good Design Builds Better Lives

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Performance-Based Seismic Design (PBSD) Procedure

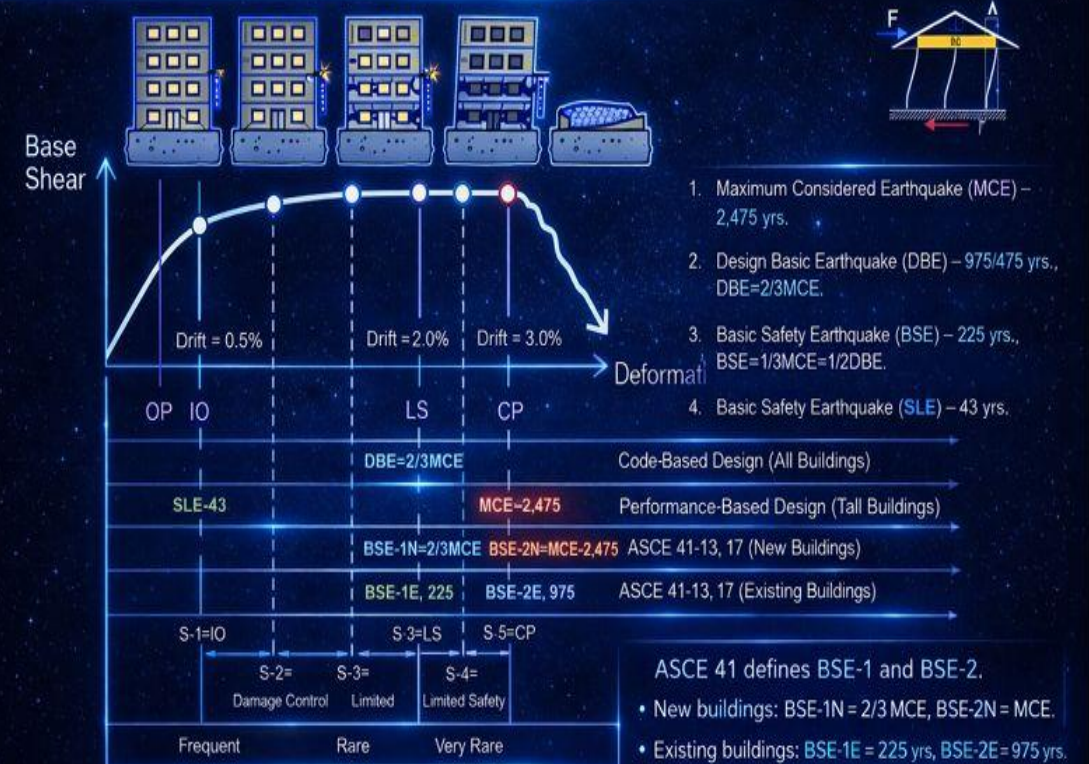
Dr. Mistreselasie S. Abate (EIT-Lecturer)



Dr. Mistreselasie S. Abate (EIT-Lecturer)

Standard Structural Performance Levels

Dr. Mistreselasie S. Abate
(EIT-Lecturer)



FEMA P695, ASCE 41-13, ASCE 41-17, TBI 2017, and LATBSDC 2020

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Structural Design Approaches

Dr. Mistreselasie S.Abate(EIT - Lecture)

Title	Types	Code-Based Design (DBE) (DBE)	Performance-Based Design (MCE) (MCE)
General Concepts		- A minimum level of safety for all types of buildings High limits for selecting seismic force-resisting system	- An alternate design with predictable and safe performance No limits for selecting seismic force-resisting system, such as outrigger, base isolation
Demand (D) F_u	Load Combinations	1.4DL 1.2DL + 1.6LL 1.2DL + 0.5LL + 1.6WL 0.9DL + 1.6WL 1.2DL + 0.5LL ± 1.0EQ 0.9DL ± 1.0EQ	1.0DL + 0.25 LL ± 1.0 EQ Ductile – the mean demands Brittle – 1.3 to 1.5 times the mean value of demand
Capacity (C) ϕF_n	Reduction Factor	$\phi = 0.65$ to 0.90	$\phi = 1.0$ (critical force-controlled action following ACI 318)
	Material Properties	Specified (nominal) strengths Concrete strength = f'_c Steel yield strength = f_y	Expected strengths: $f'_{ce} = 1.3 \times f'_c$ $f_{ye} = 1.17 \times f_y$
DCR = D/C		$D/C = F_u / \phi F_n \leq 1.0$	$D/C = F_u / \phi F_n \leq 1.0$

Material Properties

Dr. Mistreselasie S. Abate (EIT - Lecture)

Table 2. Expected Material Strengths

Material		Expected strength	
Reinforcing Steel		Expected Yield Strength, f_y , ksi	Expected Ultimate Strength, f_u , ksi
A615 Grade 60	$f_y = 60 \text{ ksi} \rightarrow 1.17f_y$	70	106
A615 Grade 75		82	114
A706 Grade 60		69	95
A706 Grade 80		85	112
A706 Grade 100		105	To be determined based on tests and documented substantiations
Structural Steel:**			
Hot-rolled structural shapes and bars			
ASTM A36/A36M		$1.5f_y^*$	$1.2f_u^{**}$
ASTM A572/A572M Grade 50		$1.1f_y$	$1.1f_u$
ASTM A913/A913M Grade 50, 60, 65 or 70		$1.1f_y$	$1.1f_u$
ASTM A992/A992M		$1.1f_y$	$1.1f_u$
Plates			
ASTM A36/A36M		$1.3f_y^*$	$1.1f_u^{**}$
ASTM A572/A572M Grade 50, 55		$1.2f_y^*$	$1.2f_u^{**}$
Concrete		$f_{ce} = 1.3f'_c$	

* f_y is used to designate the specified (nominal) yield strength of steel materials in this Guideline. It is equivalent to f_y or F_y used in ACT 318 and F_y used in AISC (2016) Specifications.

** f_u is used to designate the specified (nominal) ultimate strength of steel materials in this Guideline. It is equivalent to F_u used in AISC (2016) Specifications.

**For steel materials not listed, refer to Table A3.1 of ANSI/AISC 341-16

*** f'_{ce} = specified compressive strength. Expected strength f'_{ce} is strength expected at approximately one year or longer.

Note that the multiplier on f'_c may be smaller for high-strength concrete, and can also be affected by (1) use of fly ash and other additives, and/or (2) local aggregates.

LATBSDC 2020 (Los Angeles Tall Buildings Structural Design Council)

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Reinforced Concrete Stiffness Modification

(Ref: LATBSDC 2020)

Pramin Norachan

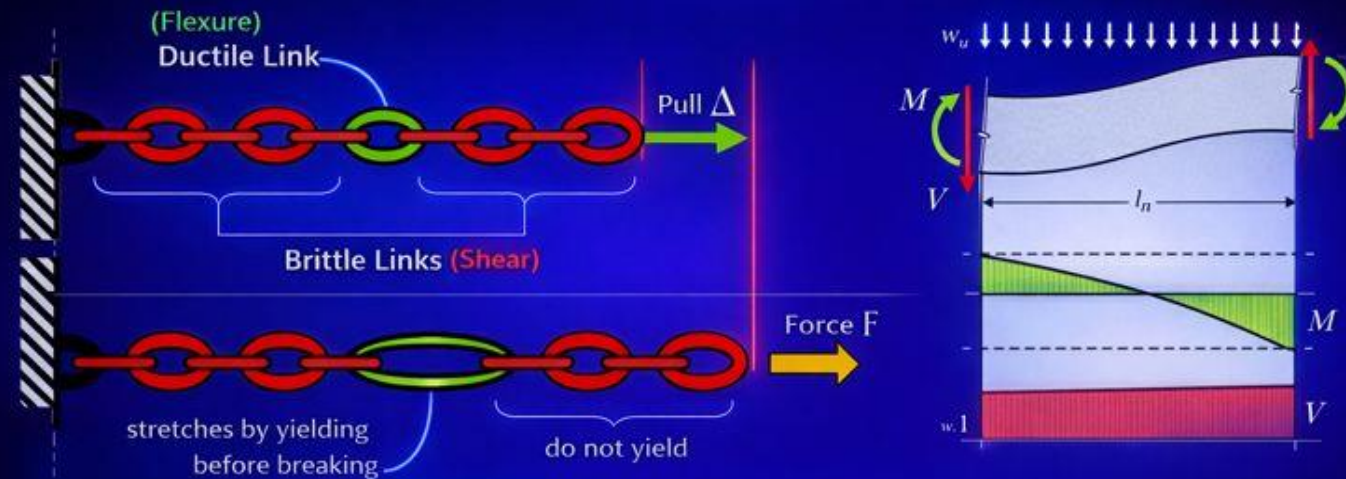
Component	Service-Level Linear Models			MCE _R -Level Nonlinear Models		
	Axial	Flexural	Shear	Axial	Flexural	Shear
Structural walls ¹ (in-plane)	$1.0E_c A_g$ or $0.75 E_c A_g^{**}$	$0.75E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.35E_c I_g$	$0.2E_c A_g$
Structural walls (out-of-plane)	--	$0.25E_c I_g$	--	--	$0.25E_c I_g$	--
Basement walls (in-plane)	$1.0E_c A_g$	$1.0E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.8E_c I_g$	$0.2E_c A_g$
Basement walls (out-of-plane)	--	$0.25E_c I_g$	--	--	$0.25E_c I_g$	--
Coupling beams with or without diagonal reinforcement	$1.0E_c A_g$	$0.07 \left(\frac{\ell}{h} \right) E_c I_g \leq 0.3E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.07 \left(\frac{\ell}{h} \right) E_c I_g \leq 0.3E_c I_g$	$0.4E_c A_g$
Coupling beams with steel-fiber reinforcement	$1.0E_c A_g$	$0.07 \left(\frac{\ell}{h} \right) E_c I_g \leq 0.3E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.07 \left(\frac{\ell}{h} \right) E_c I_g \leq 0.3E_c I_g$	$0.4E_c A_g$
Steel Coupling Beams ²	$1.0E_s A_s$	$0.07 \left(\frac{\ell}{h} \right) (EI)_{tr}$	$0.4E_s A_{web}$	$1.0E_s A_s$	$0.07 \left(\frac{\ell}{h} \right) (EI)_{tr}$	$0.4E_s A_{web}$
Non-PT diaphragms ³	$0.5E_c A_g$	$0.5E_c I_g$	$0.4E_c A_g$	$0.25E_c A_g$	$0.25E_c I_g$	$0.1E_c A_g$
PT diaphragms ³	$0.8E_c A_g$	$0.8E_c I_g$	$0.4E_c A_g$	$0.5E_c A_g$	$0.5E_c I_g$	$0.2E_c A_g$
Beams	$1.0E_c A_g$	$0.5E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.3E_c I_g$	$0.4E_c A_g$
Columns	$1.0E_c A_g$	$0.7E_c I_g$	$0.4E_c A_g$	$1.0E_c A_g$	$0.7E_c I_g$	$0.4E_c A_g$
Mat (in-plane)	$0.8E_c A_g$	$0.8E_c I_g$	$0.4E_c A_g$	$0.5E_c A_g$	$0.5E_c I_g$	$0.4E_c A_g$
Mat ⁴ (out-of-plane)	--	$0.8E_c I_g$	--	--	$0.5E_c I_g$	--

23

Reference: ASCE 41-17; FEMA 356; FEMA P695, 2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

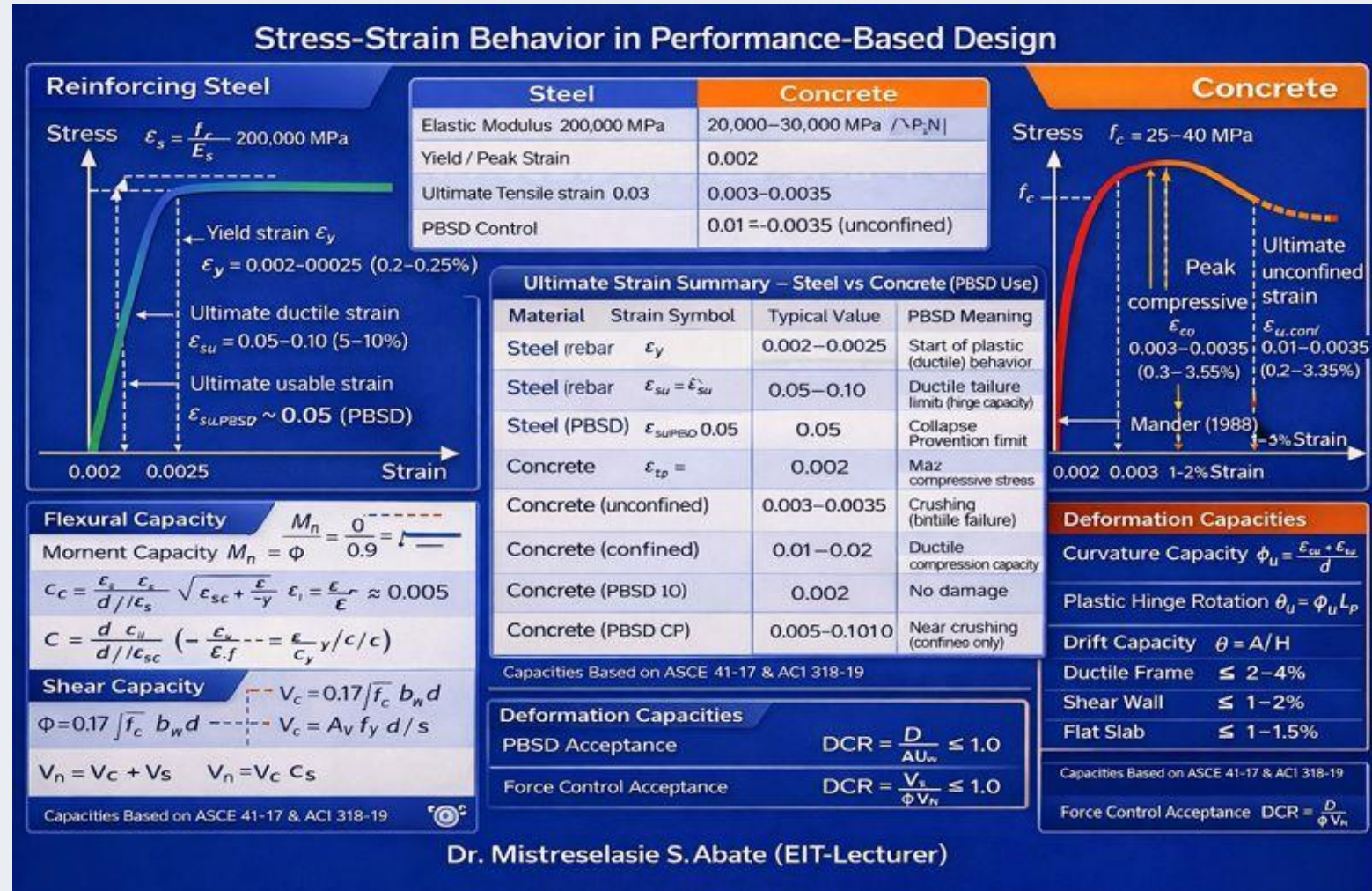
Capacity Design Concepts

Dr. Misterselasie S. Abate (EIT - Lecture)



- The chain has both ductile and brittle elements.
- To ensure ductile failure, we must ensure that the ductile link yields before any of the brittle links fails.
- The capacity design method is commonly used to proportion the structure.

Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.



Dr. Mistreselasie S. Abate (EIT-Lecturer)

Reference: ASCE 41-17; FEMA 356; FEMA P695, 2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Component Classifications

Dr. Mistreselasie S. Abate (EIT-Lecturer)

All actions (strains, displacements, rotations or other deformations resulting from the application of loads or excitations) shall be classified as either **deformation-controlled** or force-controlled.

Force-controlled action shall be further classified as **critical** or **ordinary** per definitions given below. Table 4 identifies typical force-controlled actions and their recommended categories.

- Deformation-controlled action** – An action expected to **undergo nonlinear behavior** in response to earthquake shaking, and which is evaluated for its ability to sustain such behavior.

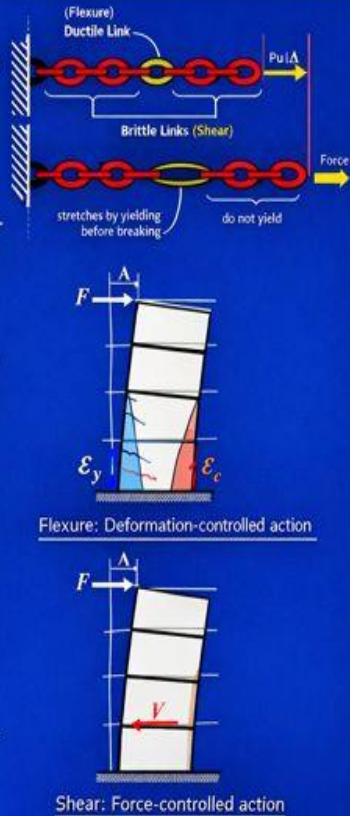
$$DCR = D/C = \Delta_u / \Delta_{limit} \leq 1.0$$

- Force-controlled action** – An action that is **not expected to undergo nonlinear behavior** in response to earthquake shaking, and which is evaluated on the basis of its available strength.

$$DCR = D/C = F_u / \phi F_n \leq 1.0$$

→ **Critical action** – A force-controlled action, the failure of which is **likely to lead to partial or total structural collapse**.

→ **Ordinary action** – A force-controlled action, the failure of which is **unlikely to lead to structural collapse** or it might **lead to local collapse** comprising **not more than one bay in a single story**.

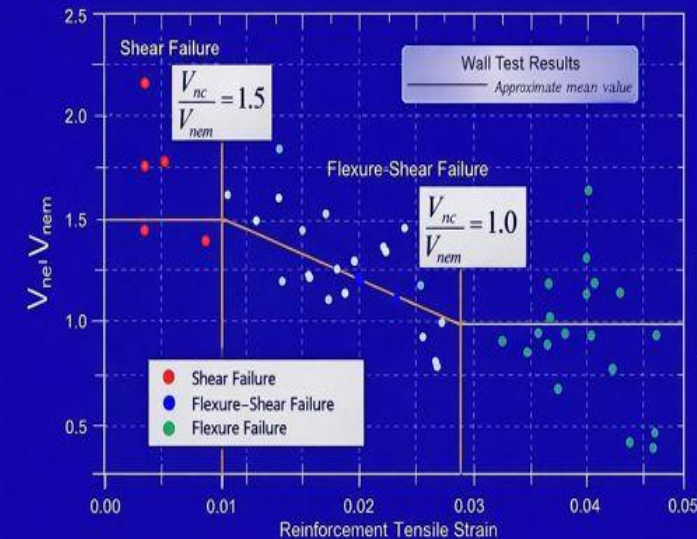


B-Values

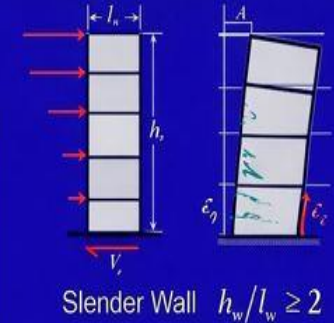
Dr. Mistreselasie S. Abate (EIT - Lecturer)

3.6.3.2.1 Force-Controlled Actions

(a) Critical Action Not Sensitive to Vertical Accelerations



Tests on slender walls failing in shear show that shear strength decreases with increasing inelastic flexure (Wallace et al, 2013; Moehle, 2014, Kim 2016).



$$B = 0.9 \left(\frac{R_{nc}}{R_{nem}} \right), R_{nem} \approx 1.15 R_n$$

Wall shear strength: ACI 318-19

$$V_{nem} = A_{cv} \left[\alpha_c \sqrt{f_{ce}'} + \rho_r f_{ye} \right]$$

$$B = 0.9 \left(\frac{V_{nc}}{V_{nem}} \right) = 0.9(1.5) = 1.35$$

V_{ne}/V_{nem} Shear
based on experiment /
Based on ACI formulation

MCE (Force-Controlled Actions)

$$\phi_s BV_{nem} = (0.75)(1.35)V_{nem}$$

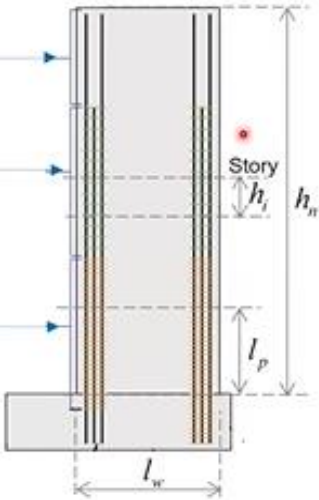
$$\approx 1.0V_{nem} = \sqrt{1.3}V_n = 1.14V_n \quad (f_{ce} = 1.3f_c')$$

Component	Seismic Action	Category	
		Critical	Ordinary
Reinforced Concrete	Below Grade Perimeter Retaining Walls		X
	Below Grade Non-Perimeter / Non-Core Walls		X
	Core Walls Above and Below Grade and All Above Grade Walls	X	
	Diaphragms with Major Shear Transfer	X	
	Coupling beams without special diagonal reinforcing including steel-fiber reinforced coupling beams*	X	
	Typical (non-transfer slab) Diaphragm Forces (excludes collectors and shear transfer to vertical element)		X
	All Drag (Collector) Members		X
	Vertical Element-to-Diaphragm Connection		X
	Gravity Columns and Special Moment Frames (Columns, Beam-Column joints) excluding, Intentional Outrigger Columns, & Columns Supporting Discontinuous Vertical Elements		X
	Special Moment Frame Beams		X
	Intentional Outrigger Columns & Columns Supporting Discontinuous Vertical Elements****		X
	Transfer Girders****		X
	Strut and Tie in strut and tie formulation		X
	Below Grade Perimeter Walls		X
	Walls, including Isolated Walls, Coupled Walls, and Core Walls	X	
	Diaphragm with Major Shear Transfer	X	
	Typical (non-transfer slab) Diaphragm Forces (excludes collectors and shear transfer to vertical element)	X	
	Drag (Collector) Members	X	
	Vertical Element-to-Diaphragm Connection	X	
	Gravity Columns excluding, Intentional Outrigger Columns, & Columns Supporting Discontinuous Vertical Elements	X	
	Special Moment Frames (Beams, Columns, Beam-Column joints) excluding, Intentional Outrigger Columns, & Columns Supporting Discontinuous Vertical Elements	X	
	Intentional Outrigger Columns & Columns Supporting Discontinuous Vertical Elements*	X	
	Transfer Girders*	X	

Reference: Los Angeles Tall Buildings Structural Design Council (LATBSDC). (2020). *An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region*. Los Angeles, California, USA. Ait.

MCE (Deformation-Controlled Actions)

Item		Engineering Demand Parameter	Acceptance Limit
 Reinforced concrete walls (outside of primary hinge zone)	No confinement	Concrete compression strain over gage length ¹	0.001/l _w
		Steel tension strain over gage length ¹	2ε _y /l _w
	Intermediate confinement per ACI 318-19 18.10.6.5	Concrete compression strain over gage length ¹	0.003/l _w
		Steel tension strain over gage length ¹	0.01/l _w
	Full confinement per ACI 318-19 18.10.6.4 except provisions of Section 18.10.6.4(i) need not be satisfied ²	Concrete compression strain over gage length ¹	0.005/l _w (0.01/l _w) ³
		Steel tension strain over gage length ¹	0.01/l _w (0.05/l _w) ³
Reinforced concrete walls (primary hinge zone)	Full confinement of the entire cross section per ACI 318-19 18.10.6.4 ²	Concrete compression strain over gage length ¹	0.005/l _w (0.01/l _w) ³
		Steel tension strain over gage length ¹	0.01/l _w (0.05/l _w) ³
Coupling beams	Conventionally-reinforced ⁴	Total chord rotation	0.04/l _w
	Diagonally-reinforced ⁴	Total chord rotation	0.06/l _w
	Fiber-reinforced ⁵	Total chord rotation	0.04/l _w
	Steel-reinforced	Total chord rotation	0.06/l _w
Slab outrigger beams	At wall end ⁶	Total rotation	0.05/l _w
	At column end ⁷ , with shear reinforcement, v _{uw} /(v _c +v _s) ≤ 0.7	Total rotation	0.05/l _w
	At column end ⁷ , with shear reinforcement, v _{uw} /(v _c +v _s) > 0.7	Total rotation	0.03/l _w
	At column end, without shear reinforcement	Total rotation	refer to ACI 318-19 18.14.5



Plastic hinge zone

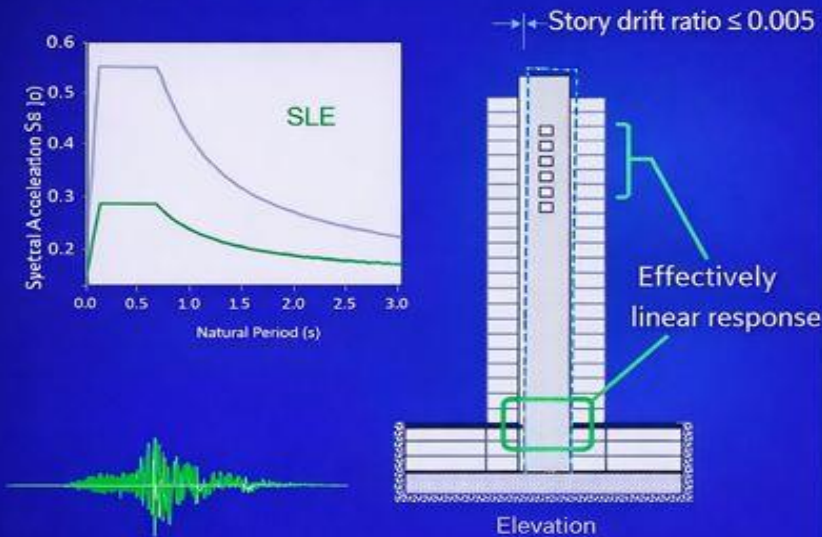
$$l_p \leq \text{minimum of } \begin{cases} 0.5l_w \\ h_i \\ 0.1h_n \end{cases}$$

$$DCR = \frac{D}{C} = \frac{\Delta_u}{\Delta_{limit}} \leq 1.0$$

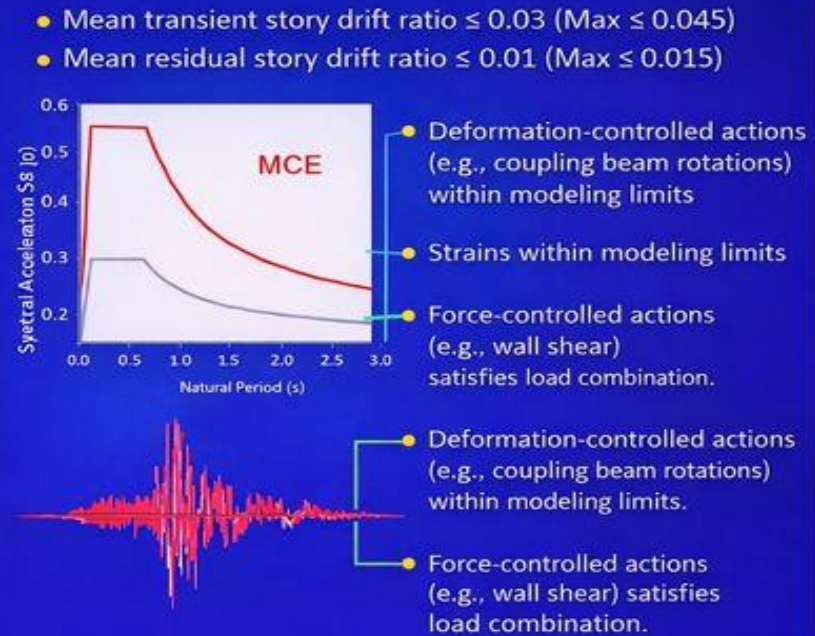
Reference: Los Angeles Tall Buildings Structural Design Council (LATBSDC). (2020). *An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region*. Los Angeles, California, USA. Ait.

Acceptance Criteria Dr. Mistreselasie S.Abate (EIT - Lecturer)

SLE



MCE



Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Application of PBS

Dr. Mistreselasie S.Abate (EIT-Lecturer)

Application of PBS in USA

Transbay Solaire
San Francisco



Transbay Solaire

Salesforce Tower
San Francisco



Salesforce Tower

Oceanwide Center
San Francisco



Oceanwide Center

Application of PBS in USA



Application of PBS in Philippines

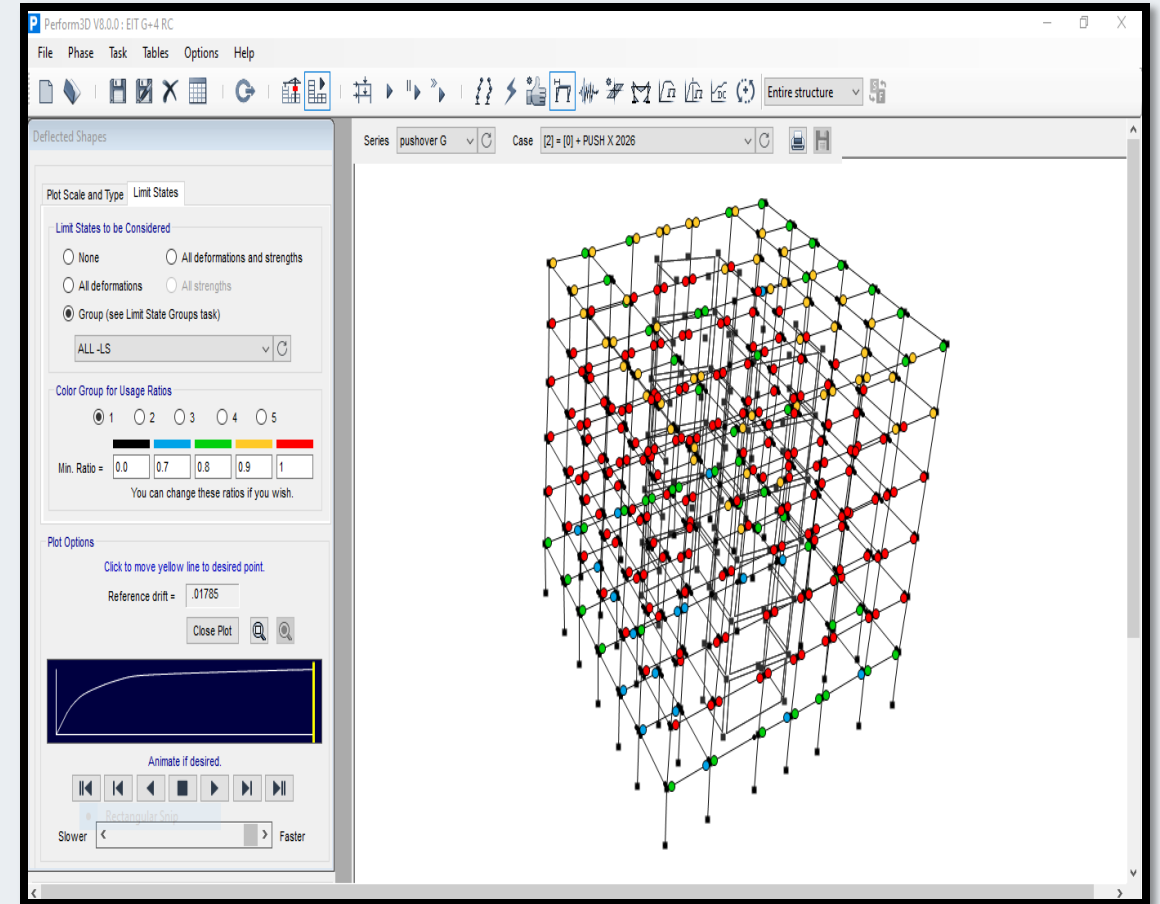
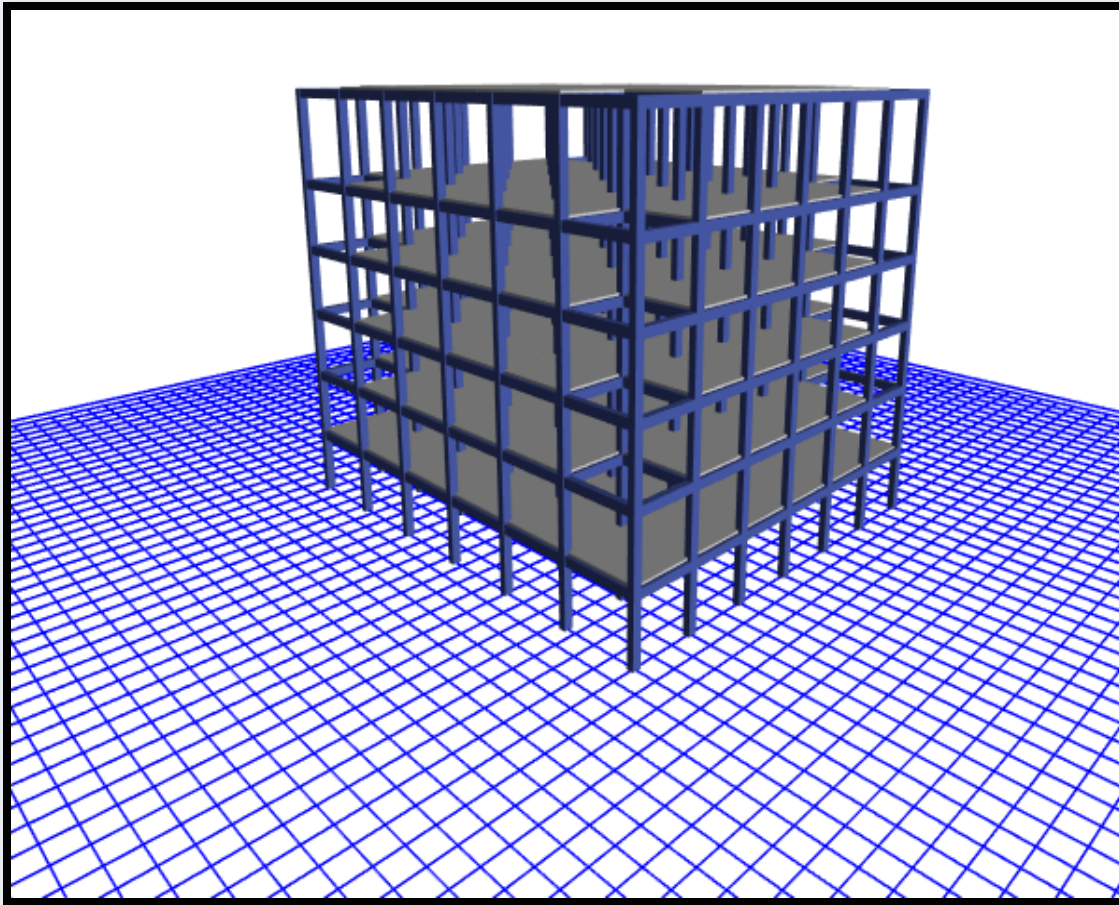


Application of PBS in Philippines



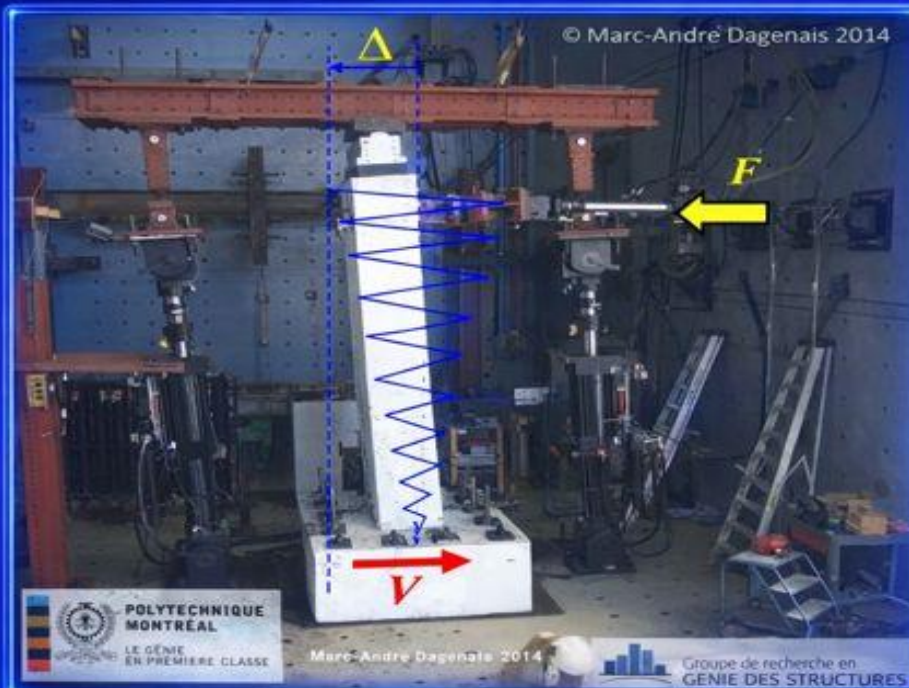
Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Sample Linear and Nonlinear Models



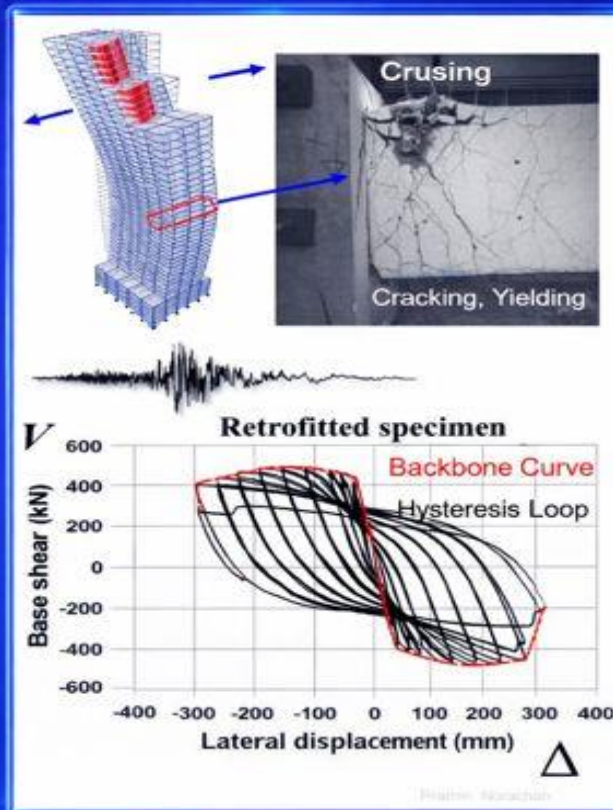
Force-Deformation Relationship

Dr. Mistreselasie S. Abate
(EIT – Lecturer)

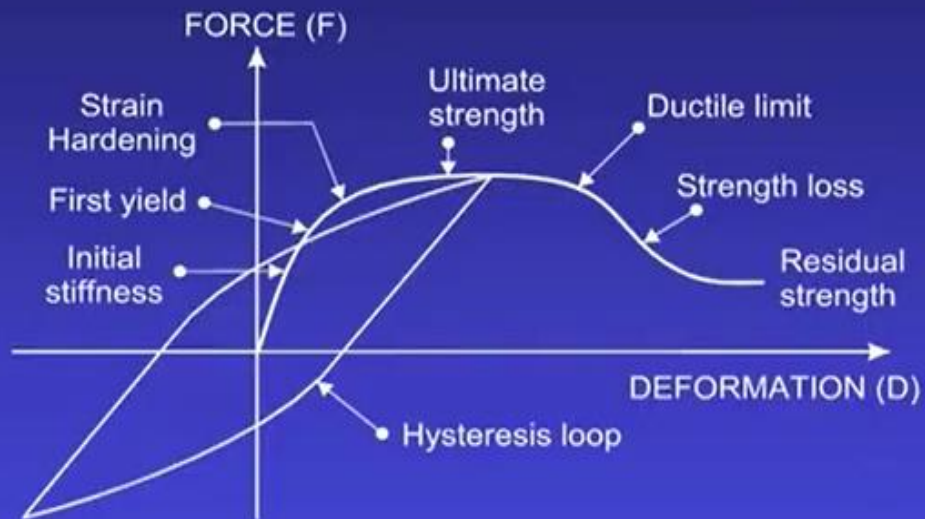


Seismic Retrofitting of Rectangular Bridges Piers with Deficient Lap Splices using Ultra High Performance Fiber Reinforced Concrete (UHPFRC)
Ph.D student: Marc-André Dagenais | Professor: Bruno Massicotte

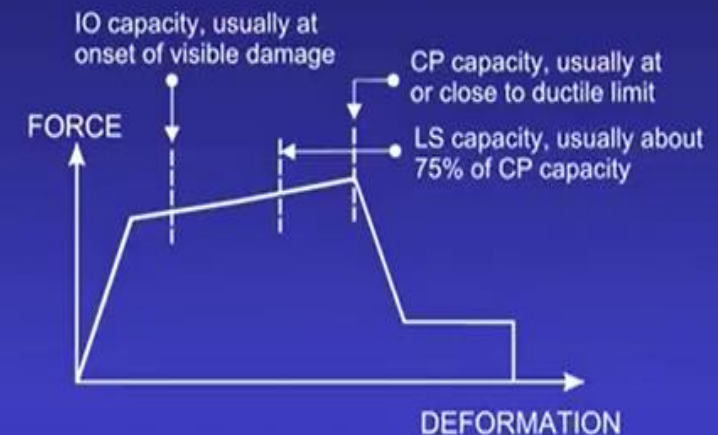
Reference: ASCE 41-17; FEMA 356; ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT



Review Main Aspects of Behavior



Typical ASCE 41 Capacities



- ASCE 41 gives values for a wide range of components.
- Alternatively, experimental results can be used.
- PERFORM-3D and this seminar use the term "capacities". ASCE 41 uses the term "acceptance criteria".

Table 10-7. Modeling Parameters and Numerical Acceptance Criteria for Nonlinear Procedures—Reinforced Concrete Beams

Conditions	Modeling Parameters ^a			Acceptance Criteria ^a		
	Plastic Rotation Angle (radians)		Residual Strength Ratio	Plastic Rotation Angle (radians)		
	a	b		Performance Level		
			c	IO	LS	CP
Condition i. Beams controlled by flexure ^b						
$\frac{V - P}{P_{bal}}$	Transverse reinforcement ^c	$\frac{V^d}{b_w d \sqrt{f'_c E}}$				
≤0.0	C	≤3 (0.25)	0.025	0.05	0.2	0.010
≤0.0	C	≥6 (0.5)	0.02	0.04	0.2	0.005
≥0.5	C	≤3 (0.25)	0.02	0.03	0.2	0.005
≥0.5	C	≥6 (0.5)	0.015	0.02	0.2	0.005
≤0.0	NC	≤3 (0.25)	0.02	0.03	0.2	0.005
≤0.0	NC	≥6 (0.5)	0.01	0.015	0.2	0.0015
≥0.5	NC	≤3 (0.25)	0.01	0.015	0.2	0.005
≥0.5	NC	≥6 (0.5)	0.005	0.01	0.2	0.0015
Condition ii. Beams controlled by shear ^b						
Stirrup spacing ≤ d/2			0.0030	0.02	0.2	0.0015
Stirrup spacing > d/2			0.0030	0.01	0.2	0.0015
Condition iii. Beams controlled by inadequate development or splicing along the span ^b						
Stirrup spacing ≤ d/2			0.0030	0.02	0.0	0.0015
Stirrup spacing > d/2			0.0030	0.01	0.0	0.0015
Condition iv. Beams controlled by inadequate embedment into beam-column joint ^b						
			0.015	0.03	0.2	0.01

Note: f'_c in lb/in.² (MPa) units.

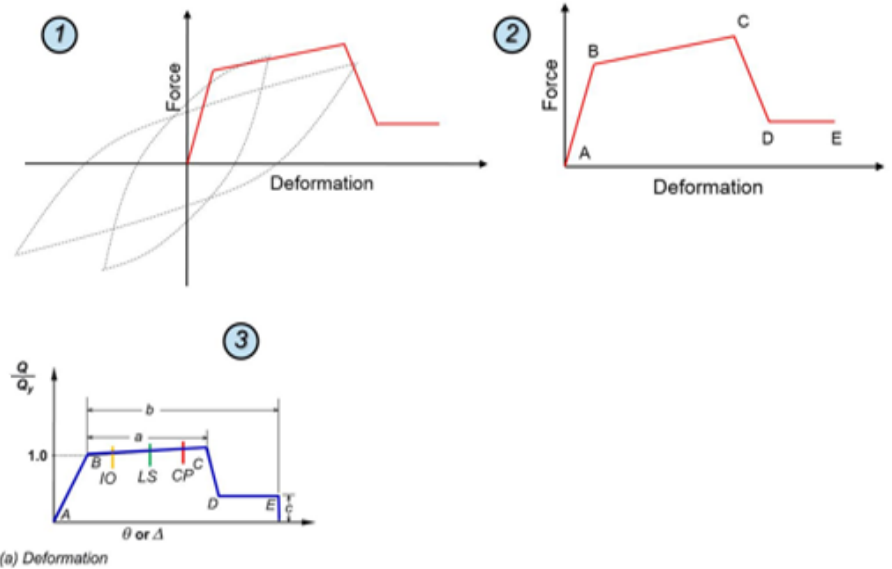
^a Values between those listed in the table should be determined by linear interpolation.

^b Where more than one of conditions i, ii, iii, and iv occur for a given component, use the minimum appropriate numerical value from the table.

^c "C" and "NC" are abbreviations for conforming and nonconforming transverse reinforcement, respectively. Transverse reinforcement is conforming if, within the flexural plastic hinge region, hoops are spaced at ≤ d/3, and if, for components of moderate and high ductility demand, the strength provided by the hoops (V_s) is at least 3/4 of the design shear. Otherwise, the transverse reinforcement is considered nonconforming.

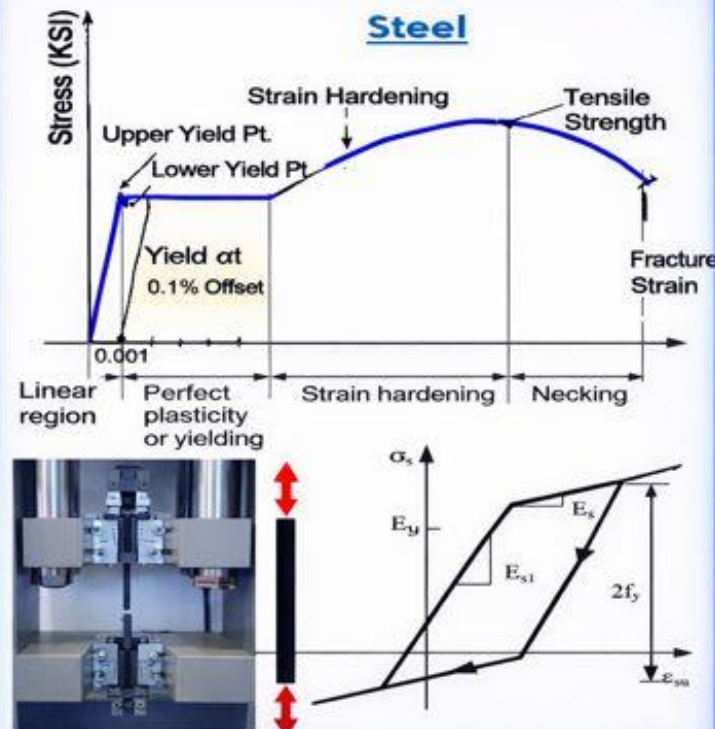
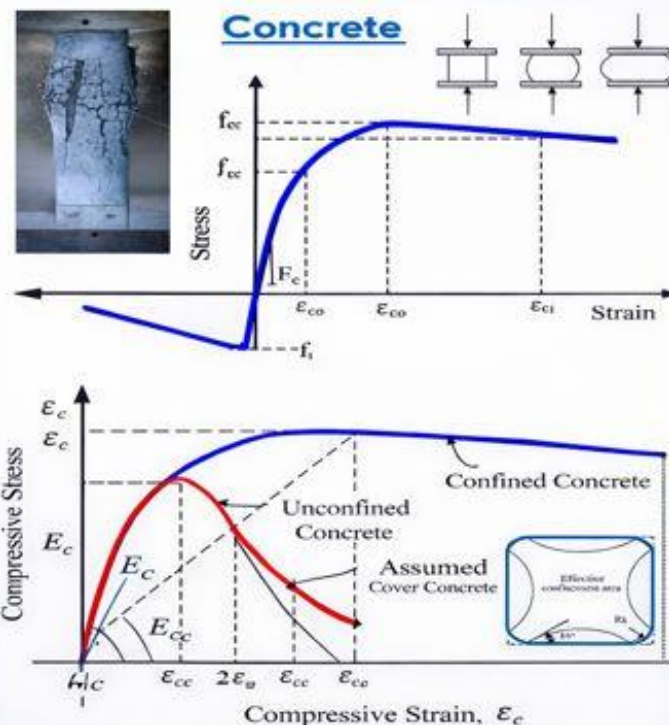
^d V is the design shear force from NSP or NDP.

Force-Deformation Relationship



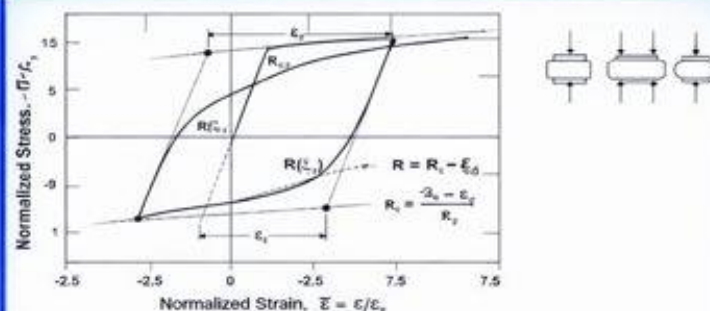
Material Nonlinearity

Dr. Mistreselasie S. Abate
(EIT – Lecturer)

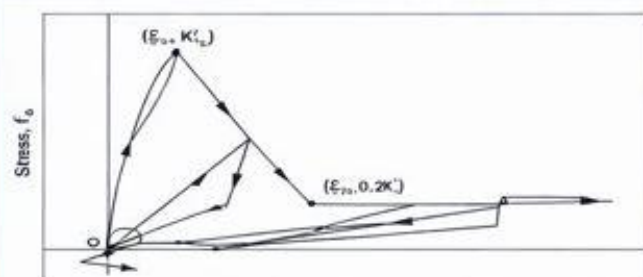


Reference: ASCE 41-17; FEMA 356, ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database:

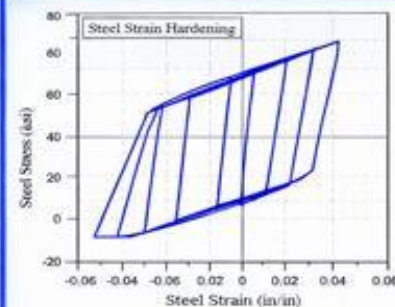
Material Models in Commercially Available Software Dr. Mistreslasie S. Abate (EIT – Lecturer)



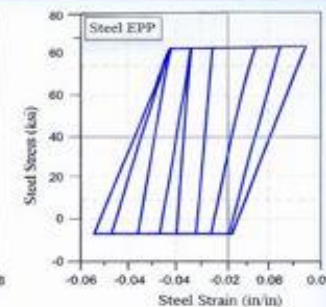
(a) Reinforcing steel (Menegotto and Pinto, 1973)



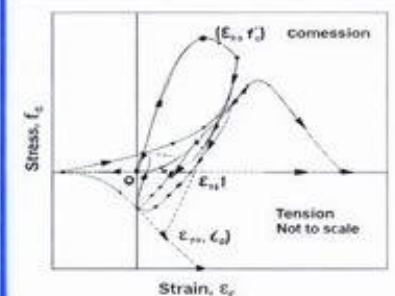
(b) Concrete (Yasin, 1994)
Exaggerated pinching



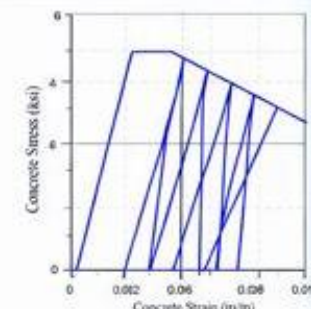
(a) Reinforcing steel model (SH)



(b) Reinforcing steel model (EPP)

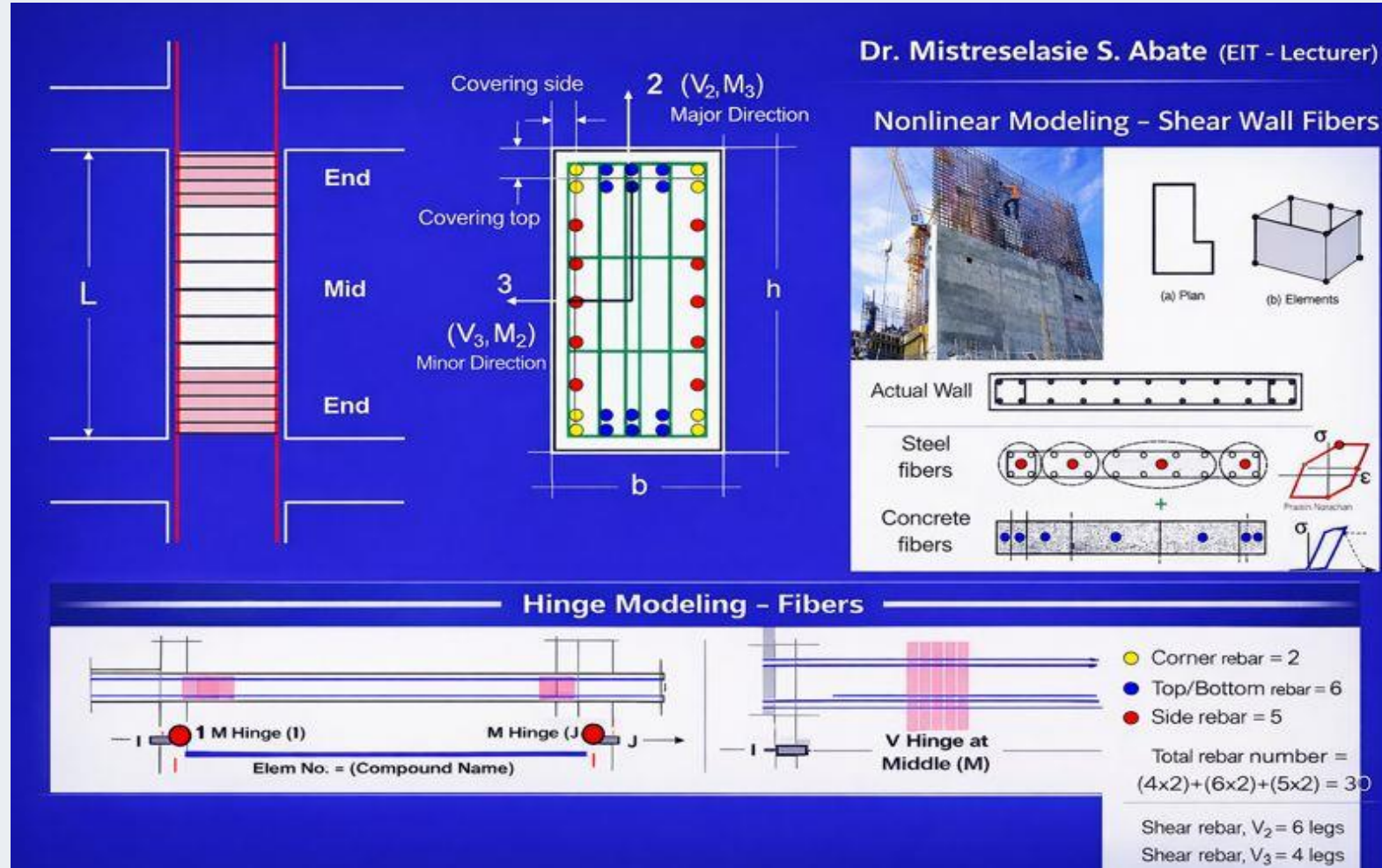


More sophisticated model



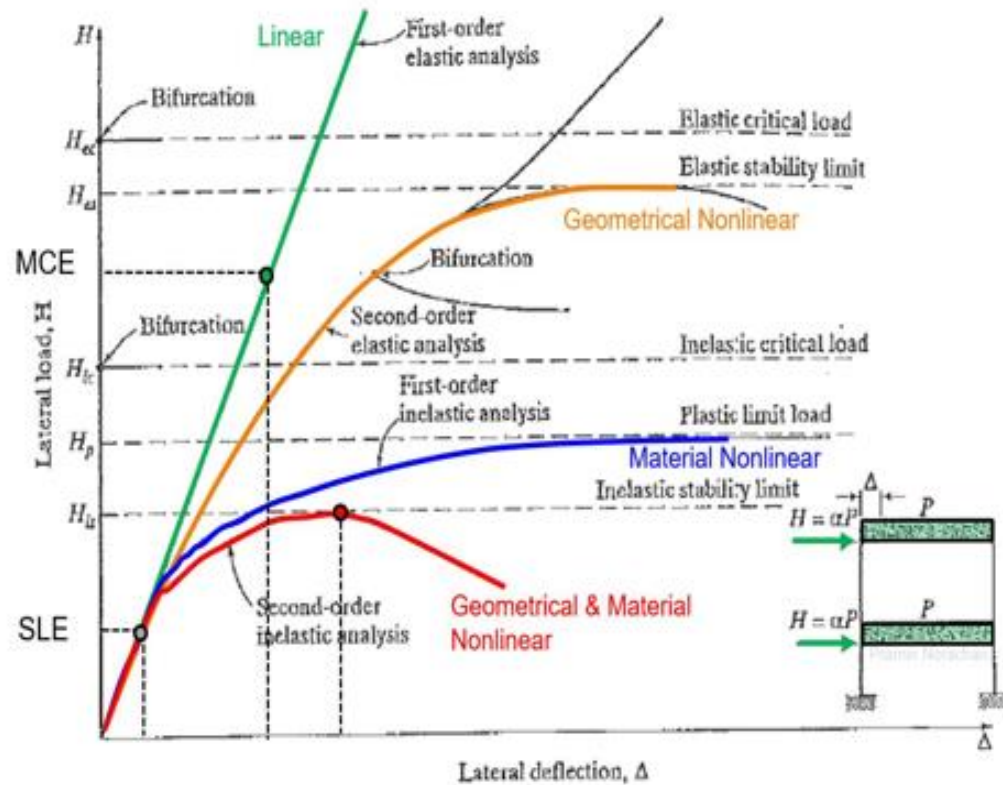
(c) Concrete model

Reference: ASCE 41-17; FEMA 356; ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT

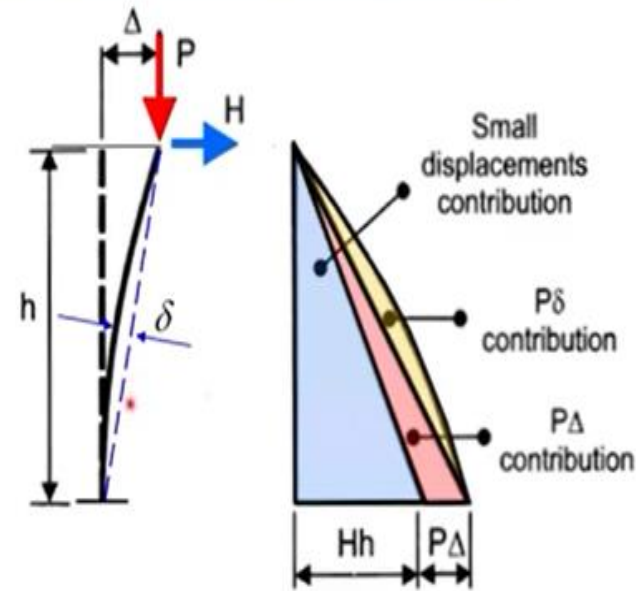


Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

Geometrical and Material Nonlinearities



Geometric Nonlinearity



$P-\delta$ effect, or P -“small-delta”, associated with deformations along the members, measured relative to the member chord (Local).

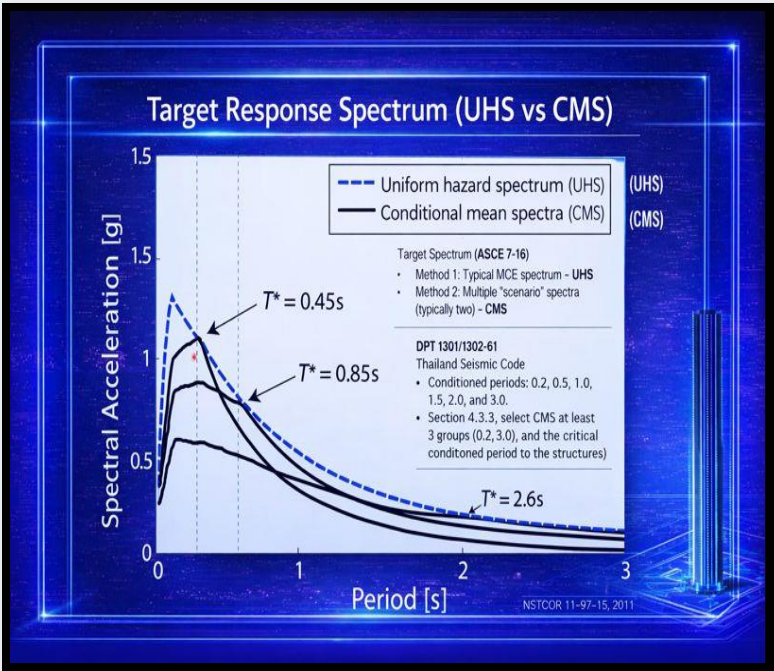
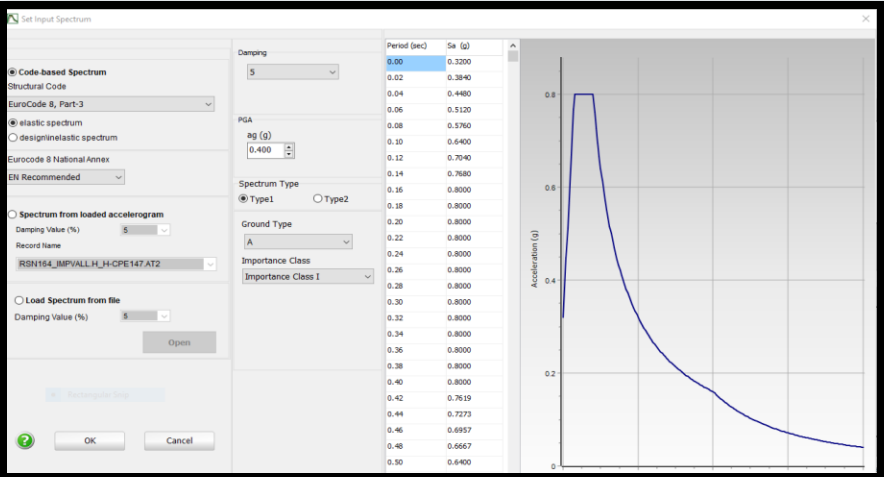
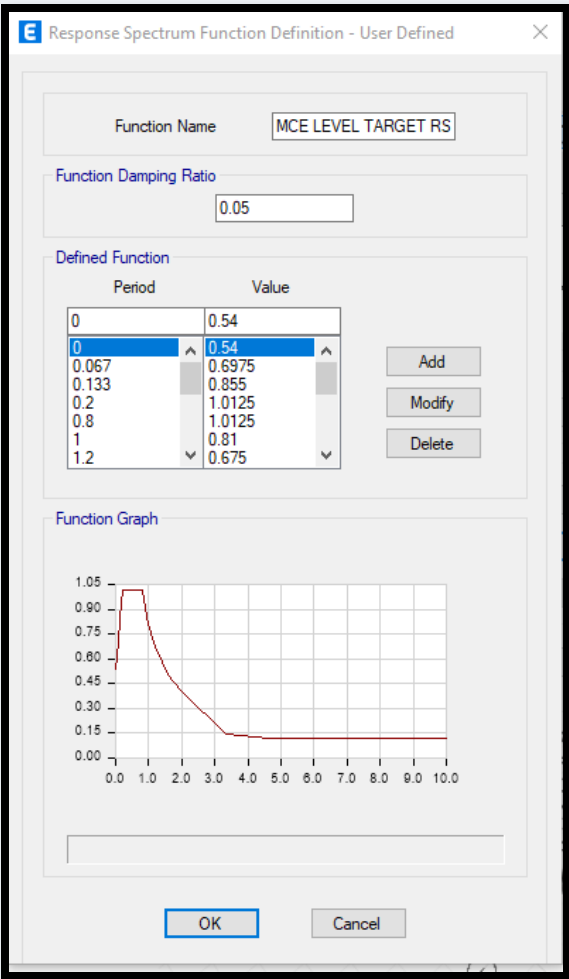
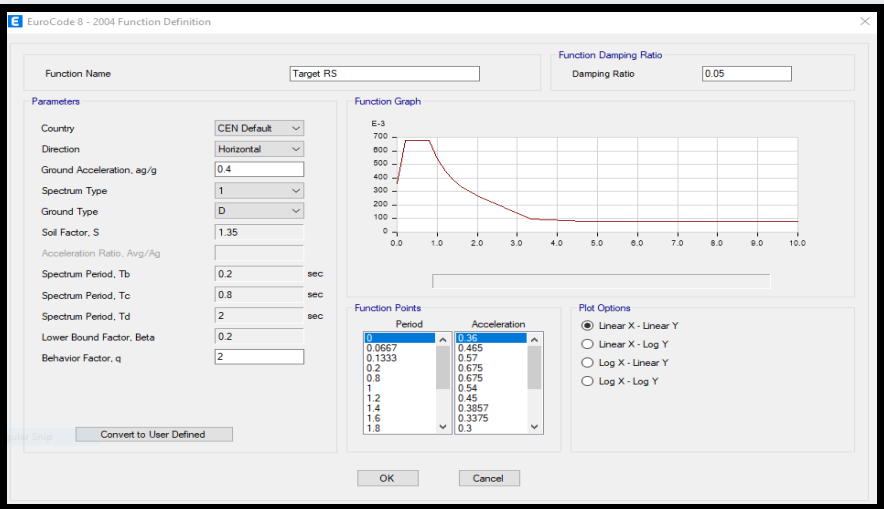
$P-\Delta$ effect, or P -“big-delta”, measured between member ends and commonly associated with story drifts in buildings (Global).

(a) Column

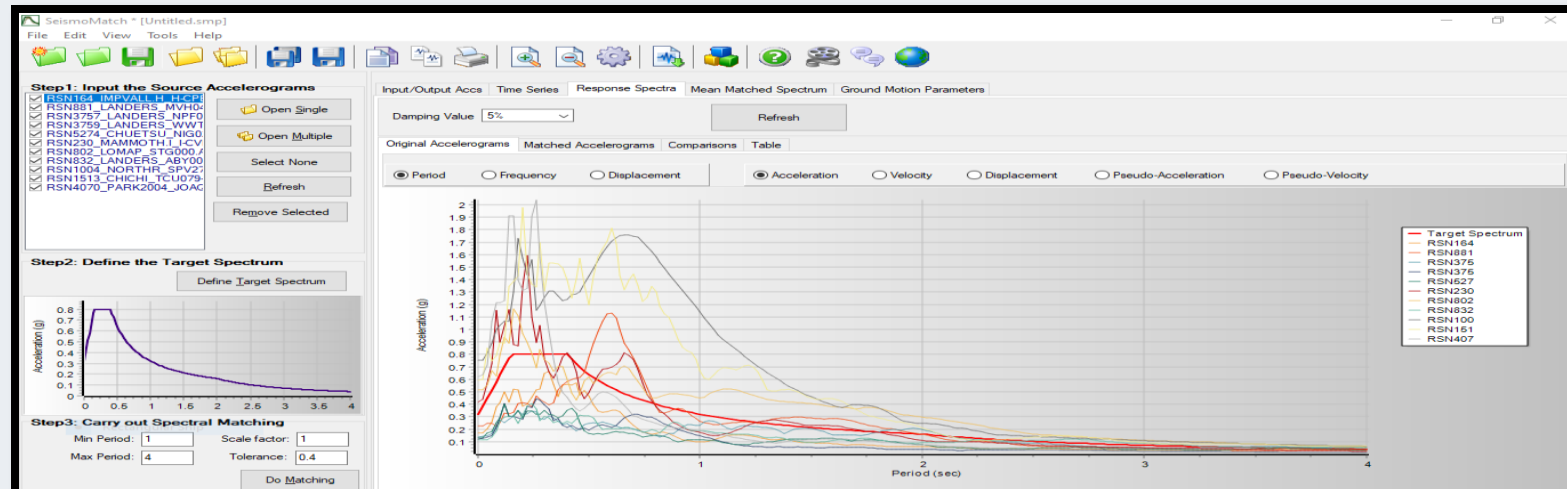
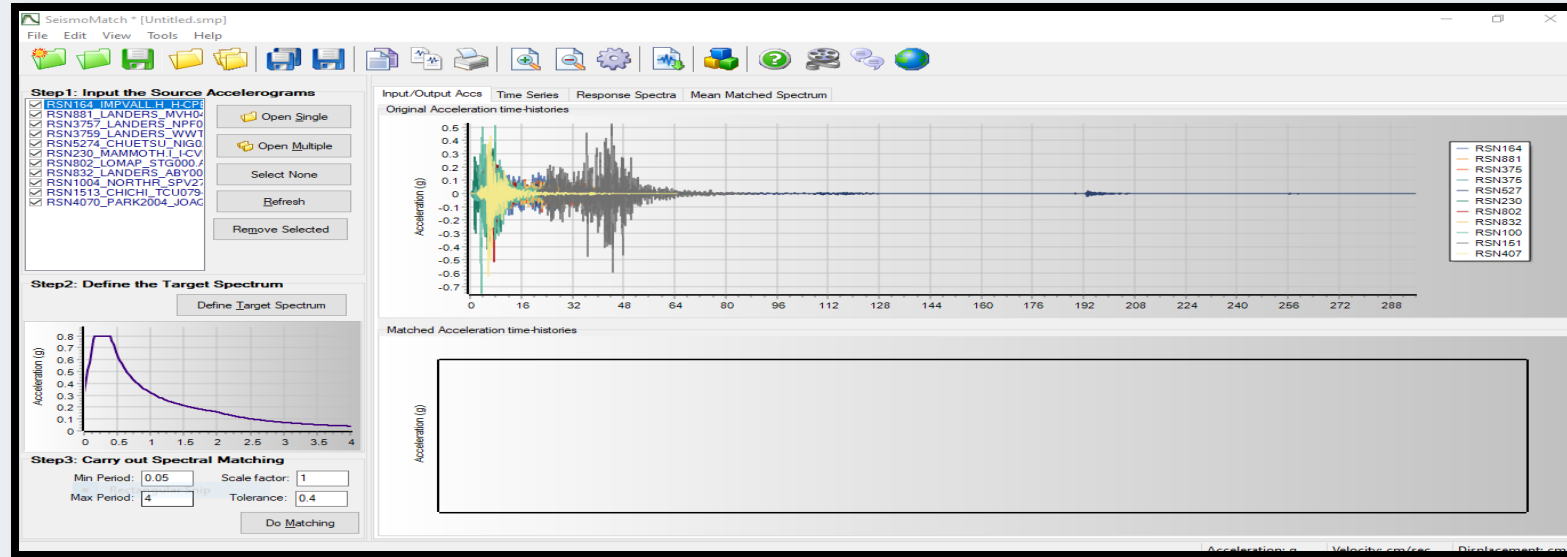
(b) Bending Moments

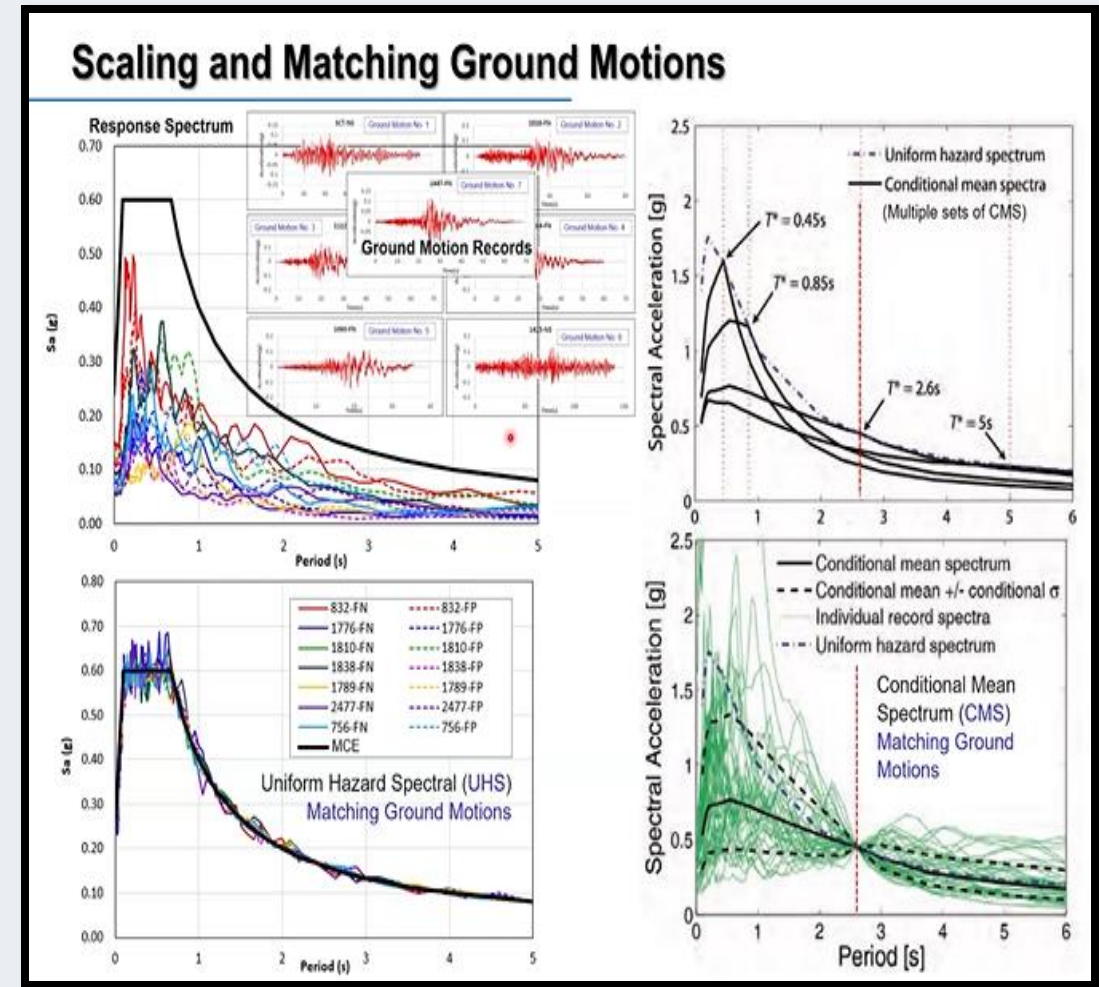
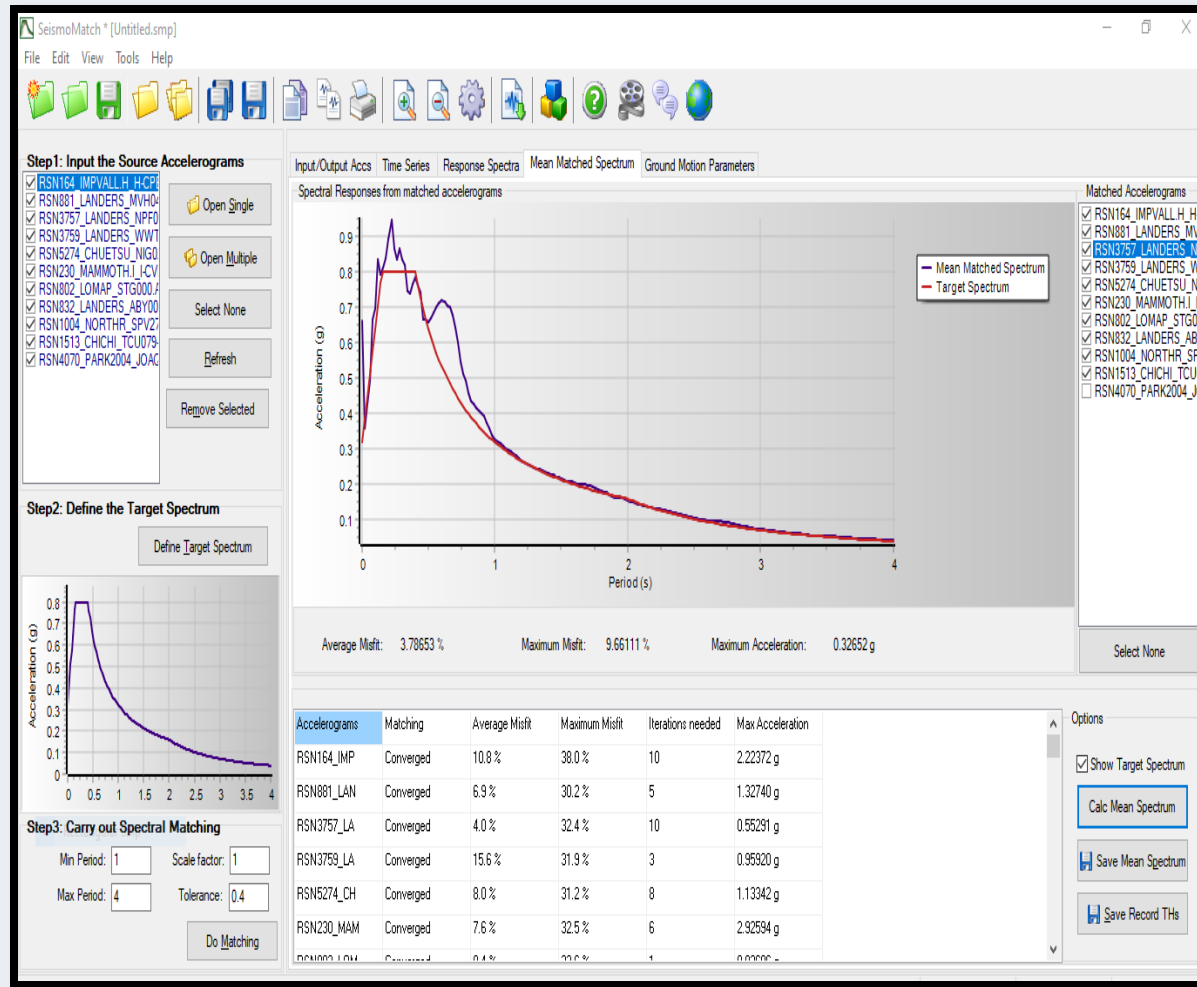
In buildings subjected to earthquakes, $P-\Delta$ effects are much more of a concern than $P-\delta$ effects. On the other hand, $P-\Delta$ effects must be modeled as they can ultimately lead to loss of lateral resistance.

Analysis

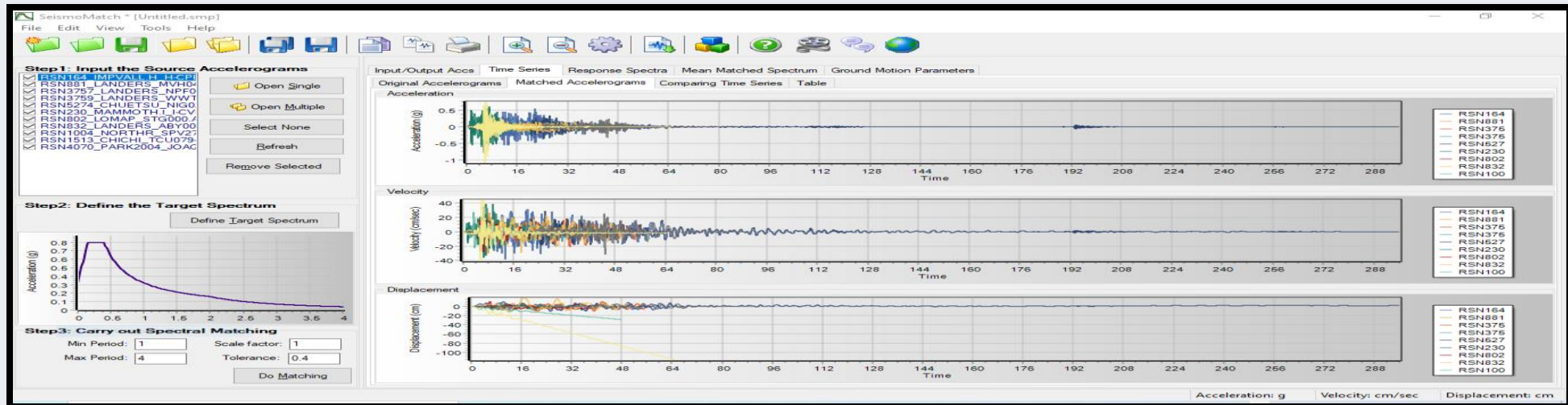
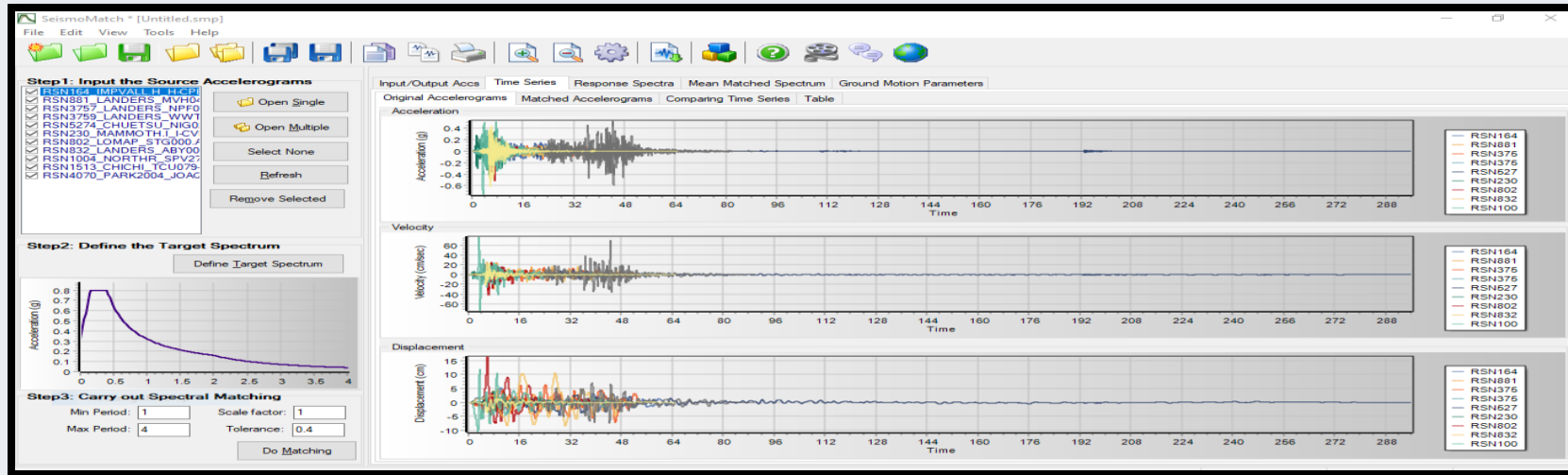


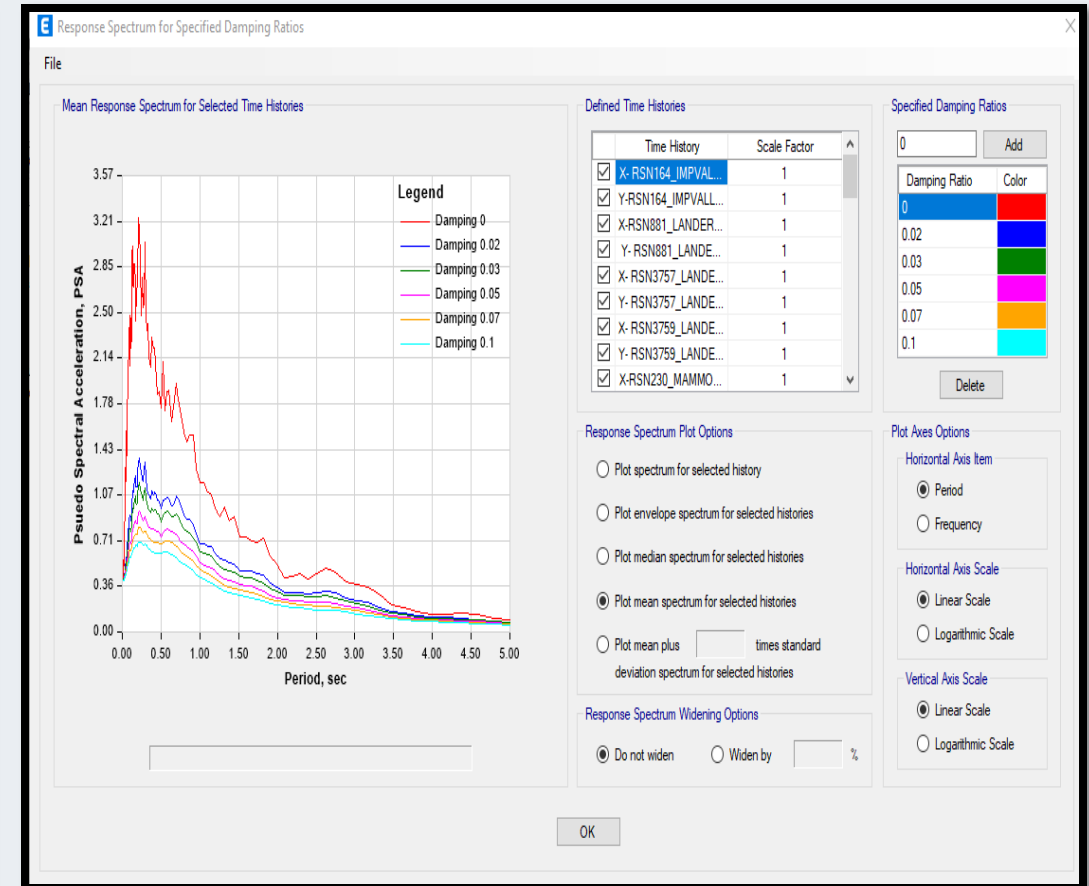
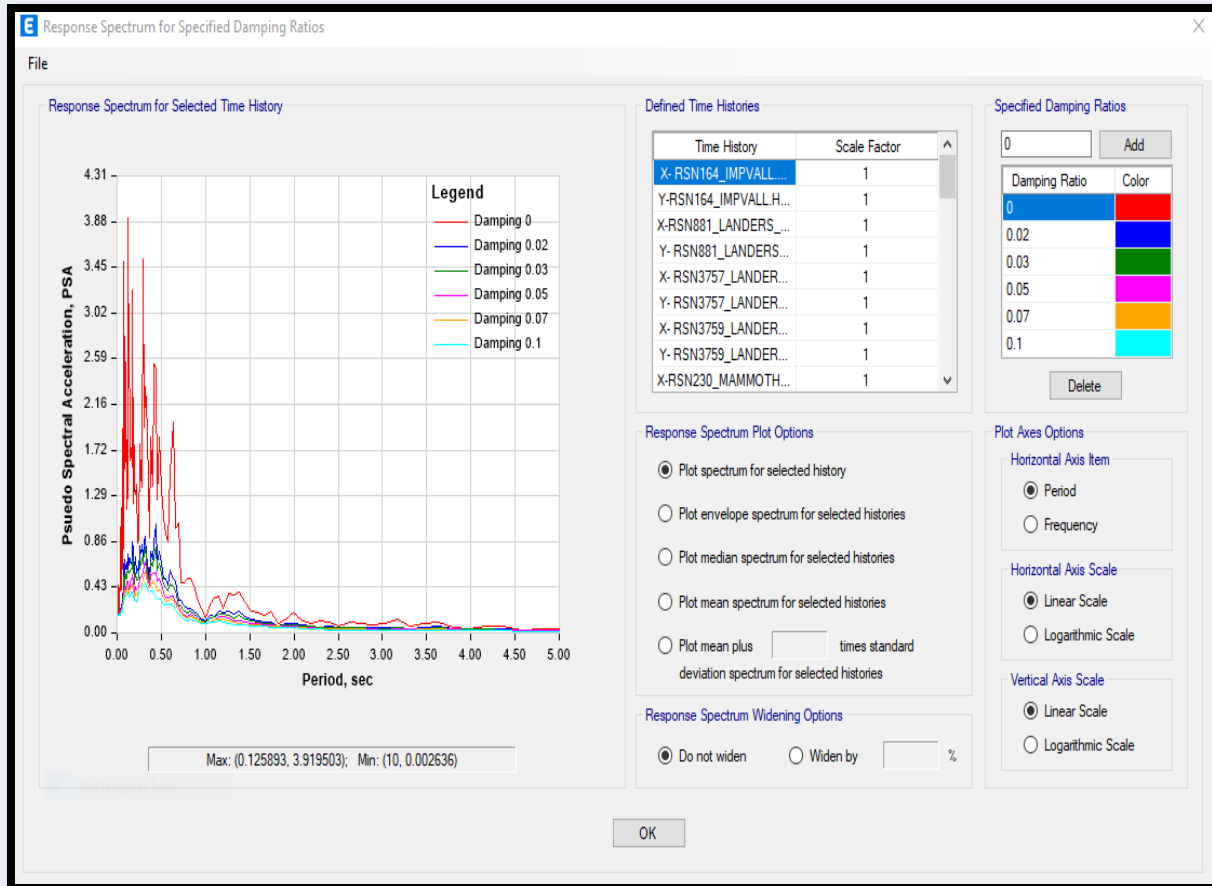
Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.





Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.





Uniform Hazard Spectrum vs Conditional Mean Spectrum

Uniform Hazard Spectrum (UHS)

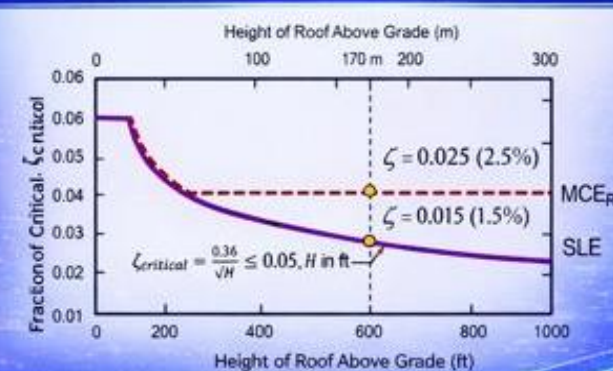
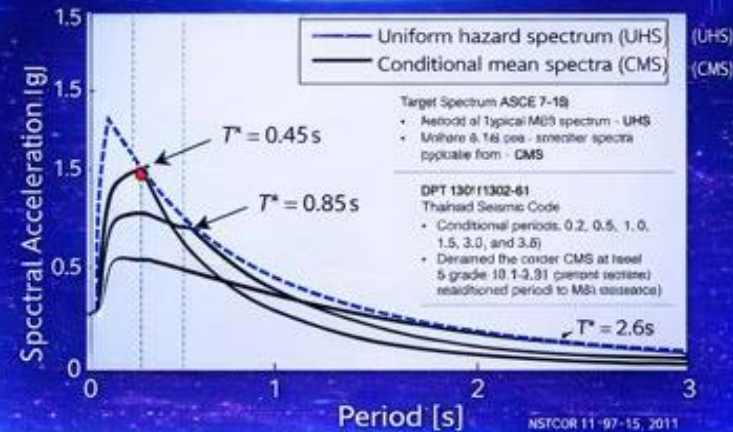
- UHS has the same probability of exceedance at all periods from consideration of many scenarios of earthquakes.
- The spectral shape of the UHS may not resemble the spectral shape of a real ground motion.
- The UHS is a conservative target spectrum for seismic analysis of buildings, especially for very rare levels of ground motion.
- Only a single set of UHS spectral matching ground motions is used to compute design force and displacement demands.

Conditional Mean Spectrum

- The CMS will match the ordinate of the UHS **only** at the interested periods.
- CMS can yield a more realistic spectral shape of earthquakes.
- Multiple sets (two or more) of CMS ground motions at **different periods** are required the inelastic dynamic responses (design force and displacement demands) of the buildings.
- The design demand values are obtained by enveloping the **mean values** or peak demands from analysis using CMS conditioned at different periods.

Code Updates: ACI Releases AC318-19, Building Code Requirements for Structural Concrete
by Jack P. Moehle, Ph.D., P.E.

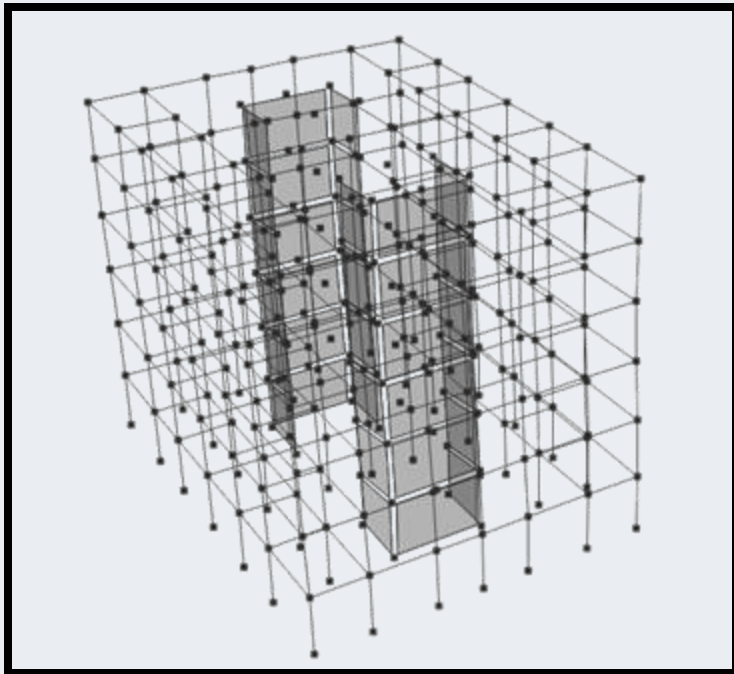
Target Response Spectrum (UHS vs CMS)



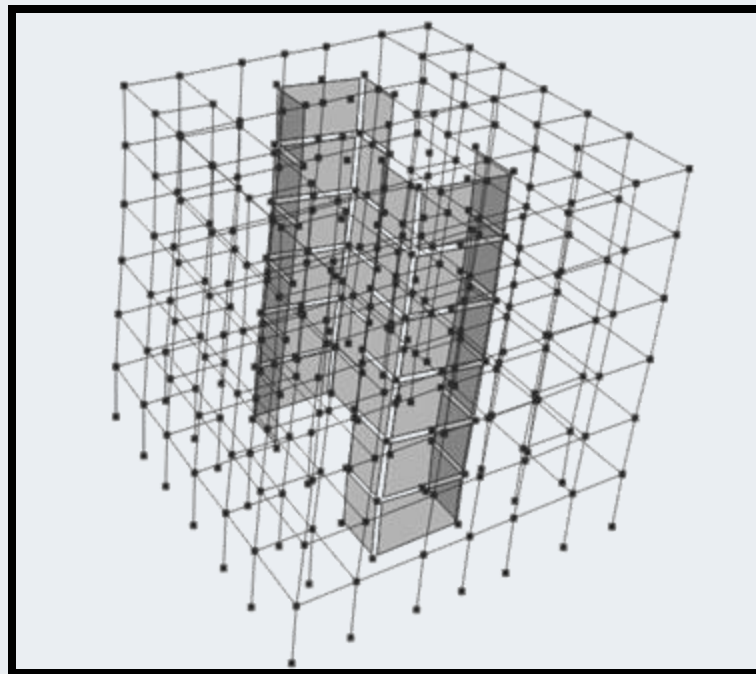
PART III - STRUCTURAL EVALUATION LOCAL AND GLOBAL RESPONSES

STRUCTURAL EVALUATION – GLOBAL RESPONSE

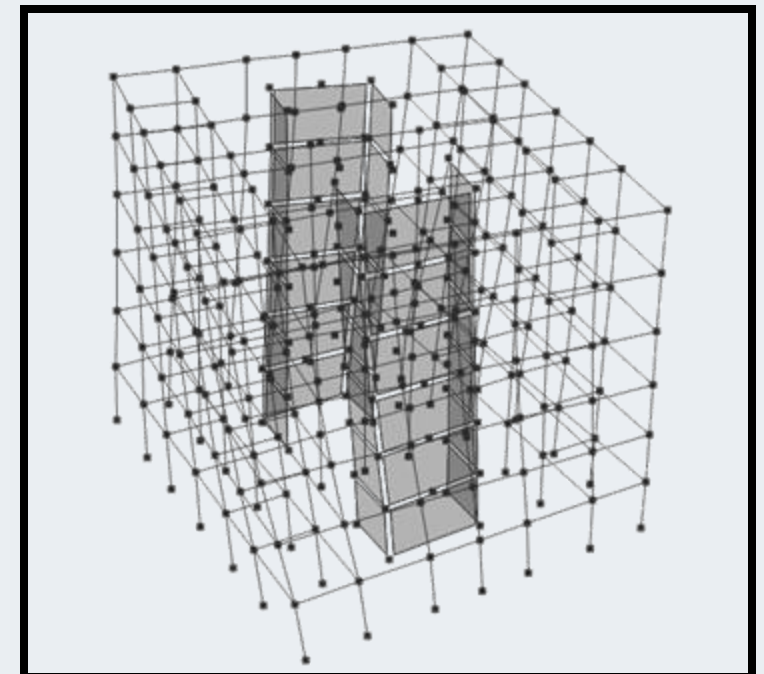
Modal Analysis Result



T_1 (Translation X)

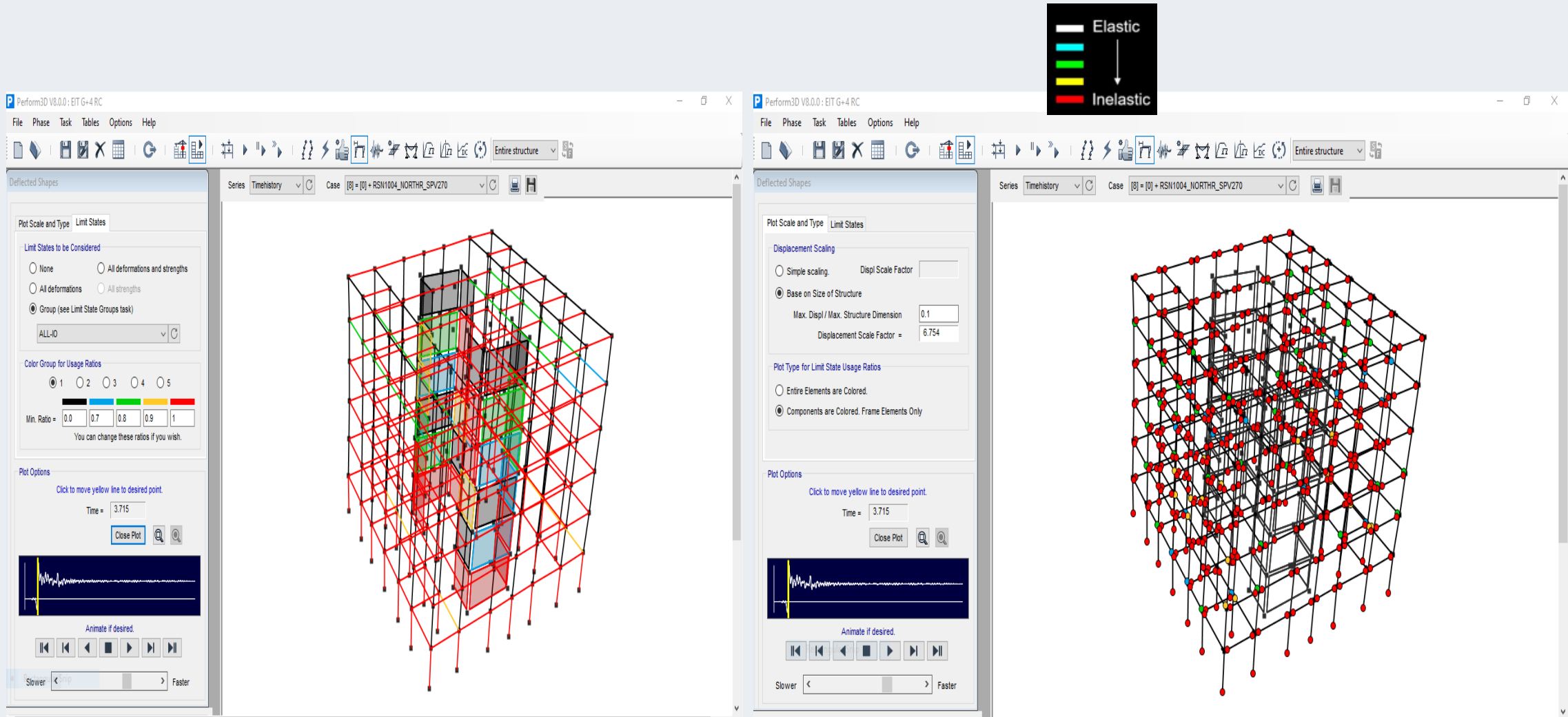


T_2 (Translation Y)

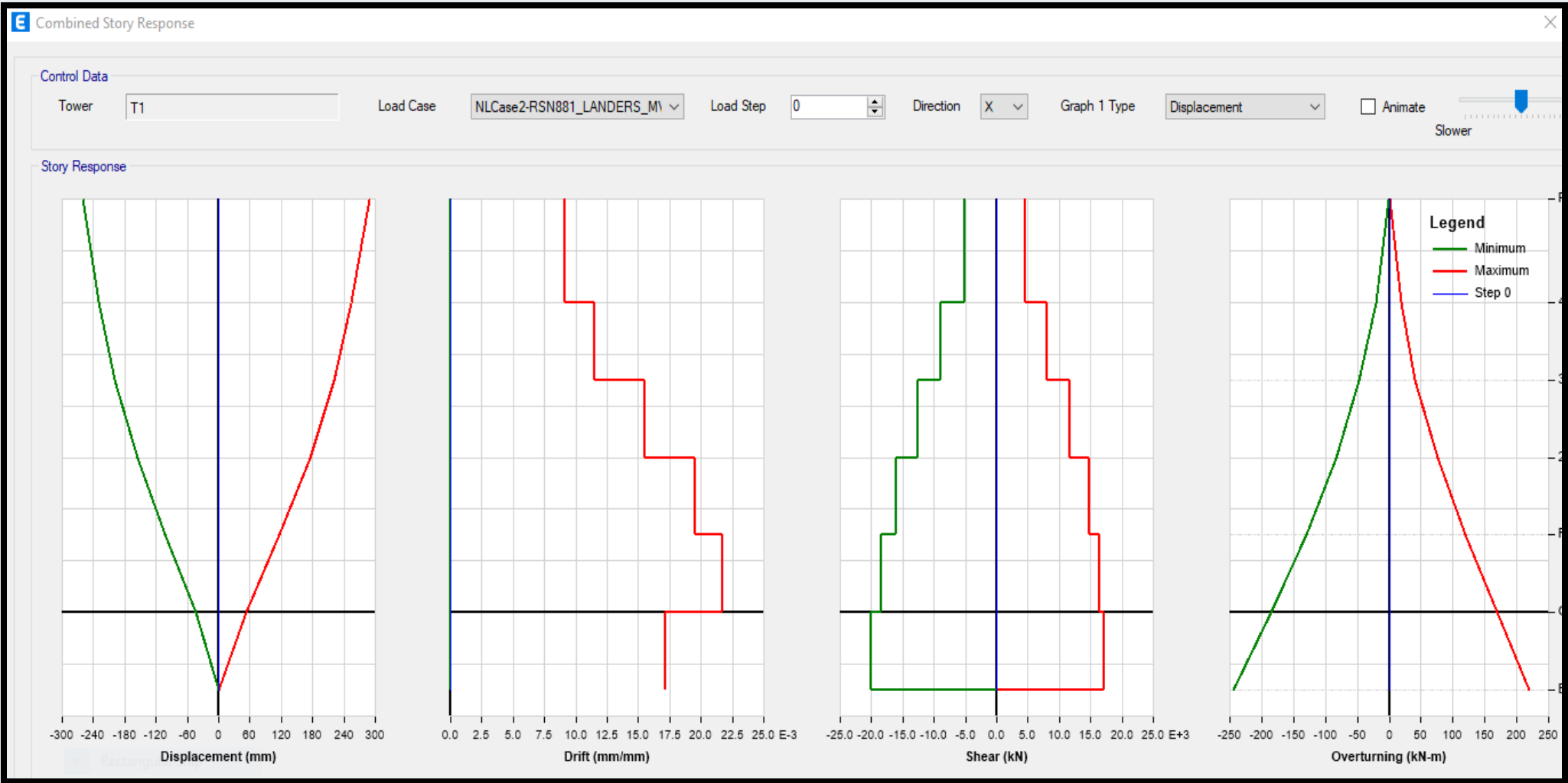


T_3 (Torsion)

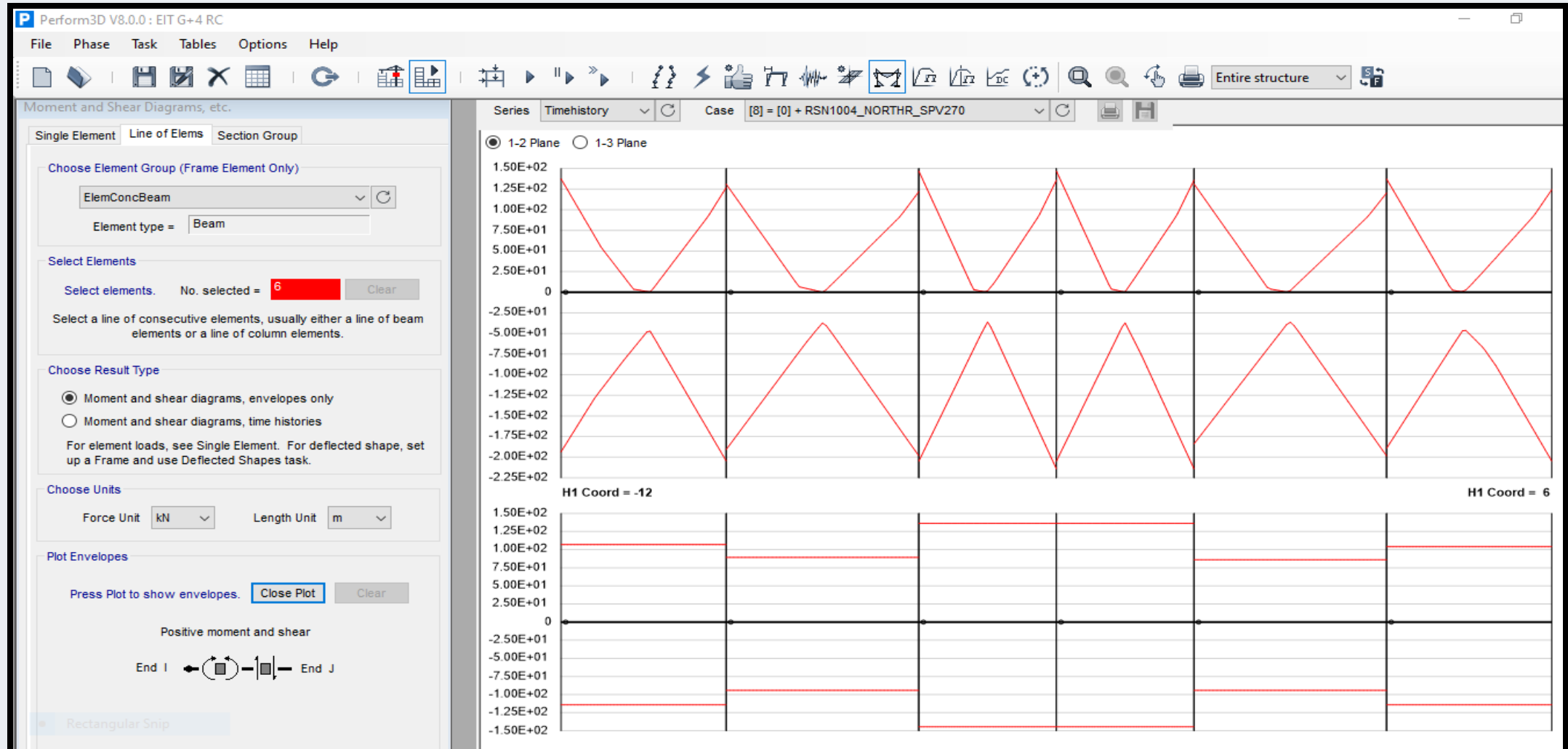
Nonlinear Time-History Analysis



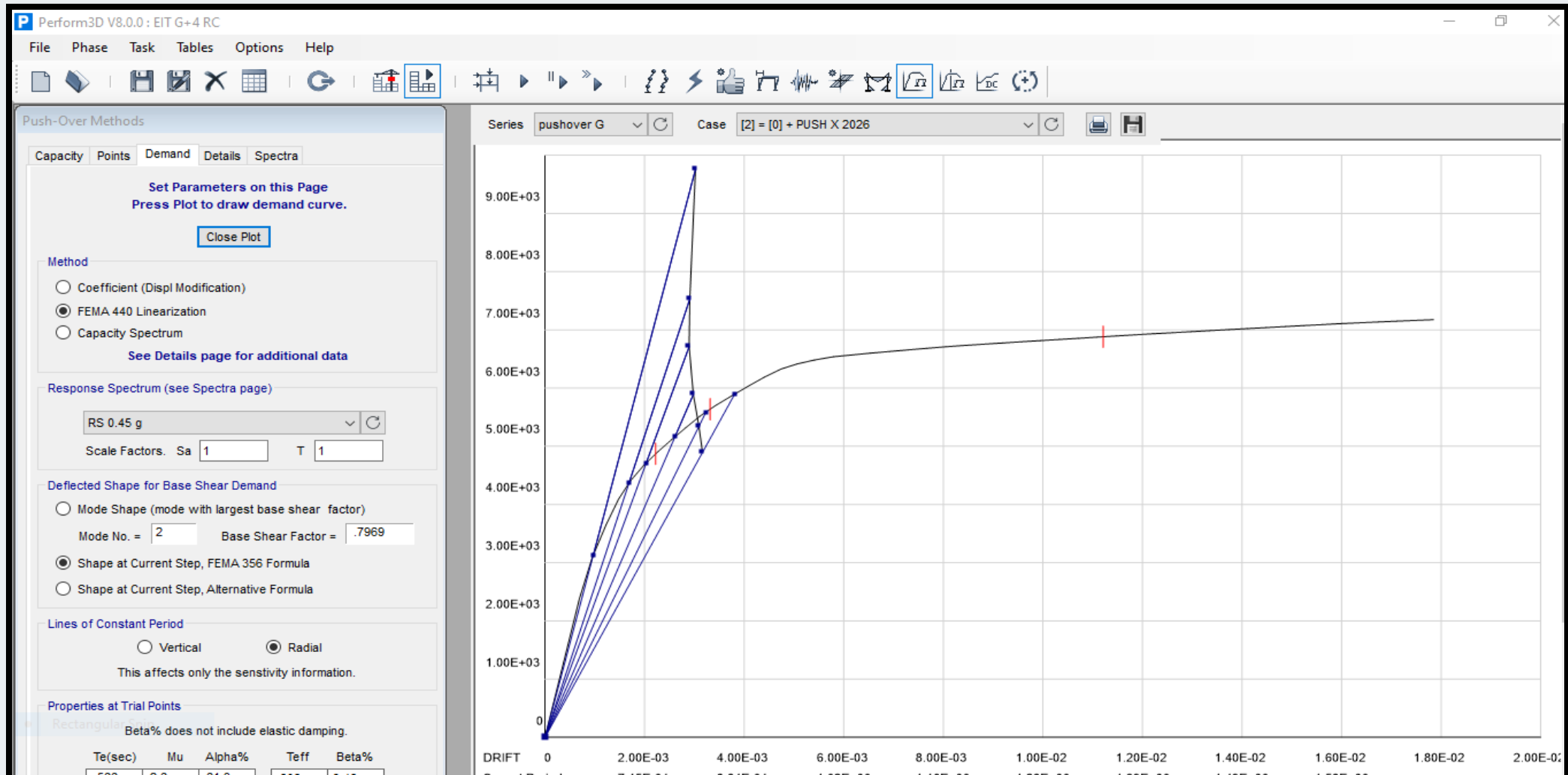
Global Response Plot ETABS RESULT



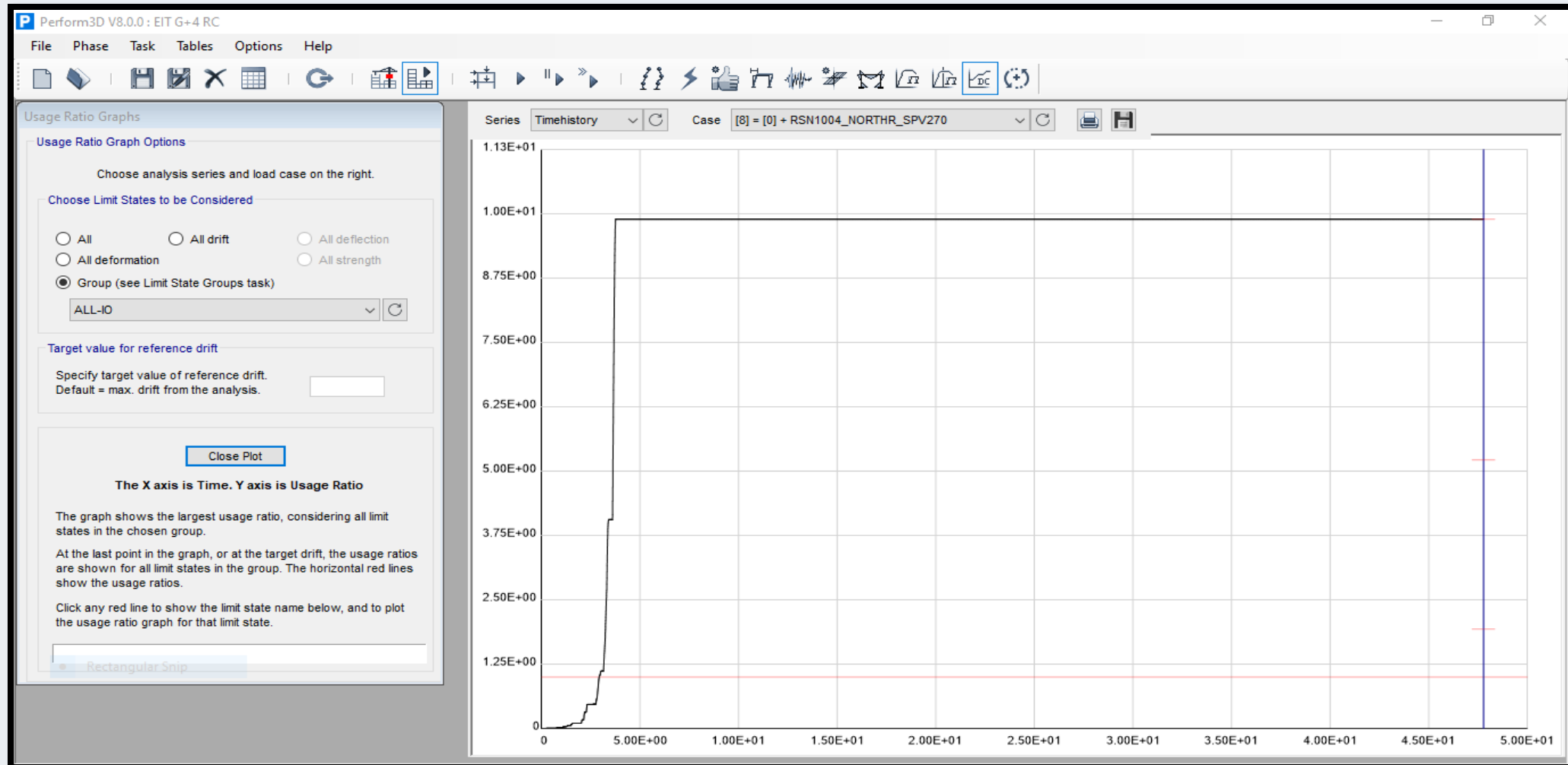
PERFORM 3D RESULT



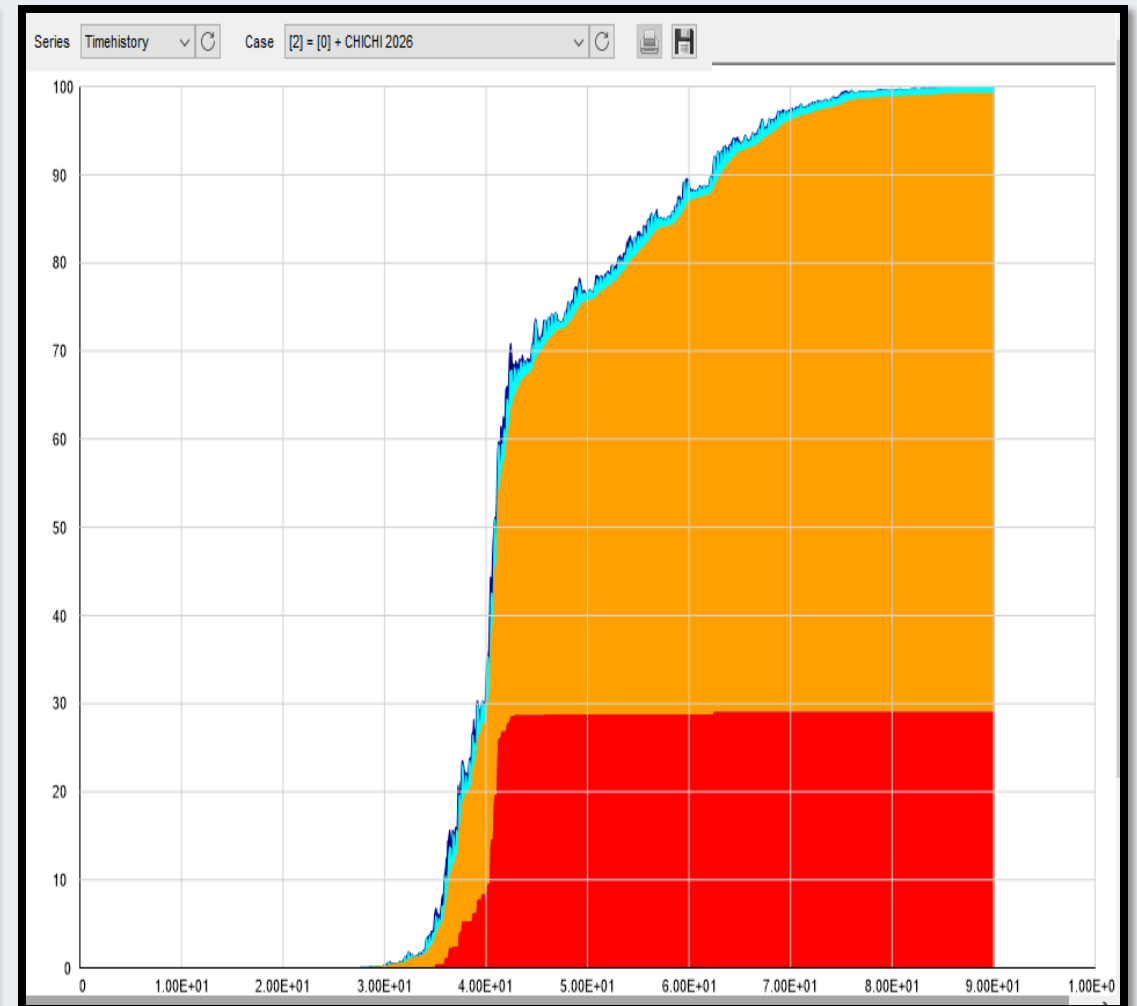
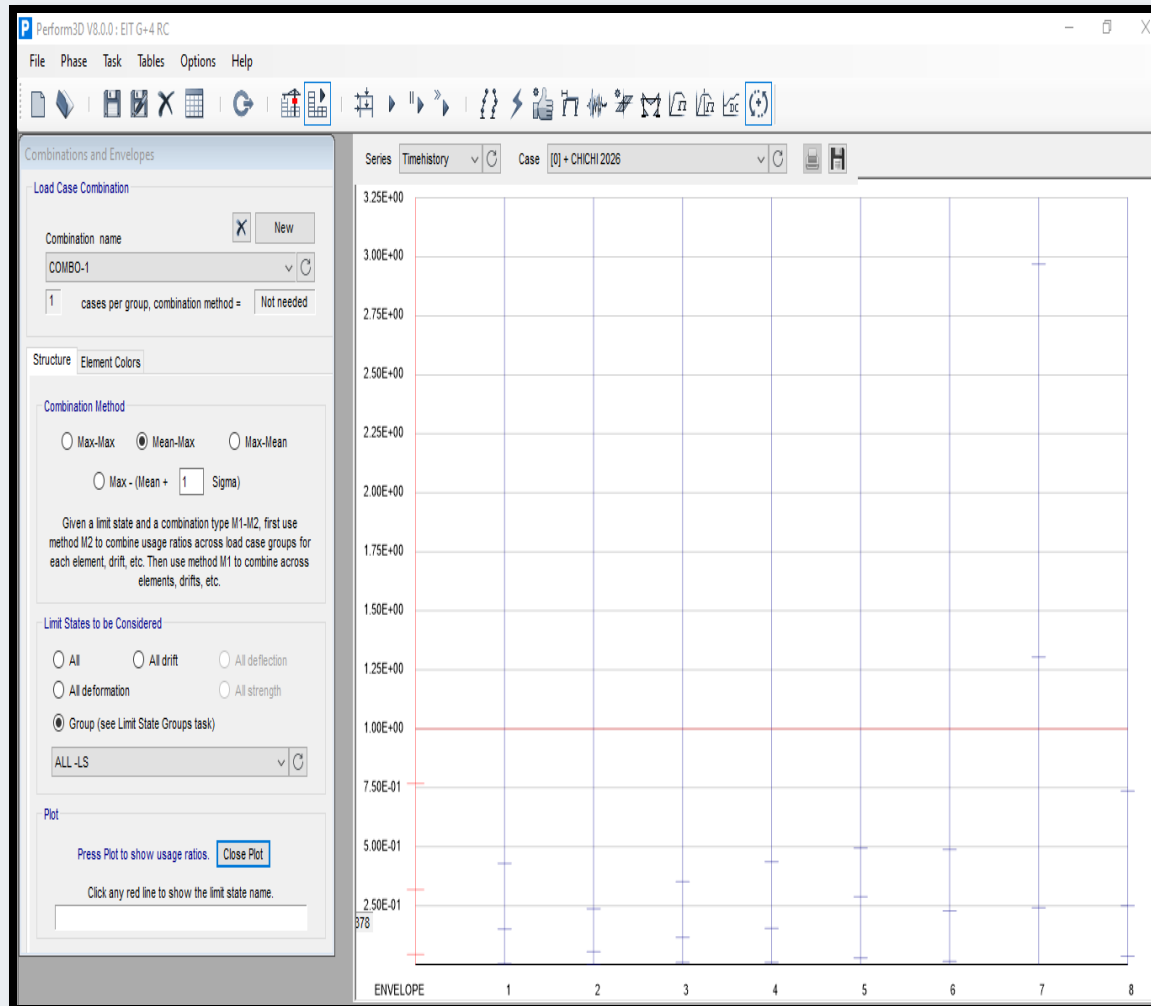
PERFORM 3D PUSHOVER CURVE RESULT



PERFORM 3D D/C RATIO RESULT



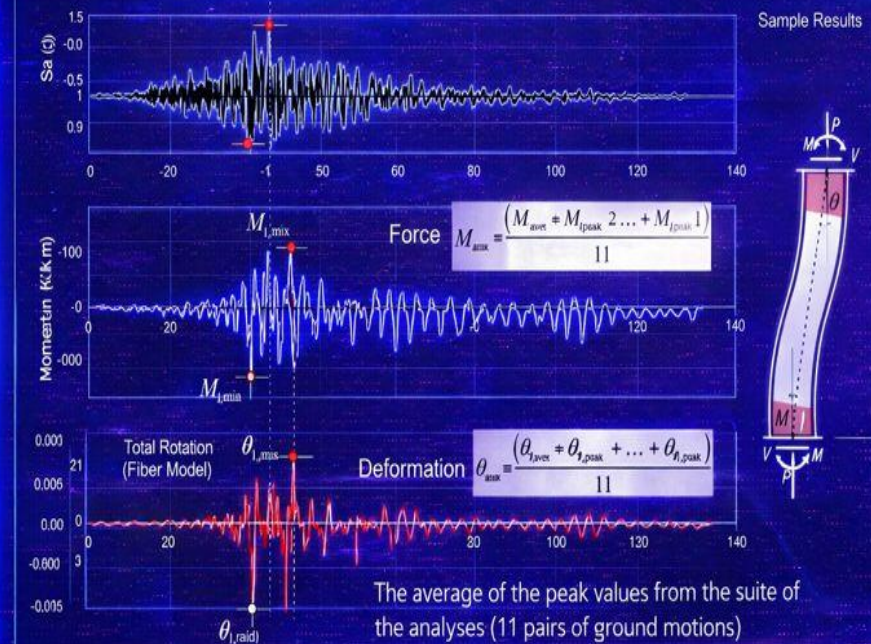
PERFORM 3D D/C RATIO



Evaluation of Local Responses

No.	Component	Action	Modeling	Classification	Response	Acceptance
1	Shear Wall	Axial-Flexure	Inelastic behavior (Fiber section)	Deformation controlled	Axial strain	Yielding = 0.002 Crushing = 0.003
2	Column	Axial-Flexure	Inelastic behavior (Fiber section)	Deformation controlled	Rotation	ASCE 41
3	Beam	Flexure	Elastic behavior (Modified stiffness)	Force controlled	Shear	ACI 318
4	Beam	Flexure	Inelastic behavior (Moment hinge)	Deformation controlled	Rotation	ACI 318
5	Beam	Shear	Elastic behavior (Modified stiffness)	Force controlled	Shear	ACI 318
6	Coupling Beam	Flexure	Inelastic behavior (Moment hinge)	Deformation controlled	Rotation	ASCE 41
5	Slab (EQ Slab Beam)	Shear	Inelastic behavior (Shear hinge)	Deformation controlled	Shear	ASCE 41

Output Data Processing

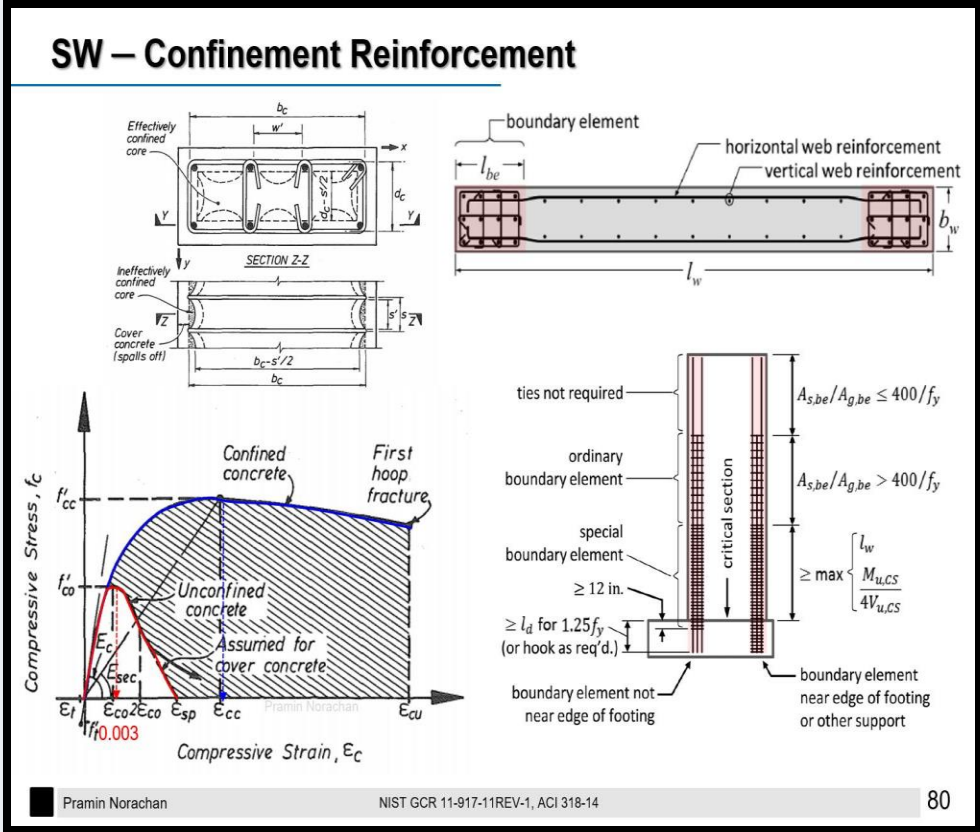
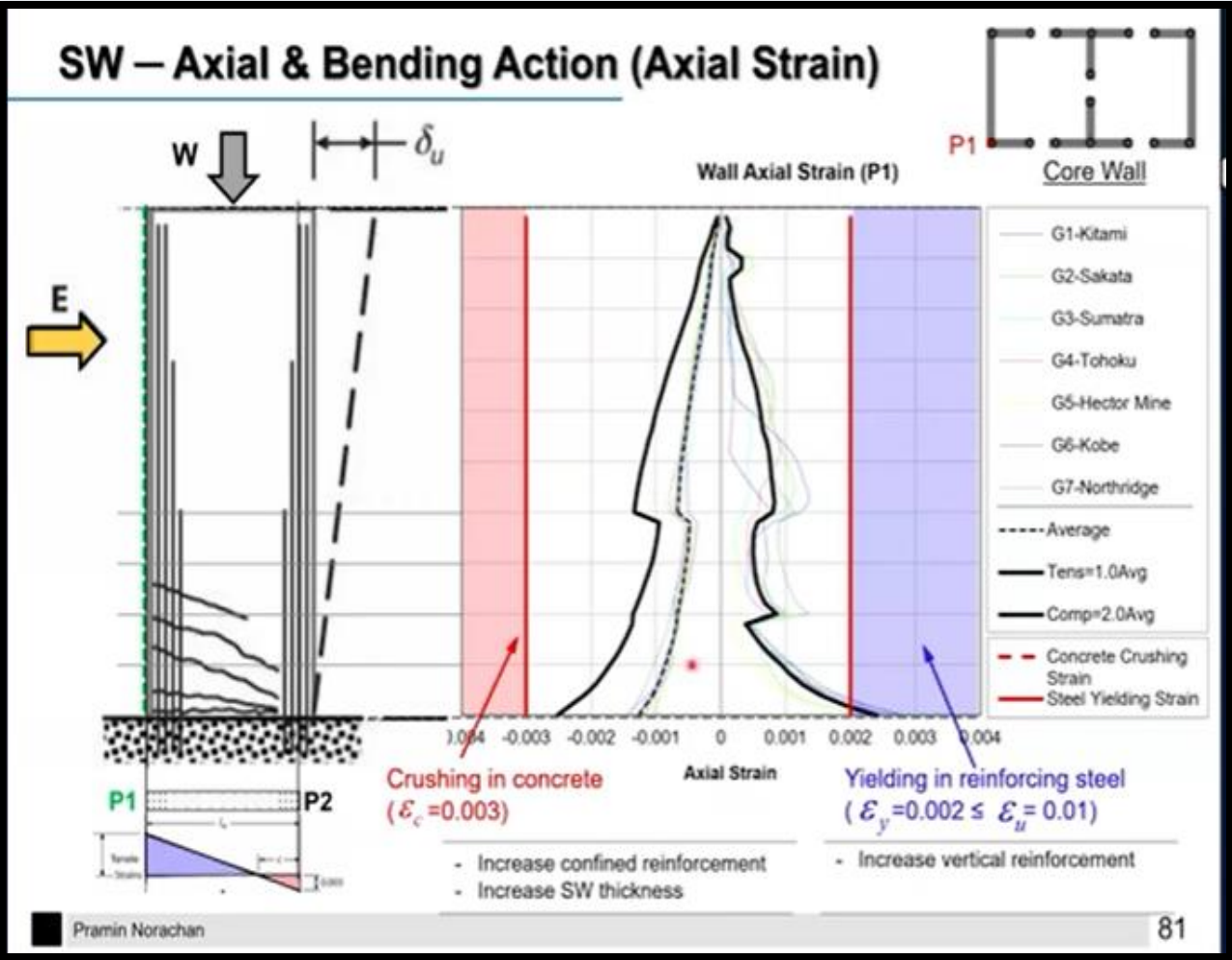


Reference: ASCE 41-17; FEMA 356; FEMA P695 ,2009 ATC-40; Eurocode 8 (EN 1998-1); ACI 318-19; CSI PERFORM-3D; PEER Database; AIT, CSI Bangkok.

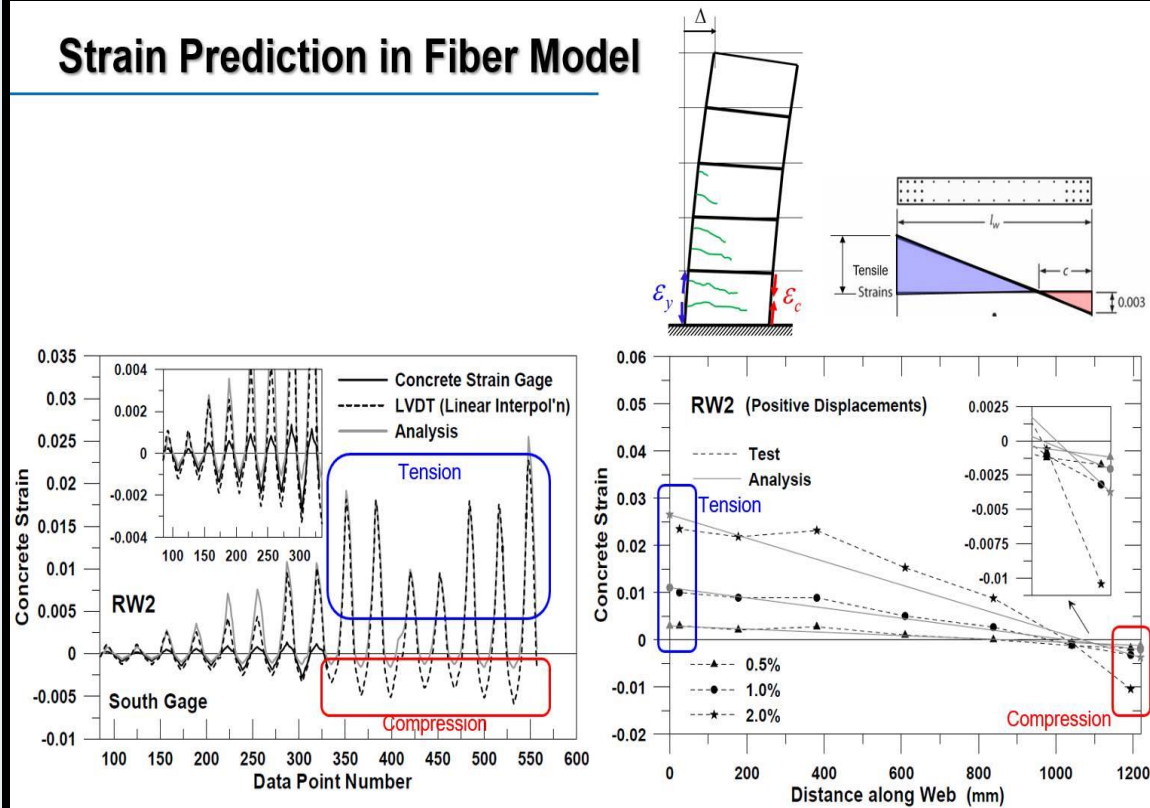
Part IV – Sample PBD Results: Structural Evaluation – Global Response Trends Among Researchers

SAMPLE PBD RESULT 2- STRUCTURAL EVALUATION

– GLOBAL RESPONSE



Strain Prediction in Fiber Model

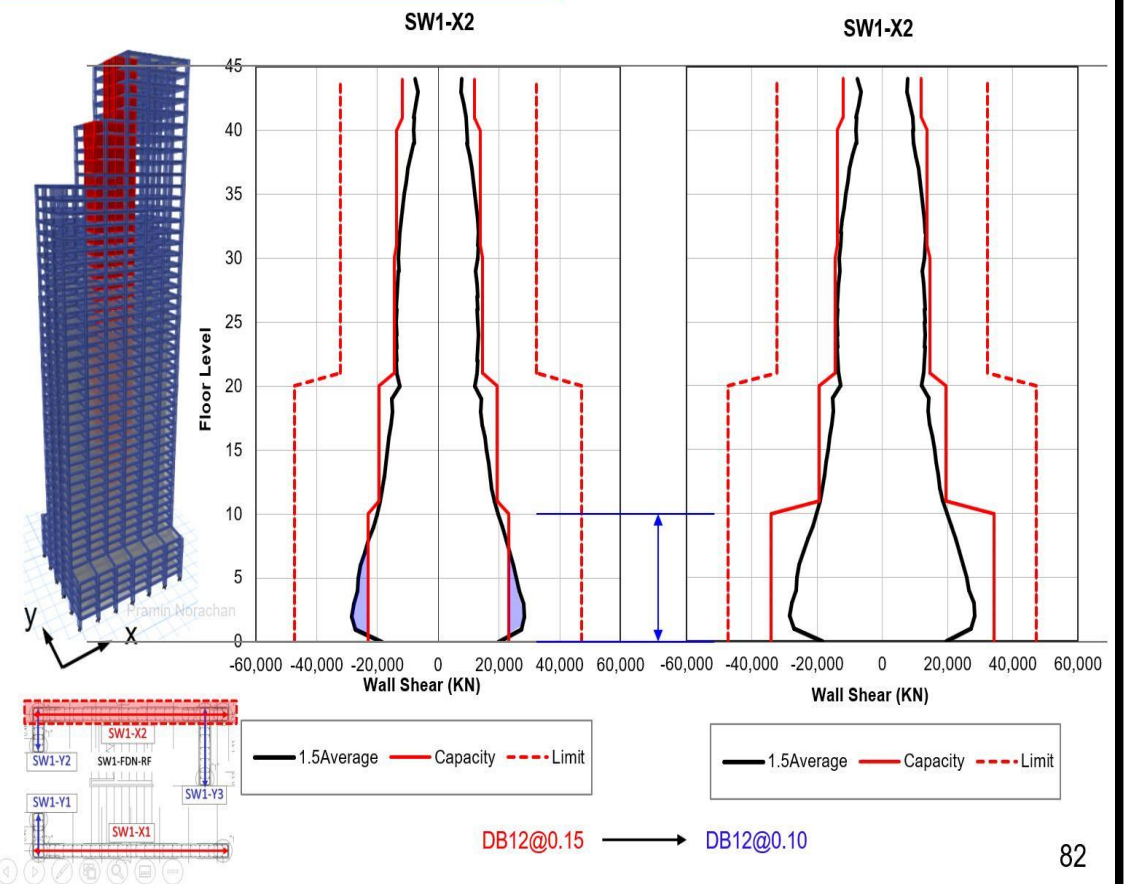


Comparison of measured versus modeled average strain in a rectangular wall section.

Curvature profiles for a rectangular wall section at three levels of Drift.

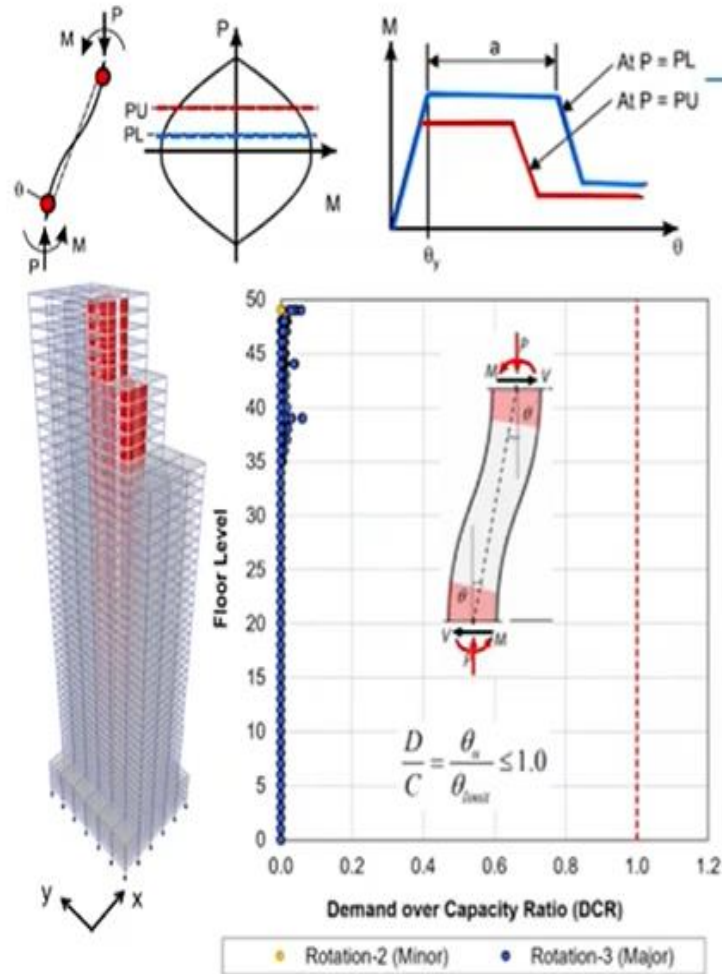
SW – Shear

Sample Results

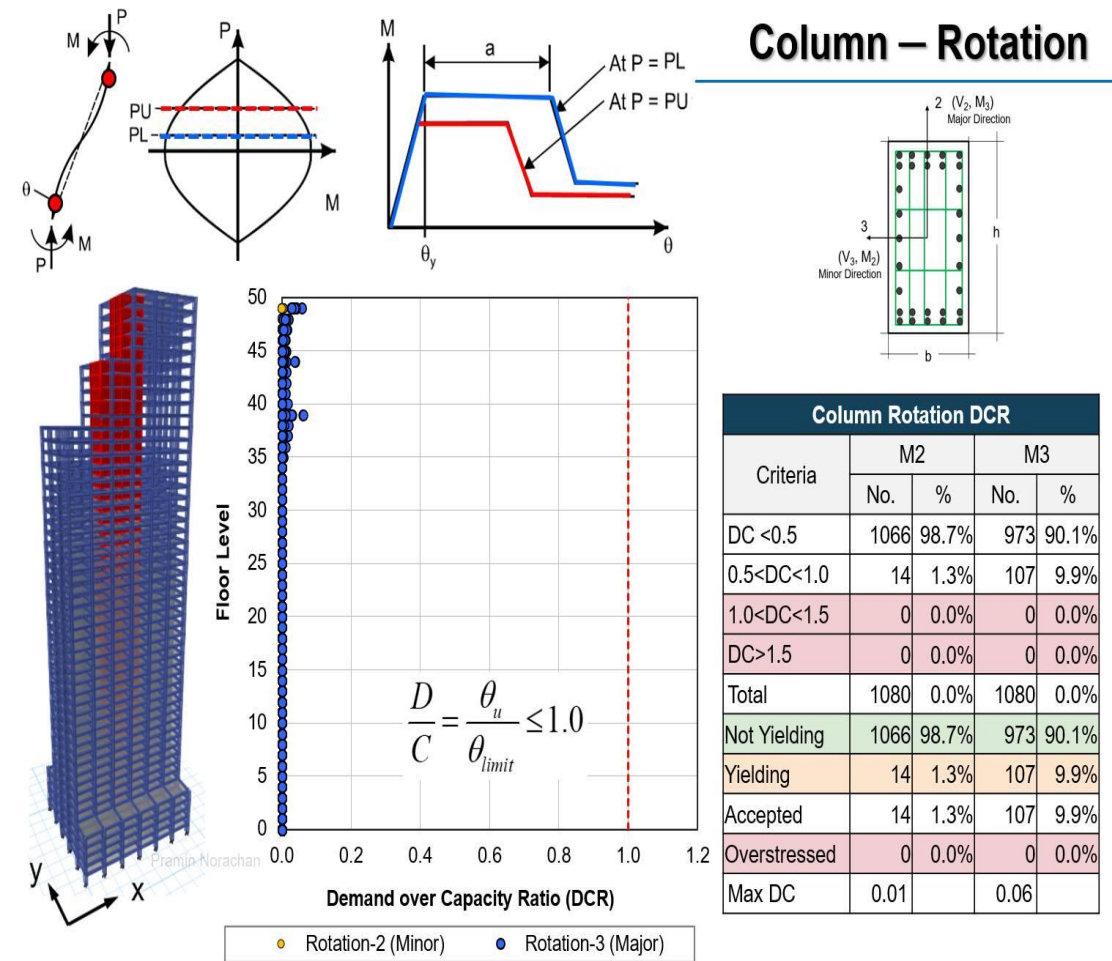


DB12@0.15 → DB12@0.10

Column – Rotation



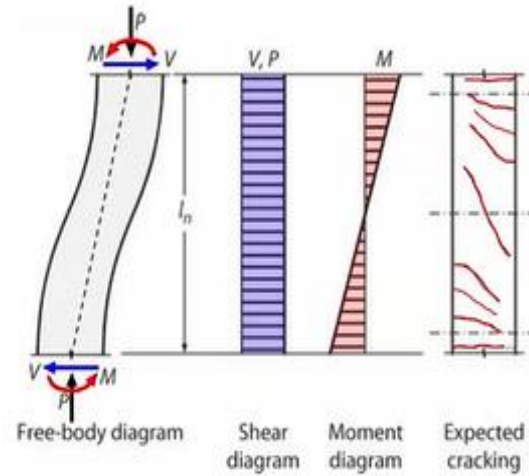
Column – Rotation



Column Rotation DCR

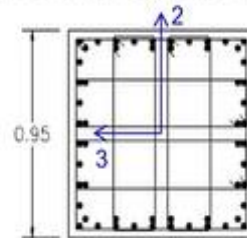
Criteria	M2		M3	
	No.	%	No.	%
DC < 0.5	1066	98.7%	973	90.1%
0.5 < DC < 1.0	14	1.3%	107	9.9%
1.0 < DC < 1.5	0	0.0%	0	0.0%
DC > 1.5	0	0.0%	0	0.0%
Total	1080	0.0%	1080	0.0%
Not Yielding	1066	98.7%	973	90.1%
Yielding	14	1.3%	107	9.9%
Accepted	14	1.3%	107	9.9%
Overstressed	0	0.0%	0	0.0%
Max DC	0.01		0.06	

Column – Shear

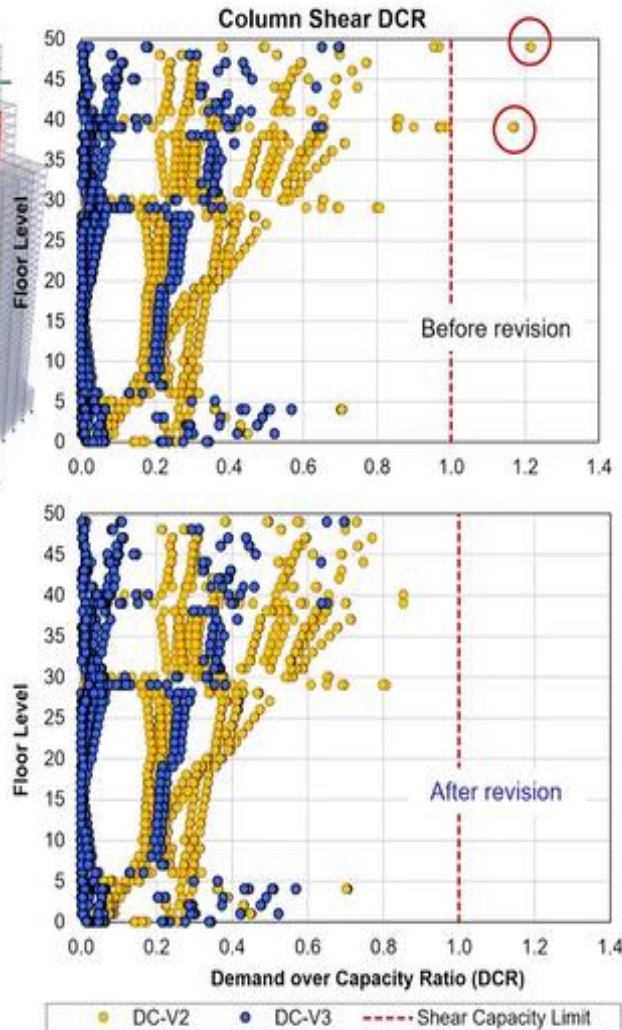


$$\frac{D}{C} = \frac{V_u}{\phi_s B V_n} \leq 1.0 \quad \phi V_n = \phi V_c + \phi V_s$$

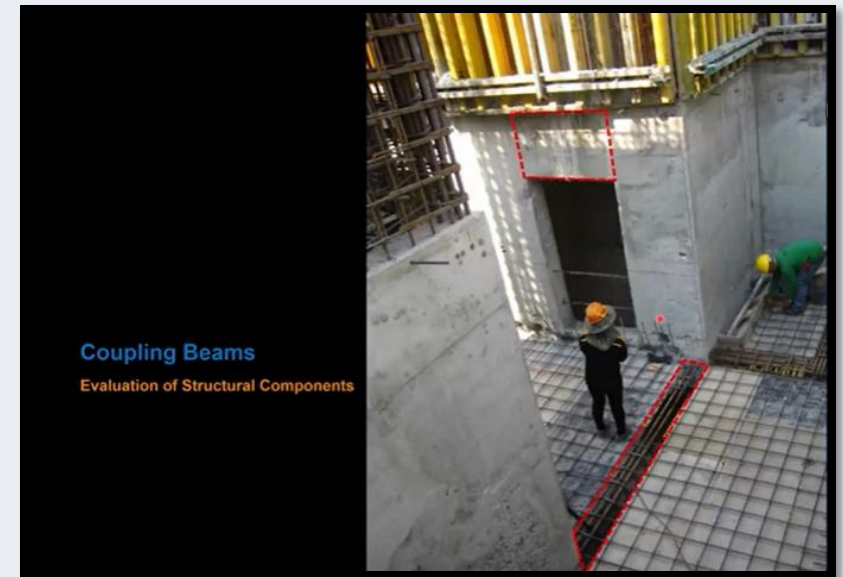
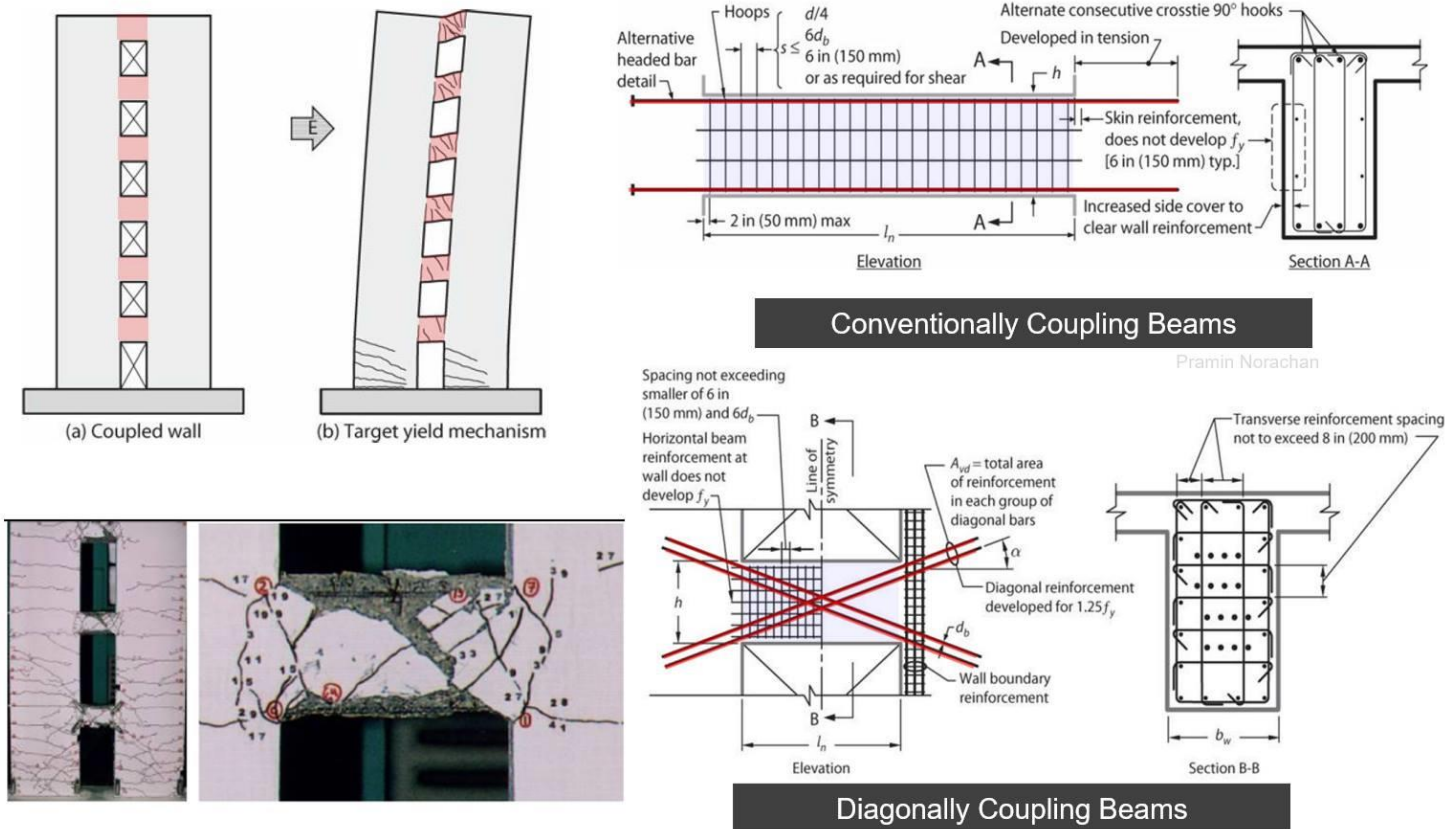
Shear demand is greater than shear capacity ($DC > 1.0$)



Increase shear reinforcement
56DB20mm
5-DB12mm@0.30
@0.25

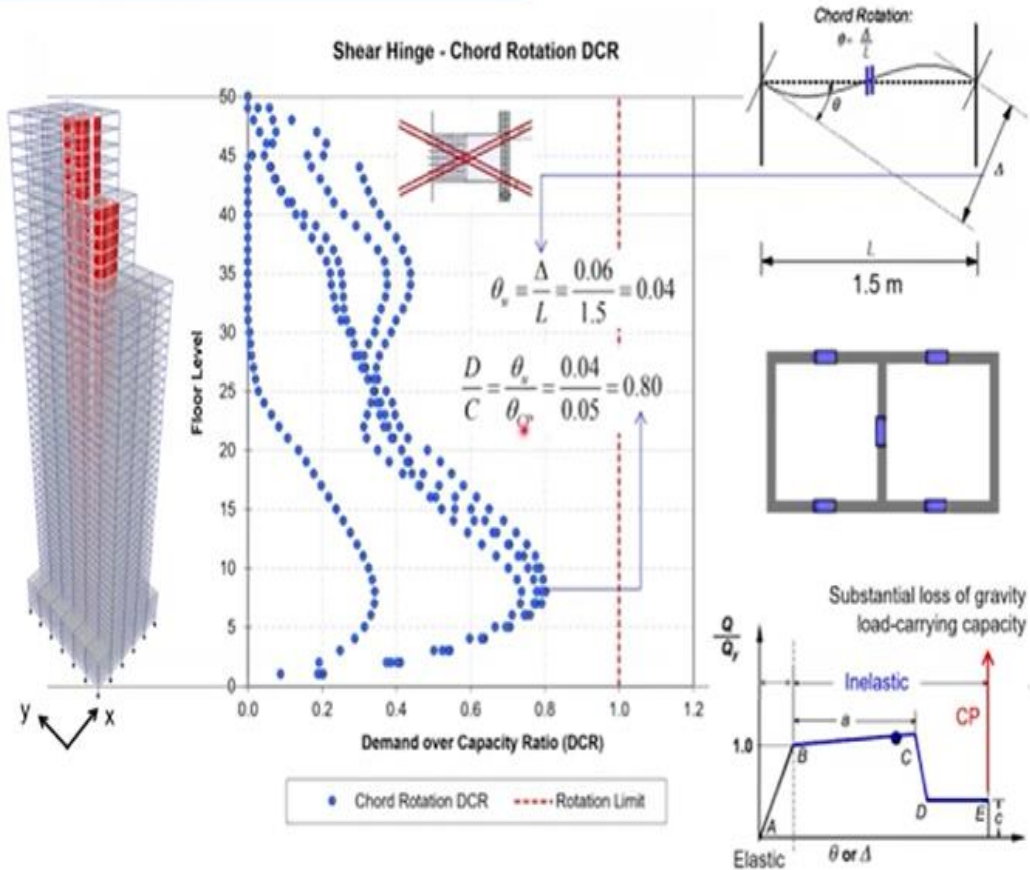


Coupling Beams



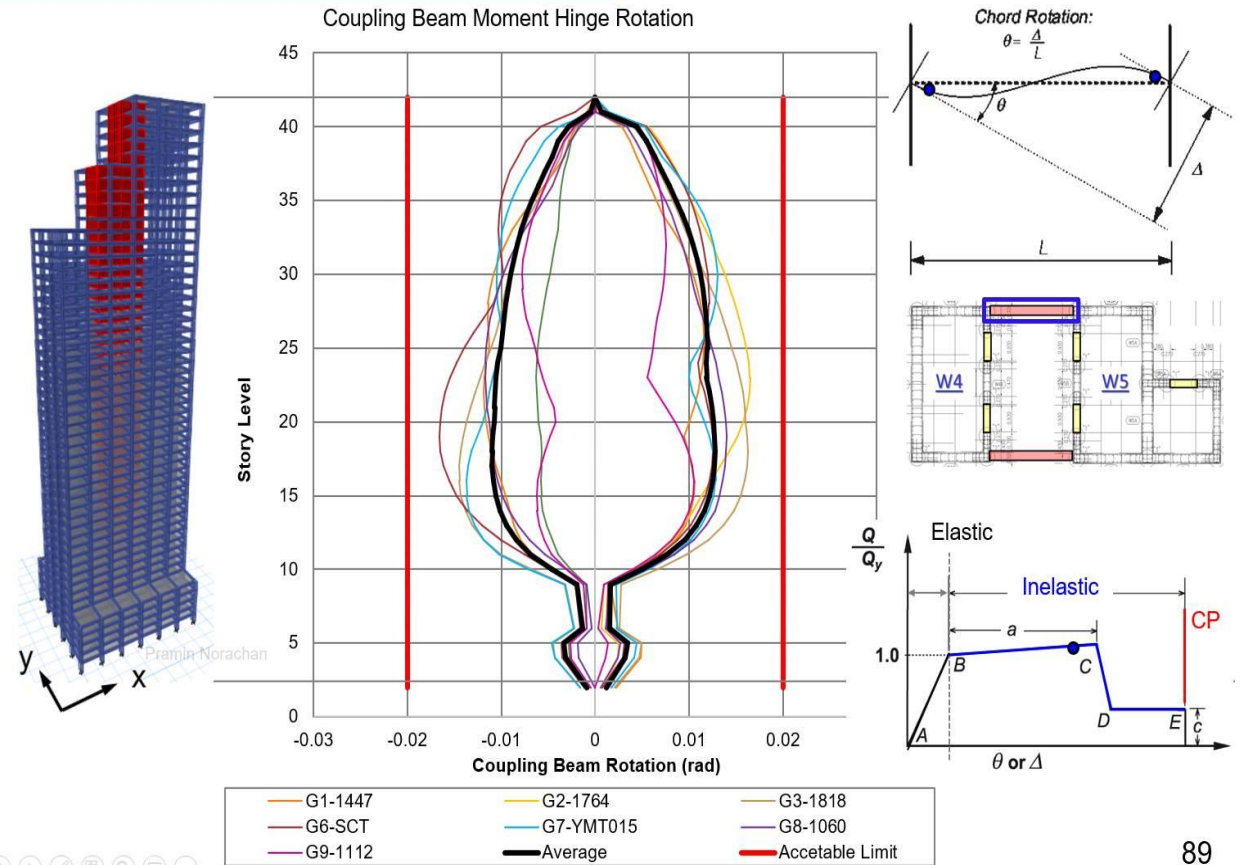
Coupling Beams – Rotation DCR

Sample Results

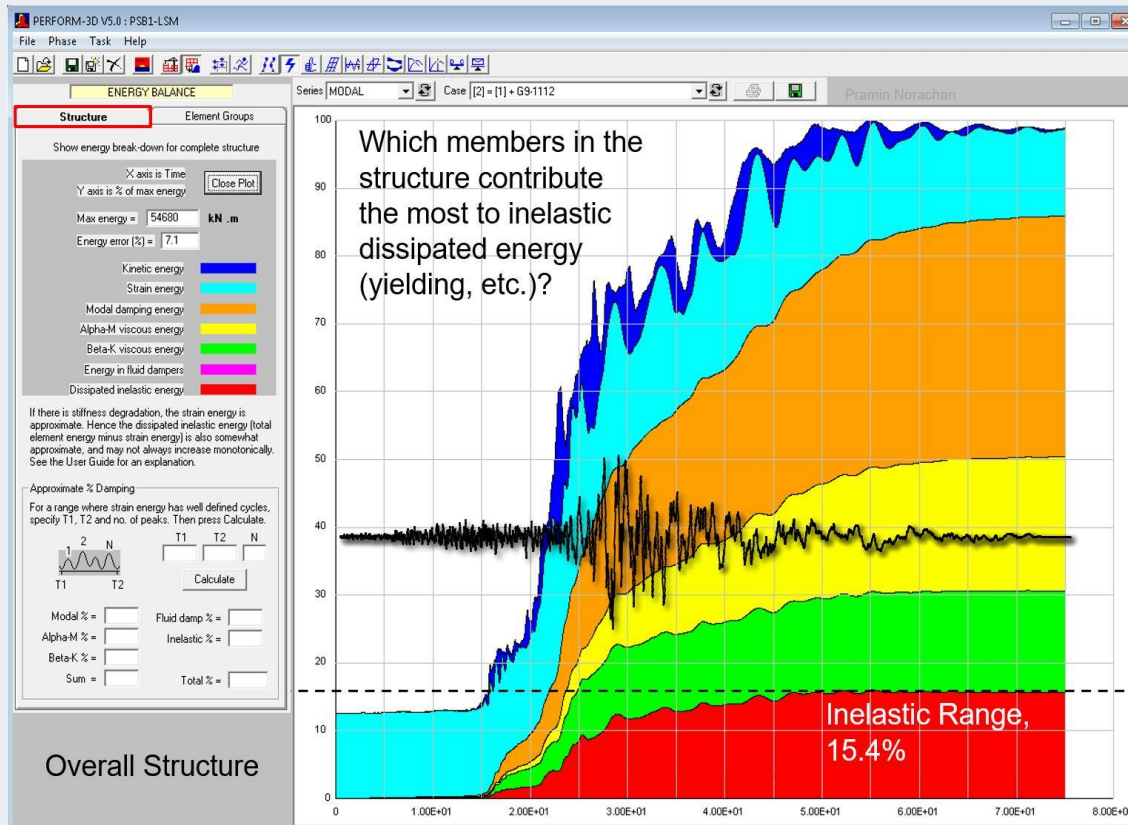


Coupling Beams – Rotation

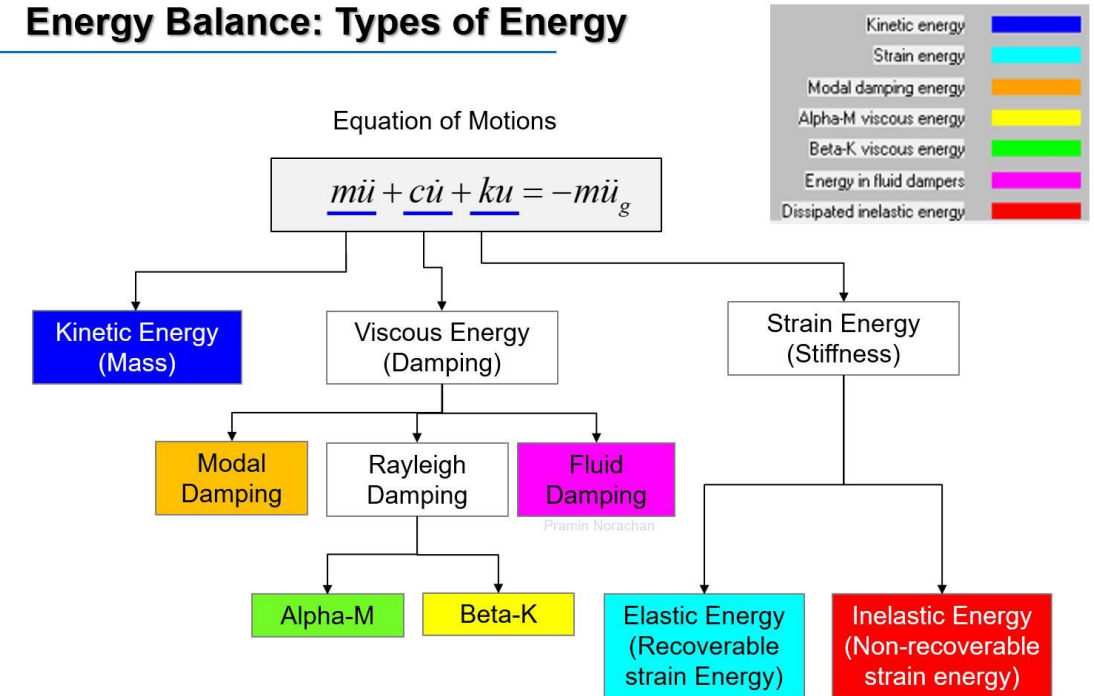
Sample Results



89



Energy Balance: Types of Energy



Advantages and Disadvantages of Performance-Based Seismic Design (PBSD)

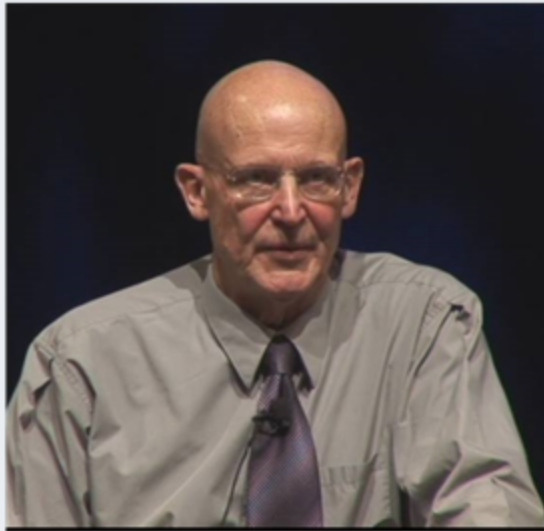
Advantages

- More reliable achievement of the intended seismic performance
- Suitable for complex buildings (irregular structures or multiple towers on a single podium)
- Allows flexibility beyond some prescriptive code requirements
- Accommodates challenging architectural features
- Enables the use of innovative structural systems and materials

Disadvantages

- High computational effort due to nonlinear modeling and complex analysis procedures
- Requires preliminary design (often starting with code-based design)
- Time-consuming analysis and design process
- Requires significant computational resources and data processing

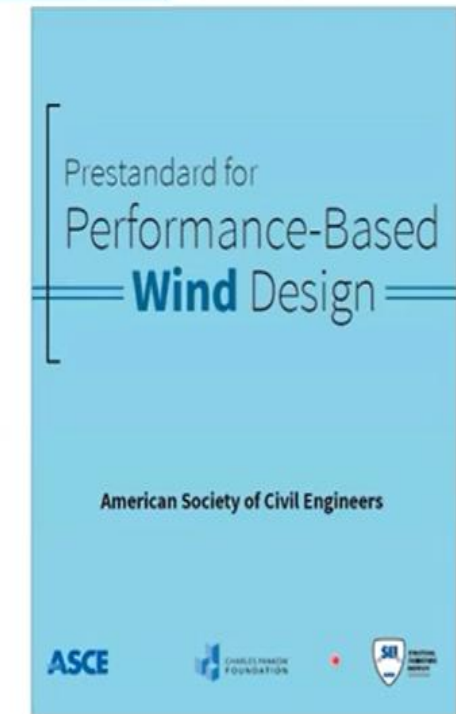
Conclusions



PERFORM-3D is an ideal tool for nonlinear performance-based analysis and design, created by **Dr. Graham H. Powell**, University of California at Berkeley Professor Emeritus of Civil Engineering.

- Estimating the **inelastic properties** for a **real component** is **not a simple task**.
- It may be tempting to argue that since the **inelastic properties** are so **uncertain**, there is little point in using inelastic analysis, and **elastic** analysis should be **sufficient**.
- If there is **substantial inelastic behavior** in an actual structure, the results of an elastic analysis may be of **uncertain value for making design decisions** and may even be misleading.
- As a tool for obtaining information for design, even a **crude inelastic model** can be more useful than an **elaborate elastic model**.
- **Please keep in mind that the goal is to get useful information for design, not to calculate "exact" response.**

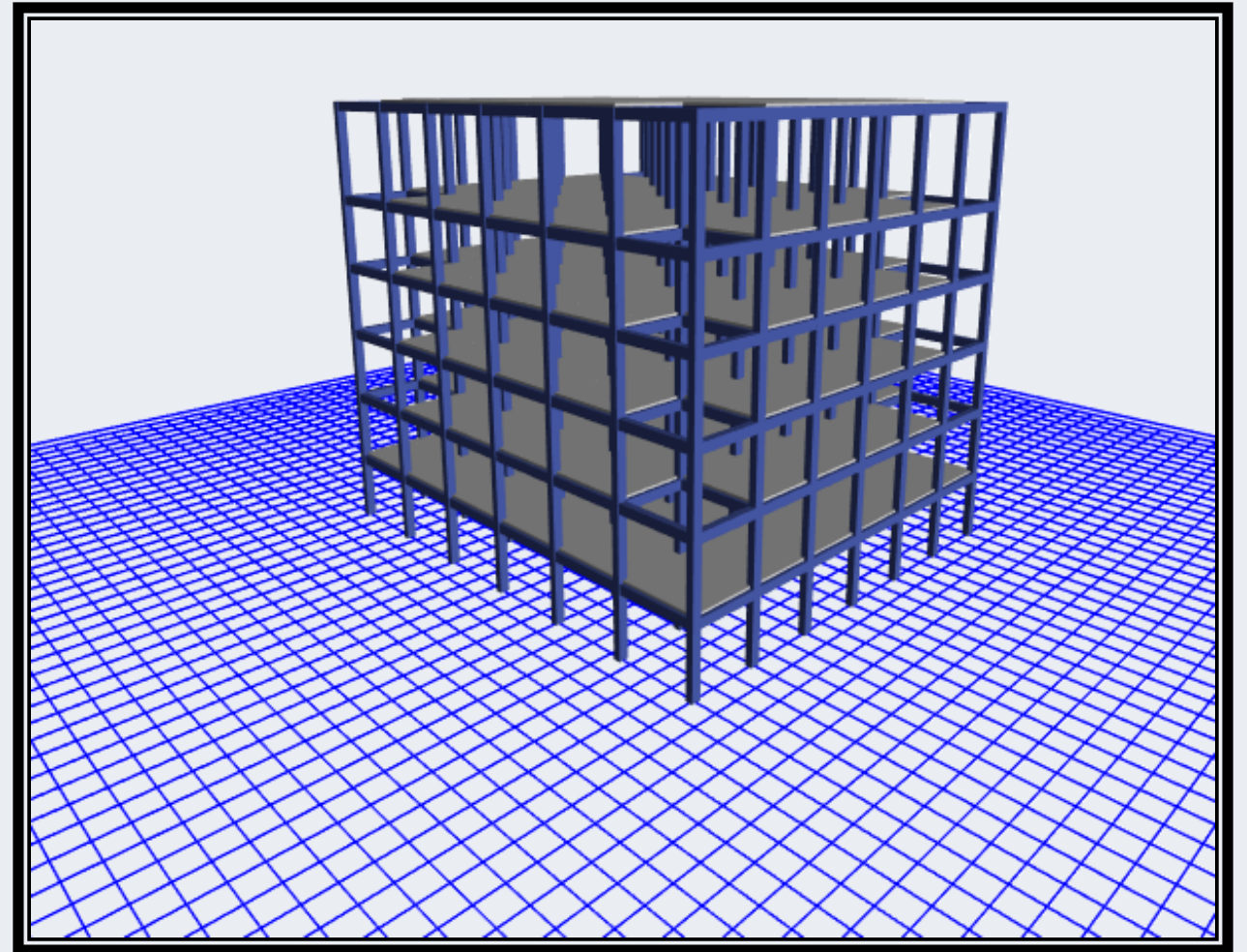
The Future of Tall Building Design



Papers published and incorporated with the overall Thesis Proposal

1. A Comparative Performance Based Analysis and Design of 44 Stories RC Building Based on EN1998-1 Building Code. .
[*published at MDPI*]
2. Comparative Response Spectrum Analysis on 15 Story Reinforced Concrete buildings having shear walls with and without openings as per EN1998-1 seismic code. [*Published :Proceedings of the 45th AUBEA Conference, 23-25 Nov. 2022, Western Sydney University, Australia*].
3. The seismic performance of 50 story R.C. building having a shear wall with and without opening under Eleven Earth quakes, including 1979 "Imperial Valley-06"-U.S. Earth Quake extracted from PEER website.
4. Comparative Analysis of G+20 RC Building Utilizing Static and Dynamic Analysis as Per Eurocode 8-2004 Standards.[*Accepted and will be published soon at the 46th Australasian Universities Building Education Association (AUBEA 2023) Conference*]
5. A comparison on Energy Dissipation Mechanism of SPO Analysis and NLTHA for 44 Story RC Building.
[*published at International Journal for Modern Trends in Science and Technology*]
6. A Comparison of Static and Dynamic Analysis of RC Buildings as per Norwegian and Ethiopia ES8-15 Corresponds to Eurocode 8-2004 Standards (based on EN1998-1) Seismic Code. [*published at MDPI*]
7. A review on challenges and solution in the adoption and use of prescribed RC design codes.
8. Comparative Response Spectrum Analysis on 15- and 50-Story Reinforced Concrete Buildings Having Shear Walls with and without Openings as per EN1998-1 Seismic Code [*published at MDPI*]
9. A Comprehensive Bibliometric Analysis of Global Research Trends in Performance-Based Design Using the Scopus Data-base. [*published at MDPI*]

LET US GO TO PERFORM -
3D, ETABS & SAP 2000
SOFTWARE FOR A LIVE
DEMONSTRATION OF
THE COMPLETE PBD
APPLICATION ON G+4 RC
BUILDING!!!!!!



[Source: CSI (2023). ETABS Documentation. Computers and Structures Inc.]

References

General References (Performance-Based Seismic Design & Codes)

1. ASCE/SEI 41-17 (2017).
Seismic Evaluation and Retrofit of Existing Buildings.
American Society of Civil Engineers, Reston, VA.
2. FEMA 356 (2000).
Prestandard and Commentary for the Seismic Rehabilitation of Buildings.
Federal Emergency Management Agency,
Washington, DC.
3. FEMA 440 (2005).
Improvement of Nonlinear Static Seismic Analysis Procedures.
Federal Emergency Management Agency,
Washington, DC.
4. ATC-40 (1996).
Seismic Evaluation and Retrofit of Concrete Buildings.
Applied Technology Council, Redwood City, CA.
5. Eurocode 8 (EN 1998-1:2004).
Design of Structures for Earthquake Resistance – Part 1: General Rules, Seismic Actions and Rules for Buildings.
European Committee for Standardization (CEN),
Brussels.
6. ACI 318-19 (2019).
Building Code Requirements for Structural Concrete.
American Concrete Institute, Farmington Hills, MI.
7. Chopra, A.K. (2017).
Dynamics of Structures: Theory and Applications to Earthquake Engineering (5th ed.).
Pearson Education.
8. CSI (2023).
ETABS & PERFORM-3D – Integrated Building Design Software Manuals.
Computers and Structures, Inc., Berkeley, CA.
9. PEER Ground Motion Database (2023).
Pacific Earthquake Engineering Research Center.
University of California, Berkeley.
10. LatBSDC (2020).
Latin American Building Seismic Design Code.

Thank You!

Upcoming Programmes

Engineering College of Technology (ECT) <i>UK-Recognised Qualifications</i>	Start Date
Bachelor of Engineering (Honours) in Industrial Automation	February 2027
Bachelor of Engineering (Honours) in Electrical Engineering	February 2027
Master of Science (Power System Analysis and Renewable Integration)	February 2027
Master of Science (Industrial Automation and Instrumentation Control)	February 2027

Professional Certificates

Looking to upskill further? Check out the Professional Certificates!

These **3-month, non-accredited Professional Certificates of Competency**, delivered by ECT's affiliated institute, EIT, are designed by industry leaders and academics for technicians, technologists, engineers, and engineering professionals seeking to advance their expertise in a specific area. Featuring live, interactive webinars led by expert instructors with technical know-how, along with dedicated learning support, these courses are the perfect complement to an existing degree, qualification, or relevant work experience.

[Find out more!](#)

Contact Us:



Website
www.ect.ac.uk



Programmes
<https://www.ect.ac.uk/programmes/>



Head Office
Whittle Way, Stevenage SG1 2FS,
United Kingdom



Phone
Inside UK: 0203 582 1389
Outside UK: +44 203 582 1389