SEISMIC VULNERABILITY ASSESSMENT OF ZONE 4 AND 5 OF ISLAMABAD

Final Year Design Project Report UG 2020

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This is to certify that the

Final Year Project Titled

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DEDICATION

We owe a debt of gratitude to our teachers, whose guidance and inspiration have shaped us throughout our journey in life. Their unwavering support and mentorship have been instrumental in our development and success. They have not only imparted knowledge but also instilled in us a love for learning and a sense of purpose. Our teachers have been pivotal in nurturing our potential and preparing us for the challenges ahead. Their dedication and passion for education have left an indelible mark on our lives, equipping us with the tools and wisdom to navigate the complexities of the world.

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CHAPTER 1

ABSTRACT

Pakistan's construction sector is undergoing continuous improvement, reflected in the recent update of its building code. This research explores the transition from the previous Building Code of Pakistan (BCP-07) and utilizing peak ground acceleration (PGA) for seismic design, to the new BCP-21. BCP-21 for a more comprehensive assessment of seismic demands on structures. This research builds upon existing seismic vulnerability assessments of RC structures by focusing on present-day construction practices in Pakistan. The initial phase involves calibrating of a joint assembly in PERFORM 3D to understand joint shear degradation. This model is validated against experimental data provided. Furthermore, a seismically deficient RC frame is modelled and analysed using time-history analysis. This framework is applied to assess the vulnerability of typical RC structures of zone 4 and 5 of Islamabad. Buildings are separated into pre-code and post-code to draw conclusions and propose recommendations for enhancing the seismic performance of these structures.

CHAPTER 2

INTRODUCTION

Pakistan lies in an earthquake prone zone as ⅔ of Pakistan lies on fault lines. Furthermore, the quality of construction in Pakistan is not up to the mark due to various factors like lack of site supervision, poor construction practices, and changes in designs. This leads to a significant reduction in the strength of the structure.

There is a great percentage of deficient structures in Pakistan. This means that hysteresis parameters like Bar Pull Out and Joint shear have been neglected, leading to the actual behaviour of buildings being far different than from the analytical assessed behaviour.

According to BCP-2007, Islamabad lies in Zone 2B, having PGA 0.16 - 0.24. However, in the updated BCP 2021, there has been a 40% increase in PGA for the same region, making the buildings in that same region more susceptible to seismic events.

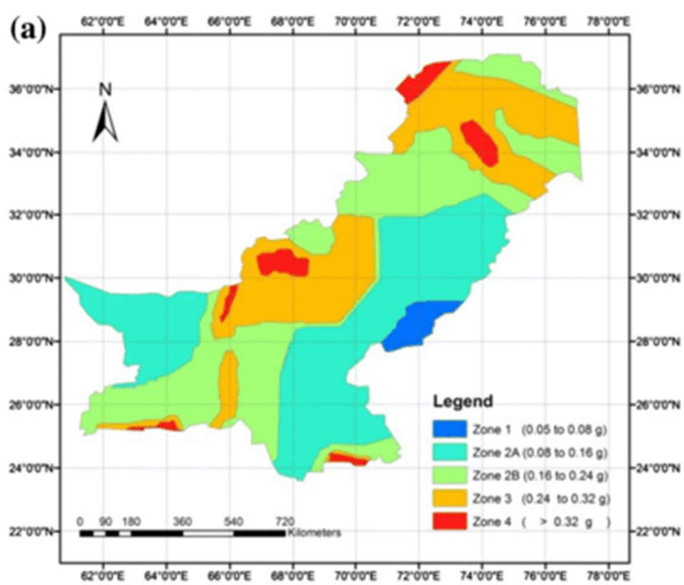


Figure 1 BCP 2007

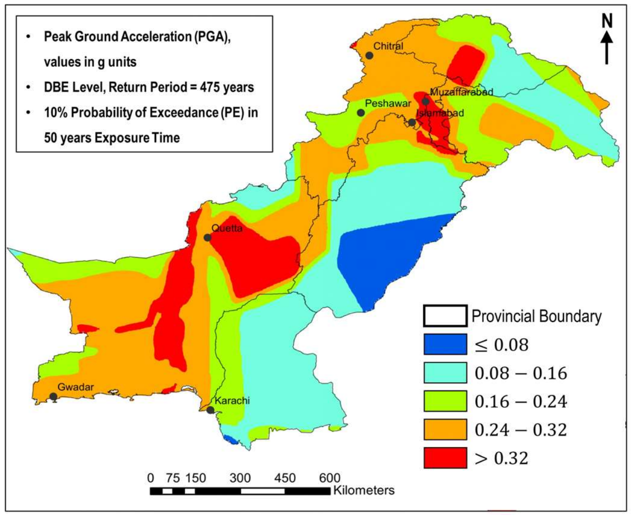


Figure 2 BCP 2021

Islamabad is divided into 5 major zones; we will be focusing on zone 4 and 5 of Islamabad. Zone 4 consists of Lethrar Road, Bani Gala, Chak Shahazad. Zone 5 comprises Bahria Town, DHA, PWD.

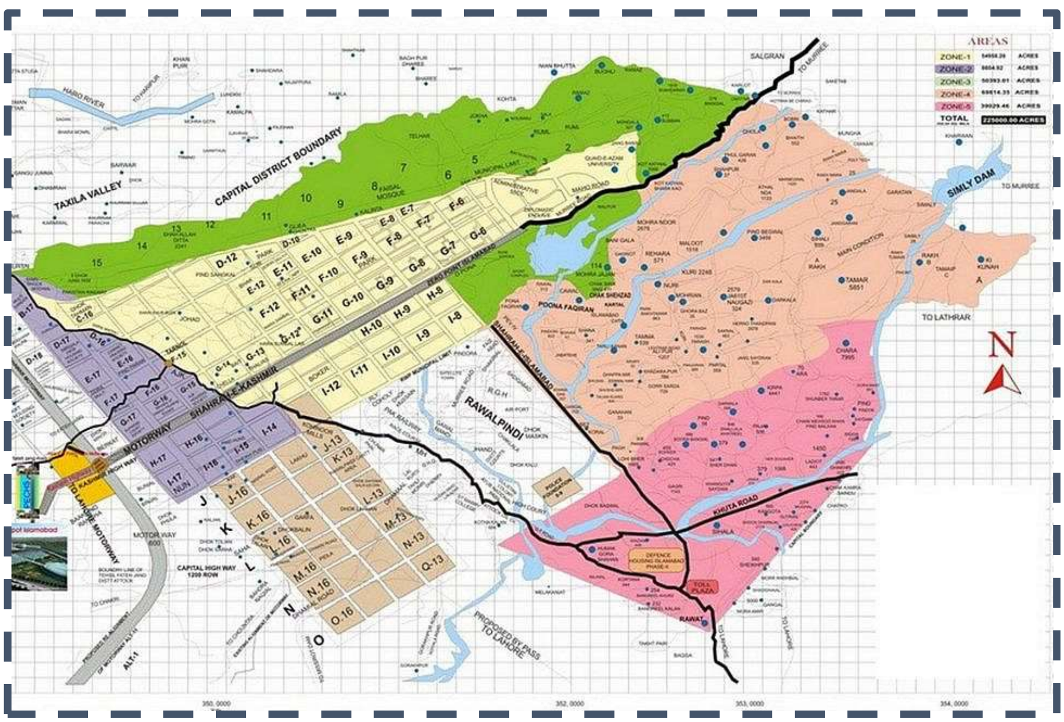


Figure 3 Master Plan of Islamabad

2.1 LITERATURE REVIEW

Seismic Risk Assessment comprises of 3 categories:

- Hazard
- Vulnerability
- Exposure

We will be focusing on vulnerability as there is comprehensive research on seismic risk assessment.

- **Modelling Reinforced-Concrete Beam-Column Joints Subjected to Cyclic Loading (Laura N. Lowes, Arash Altoontash)**

  A model is proposed for use in simulating the inelastic response of typical beam-column joints in 2D. It elaborates the Inelastic joint behaviour through the action of bar-slip and joint shear.

- **Vulnerability Assessment of Typical Buildings in Pakistan (Dr. Khan Shahzada)**

  It provides an understanding of the capacity curve alongside the performance levels and deduces that construction of reinforced concrete buildings is recommended for three stories or more.

- **Seismic Vulnerability Assessment of Deficient RC Structures with Bar Pull Out and Joint Shear Degradation (Arslan Mushtaq, Dr. Shaukat Ali Khan, Dr. Hamza Farooq Gabriel, Dr. Sajjad Haider)**

  Gives understanding of deficient structures that are more prone to seismic risk due to neglecting of hysteresis parameters. Furthermore, generation of vulnerability curves using Capacity Spectrum Analysis.

- **Nonlinear Structural Analysis for Seismic Design (Dr. Gregory G. Deierlein, Dr. Andrei M. Reinhorn, Michael R. Willford)**

  Plasticity is explained with distribution or concentration. Disturbed is when each fibre of a column or bean is considered whereas the concentrated is at the node. It considers both the non-linearity f geometry as well as material that we have considered in our research as well.

Relevant Codes that having been considered:

- FEMA 440
- FEMA 356
- CEB-FIP
- FEMA 154

2.2 OBJECTIVES

Considering the available research and some areas for improvement, and catering to the needs of Pakistan's construction industry, we have set up the following objectives for our research.

- Perform the detailed data analysis of compiled data.
- Perform seismic performance assessment of RC buildings using nonlinear static analysis.
- Determine the level of vulnerability, assessing physical damage and its relationship to performance level.

The aim is to determine the seismic vulnerability imposed by different structural systems using the Non-Linear Pushover Analysis approach.

CHAPTER 3

METHODOLOGY

Comprehensive literature review was performed to get a detailed understanding of the vulnerability assessment. Furthermore, the data of Zone 4 and 5 was provided in FEMA 154 form that was used to compile the data to get a more sort out data. Zone 5 comprised following regions:

- Bahria 1
- DHA
- Bahria 2
- PWD

Using statistical analysis tools of OriginPro, detailed analysis was carried out based on different statistical parameters.

To validate the results, we used the LaFave Joint Subassembly and Sacley Frame to model them on Perform 3D. Using the static pushover analysis, backbone curves were drawn from hysteresis parameter, and were validated using the FEM Model of LaFave.

With the calibration done, models of Zones 4 and 5 were drawn on Perform 3D and analysed to generate backbone curves. Based on the backbone curves, performance levels were identified.

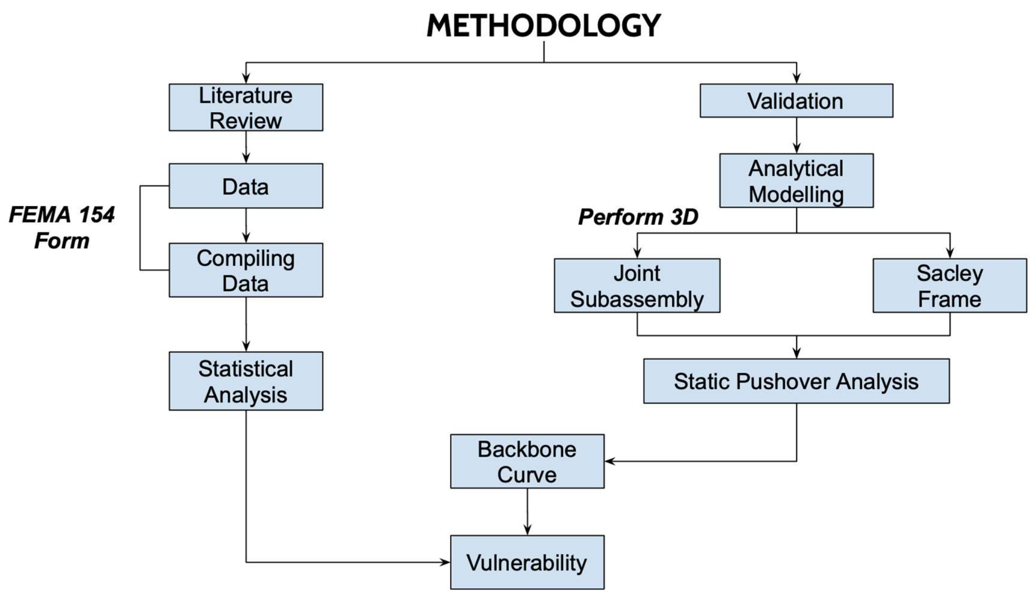


Figure 4 Methodology Chart

CHAPTER 4

DATA COMPILATION

4.1 SORTING DATA

Zone 4 data consisted of 76 buildings, and the following parameters of the buildings were identified:

Sector	No of Buildings	76								
Zone 4	Parameters	No of End Bays (x)	Spacing - ft	No of Rest Bays (x)	Spacing - ft	No of Rest Bays (y)	Spacing - ft	Number of Stories	Column Area - in^2	FEMA Score
	Mean	2.05	15	2.76	16.49	3.46	15.82	4	346.9	0.8
	Standard Deviation	0.48	5.14	1.45	6.48	0.97	6.21	1.16	167.73	0.3
	Mean + SD	2.53	20.14	4.21	22.97	4.43	22.03	5.16	514.63	1.1
	Mean - SD	1.57	9.86	1.31	10.01	2.49	9.61	2.84	179.17	0.5

Table 1 Zone 4

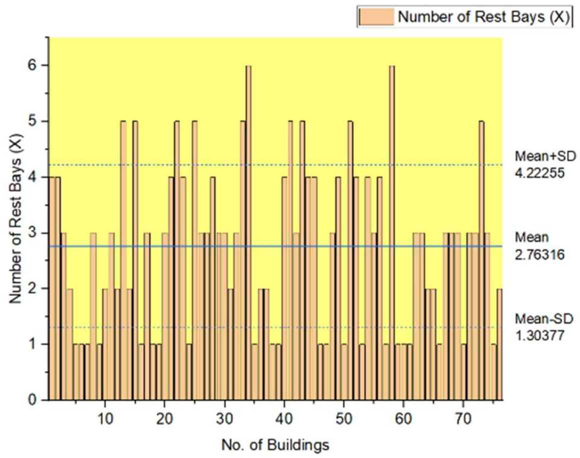
Zone 5 data consisted of 272 buildings, and the following parameters of the buildings were identified:

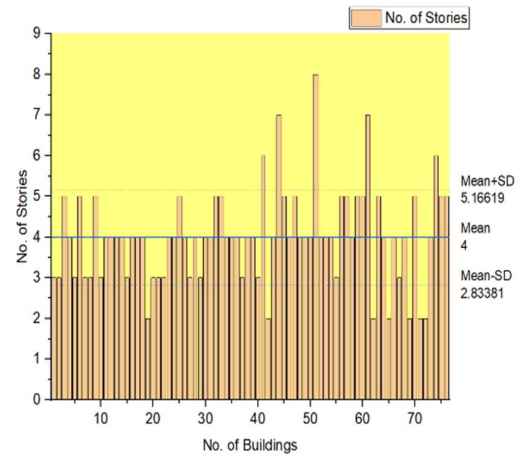
Sector	No of Buildings	272						
	Parameters	**No of Rest Bays (x)**	**Spacing - ft**	**No of Rest Bays (y)**	**Spacing - ft**	**Number of Stories**	**Column Area - in^2**	**FEMA Score**
Bahria 1	**Mean**	6	11.45	5	11.55	7	889.55	2.2
PWD		3	17.88	4	17.66	4	367.3	
DHA		3	13.29	4	12.38	5	482.2	
Bahria 2		3	15.06	3	13.81	7	838.75	

Table 2 Zone 5

4.2 STATISTICAL ANALYSIS

Detailed statistics analysis was carried out using OriginPro of different parameter.





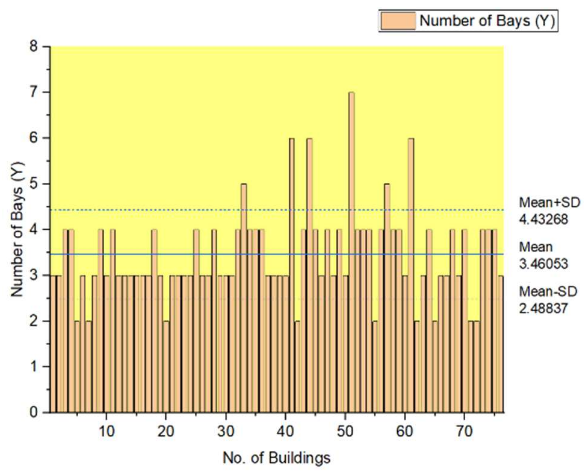


Figure 5 Graph Zone 4

CHAPTER 5

CALIBRATION

Perform 3D is a software developed by Computers and Structures Institutes (CSI) that is used for nonlinear analysis behaviour of structures.

5.1 LAFAVE MODEL

The LaFave model highlights the joint-shear failure. This phenomenon occurs when the shear forces acting on a joint or interface within a material or structure exceed the joint's shear strength, leading to a failure along that plane. Moment reversal happens when the direction of these bending forces changes, often due to dynamic loads. When moment reversal occurs, it can place alternating tension and compression on the joints within a structure. This change in loading conditions can weaken the joints, making them more susceptible to shear failure.

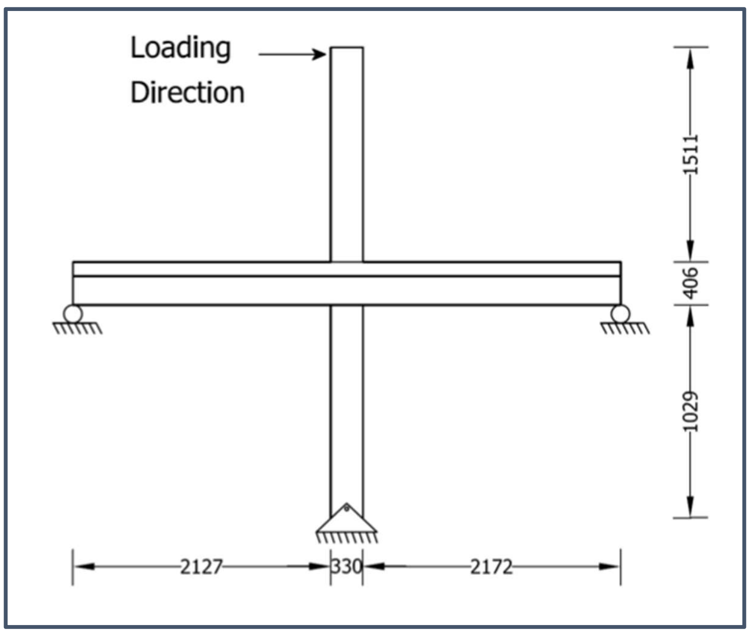


Figure 6 Joint Assembly

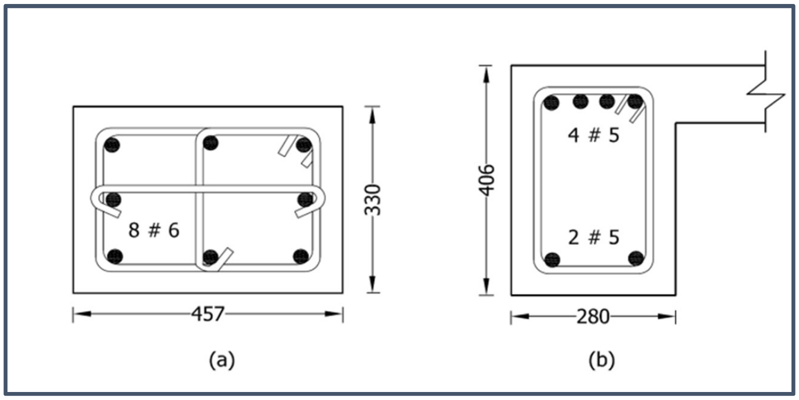


Figure 7 Cross Sections (a) Column (b) Beam

5.1.1 MODELLING

Material properties for concrete and steel are defined using a tri-linear relationship of stress strain. In the following figures, showing material stress strain curves for concrete and steel respectively.

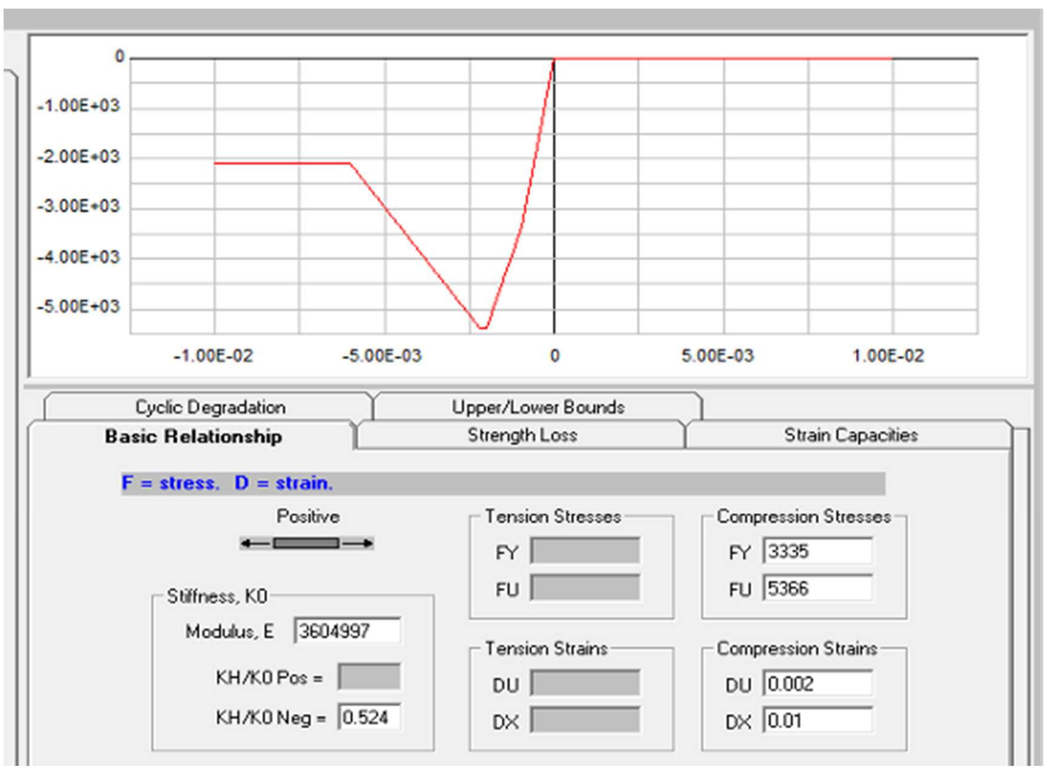


Figure 8 Concrete Material

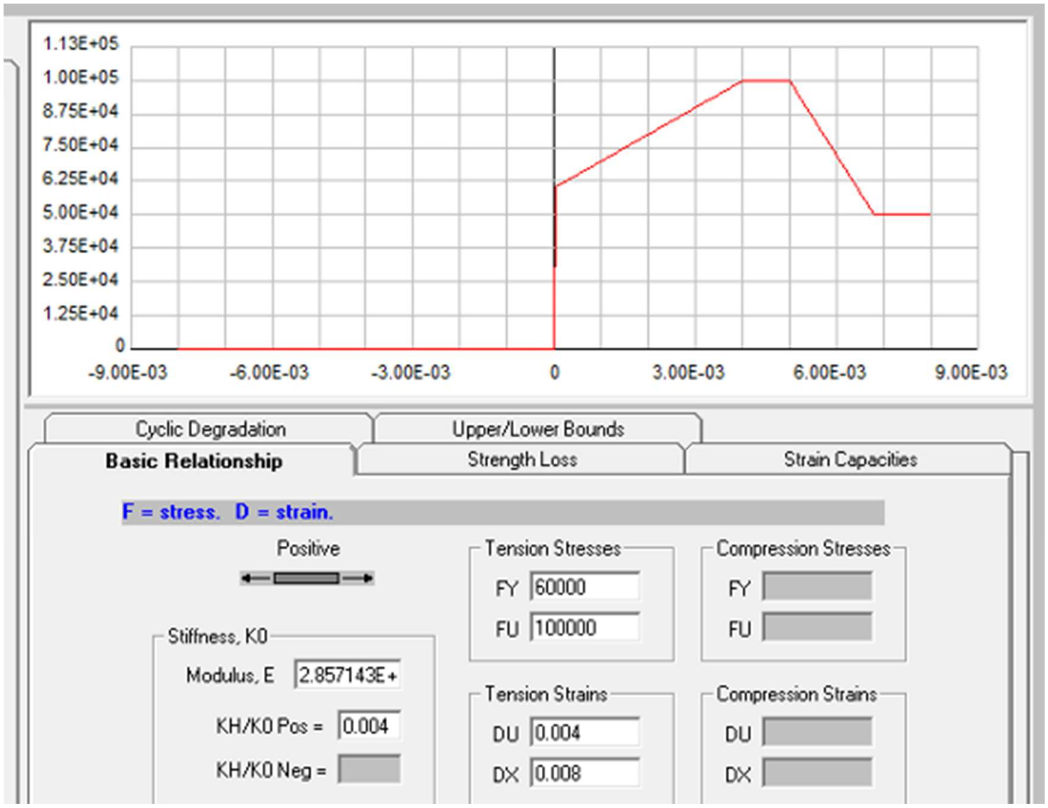


Figure 9 Steel Material

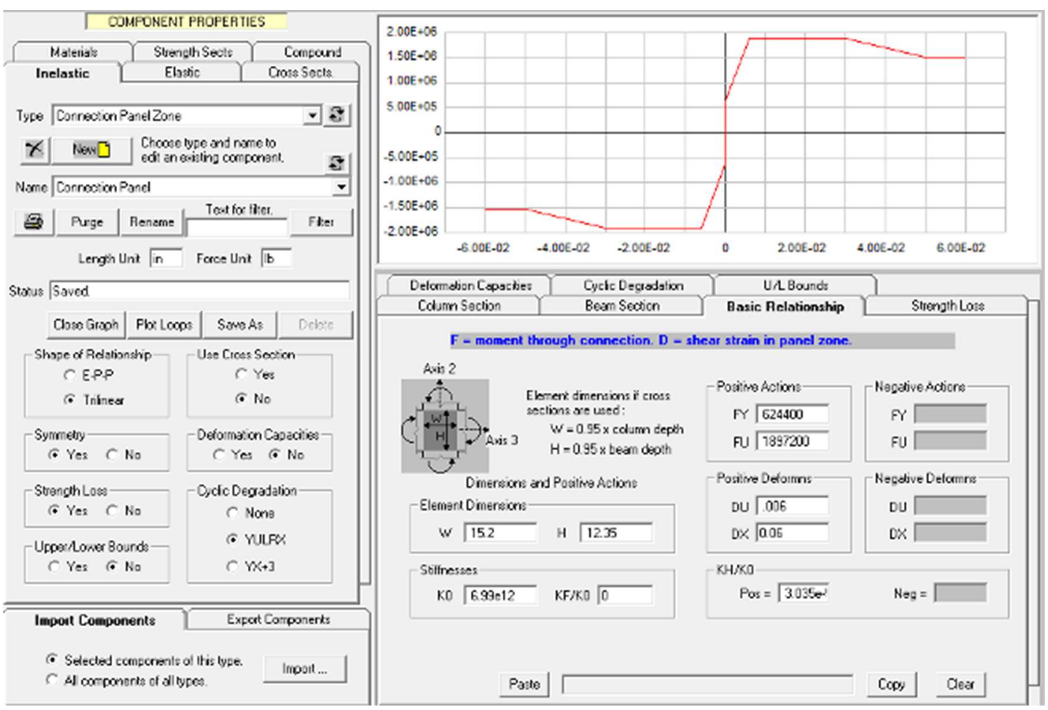


Figure 10 Joint Shear Degradation

For the next step, we define the cross section of the members. Cross section tab in PERFORM 3D allows defining of inelastic beans and column fibres.

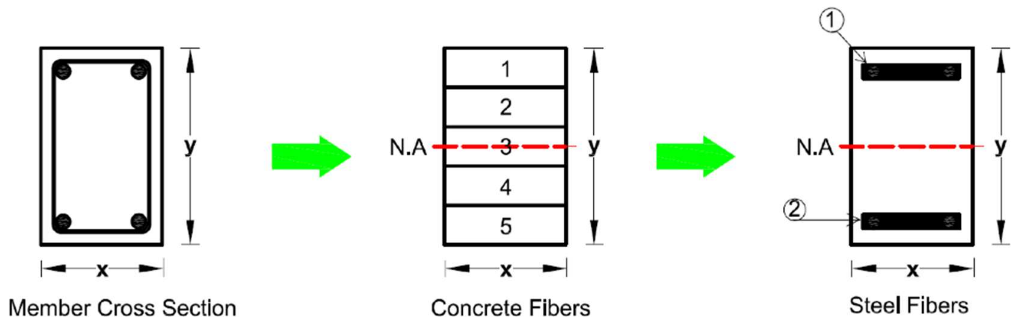


Figure 11 Fibres

The LaFave model is developed with the same characteristics in ETABS to get the inelastic fibres of steel and column respectively. After running the analysis in ETABS, an excel sheet is generated defining the fibres that are then added in PERFORM 3D under the cross-section tab.

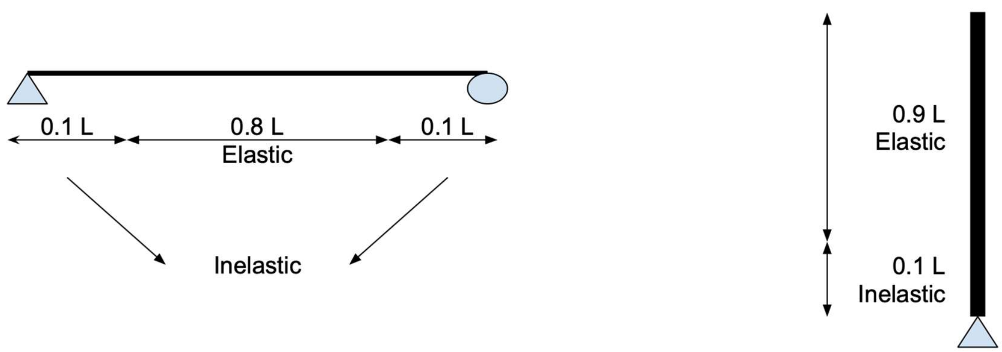


Figure 12 Inelastic Fibres

5.1.2 ANALYSIS

Joint assembly after modelling is shown below with all the parameters defined as well as support conditions. In the centre, the connection panel zone is defined.

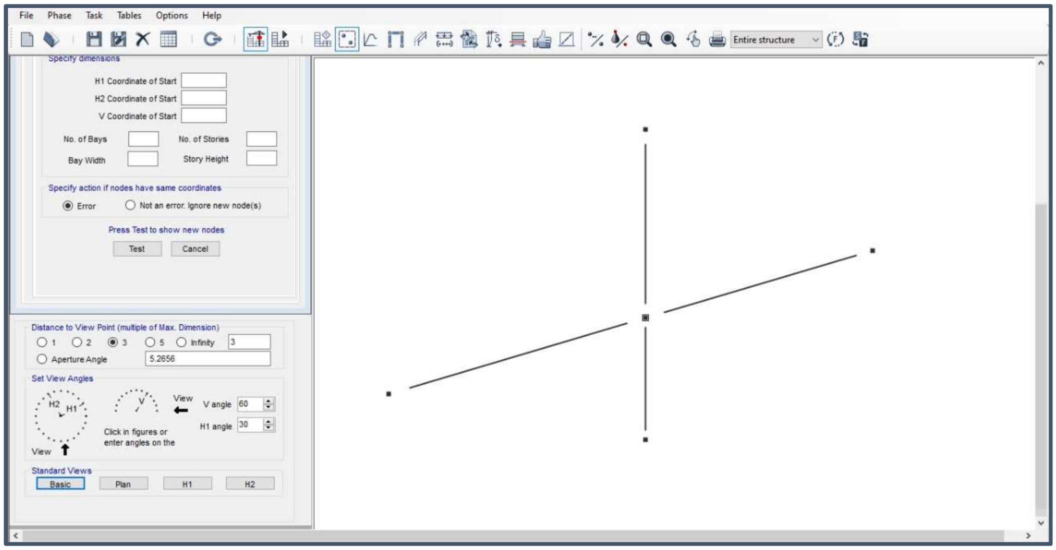


Figure 13 PERFORM 3D Model.

For analysis of the structure, static pushover analysis must be performed to observe the structural behaviour against earthquake excitation. From theory we get to perform nonlinear static procedures where the magnitude of the loading is increased in constant increments. Here is a flow chart that explains the analysis procedure:

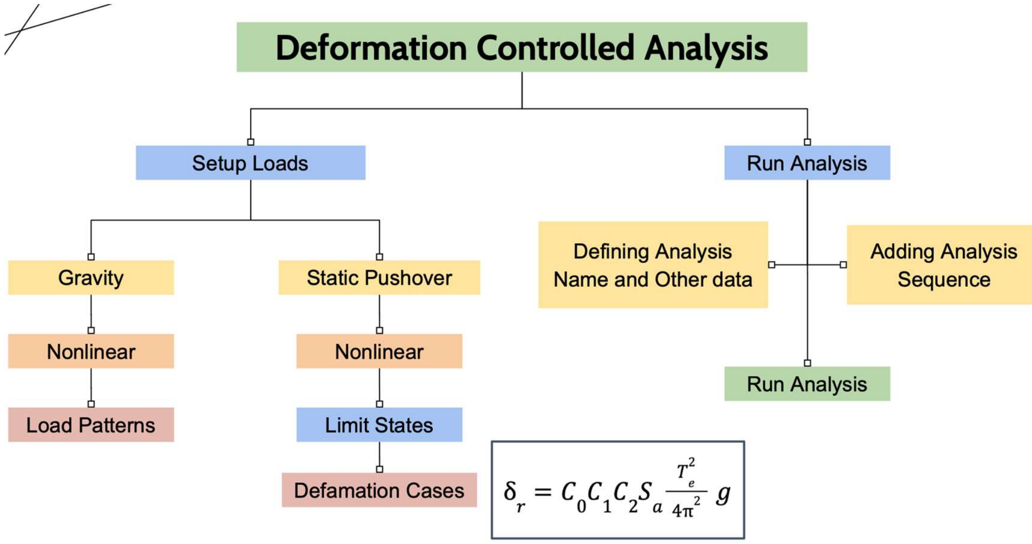


Figure 14 Analysis

Starting with setting loads, initially gravity loads are assigned in nonlinear analysis. Moreover, limit states are assigned with increment of 0.001 in load up to 8%. The deformation cases are derived from the above displayed formula. These load cases are incremented in both directions to get hysteresis loop of the building.

After setting up loads, analysis sequence is added in PERFORM 3D and analysis is run. Hysteresis loop is generated as shown below:

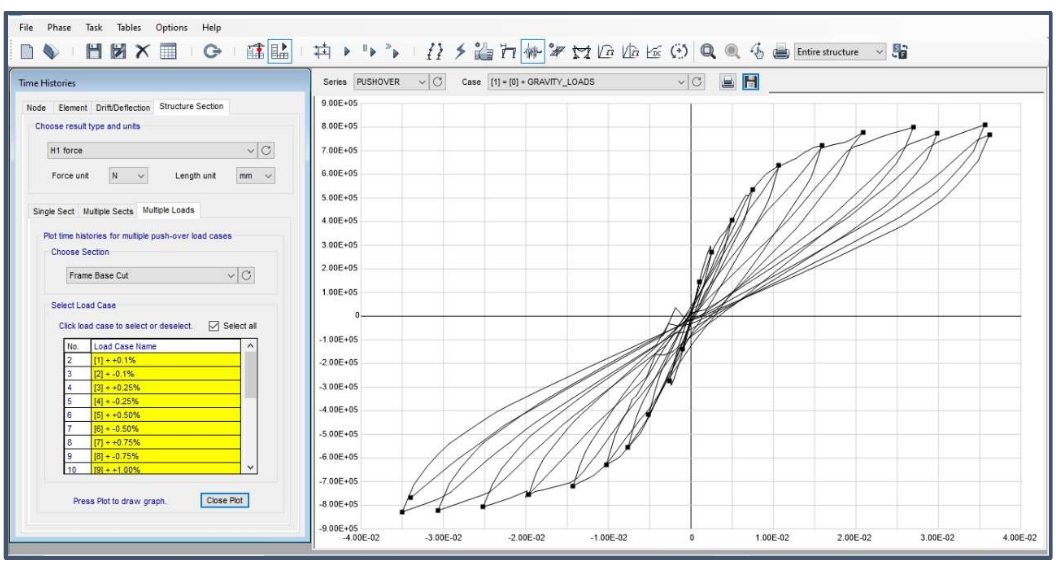


Figure 15 LaFave Hysteresis Loop

With the load cases highlighted in yellow, hysteresis loop is generated. To get a better understanding, we develop backbone curves from the loop.

The backbone curve represents the relationship between load and displacement for a material or structural element under cyclic loading. This curve is derived from the peaks of the hysteresis loops obtained during cyclic loading tests. We get the backbone curve of the LaFave model and draw a comparison with the FEM and experimental model.

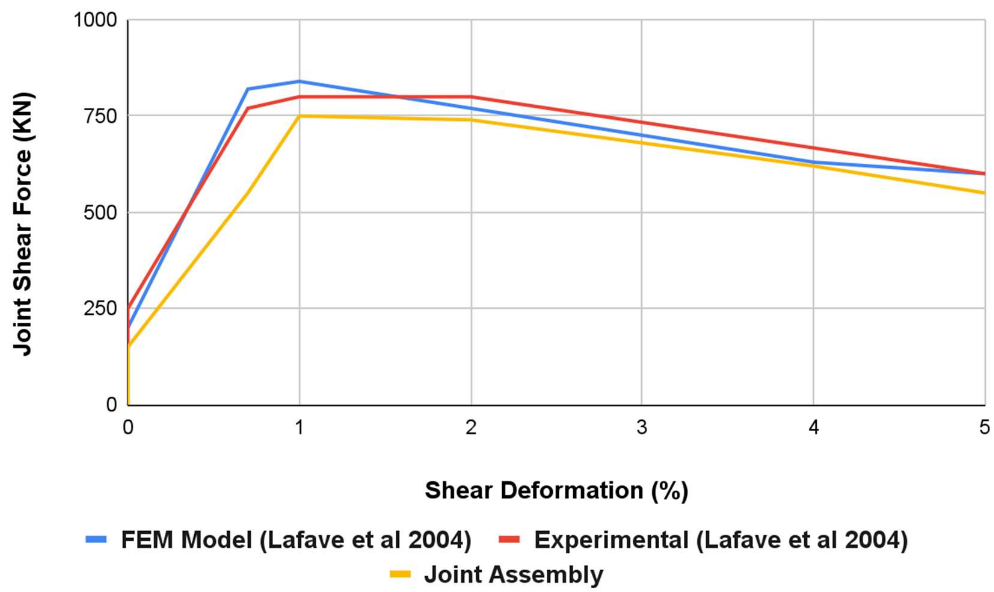


Figure 16 Backbone Curve

The joint assembly model coincides the FEM model, this shows that the calibration of model is accurate and can be used for real world models to assess their behaviour under nonlinear pushover analysis.

CHAPTER 6

MODELLING AND ANALYSIS

6.1 Zone 4

Zone 4 are the pre-code buildings that have used 3000 psi concrete along with 40 grade steel. The reinforcement detailing's considered are:

- 0.9 % for Column
- 0.5 % for Beam

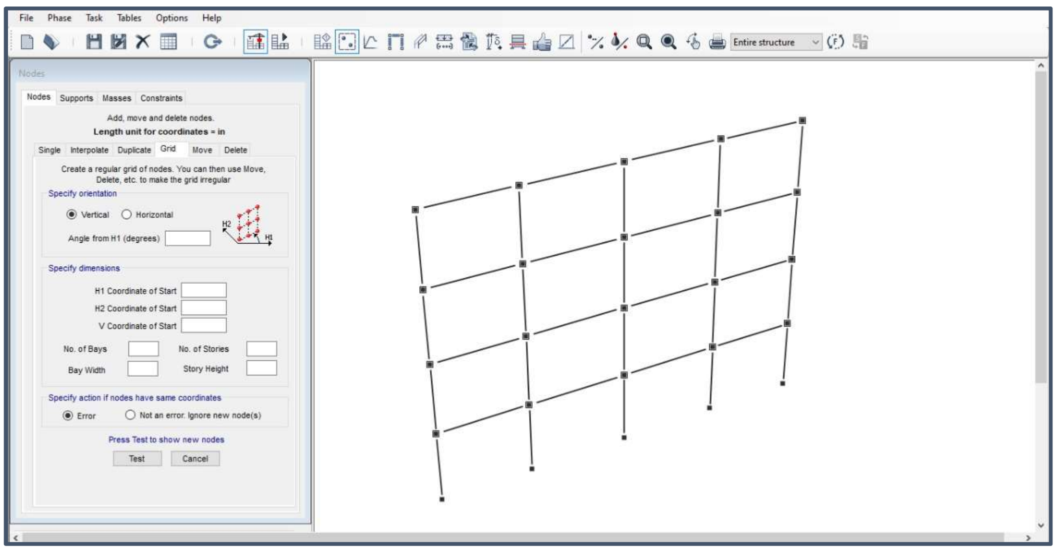


Figure 17 Zone 4 Model

The above figure shows the Zone 4 model with following specifications:

No. of x Bays	No. of Storeys	Total Height (ft)
4	3	48

Table 3 Zone 4 Data

Defining the load cases and performing an analysis hysteresis loop is generated.

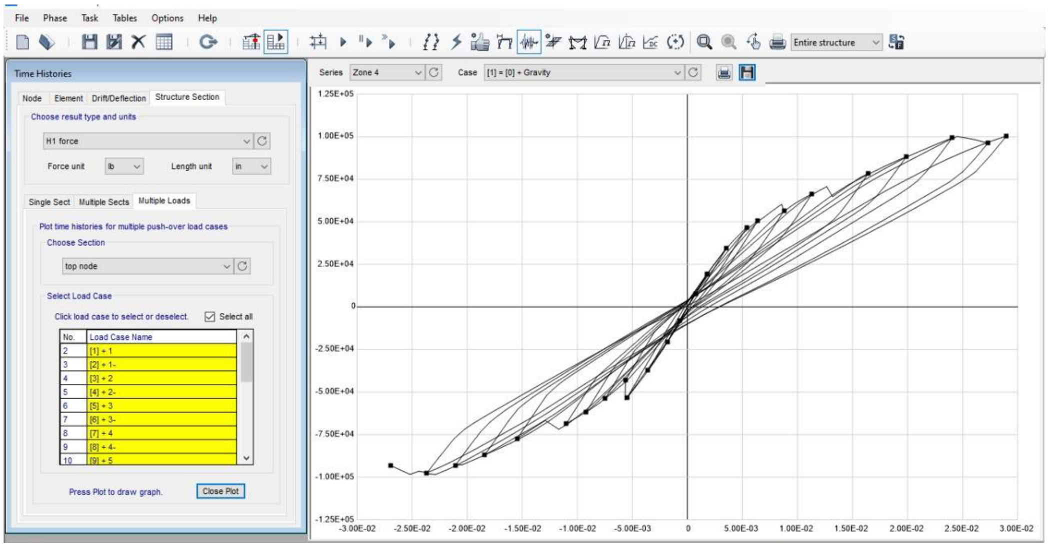


Figure 18 Zone 4 Loop

6.2 Zone 5

Zone 5 are the post-code buildings that have used 4000 psi concrete along with 60 grade steel. The reinforcement detailing's considered are:

- 1.5 % for Column
- 0.6 % for Beam

6.2.1 Bahria 1

Specifications:

No. of x Bays	No. of Storeys	Total Height (ft)
6	7	84

Table 4 Bahria 1 Data

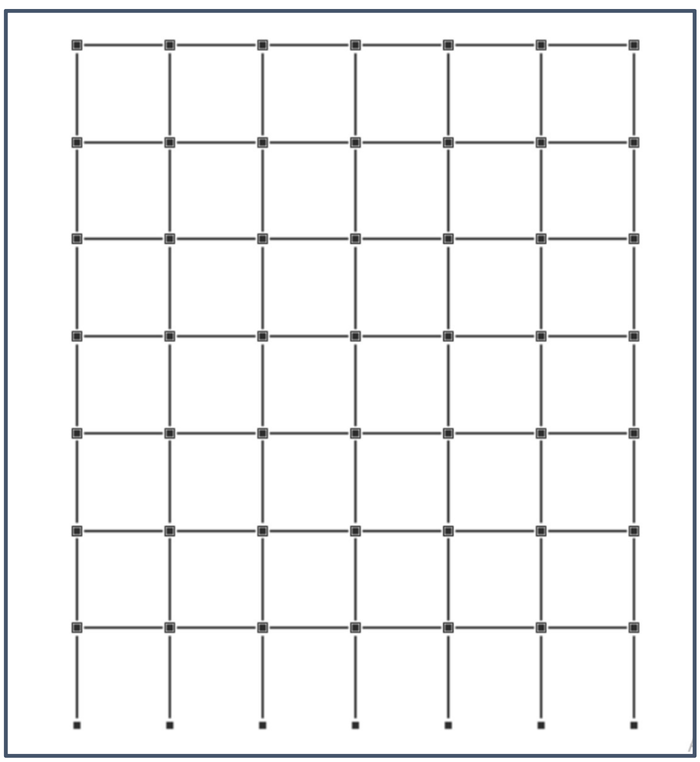


Figure 19 Bahria 1 Model

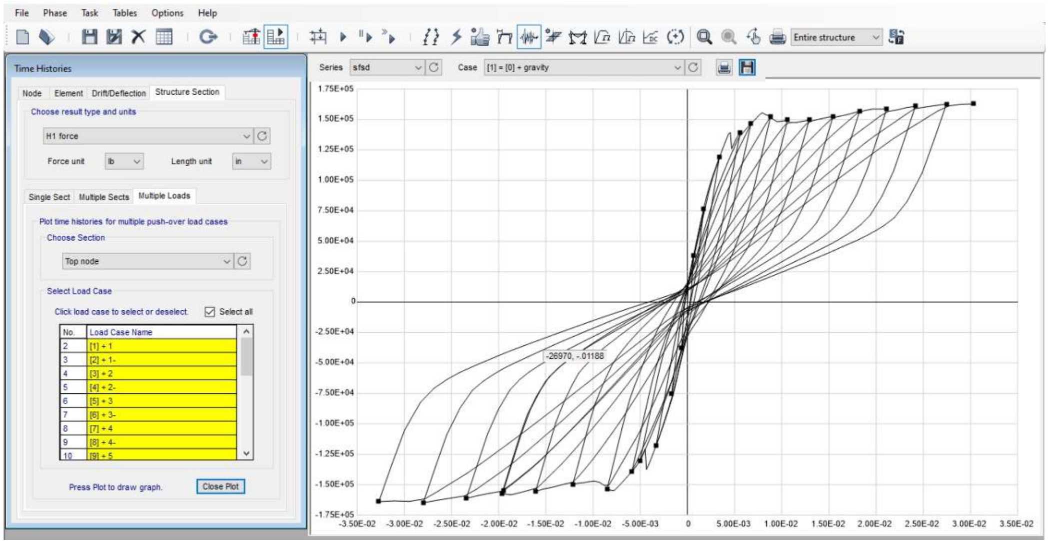


Figure 20 Bahria 1 Loop

6.2.2 Bahria 2

Specifications:

No. of x Bays	No. of Storeys	Total Height (ft)
3	7	84

Table 5 Bahria 2 Data

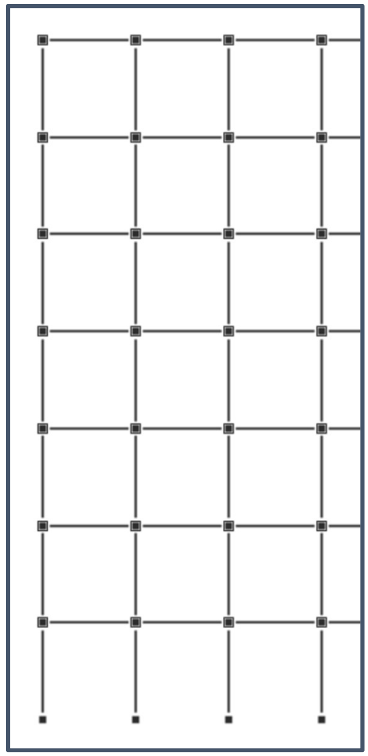


Figure 21 Bahria 2 Model

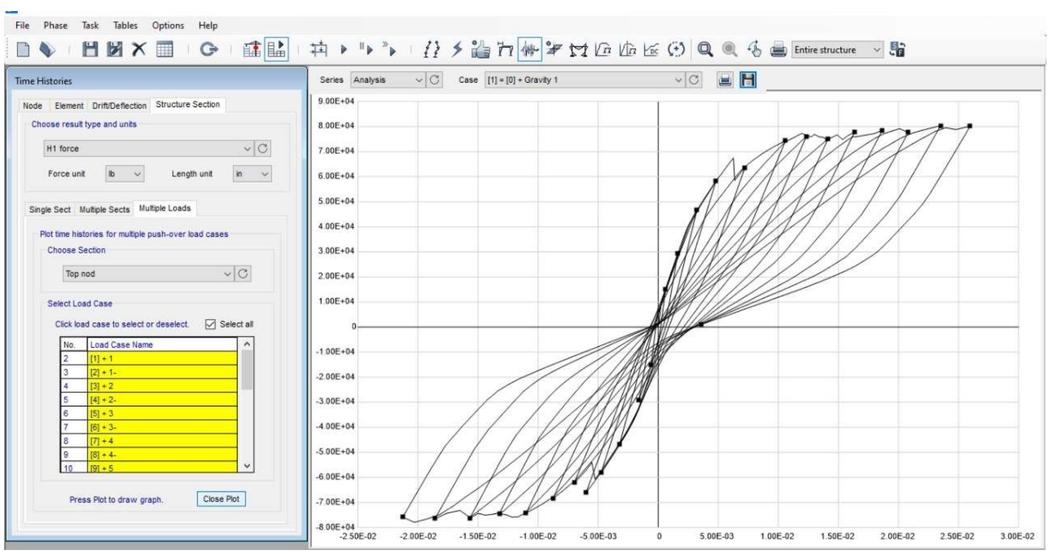


Figure 22 Bahria 2 Loop

6.2.3 DHA

Specifications:

No. of x Bays	No. of Storeys	Total Height (ft)
3	5	60

Table 6 DHA Data

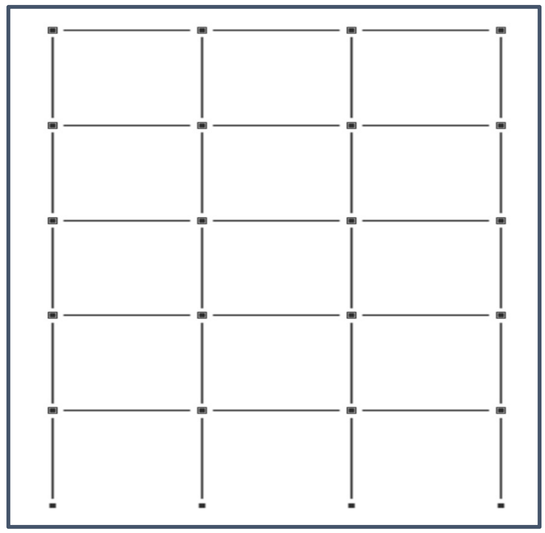


Figure 23 DHA Model

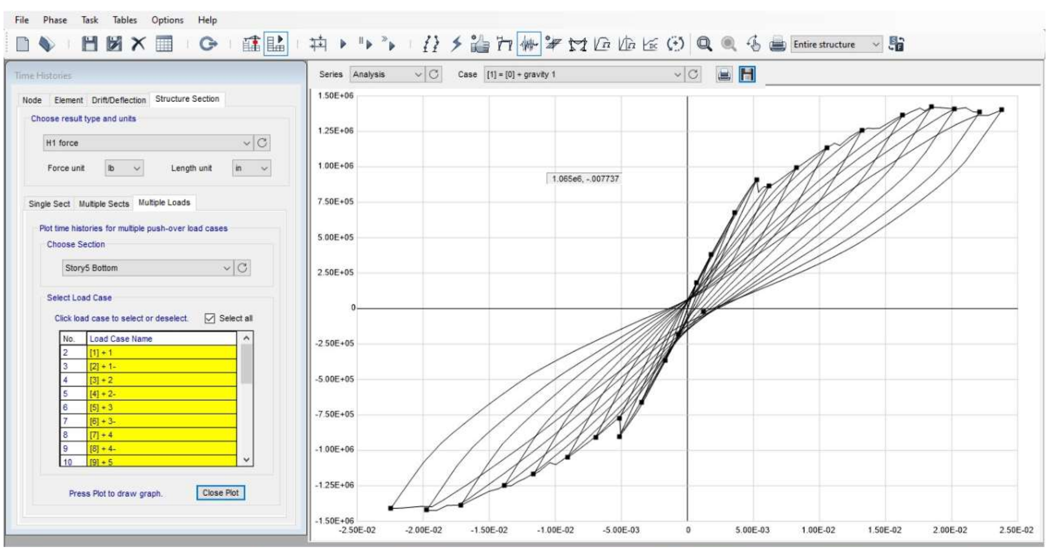


Figure 24 DHA Loop

6.2.4 PWD

Specifications:

No. of x Bays	No. of Storeys	Total Height (ft)
3	4	36

Table 7 PWD Data

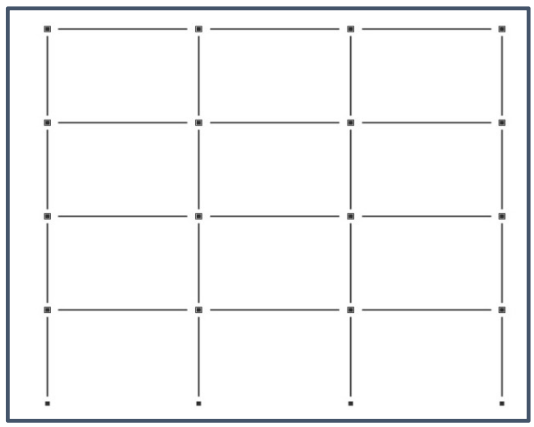


Figure 25 PWD Model

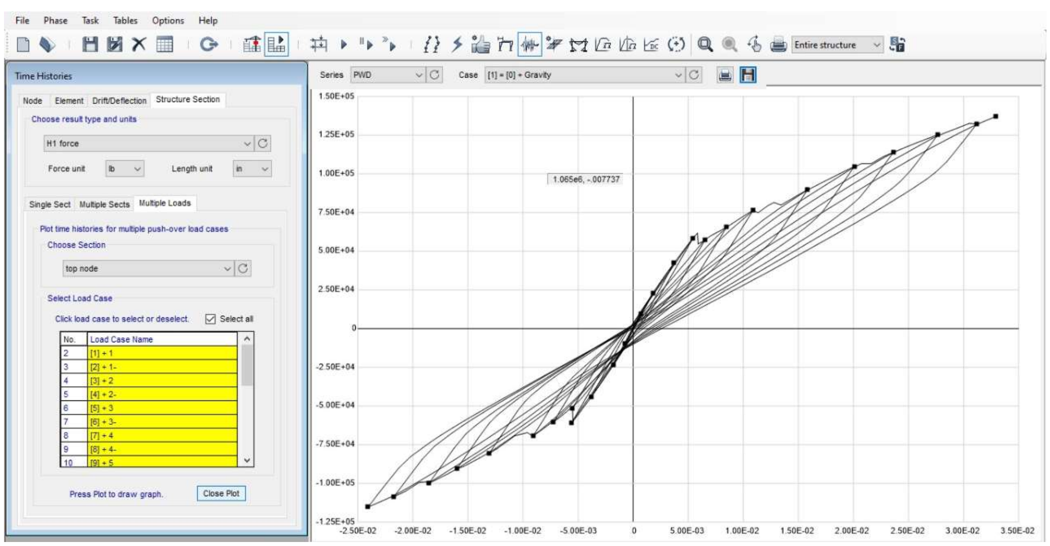


Figure 26 PWD Loop

6.3 Backbone Curves

All the data models of zones 4 and 5 are used to draw their backbone curves from hysteresis loop. Below is the comparison between different backbone curves.

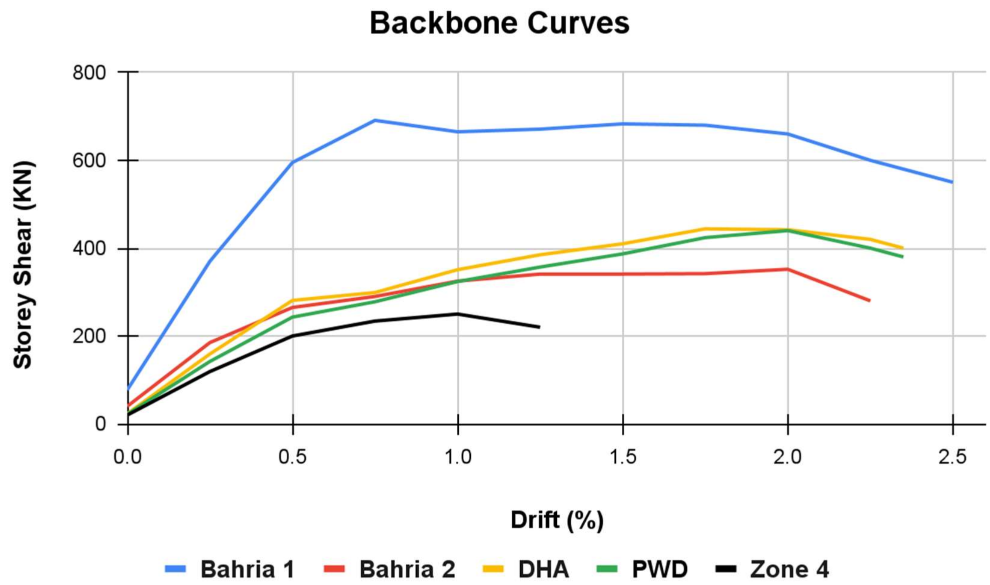


Figure 27 Backbone Curves (Data)

From the curves Bahria 1 has the highest storey shear as it has the greater number of bays alongside the max number of storeys. Furthermore, Zone 4 graph being at the bottom reaffirms that it consists of pre-code buildings whereas the Zone 5 are post-code.

CHAPTER 7

PERFORMANCE LEVELS

Performance levels describe the expected behaviour and condition of a structure during seismic events. These levels help to meet the usability criteria. Here are the common performance levels:

1. Operational (OP)

- The structure remains fully operational with minimal or no damage.
- Negligible structural and non-structural damage.
- The building can be used immediately after the event without any repairs.

2. Immediate Occupancy (IO)

- The structure retains its overall integrity and is safe to occupy immediately after the event.
- Minor to no structural damage
- Occupants can remain in the building, but minor repairs might be necessary.

3. Life Safety (LS)

- The structure protects occupants' lives during the event but may not be usable afterward without repairs.
- Structural damage is controlled to prevent collapse.
- Moderate structural damage
- Evacuation is necessary.

4. Collapse Prevention (CP)

- The structure is on the verge of collapse but retains enough integrity to prevent a total collapse.
- Severe structural damage
- The building is not safe for occupancy.

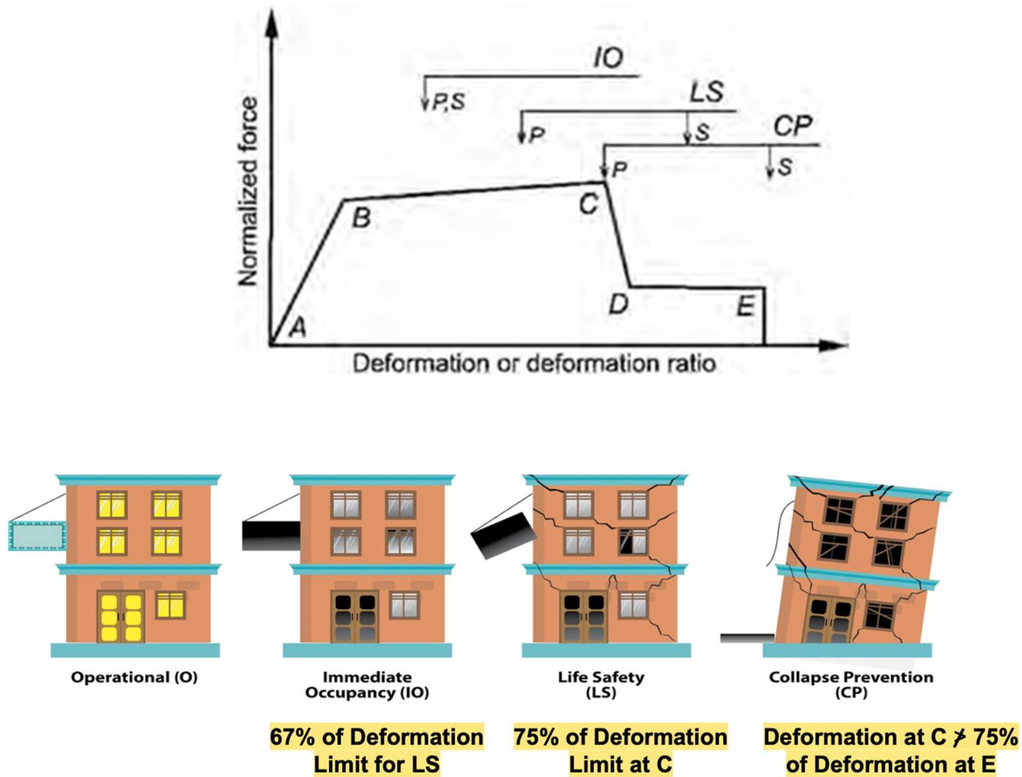


Figure 28 Acceptance Criteria

The graph shows the acceptance criteria of how it is applied on the backbone curve to get performance levels. Each performance level is a certain percentage of a particular point.

Applying the performance levels on data models below are backbone curves with marking of performance level.

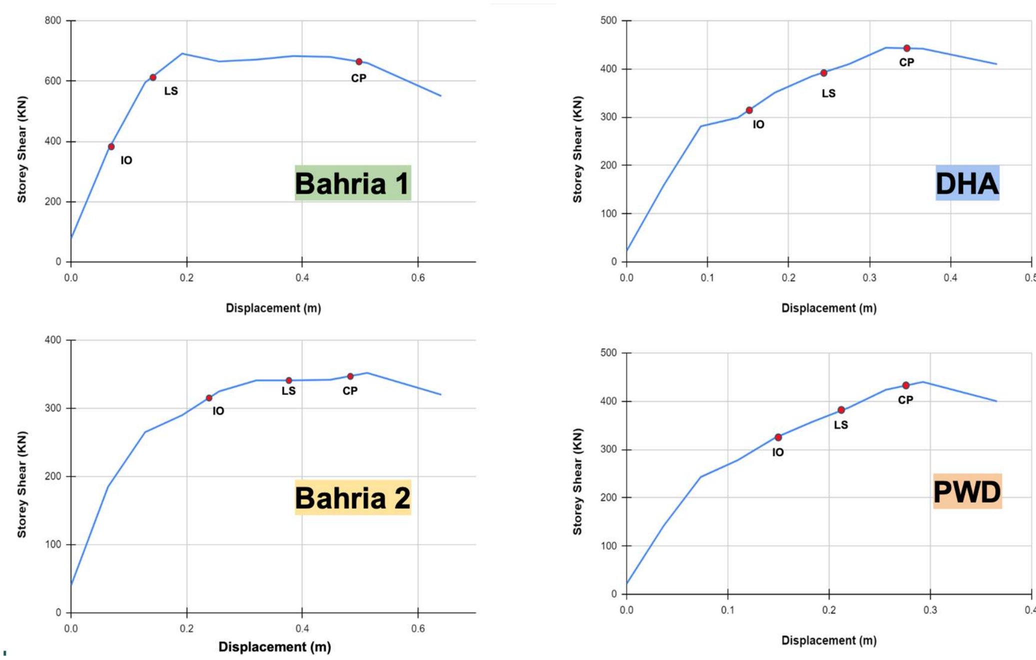


Figure 29 Zone 5 Levels

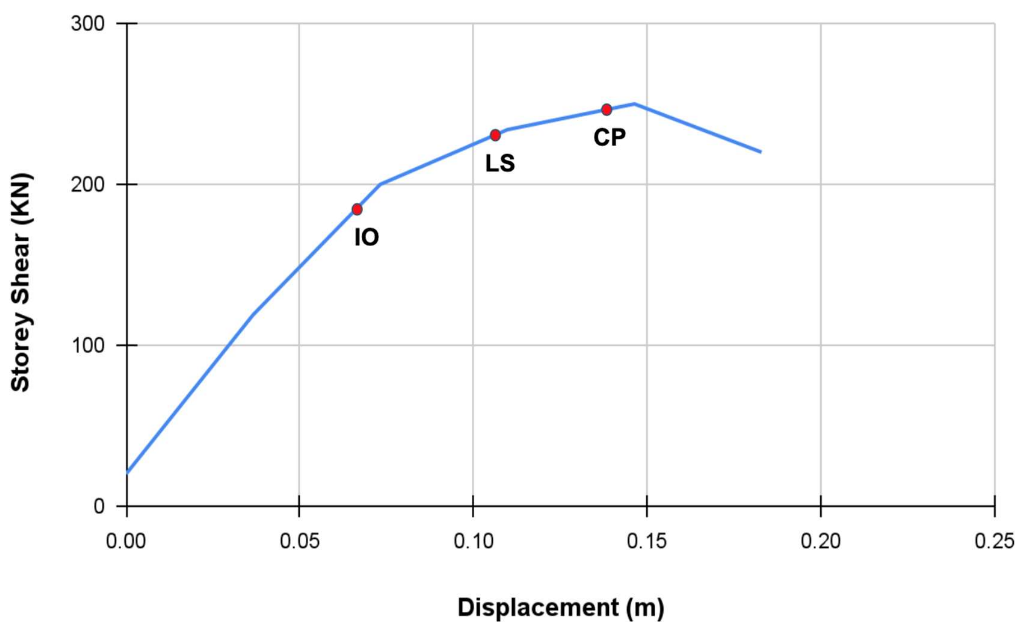


Figure 30 Zone 4 Levels

In zone 5, divergence of performance levels can be seen whereas in Zone 4 the performance levels are close to each other. Thus, it shows that zone 5 has a ductile behaviour whereas the pre-code buildings in zone 4 are brittle.

CHAPTER 8

FUTURE PROSPOECTS

8.1 Vulnerability

The Capacity Spectrum Method (CSM) is a widely used approach in performance-based seismic design and assessment of structures. It combines the structural capacity (represented by a pushover curve) with the seismic demand (represented by a response spectrum) to estimate the expected performance of a structure during an earthquake.

Steps in the Capacity Spectrum Method:

1. Pushover Analysis:
    - Perform a nonlinear static pushover analysis of the structure to generate a pushover curve. This curve shows the relationship between the base shear force and the roof displacement, representing the structure's capacity.
2. Conversion to Capacity Spectrum:
    - Convert the pushover curve from base shear vs. displacement to spectral acceleration (Sa) vs. spectral displacement (Sd) using appropriate transformation formulas:

$$S_a = \frac{V_b}{M}$$

$$S_d = \triangle . \frac{\frac{g}{T^2}}{(2\pi)^2}$$

where Vb is the base shear, Δ is the roof displacement, M is the effective modal mass, gg is the acceleration due to gravity, and T is the fundamental period of the structure.

3. Response Spectrum:

    - Develop a seismic demand response spectrum for the site conditions and design earthquake. This spectrum is typically given in terms of spectral acceleration vs. period.

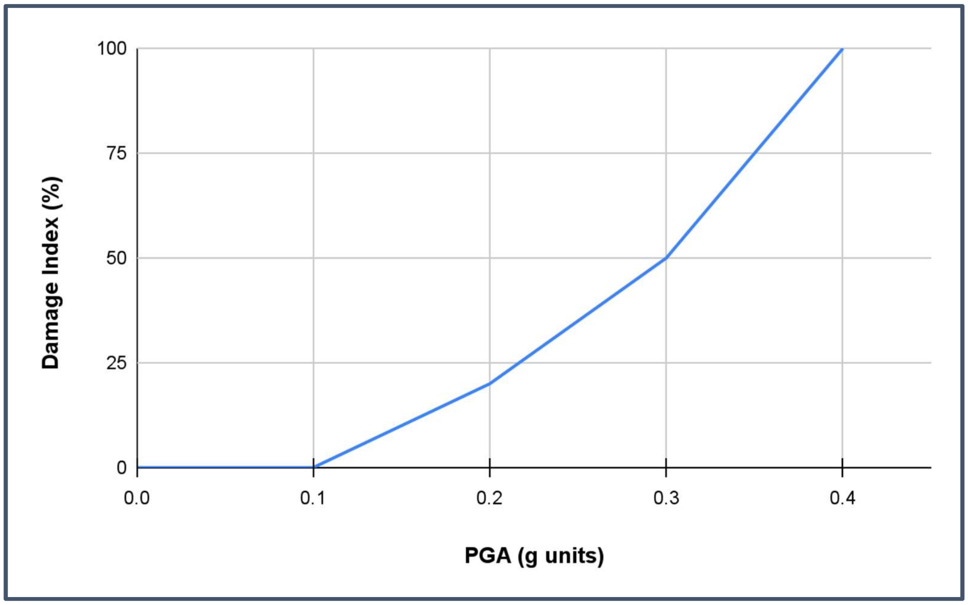


Figure 31 Kyriakides (2007)

8.2 Risk Map

With hazard maps widely available, vulnerability assessment can assist in developing risk maps as it links seismic exposure as well. This will draw a map of current structures and determine in case of a seismic event how many human lives will be affected. Moreover, the buildings that are not up to the mark can be retrofitted using various techniques.

In case of a seismic event the total damage can be quantified against the loss, risk mitigation measures can be initiated to provide relief to damage prone areas.

With the available performance levels, after a seismic event their rehab can be studied, and the required measures can be taken to develop structure again in the region.

CHAPTER 9

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- Nonlinear Structural Analysis For Seismic Design
- Seismic Vulnerability Assessment of Deficient RC Structures with Bar Pull-out and Joint Shear Degradation
- Modelling Reinforced-Concrete Beam-Column Joints Subjected to Cyclic Loading | Request PDF
- Vulnerability Assessment of Typical Buildings in Pakistan
- Description of the seismic risk | Dipartimento della Protezione Civile
- Two-third of Pakistan lies on fault lines.
- Seismic Activity along the Main Boundary Thrust (MBT), Pakistan
- Building Code of Pakistan Pakistan Engineering Council - PEC
- Probabilistic Seismic Hazard Analysis of Pakistan – Fawad Najam