FYP Final Report

SEISMIC PERFORMANCE EVALUATION OF RC BUILDINGS DESIGNED AS PER BCP-2007 AND BCP-2021

Final Year Project Report

by

Muhammad Abu Bakar

Muhammad Anique

Roshan Ahmed

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology,

Islamabad, Pakistan

2022

This is to Certify that the

FINAL YEAR PROJECT TITLED

SEISMIC PERFORMANCE EVALUATION OF RC BUILDINGS DESIGNED AS PER BCP-2007 AND BCP-2021

Submitted by

Muhammad Abu Bakar (GL)

Muhammad Anique

Roshan Ahmed

Has been accepted towards the requirements for the undergraduate degree

In

CIVIL ENGINEERING

____

Dr Ather Ali

Assistant Professor

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology,

Islamabad, Pakistan

ACKNOWLEDGEMENTS

This research is due to dedicated input of my Research Supervisor, Dr Ather Ali, always remained very calm, humble, and helpful throughout the project. In fact, it is not out of place to mention here that, Dr Ather Ali has proved himself more than a supervisor. Along with the supervisor I also want to thank our Co-Supervisor Dr Fawad Najam who was always there to help and guide. Apart from the faculty members my group members Mr. Muhammad Anique and Mr. Roshan Ahmad have played a very important role to completion of the project and compilation of results. These fellows were helpful during phase of literature review, Designing of structures, compilation of result and thesis writing. Being a student of engineering, I thank administration of NICE, NUST which provided us the resources and for their continuous support. May Allah bless all.

Thanks

Muhammad Abu Bakar

B.E. Civil NICE,

NUST,

Islamabad

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Pakistan is still striving for improvements in construction industry. Major construction in private sector is carried out as non-engineered; there are very few projects that are properly designed for gravity and lateral loads, which is main cause behind deaths in major earthquakes. For example, Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Nevertheless, after the Kashmir-Hazara (2005) earthquake, the government and engineering commission stressed on execution of a seismic code and introduced Seismic Provisions of Building Code of Pakistan-2007.

The same building code of BCP-2007 was being used till 2021 but now the government has introduced a new building code known as Building Code of Pakistan-2021. The major change that is adopted in new building is the change in seismic hazard parameter that is changed from peak ground Acceleration (PGA) to spectral Acceleration. In previous code based on PGA values the whole country was divided into five zones whereas the new code gives short and long period acceleration for each city. The concept of risk category is introduced in the new building code which is utilized to find the seismic design category which is a new concept that was not there in the previous code these changes will change the construction industry and these changes need to be addressed by comparing design of both the codes

Three sample buildings were selected 4, 8 and 13 Storey. All three building were moment resisting frames which is a common practice in Islamabad. Our study is focused for the region of Islamabad. For the analysis of all three structure both BCP-2007 and BCP-2021 were utilized. Comparison of global and local responses was being made as per the load pattern of BCP-2007 And BCP-2021 the responses were more for the later code. Further by utilizing the design actions as per both codes, All the three buildings were designed. After designing the comparison of the quantities was made for all three structures that were designed as per both codes, quantities as per BCP-2021 were more.

8 storey structure was selected as representative building for non-linear seismic performance assessment. For this non-linear static pushover analysis was performed for both the designs that were as per BCP-2007 and BCP-2021. After doing Push-over analysis of these structures results showed weak behavior of BCP-2007 design which was quantified using the backbone curves of these structures.

Chapter 1

INTRODUCTION

Pakistan is striving for the improvement of the construction industry. Majorly the construction in private sector is done in a non-engineered way; Only a few projects are designed for dead as well as lateral load, which is main cause behind deaths in major earthquakes. Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Nevertheless, after the Kashmir- Hazara (2005) earthquake, the government and engineering commission stressed on execution of a seismic code in this regard Building Code of Pakistan 2007 was introduced.

The Building Code of Pakistan 2007 was in use till end of 2021 but now a new code has been introduced by the government of Pakistan This code is known as Building Code of Pakistan 2021. So, in the new code the seismic provisions has changed from the first code. First Code that is BCP-2007 was based on Universal Building Code-97 and the new code is based on International Building Code. So Due to change in the code the seismic parameter has changed. In the first code Peak Ground Acceleration was used as the main seismic hazard parameter which is basically the peak acceleration with which the ground shake during an earthquake, Whereas the new code uses spectral acceleration as the main hazard perimeter which is basically related to the acceleration of the structure. In the previous code the whole country was divided into five zones based upon the range of the PGA values whereas the new code gives value of short period and long period acceleration for all the cities. There was a concept of Occupancy category which in the later code is replaced by the risk category which is utilized to find the importance factor and seismic design Category which is new concept this seismic design category is utilized to select the analysis procedure for the design and the height limitation etc. Apart from the distribution of base shear along the height was linear in the previous code whereas in the new code the distribution of vertical forces may linear or in curve based upon the time period of structure. These changes cause the base shear coefficient to change which results in change in base shear which eventually results in the design. These changes in the building code are to be addressed

To address this change, we decided to do seismic performance evaluation of the structures that are designed as per both codes BCP-2007 and BCP-2021. In this regard we selected three buildings for our research. These three buildings were of 4,8 and 13 storey the main aim behind selecting these stories is so that our research is applicable or true for all storey ranges and height. So, our comparative study is mainly focused on the city Islamabad and the soil condition for all three soil is uniform that is stiff soil of category D. So, all the three building were designed using the design action that were obtained by analysing the structures as per BCP-2021 and BC-2007. The change in design was observed due to two things at first the change in seismic hazard parameter and the other due to change in structural system because our building lies in the seismic design category D, in this category Intermediate moment resisting frames are not allowed so all the three buildings as per the new building code is special moment resisting frames and as per old code all three buildings were moment resisting frames

After the selection of the building's irregularity checks were being applied at all the three buildings as per both codes. All plan and vertical irregularities were checked as per both codes. There was torsional irregularity in 4 and 13 storey buildings to cater for these irregularities torsional amplification factor was found as per both codes. This amplification factor is multiplied by the initial accidental eccentricity of five percent to find the amplified eccentricity. After from these irregularities storey drift limitation was checked for all the three buildings as per both codes. The storey drift was within limits.

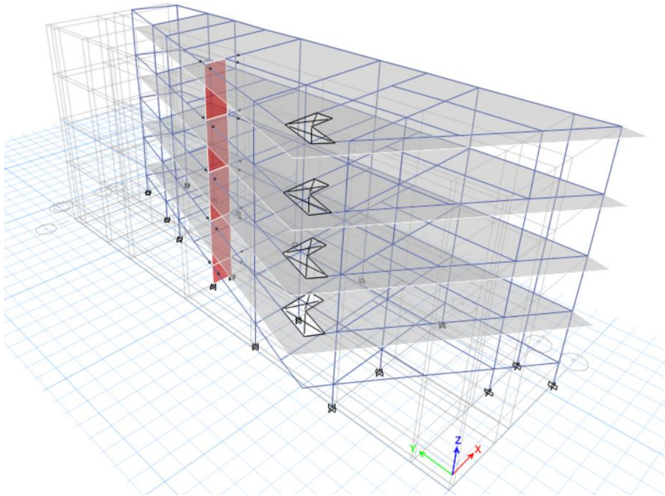


Figure 1: four storey

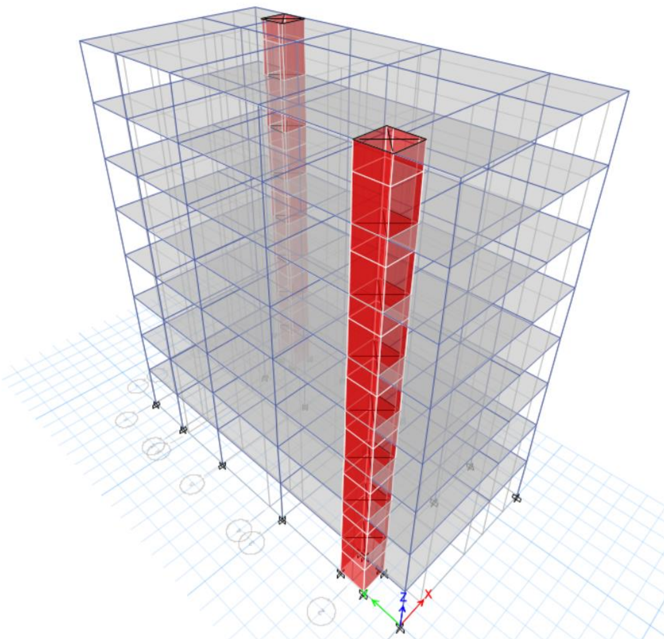


Figure 2: eight storey

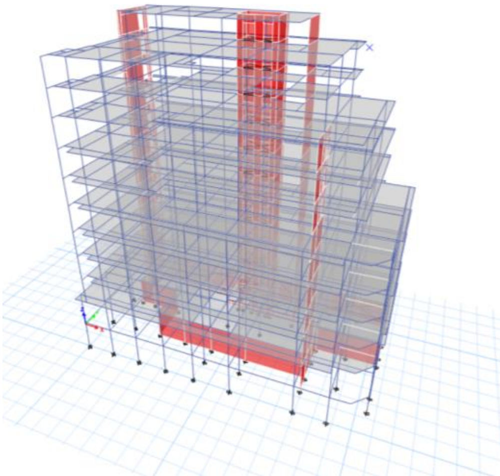


Figure 3: thirteen storey

Technical comparison between both the building codes was done. It includes the comparison of the local and the global responses. Global responses that were compared was Storey displacements, storey drifts, Storey Shear and Overturning Moments. The global responses as results of BCP-2021 were more as compared to that of BCP-2007. In local responses Shear force and bending moments diagrams were compared for the critical beams and columns in all the buildings. Apart from these all three buildings were designed as per both the codes and quantities of design of all the three buildings were compared for both the codes

In the final step Eight storey building was chosen as the representative to be used for the purpose of seismic performance evaluation. So, in this phase non-linear models were made for both design of BCP-2007 and BCP-2021.Further to check the performance of both designs non-linear static pushover analysis was done. Further the performance of the designs was compared by using the pushover curve. Further target displacement as per the seismic hazard of the new code by using ASCE 41-13 NSP procedure. And the performance of both codes at target displacement was compared in the form of damage at different performance levels. The same comparison was also made at the final step of the pushover load.

1.1. Objectives of Research

The main objective of our research is to address the change that is going to occur in the construction industry due to this upgradation of building code. How this change is going to affect the design of the structures, what will be the effect of these changes on the quantities of concrete and reinforcements in the structures, this comparison of quantities will also give us idea about the cost implications. The other derived objective of this study is how will the old building that were designed as per the old building will perform under the hazard of the new building code, in this regard we have divides our study into the following objectives to fulfill our aim of seismic performance comparison of the RC buildings designed as per BCP-2007 and BCP-2021

- Modelling of Structures
- Analysis of Structure as per BCP-2007 and BCP-2021
- Design as per ACI 318-19 by using ETABs
- Technical and Quantity Comparison
- Seismic performance assessment

The idea behind the study is to account for the changes that will occur due to upgradation of the building code.

1.2. Background

Pakistan is striving for the improvement of the construction industry. Majorly the construction in private sector is done in a non-engineered way; Only a few projects are designed for dead as well as lateral load, which is main cause behind deaths in major earthquakes. Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Nevertheless, after the Kashmir- Hazara (2005) earthquake, the government and engineering commission stressed on execution of a seismic code in this regard Building Code of Pakistan 2007 was introduced. This building code was in use since 2021 but now an upgraded building code has been launched, the background of our study is this major change that has been observed in the construction industry of Pakistan, this change will have implications on clients, contractors and specially consultants so to observe this change we have conducted this research which will give us a comparative picture of both the codes. So, for this purpose three structures have been considered

1.3. Problem Statement

As the building code of Pakistan has been upgraded from BCP-2007 to BCP-2021. Due to this change many of the seismic provisions have been changed in the equivalent lateral force procedure in the new building code as compared to the old one. Since we have used this equivalent lateral force procedure of the code for design of the structure which is a general practice in the industry. So due to these changes the seismic design requirements has changed. Due to change in requirements the design of old and new code will be different. These changes are new to the industry of Pakistan. So, it is important that these changes are addressed so that everyone related to construction industry should know how these changes are going to affect the local industry. How the design will change, whether the quantities as result of new code will be greater or lesser as compared to that of old code. So, this is the gap that we want to bridge in result of this study that we are conducting

1.4. Specified Parameters

Four Storey Building with total height of 47 Feet, Time-period of 0.96 sec. Eight storey building with height of 88 feet, and Time-period of 1.23 sec. Thirteen storey Building with height of 130 feet, and Time-period of 1.82 sec.

All the three buildings are in the city of Islamabad with the same soil condition that is stiff soil which is uniform for all three buildings. All the three buildings are moment resisting frames. As per old code these are IMRF and as per new code these are SMRF

In all the three buildings Concrete of 4000 psi strength has been used, steel reinforcement of 60 ksi has been used in this research. The selection of concrete and reinforcement was based on the local field conditions

Chapter 2

LITERATURE REVIEW

The literature shows the considerable working and study on comparisons of different building codes and performance based seismic assessments of different buildings.

2.1 PAPERS RELATED TO CODE COMPARISONS:

Several codes were discussed and compared based on the results they showed under same loading conditions. These works are reviewed keeping in view the methodology, principles, and various aspects of building codes. Some of related works are discussed below.

- **Marjan Faizan and Yuji Ishiyama**

Compared the Seismic code of Japan, USA and Iran. The study shows what parameters (base coefficient, soil effect, importance factor, fundamental period) are used to compare different building codes.

- **Shodolapo Oluyemi Franklina and Kenneth Kwesi Mensahb**

Worked on the analysis and design of main elements of a four-storey building based on the Eurocode and the British Standards. The main emphasis was on examining the bending moment diagrams of critical continuous beam span for both codes.

- **Tabish Izhar, Samreen Bano, Neha Mumtaz**

Conducted a comparative Study of for analysis and design of Reinforced Concrete Building under Seismic loading four codes (Indian Standards, Eurocode, Japan Code and ASCE 7-16) The comparisons were made on bending moment, shear force, base shear, percentage of steel etc. Seismic analysis and design of elements like beams and columns is also compared.

2.2 PAPERS RELATED TO PERFORMANCE BASED SEISMIC ASSESSMENTS:

Articles related to performance based seismic assessments gives us an overview of type of performance based seismic assessments, what criteria are they based on (IO, LS, CP) and the main philosophy behind it. Some of the articles are discussed below:

- **Mohd. Zameeruddin, Keshav K.Sangle**

Assessed the performance of various moment resisting frames subjected to different lateral load patterns. The performance assessment was based on fundamental period, roof displacement, inter storey drift ratio and base shear. Response modification factor using various performance limits was also determined.

- **J N Priestley**

Compared the three methods of seismic design and discusses them in the context of traditional force-based seismic design and earlier design approaches which contained some elements of performance-based design. The three methods that have been discussed are: the capacity spectrum approach, the N2 method and direct displacement-based design.

- **JDilip J. Chadhari, Gopal O. Dhoot**

Their study includes the importance of performance based seismic design in contrast to force-based design approaches and four building performance levels which are operation, immediate occupancy, life safety and collapse prevention. Story drift performance was recognized as an important measure of structural and non-structural damage under various levels of earthquake.

- **G.V. Sai Himaja, Ashwini .L.K, N. Jayaramappa**

Evaluated and compared the response of thirty reinforced concrete buildings, systems with different with and without infill materials using methodology namely the ones described by the FEMA-273 using nonlinear static procedures, with described acceptance criteria.

- **Davit Shahzazaryan, Gerard J. O'Reilly**

Outlined an integrated performance-based seismic design (IPBSD) method that uses expected annual loss (EAL) and mean annual frequency of collapse (MAFC) as design parameters

- **Helmut Krawinkler, G.D.P.K. Senerviratna**

The purpose of the paper is to summarize basic concepts on which the pushover analysis can be based, assess the accuracy of pushover predictions, identify conditions under which the pushover will provide adequate information and, perhaps more importantly, identify cases in which the pushover predictions will be inadequate or even misleading.

From the articles we note that what are the parameters necessary for the comparison of buildings designed as per different building codes and how their performance-based design can help us achieving better results in terms of their performance using Static Pushover Analysis.

Chapter 3

METHODOLOGY

To understand the performance of reinforced concrete building designed as per Building Code of Pakistan 2007 and Building Code of Pakistan 2021, "ETABS 2019" was used to analyse and design the structures. Earthquake loadings from two different building codes were applied on three separate buildings, global level and local level responses of structures were measured and the graphs were established for all responses. All three structures were then designed using ACI 318-19 and quantities were compared and at last one building was selected for non-linear modelling and performance of the building was checked.

For carrying out our project successfully, it was necessary to accomplish the following steps:

1. Discussions about the necessity and purpose of the project with the director of the thesis.
2. Preliminary information regarding literature in this domain and general aspects of the non-linear modelling.
3. Creating linear model of all three buildings in ETABS 2019.
4. Applying gravity loads on all three buildings.
5. Applying seismic loads on all three buildings as per both codes i.e., Building Code of Pakistan 2007 and Building Code of Pakistan 2021.
6. Analysing the buildings and checking their Global and Local level responses under these loadings.
7. Designing the buildings according to ACI 318-19.
8. Quantity Estimation of both designs of 3 buildings using CSI Detail 18.2.
9. Making Non-Linear Model of two designs of one selected structure.
10. Non-Linear Static Push-Over analysis of both Non-Linear models.

11. Calculated Base Shear produced against deflections and plot the graph.

12. Establishing Backbone Curve.

13. Calculate Target Displacement according to ASCE 41-13 for BCP 21 level of earthquake for both designs.

14. Check damages in both designs at target displacements and at 4.7% drift.

15. Compiling the results together at the end and study which system performs better.

16. Data was compiled, and graphs were established in MS Excel.

17. Evaluation of the results.

18. Writing of the thesis.

Chapter 4

MODELING ANALYSIS AND DESIGN OF STRUCTURES

4.1 INTRODUCTION OF ETABS 2019

ETABS is an engineering software tool that aids in the design and study of multi-storey buildings. ETABS has modelling tools and templates built in, as well as specified loads and their types, analysis methods, and solution strategies, all of which are useful when dealing with grid-like geometry specific to a certain type of structure. The cutting-edge and ground-breaking new ETABS is the ultimate integrated software solution for structural analysis and design.

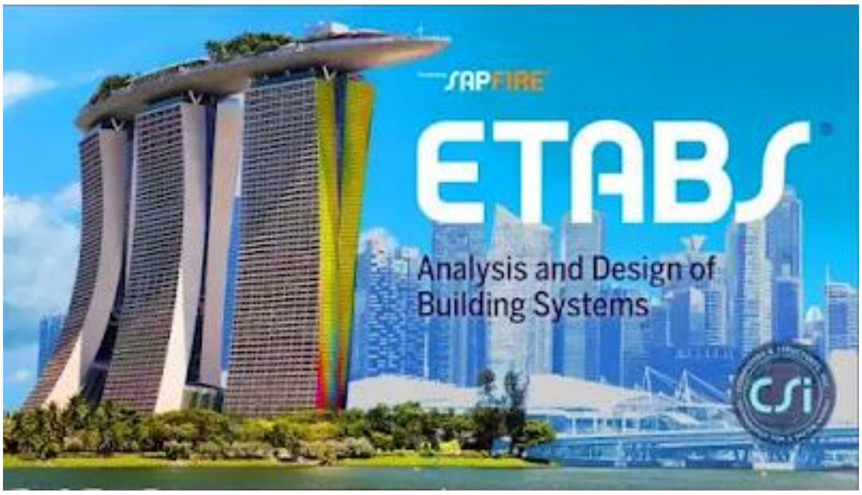


Figure 4: ETABS software

ETABS can analyze any type of structure and can design the following:

- Design of frames (either steel or concrete structure)
- Composite beams and columns system
- Steel joists system

- Concrete and masonry shear walls
- Capacity check for steel connections and base plates.

4.2. MODELING IN ETABS

All Structures were modeled in CSI ETABS 2019. The structure modeled have been shown in figure 7,8 and 9 respectively. All structures are Beam-Column structures and have shear walls. All building systems are intermediate moment resisting frames (IMRF), when designing according to BCP 2007 and all building systems are special moment resisting frames (SMFR) when designing according to BCP 2021 as IMFR is not allowed in seismic design category D. We provided moment releases on beams connecting in shear walls to make our structures moment resisting frames.

Given below are the models of all of three structures that were modeled in ETABS 2019,

1) FOUR STOREY STRUCTURE

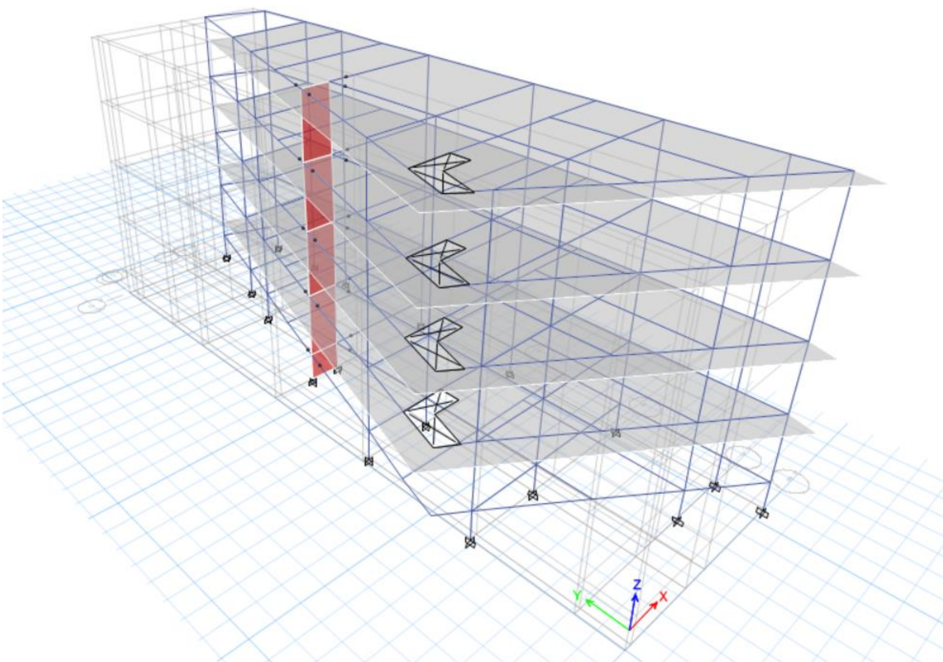


Figure 5: four storey structure

2) EIGHT STOREY STRUCTURE

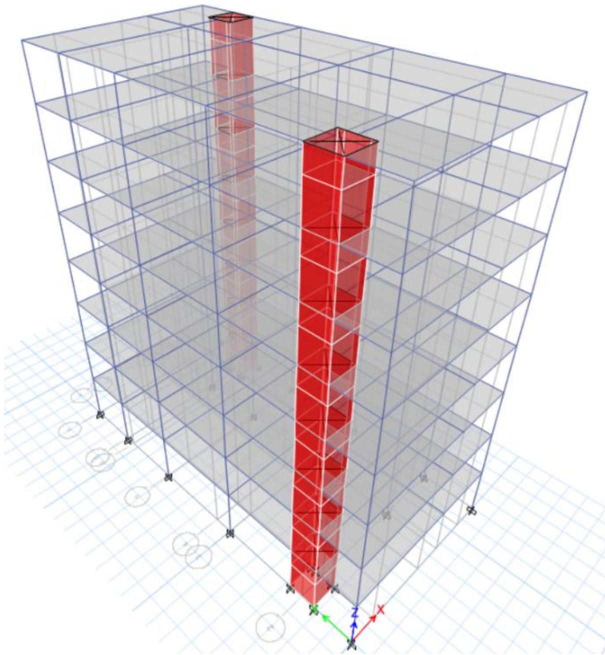


Figure 6: eight storey structure

3) THIRTEEN STOREY STRUCTURE

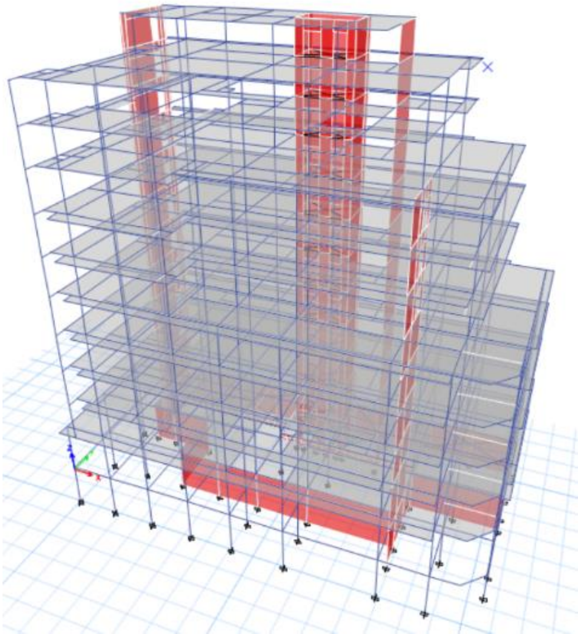


Figure 7: thirteen storey structure

Firstly, grids were defined for our structures. After that, materials were defined which were given in building characteristics. After that, frame sections were defined which were specified by the architect in architectural drawings. Frame sections consists of beams and columns. The building consists of same columns throughout. As all structures must be designed therefore reinforcement to be designed option was marked. At the end, Stiffness modifiers were applied to all sections.

The next step after defining frame sections, area sections were defined. All slabs of all structures are 6" thick. At then area load was assigned to the structure.

4.3. ASSIGNING SEISMIC LOADS TO STRUCTURES

As BCP 2007 was based on UBC 1997 so we make two seismic load patterns according to UBC 97. One in x-direction with eccentricities also in x-direction, and one in y-direction with eccentricities also in y-direction.

And as BCP 2021 was based on IBC 2021 and IBC 2021 refers ASCE 7-16 for seismic design requirements so two load patterns were defined according to ASCE 7-16. One in x-direction with eccentricities also in x-direction and one in y-direction with eccentricities also in y-direction.

4.4. ANALYZING THE STRUCTURES

First, modal analysis was done on all three structures and time periods and governing mode shapes were checked. Then seismic analysis was run on the structures and Global Level and Local Level responses were checked.

Following are Global Level response that were checked:

- Maximum Storey Displacement

- Maximum Storey Drift
- Storey Shear
- Overturning Moments

Following are Local Level response that were checked:

- Shear Force
- Bending Moments

4.5. DESIGNING THE STRUCTURES

After analysis, design combinations were defined and designing of the structures was carried out. For this purpose, first of all, in design preference tab concrete design code ACI 318-19 was selected, and other parameters were input.

After running the design in ETABS 2019, cross-sectional sizes of failing frame elements were updated and then reinforcement ratios were checked if they are exceeding 2% or not.

4.6. QUANTITY ESTIMATION

After designing the structures in ETABS 2019, we got 2 different designs of each structure, so we have 6 designs in total. For Quantity Estimation purpose we used CSI Detail 18.2.0.

CSI DETAIL:

CSI Detail is a product of Computers and Structures, INC. It imports files from ETABS and SAFE and automatically creates detailing and drawings that can be used in BIM software. In addition to that it also automatically calculates the material quantities.

Figure 8: CSI detail software

Both designs of each structure was then exported to CSI Detail and rebar quantity was calculated for beam, columns and slab separately and then quantities were compared and show in the form of bar charts which were made in MS Excel.

Chapter 5

SEISMIC PERFORMANCE EVALUATION

5.1 PUSH-OVER ANALYSIS

"*Pushover analysis is a nonlinear static analysis method in which the structure is subjected to progressively increasing lateral stresses until a desired displacement is obtained*." Gravity loads are applied first to a mathematical model of the building that contains load-deformation diagrams of all lateral force resisting parts. Then a predetermined lateral load pattern is applied, which is dispersed across the building height.

It is a static and nonlinear analysis method in which the structure is subjected to gravity loading and displacement-controlled lateral loading, which gradually increases through elastic and inelastic stages until the structure breaks.

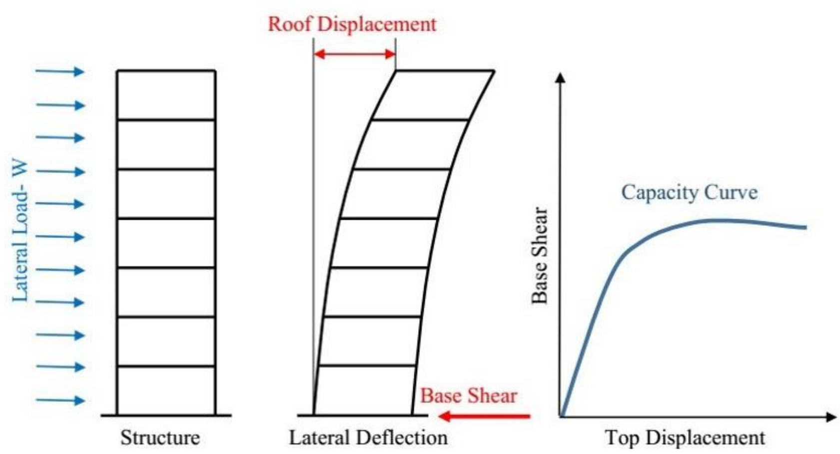


Figure 9: push over analysis

Built in plastic hinges were used in structures. In frame structure, M3 hinges were used for beams and P-M2-M3 hinges were used for columns.

Basically, we have modelled column and shear wall using fibre hinge approach in which we introduce nonlinearity at material level whereas for beams we used plastic hinges approach in which we introduce nonlinearity at member level by giving the moment rotation curve for the member.

5.2 TYPES OF PUSHOVER ANALYSIS

There are two forms of pushover analysis. It can be performed using either force or displacement control. It's referred to as forcibly controlled when the loading is known (such as gravity loads). While the mechanism used in the displacement-controlled method is understood, the amplitude of applied loads or loading is unknown.

Alternate loads are applied to achieve a certain displacement against each loading until the structure fails at a specific displacement or deflection. Slab displacement is commonly referred to as the control displacement. Internal forces and deformations at a given displacement provide inelastic strength and deformation demands, which are then compared to available capabilities to determine a performance point. This research employed a displacement-based method for earthquake loading and a forced-based method for gravity loading.

5.3 LIMITATIONS OF PUSHOVER ANALYSIS

Though pushover analysis offers advantages over elastic analysis techniques, it does have some limits that must be understood before it is used. Approximation of goal displacement, transverse loading pattern selection, and detection of failure mechanisms due to larger modes of vibration are all key issues that skew pushover study results. To derive the attributes of an equivalent SDOF system, a shape vector exhibiting the deformed shape of the MDOF system is used.

Since, in pushover analysis, a usually comparable transverse loading pattern is applied throughout, the distribution of inertia forces varies with the amplitude of seismic loading and the time during such seismic loading. The product of storey mass and displacement associated with a shape vector at the storey under consideration is directly proportional to the transverse loading patterns employed in pushover analysis. Uniform, elastic first mode, "code" distributed, and a single transverse loading at the top of the structure are the most common transverse loading patterns. Due to the identical lateral loading patterns, failure mechanisms driven by higher mode effects in the middle or upper storey could not be expected. If higher mode effects are not insignificant, constant loading patterns can offer adequate estimates. Many researchers have recommended adaptive loading patterns that consider differences in inertial forces as a function of inelasticity because of these constraints. While adaptive loading patterns have provided some better approximations, they make pushover analysis computationally and conceptually problematic.

5.4 NON-LINEAR MODELLING

5.4.1 Cross-Sectional Details

So, for non-linear analysis we must first make non-linear model. After designing the buildings as per the BCP-2007 and BCP-2021. For the performance assessment we have used our 8-storey Model as a sample building. So, for making non-linear model we must give details of all the cross-section that include the reinforcement detail and distribution as well. So, we defined the section for beams, columns, and shear walls. This reinforcement will further help to assign default hinges and will be utilized in non-linear static push-over analysis.

5.4.2 Input Parameters for Hinges

For pushover analysis the initial input was the hinge assignment. Hinges can be assigned to beam or column at any location. Hinge can be defined for Uncoupled moment (M2 and M3), torsion (T), axial force (P) and shear (V2 and V3) force-displacement relations. For columns axial load changes under lateral loading, there is also a coupled P-M2-M3 hinge which yields based on the interaction of axial force and bending moments at the hinge location. More than one type of hinge can be assigned at the same location of a frame element. ETABS considers three types of hinge properties.

The built-in default hinge properties for steel and concrete members are based on ASCE 41_13 and idealized flexural hinge criteria. Based on the above discussion we have defined default hinges according to ASCE 41_13 at both ends (i.e., at relative distance 0 and 1) in beams and for beams we use moment M3 hinges. For column and shear wall we have introduced fiber hinges in which actually it divides the whole cross-section into fibers, and we have to give non-linear properties at material level and those non-linear properties are a stress strain curve and the hysteresis are given as the input for steel and concrete. Further for column we used Fiber P-M2-M3 default hinges whereas for shear walls we used Fiber P-M3 default hinges. These hinges are then overwritten by using hinge overwrite command. Hinge Assignment step is necessary to check formation of hinges at different levels i.e.

- IO (Immediate Occupancy)
- LS (Life Safety)
- CP (Collapse Prevention)

5.4.2.1 Non-Linearity at Material Level

So, for assigning hinges for column and shear wall we must define non-linearity at material level.

- So, in our case the performance level for steel is

Acceptance Criteria	Description
Compression	
IO	Onset of compression yielding
LS	2 times of compression yielding
CP	3 times of compression yielding
Tension	
IO	Onset of tensile yielding
LS	3 times of tensile yielding
CP	5 times of tensile yielding

Table 1: performance levels for steel

- And acceptance criteria for different levels in **concrete** is

Acceptance Criteria	Description
Compression	
IO	Onset of compression cracking
LS	Peak stress achieved
CP	Onset of significant strength degradation
Tension	
IO	Onset of tensile cracking

Table 2: performance level for concrete

- The nonlinear properties that were assigned at material level for **concrete** are

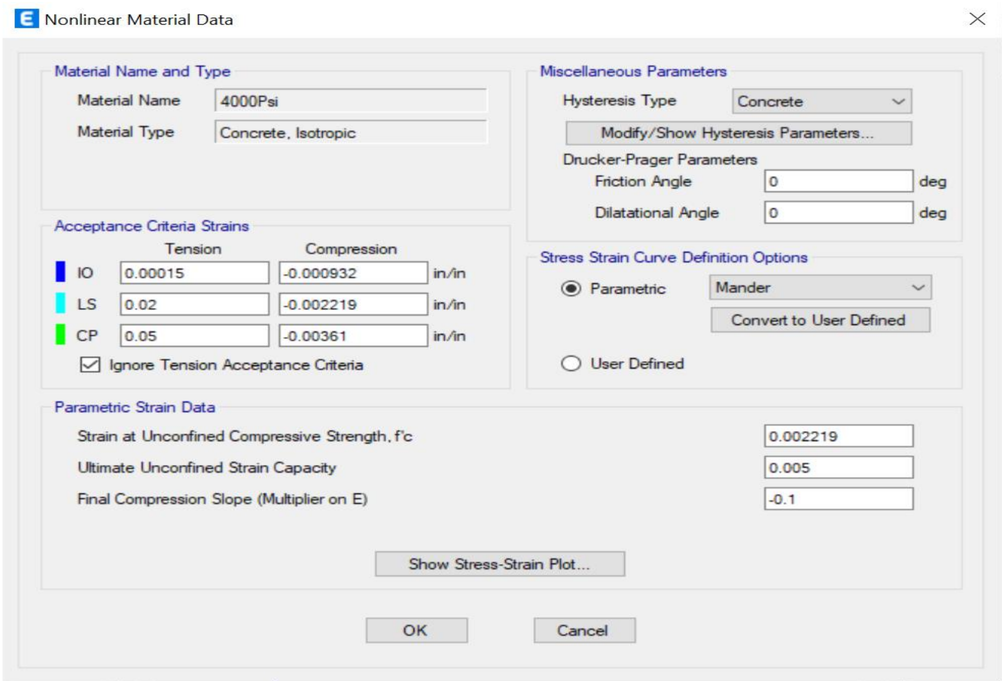


Figure 10: nonlinear material data for concrete

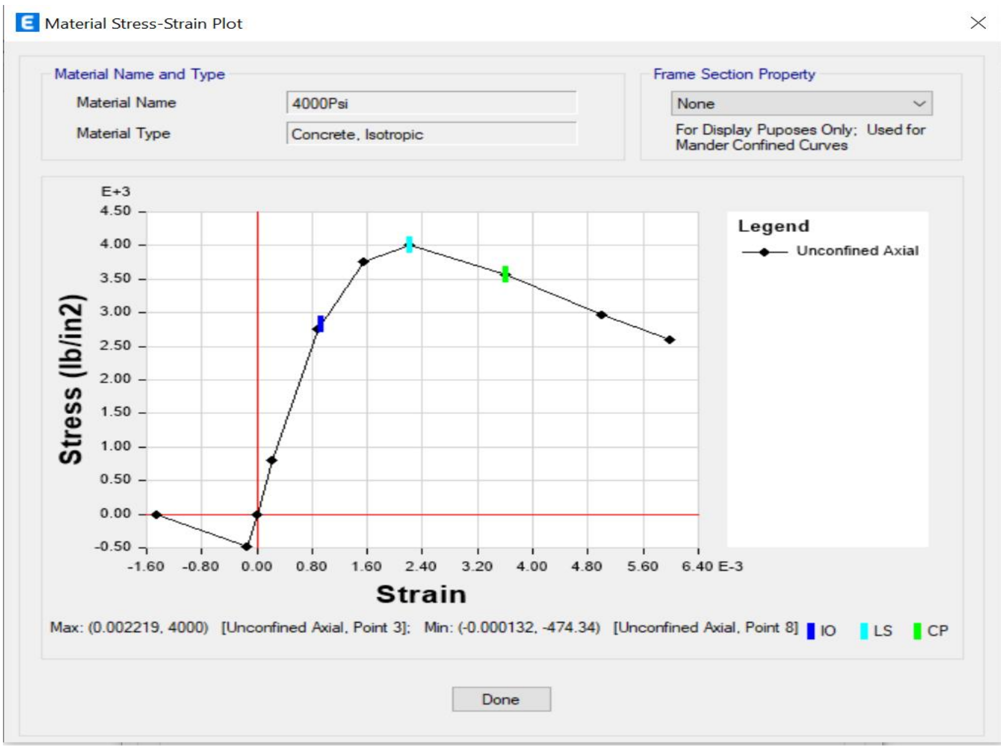


Figure 11: stress-strain curve for concrete

- The nonlinear properties that were assigned at material level for **steel** are

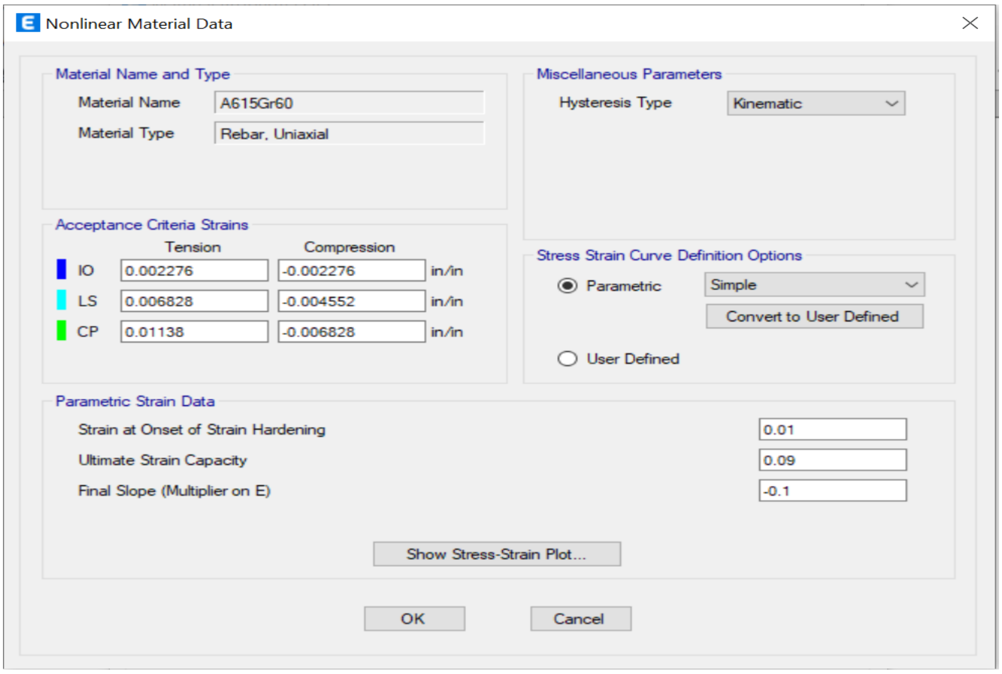


Figure 12: nonlinear material data for steel

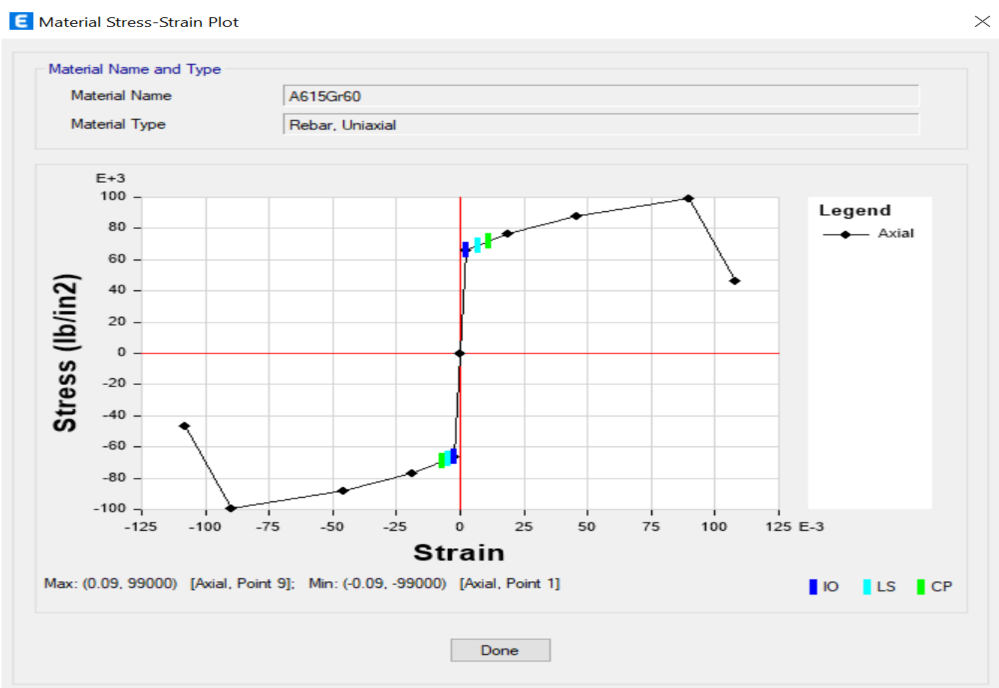


Figure 13: stress-strain curve for steel

5.4.2.2 non-Linearity at Member Level

For **beams** we have used plastic hinges for that we give force deformation curve to define hinges. We have defined auto hinges using ASCE 41-13

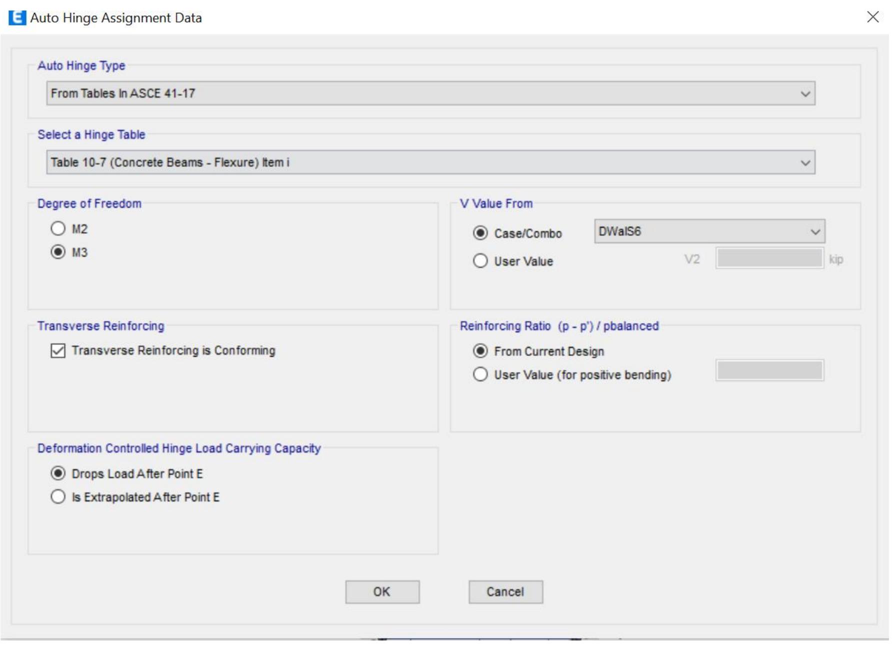


Figure 14: automatic hinge assignment for beams

By assigning auto hinges using ASCE 41-13. It gives for deformation curve to the member like that shown in the figure below

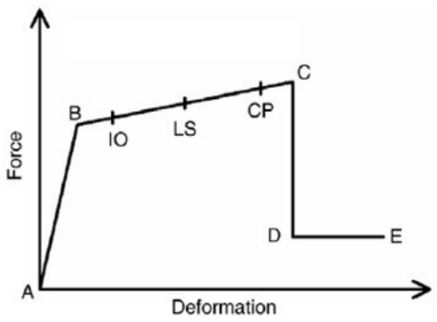
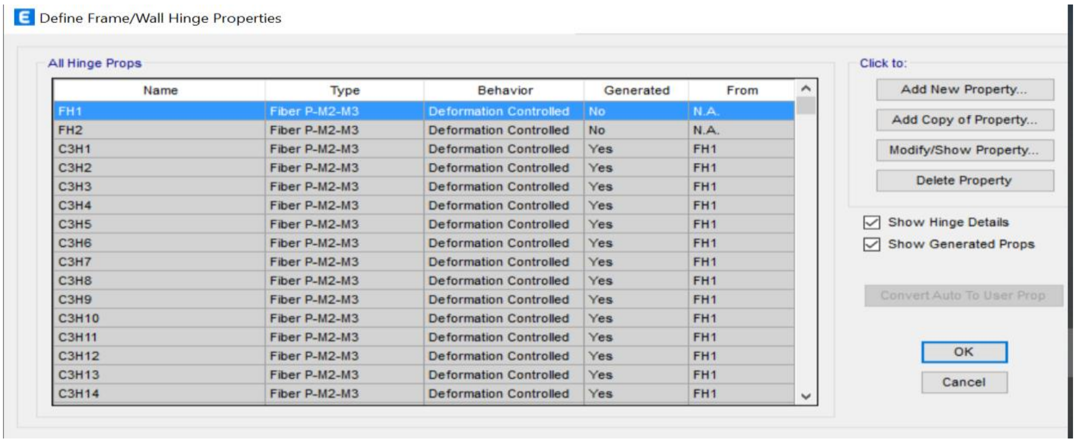


Figure 15: plastic hinges

5.4.3 Sample Assigned Hinges

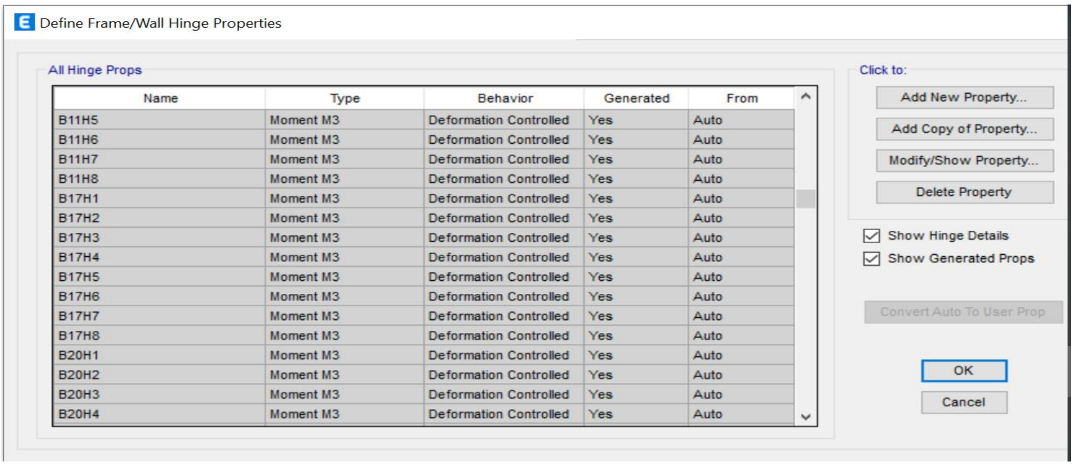
- Some of the sample hinges that are being assigned to column



Name	Type	Behavior	Generated	From
FH1	Fiber P-M2-M3	Deformation Controlled	No	N.A.
FH2	Fiber P-M2-M3	Deformation Controlled	No	N.A.
C3H1	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H2	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H3	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H4	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H5	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H6	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H7	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H8	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H9	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H10	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H11	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H12	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H13	Fiber P-M2-M3	Deformation Controlled	Yes	FH1
C3H14	Fiber P-M2-M3	Deformation Controlled	Yes	FH1

Figure 16: Sample hinges for column

- Some of the sample hinges that are being assigned to the beams



Name	Type	Behavior	Generated	From
B11H5	Moment M3	Deformation Controlled	Yes	Auto
B11H6	Moment M3	Deformation Controlled	Yes	Auto
B11H7	Moment M3	Deformation Controlled	Yes	Auto
B11H8	Moment M3	Deformation Controlled	Yes	Auto
B17H1	Moment M3	Deformation Controlled	Yes	Auto
B17H2	Moment M3	Deformation Controlled	Yes	Auto
B17H3	Moment M3	Deformation Controlled	Yes	Auto
B17H4	Moment M3	Deformation Controlled	Yes	Auto
B17H5	Moment M3	Deformation Controlled	Yes	Auto
B17H6	Moment M3	Deformation Controlled	Yes	Auto
B17H7	Moment M3	Deformation Controlled	Yes	Auto
B17H8	Moment M3	Deformation Controlled	Yes	Auto
B20H1	Moment M3	Deformation Controlled	Yes	Auto
B20H2	Moment M3	Deformation Controlled	Yes	Auto
B20H3	Moment M3	Deformation Controlled	Yes	Auto
B20H4	Moment M3	Deformation Controlled	Yes	Auto

Figure 17: sample hinges for beams

- Some of the sample hinges that are being assigned to the shear walls

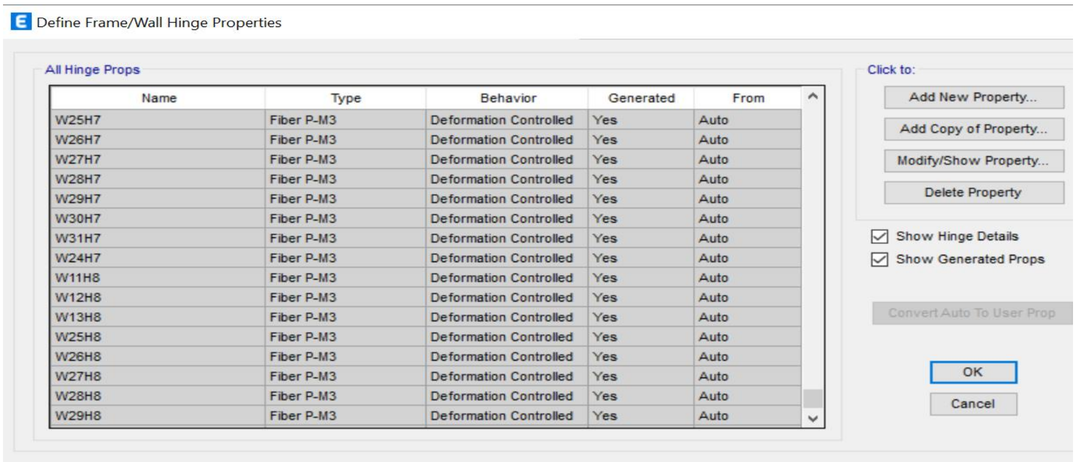


Figure 18: sample hinges for shear walls

5.5 LOAD CASE FOR PUSHOVER ANALYSIS

- We have used single mode pushover analysis by introducing a non-linear pushover case in the single direction. For that first we need to introduce the gravity non-linear case because that is the requirement for pushover analysis. The gravity Non-linear is started from zero initial condition.

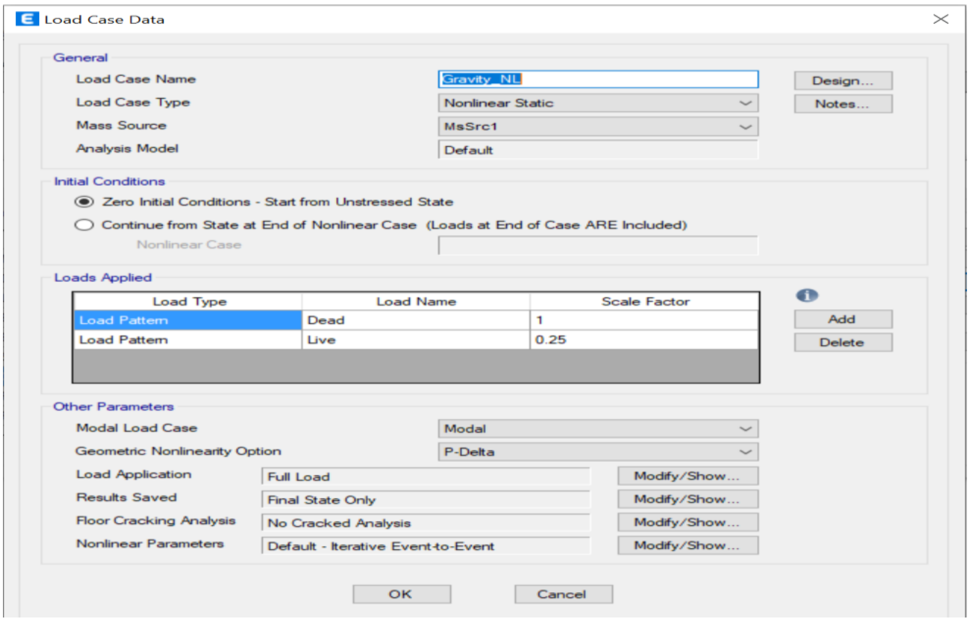


Figure 19: dialog box for Gravity nonlinear load case

- After applying the gravity non-linear case we have to apply push-over mode case in x-direction. Now in this case we continue the load case at end of non-linear gravity case

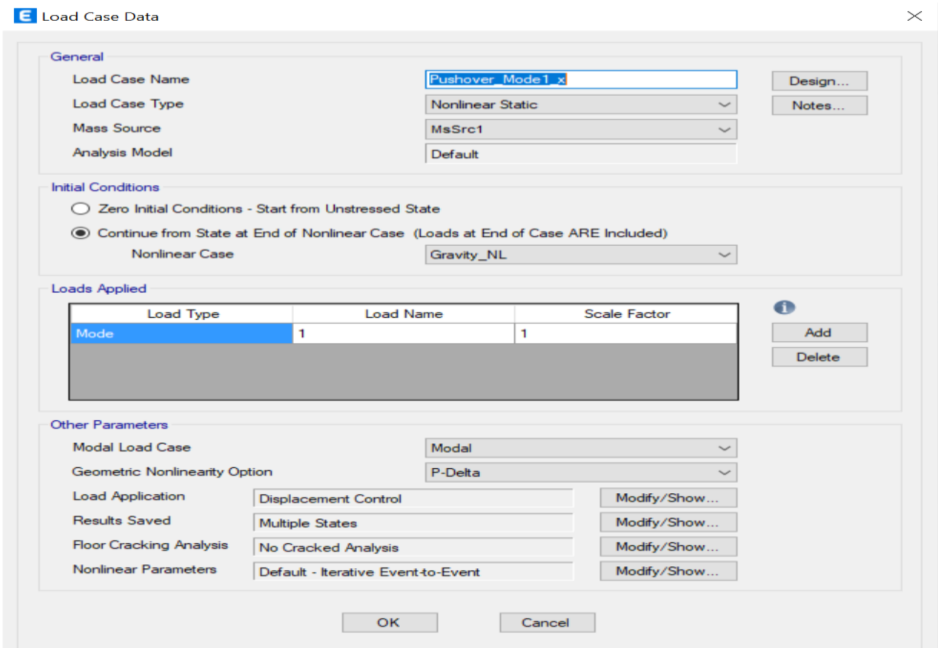


Figure 20: dialog box for modal pushover load case

- After this we ran both of above cases and after that we will get backbone curve and all the other pushover results

5.5.1 Evaluating the performance at target displacement:

As per the non-linear static procedure in ASCE 41-13 we found the target displacement. For calculating the target displacement, we utilized the hazard level of new code. By using that hazard level, we found target displacement for design of both BCP-2007 and BCP-2021 by using the option of NSP ASCE 41-13 in ETABS. After determining the performance point, we evaluate the performance at those displacements. The performance was evaluated in the form of performance of hinges that we defined earlier. We assessed the damage in the form of number of members that have passed different safety level. These three levels as defined earlier are Immediate Occupancy IO, Life safety LS, Collapse prevention CP.

Chapter 6

RESULTS AND DISCUSSION

So, below are the results for technical comparison, comparison of quantities, and comparison of performance. For technical comparison the responses were more as per the loading of new code that is BCP-2021, The quantities as per new code were also observed to be more, and the seismic performance of the new code BCP-2021 was observed to be better than the old code of BCP-2007

6.1 TECHNICAL COMPARISON

The technical comparison includes the comparison of responses at global level that is at the structure level and the comparison of responses at local level that is at member level.

6.1.1 Comparison of Global Responses:

As per the results all the global responses that are generated in case of the new building code that is BCP-2021 is more than that of BCP-2007

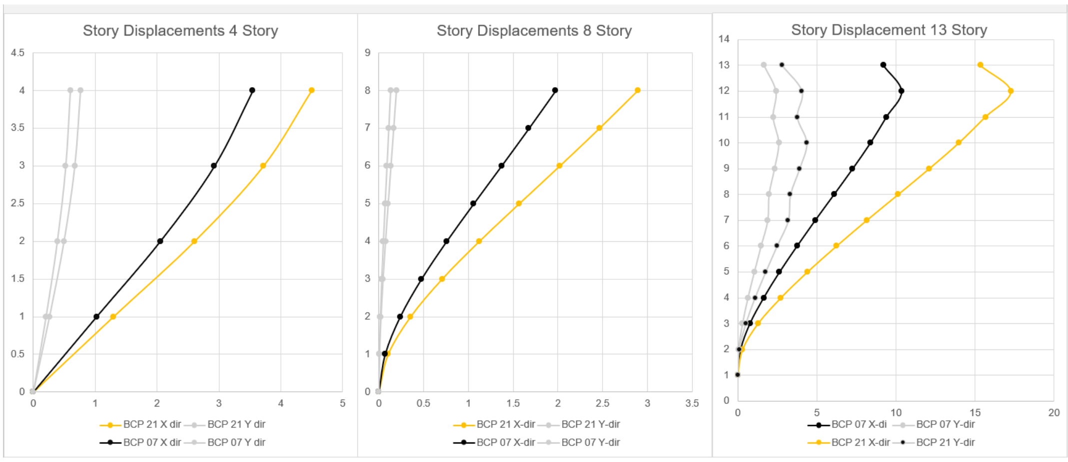


Figure 21: graphs for maximum storey displacements

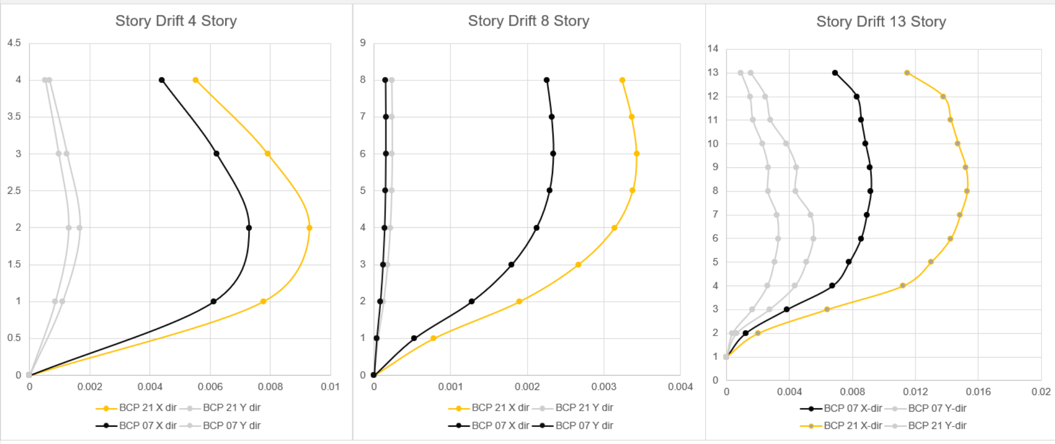


Figure 22: graphs for maximum storey drifts

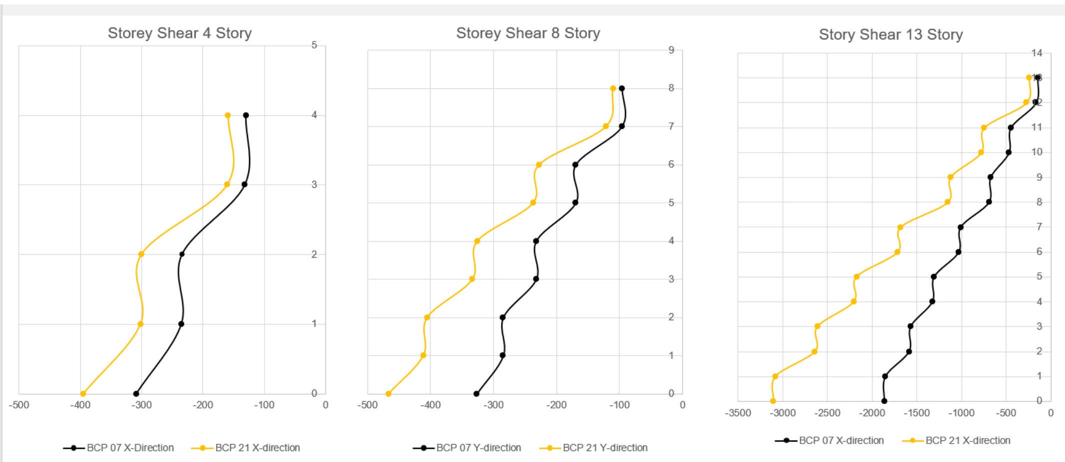


Figure 23: graphs for storey shears

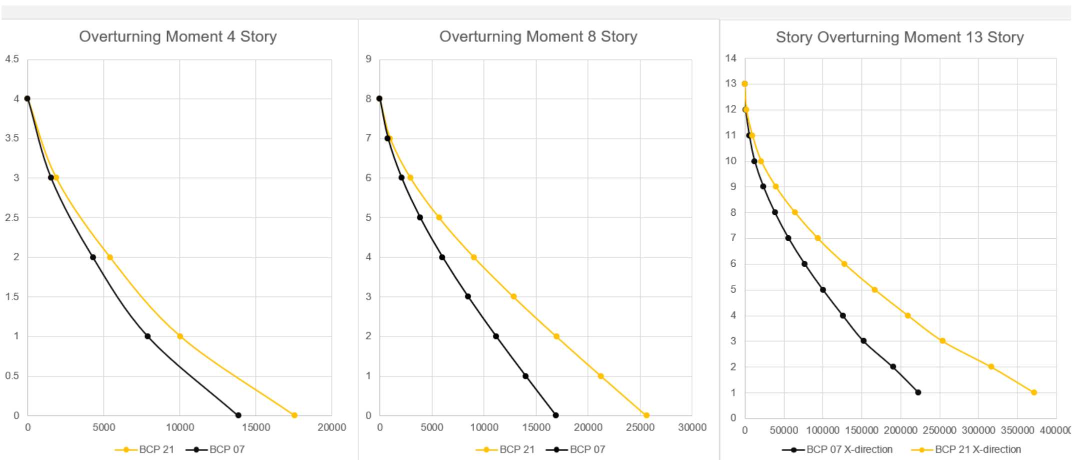


Figure 24: graphs for overturing moments

6.1.2 Comparison of Local Responses:

After comparing the SFD and BMD for beam and column it was observed that enhanced or more forces were observed as per the loading of the new code. In all the picture below the shear forces are in kips and the bending moments are in kip-ft

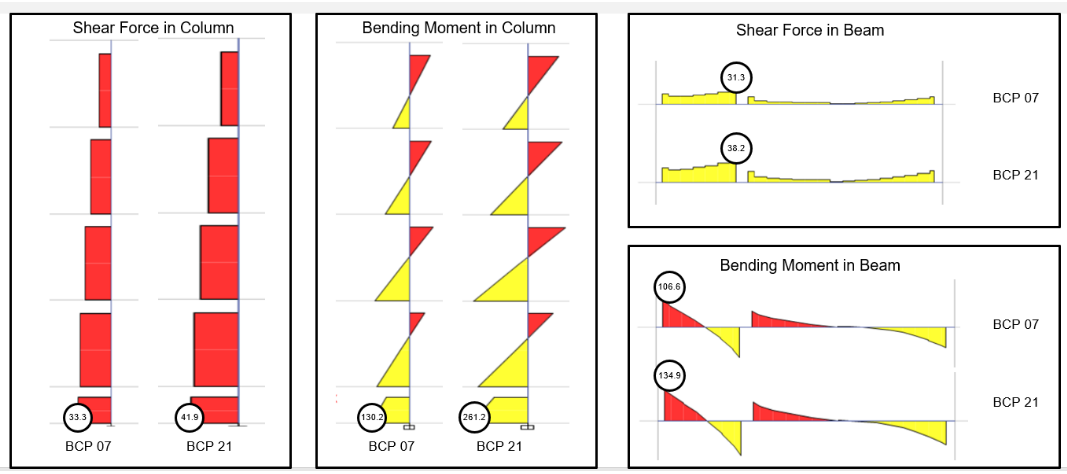


Figure 25: local level responses for 4 storey structures

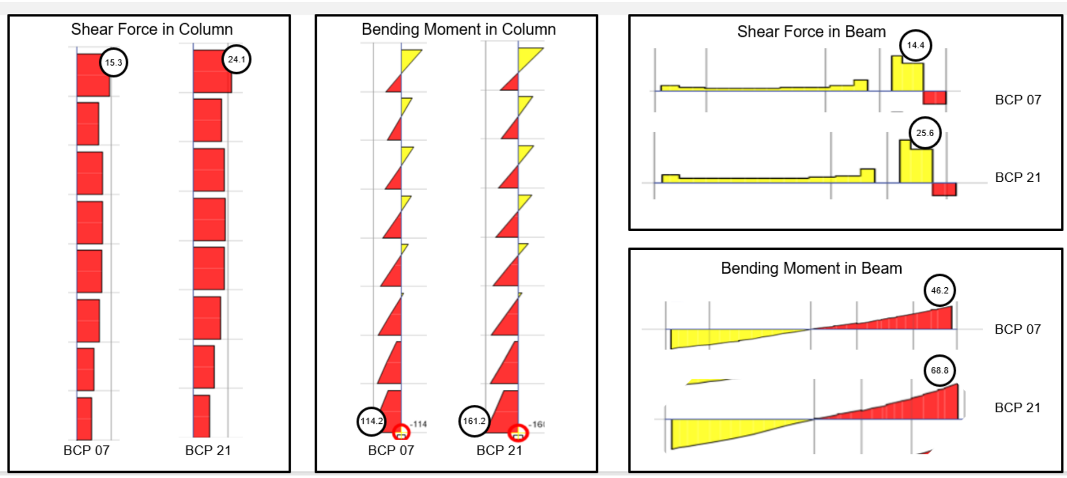


Figure 26: local level responses for 8 storey structures

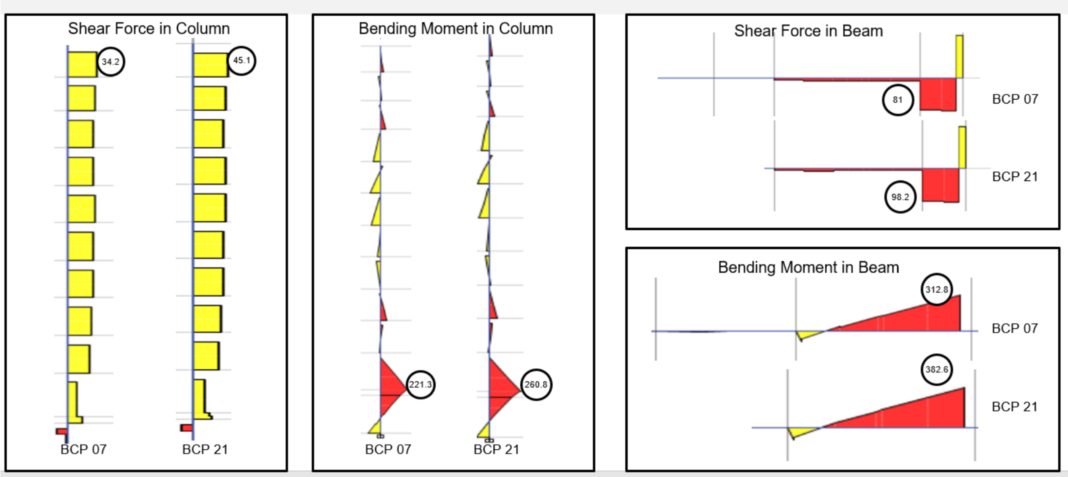


Figure 27: local level responses for 13 storey structure

6.2 COMPARISON OF QUANTITIES

No significant changes were observed in the quantities of concrete for both the designs that is BCP-2007 and BCP-2021. Whereas for reinforcements significant changes were observed.

Figure 28: rebar quantity comparison

6.3 COMPARISON OF SEISMIC PERFORMANCE

The seismic performance is evaluated by utilizing backbone curve and by evaluating the design as per both code at performance point.

6.3.1 Pushover/ Back-Bone Curve:

From back-bone curve the performance of the building designed as per BCP-2021 was better that that designed as per BCP-2007.

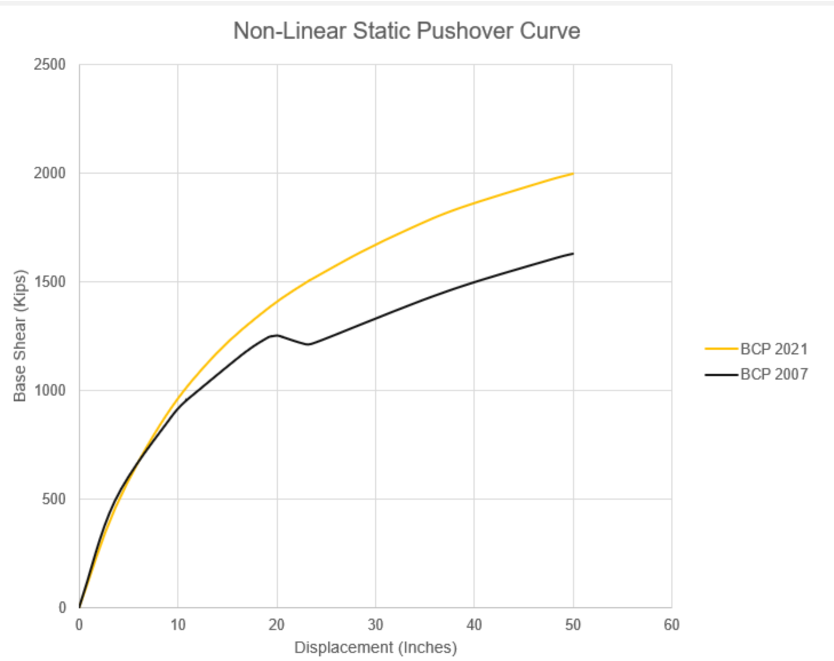


Figure 29: pushover curves for both designs

6.3.2: Evaluation at Performance Point

After evaluating both structure at target displacement which was 9.01 inches as per BCP-2007 and 9.75 inches as per BCP-2021. As per BCP-2007 15 members passed the IO level whereas as per BCP-2021 only 4 members passed the IO performance level which shown enhances performance of the building that was designed as per new code.

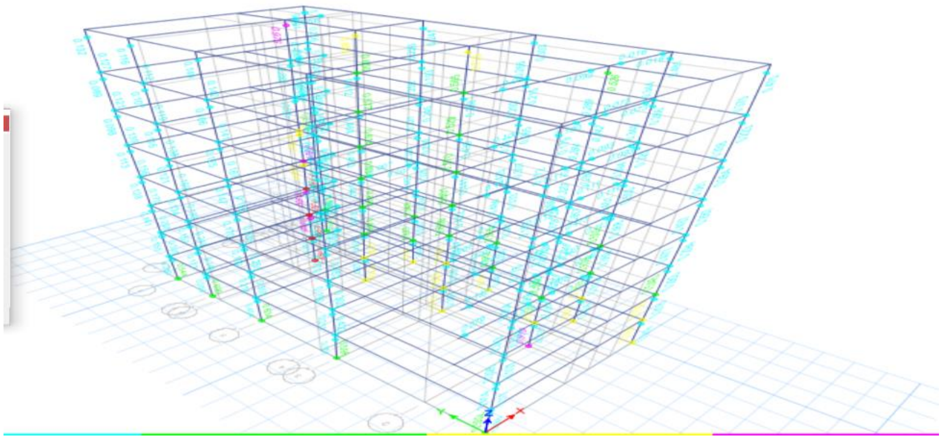


Figure 30: IO performance check at target displacement for BCP-21 design

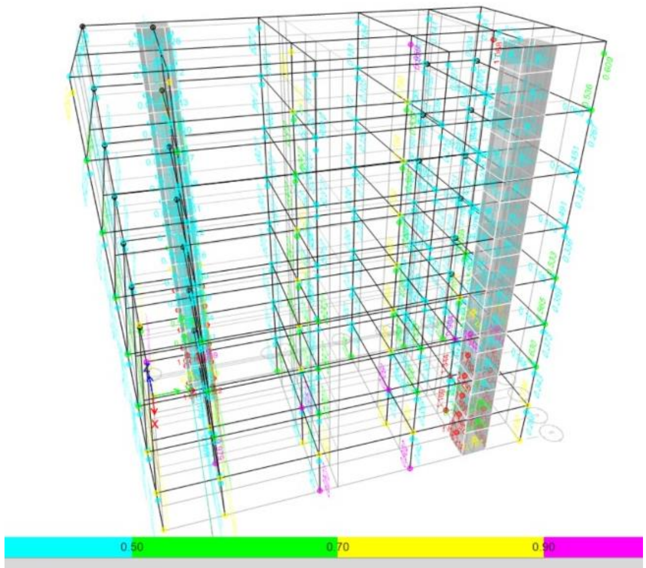


Figure 31: IO performance check at target displacement for BCP-07 design

Chapter 7

CONCLUSION AND FUTURE RECOMMENDATIONS

7.1. CONCLUSION

These remarks are for the city of Islamabad and for the stiff soil condition. Due to upgradation of building code of Pakistan there were many changes that were observed the main change was the hazard perimeter that was changed from Peak ground acceleration to spectral acceleration. The procedure to calculate the base shear is changed in new code. Due to these changes, there were changes in global responses, local responses, Quantities of both designs and the seismic performance.

After performing the technical comparison, it can be concluded that global responses that includes maximum story displacements, Maximum story shear, Base Shear, and overturning moments developed as per the loading of BCP-2021 were more than that developed as per BCP-2007. The same behaviour was observed for the local responses, the shear force and bending moment developed into any beam or column as per the loading of BCP-2021 were more than those developed as per the loading of BCP-2007.

Quantity comparison suggest that there were no significant changes in the quantity of concrete for both the design of BCP-2007 and BCP-2021. Whereas in case of reinforcement there was a significant change, the quantity in reinforcement of BCP-2021 design were more than that of BCP-2007.

From back-bone curve the performance of the building designed as per BCP-2021 was better that that designed as per BCP-2007. We can safely conclude that the buildings designed according to BCP 2021 will have greater seismic capacities, more strength and will be more ductile as compared as compared to the previous buildings based on the previous Building code.

It is to be noted that as per new code there are also some new restrictions on the allowed building systems. As in our case in seismic design category D. The new code doesn't allow IMRF which was allowed by previous code only SMRF can be constructed.

7.2. FUTURE RECOMMENDATIONS

In future, studies could be done on buildings with more than two stories, unsymmetrical plans, and complex design. Also, dynamic analysis i.e., time history analysis and response spectrum analysis should be done to obtain more precise and accurate results. As the time-history analysis is the nonlinear dynamic analysis procedure so here we can apply a real time earthquake which is a more realistic scenario as compared to that of applying a static pushover case. Further the study can be extended to a high-rise structure.

Chapter 8

REFERENCES

Chaudari D., Dhoot G., (2016), *"Performance based seismic design of reinforced concrete building",* Open journal of Civil Engineering

Faizian M., Ishiyama Y., (2004) "*comparison of seismic codes of 1981 Japan (BSLJ), 2000 USA (IBC) and 1999 Iran (ICS)",* 13th World Conference on Earthquake Engineering Vancouver, B.C., Paper No. 3168

Franklin S., Mensah K. (2011), *"A comparative study of EC2 and BS8110 Beam Analysis and Design in a Reinforced Concrete Four Storey Building",* Journal of Basic and Applied Scientific Research

Himaja G., Ashwini K., Jayaramappa N., (2015), *"Comparative Study on Non-Linear Analysis of infilled frame for vertically Irregular Buildings"*, International Journal of Engineering Science Invention

Izhar T., Bano S., Mumtaz N., (2019), *"Comparative Study oon Analysis and Design of Reinforced Concrete Building under Seismic Forces for Different Codal Guidelines",* International Journal of Trend in scientific Research and Development, Volume 3 (4)

Krawunkler H., *"Pushover Analysis: Why, How, When and When Not to Use it"* Structural Engineers Association of California

Najam F., *"Understanding Structures with Dr Fawad Najam"*, https://www.youtube.com/c/fawadahmednajam

Priestley M., (2000), "Performance based seismic design", Bulletin of the New Zealand society for earthquake engineering

Shahnazaryan D., Reilly G., (2022), *“On the seismic loss estimation of integrated performance-based designed buildings”*, Earthquake Engineering and Structural Dynamics

Zameeruddin M., Sangle K., (2020), *“Performance based seismic assessment of reinforced concrete moment resisting frames”*, Journal of King Saud University Engineering sciences