FYP Final Report

SEISMIC PERFORMANCE EVALUATION AND COST COMPARISON OF DIFFERENT STRUCTURAL SYSTEMS, USING BCP-07 AND BCP-21

Final Year Project Report

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FINAL YEAR PROJECT TITLED

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In

CIVIL ENGINEERING

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ACKNOWLEDGEMENTS

بسم الله الرحمن الرحيم

This research has come to fruition due to several people, the most involved of which is my Research Supervisor, Dr Sarmad Shakeel. He has been very helpful throughout the project, guiding us at every step along the way and always taking out time for me and my group members. It would not be an overstatement to say that Dr. Sarmad Shakeel has proved himself to be more than just a supervisor. Additionally, my group members, Mr. Syed Aayan Saqib, Mr. Muhammad Awais Khan, and Mr. Muhammad Abdul Moiz Khan have played a significant role in the completion of the project. It would not have been possible without their tireless efforts. I would also like to thank the administration of NICE, NUST for their continuous support and motivation.

Thank You,

Saadan Hussain Khan,

B.E. Civil NICE,

NUST, Islamabad.

LIST OF TABLES

LIST OF FIGURES

Contents

CHAPTER 1

ABSTRACT:

Pakistan is a developing country with continuous advancements in the construction sector. In attempt to advance the construction practices in the country, the building code of Pakistan has been updated in 2021, to BCP-21 (Building Code of Pakistan 2021). Previously BCP-07 was being practiced, which was based on UBC-97 (Uniform Building Code 1997), which uses PGA as a seismic parameter. The new building code of Pakistan, BCP-21 is based on IBC-21 (International Building Code 2021), which uses spectral acceleration Ss and S1 as seismic parameters for estimating the seismic demands.

The change in the building code would lead to a change in construction practice and there arose a need to assess the seismic performance and cost difference of the buildings designed as per the new code. This thesis involves the study of 6-storey buildings, designed as MRF and Dual structural systems, using BCP-07 and BCP-21. The effect of change of code on MRF and Dual structure buildings was studied, using linear and non-linear approaches. The difference in the Concrete and steel quantities and the overall costs of buildings was also estimated.

A real 6-storey building was selected and modelled as MRF and Dual system. These models were analyzed and designed under the seismic hazard parameters of two locations, under BCP-07 and BCP-21. Due to different levels of seismicity, Islamabad and Abbottabad were selected as the locations for these models, in order to extract more precise and realistic conclusions. The seismic performance was assessed after the linear analysis and design, showing the difference in seismic demands and capacities of buildings under both codes. The quantities of concrete and steel were compared for all the models and the difference was estimated in the costs of buildings.

For more detailed analysis, the nonlinear seismic performance of the models was assessed using the non-linear static pushover analysis. A 6-storey building designed as per BCP-07 and BCP-21, was analyzed under the latest seismic requirements, using MRF and Dual structural systems. The pushover curves were analyzed, and useful conclusions were extracte

CHAPTER 2

2.1 INTRODUCTION:

Pakistan's construction industry plays a massive role in its economy. With time, advancements are being made and need to be continued to let the construction sector flourish providing economic and safe solutions for the building of all types of structures. To serve this purpose, the need was felt for the organization and implementation building code and for enhancing the construction practices, using up-to-date Research and professional practices. The Kashmir Hazare earthquake (2005) resulted in the loss of more than 85,000 human lives. However, after the Kashmir Hazara earthquake (2005), the government and the technical committee emphasized the implementation of seismic codes in this area, and the Pakistan Building Code was introduced in 2007.

Pakistan Building Code 2007 was used until the end of 2021, but now new standards have been introduced by the Government of Pakistan. This code is known as Pakistan Building Code 2021.BCP-2007(BCP 2007, 2007) was originally based on UBC-97 whereas BCP-21(BCP-2021, 2021) is based on the IBC-21.

This change in the code changed the seismic parameters. In the first regulation, peak ground acceleration (PGA) was used as the primary seismic hazard parameter, which is the maximum acceleration at which the ground vibrates during an earthquake. While the previous code divided the entire country into five regions based on the range of PGA values, the new code provides short-term and long-term acceleration values (Ss and S1) for all cities.

The new code uses the seismic design categories, which is a new concept. This category of seismic design includes design and height restrictions. Apart from the distribution of base shear along the height, which was linear in the previous code, the new code may have a linear or curved normal force distribution based on the period of the structure. These changes change the base shear modulus, which ultimately leads to changes in the base shear. These changes need to be considered in the industry for design and there is a need to evaluate the changes made in a real-time structure and how these changes affect the seismic and cost requirements of the structures.

Furthermore, we have two main structural systems that are commonly used in Pakistan's construction industry, MRF Structure, known as, Moment Resisting Frame Structure, and Dual Structural System, which includes Stiff Shear walls along with the MRF. Though commonly used in mid-rise and high-rise structures, there needs to be a consideration of using shear walls in under 10-storey structures, which are the most common in Pakistan's Construction industry.

2.2 LITERATURE REVIEW

The first step includes the review of already available literature and research on relevant topics, the research papers were analyzed and studied to get a better understanding of the work already done as well as to find the areas that need to be improved. Following is a brief discussion of some relevant research papers on all the topics covered in the thesis.

Shodolapo et al (Shodolapo, 2011) performed study of two codes, EC2 and BS8110. They used a four-storey building for analysis. They studied the effect of codes only on some of the critical sections (mainly beams). The parameters compared were the bending moments and shear forces developed in the critical sections. The study was primarily focused on beams and cannot be used to predict structural behavior.

Izhar et al. (Izhar et al., 2019) compared four codes (IS 2002, Euro code 8, Japan-2007 and ASCE: 7-10). They compared the bending moments, shear forces, steel percentage, story drifts and displacements. The buildings were analyzed under the codes and the mentioned parameters were compared from analysis results. This study did not consider multiple hazards or the non-linear performance assessment.

Scoe et al (Scoe, 2021) conclude that the Shear walls increase stiffness but also increase the self-weight which in turn increases the seismic demand and the Base Shear, needing high structure stiffness. Whereas mere MRF is less stiff and imposes less base shear but also less resistance against possible earthquakes. Multiple high-rise buildings were assessed to conclude these points.

Chandurkar et al.(Chandurkar & Pajgade, 2019) compared different sizes and locations of shear walls using different building models. They concluded from their research that, as opposed to High-rise buildings, in under 10-storey buildings, long span shear walls are not required and short span shear walls at corners are economical.

Varsha R. Harne et al.(Harne, 2014) conducted research on the effect of location of shear walls in low rise buildings. Multiple buildings were compared using core shear walls, coupled shear walls, L-shaped shear walls and planar walls. All the shear walls perform better against seismic lateral loads. L-shaped walls at corners are more effective against the torsional movement of the building and result in reduced periphery stresses in structures.

Rizwan Rashid et al.(BAIG & Rashid, 2020) compared building models using MRF and Dual systems and determined responses such as displacements against seismic and gravity loadings. They concluded that under 10 stories, shear walls make the structure uneconomical. Though each building has its own specific case but in general cases, under 10-storey buildings perform well without shear walls. The conclusions were derived merely on seismic responses and not through quantity estimation.

R. Hasan et al. (Hasan et al., 2001) have presented computer-based simple pushover analysis techniques for buildings subjected to earthquake loading. Based on conventional method of elastic analysis they identified component and system level deformation of pushover analysis with accuracy comparable with Dynamic analysis and 4 levels of safety i.e., OL, IO, LS, and CP were ensured to avoid any uncertainty.

Manjunath et al.(Manjunath, 2017) compared the performance of different type of RCC structures, which is evaluated using pushover analysis, with the results of different type of other analysis methods. It is concluded that pushover effectively predicts the RCC behavior. Its limitations, advantages and disadvantages are discussed comparing with other analysis methods.

Soni et al.(Soni et al., 2018) compared the accuracy and efficiency of traditional non-linear static pushover analysis and the displacement-based adaptive pushover analysis method using three different types of buildings. It was revealed that the displacement-based adaptive pushover analysis method is more efficient and accurate as compared to traditional nonlinear static pushover analysis. It also emphasizes accurate modelling of non-linear behavior of structures in seismic analysis methods.

The research work shows that Dual Systems are more efficient against seismic loads as compared to MRF structures. It also shows that in low rise buildings shorter spans of shear walls prove to be efficient economically. It is also agreed that the Non-linear methods, including the pushover static method, are a better means to study the behavior of the buildings, as compared to linear analysis. There have been multiple studies on code comparisons. The responses such as bending moments, shear forces, story drifts and displacements are considered as a measure for comparison.

CHAPTER 3

3.1 RESEARCH GAP

After the study of the research already done on similar topics, we found some areas that need to be improved. There has been a lot of focus discussing the high-rise buildings and the effective structural systems to be used but lesser attention seems to be given to the commonly used, under 10-storey buildings with regards to incorporating the Dual system (MRF + Shear walls), because usually Shear walls are not considered for low rise buildings. Also, the quantity and cost comparison are not seen for such cases.

There has been some work done on code comparison between BCP-07 and BCP-21, but the effect is not studied using different structural systems. The difference in structural system can contribute to the effect of change of building code.

Moreover, research has been done considering a single location i-e single seismicity. There seems to be a need to evaluate the technical and quantity differences at different seismic hazards, requiring more than one specific base location.

Much of the research was done using dummy or arbitrary models, which cannot be the exact representation of a real model, so there seems to be a need to evaluate the performance of a real structure to get the precise implication of the results in the real field.

In this thesis, low rise buildings are specifically targeted and real buildings are used for study purposes. The effect of change of the building code, from BCP-07 to BCP-21, is studied using different structural systems, MRF and DUAL system. Furthermore, linear as well as non-linear approaches are used for in depth study and the quantity estimation is paid attention to, for checking the economical suitability.

3.2 OBJECTIVES

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

- Structural Analysis and Design using MRF and Dual Structural Systems.
- Structural Analysis and Design using BCP-2007 and BCP-2021.
- Quantity comparison of all the structures.
- Linear and Non- Linear seismic evaluation of all the structures.

The aim is to evaluate the Seismic and cost differences, imposed by different structural systems and different building codes, using Linear Static and Non-Linear Pushover Analysis approaches.

CHAPTER 4

4.1 METHODOLOGY:

A reality-based 6-storey apartment building was selected. The structure was modeled using two structural systems, MRF and the Dual system to observe the changes in seismic requirements of the structure. These two structures were then assigned seismic demands as per both the building codes, BCP-07 and BCP-21, to evaluate the effect of the change of the code on the structure's seismic requirements.

The structure was assigned seismic demands based on the seismic parameters of two different locations, Islamabad, and Abbottabad, to get a better degree of understanding. The reason for using two different locations was to evaluate the structural performance at different seismic hazard parameters.

After performing the linear analysis and design and the study of differences in terms of seismic performance and the cost implications in all the cases. Two models were prepared for non-linear performance assessment, which gives a more realistic and detailed approach to understanding the behavior of the structures under different seismic demands. The non-linear pushover analysis was done, and the results were compared and verified for both models.

For analysis and design purposes, ETABS 2020 (CSI ETABS) was used while CSI DETAIL(CSI DETAIL) was used for quantity estimation. The methodology followed to carry out the research is summarized below.

1. Selecting suitable locations and architectural drawings of a real building.
2. Creating linear ETABS models of the building, based on the seismic demands for multiple locations and two codes (BCP-2007 and BCP-2021) and two structural systems, MRF and Dual system.
3. Analysis of all the models using Load combinations for serviceability and design from ASCE 7-16 and comparing the parameters.
4. Design as per the guidelines of ACI 318-19.
5. Quantity Estimation of all the designed building models and comparison of useful insights.
6. Creating non-linear models for two designs and performing non-linear static Pushover analysis.
7. Comparison of the results and extraction of conclusions.

CHAPTER 5

SELECTION OF THE BUILDING AND MODEL PREPARATION:

5.1 Selection of the building

A real-life existing structure has been selected for the execution of our objectives. The existing structure is a 13-story building with a Dual Lateral Load Resisting System and is located in Islamabad.

For the sake of our project, the number of stories have decreased to 6 (excluding Mumty) while keeping everything else constant. This is done so to make 2 different models based on the existing structure for resisting the lateral loads:

- MRF (Moment-Resisting Frame)
- Dual System (Combination of Shear Walls with MRF)

Above 6 stories, the MRF system becomes too overstressed and shows exaggerated results which makes the comparison between the two systems less meaningful. This is because for above 6 stories, the base shear demand increases far too much because of the seismic weight of building for the columns to resist it. This would mean that very bulky column sizes will have to be used to control the deflections and very strict detailing will have to be done. Moreover, the bulky columns will be a nuisance to the aesthetics of the building.

5.2 Selection of the Locations

The 2 structural systems will be modelled and designed for 2 different locations having different seismicity. Zone 2B and Zone 3 are selected for the sake of our project. The locations chosen for these zones are Islamabad and Abbottabad respectively. These two locations show an apparent change in their seismic demand as per the new code BCP 2021.

5.3 Model Preparation

Description:

The description of the project is as follows:

Table 1 Description of Building

Sr. No.	Parameter	3-Bed Apartment, 4 Units each Floor, G+5, Islamabad
1	Height (ft) and Size(ft)	71.5 ---- 150×90
2	Gravity Load Resisting System	RC Slab-Beam Floor System Supported on RC Columns
3	Lateral Load Resisting System	a) RC Moment Resisting Frame (MRF) b) RC Moment Resisting Frame (MRF) with Shear Wall (Dual System)
4	Shear Wall Configuration	Combination of Coupled Core Walls and Planar Walls
5	Gravity Load Reference	ASCE 7-16 and UBC-97
6	Seismic Analysis Reference	BPC 2007 (UBC 97) and BCP 2021 (IBC 2021)
7	Concrete Design Code	ACI 318-19

Models:

The Architectural Drawing (Plan View) of the building is as follows:

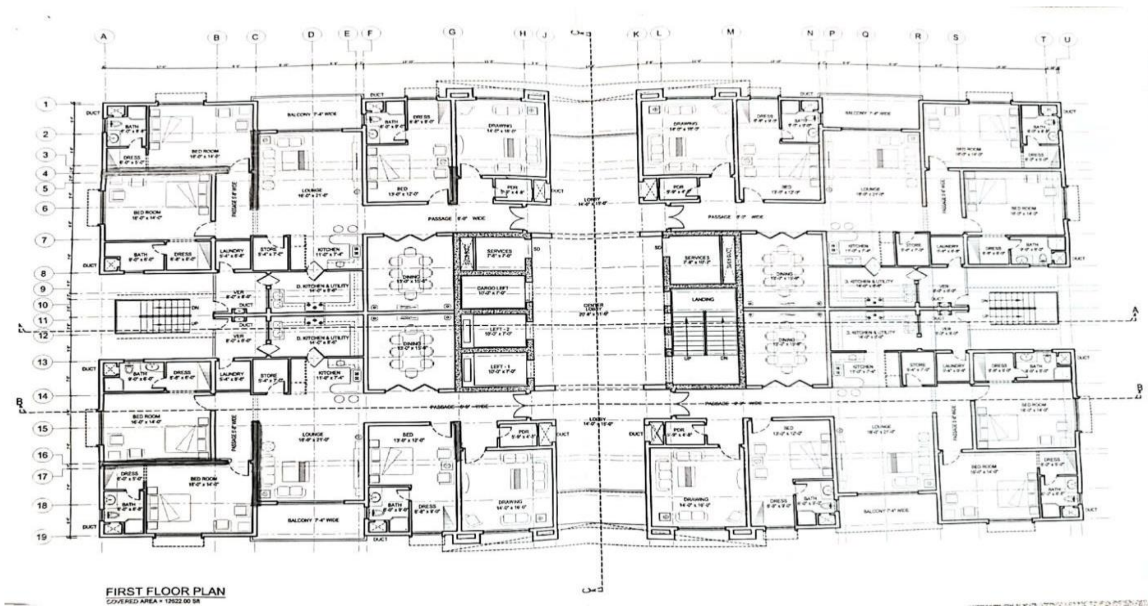

Figure 1 Architectural Plan of The Building

ETABs 2020 has been used for modelling the building using the two different structural systems. The models are as follows:

a) MRF System:

The Plan and 3D views of the MRF system modelled in ETABs are as follows:

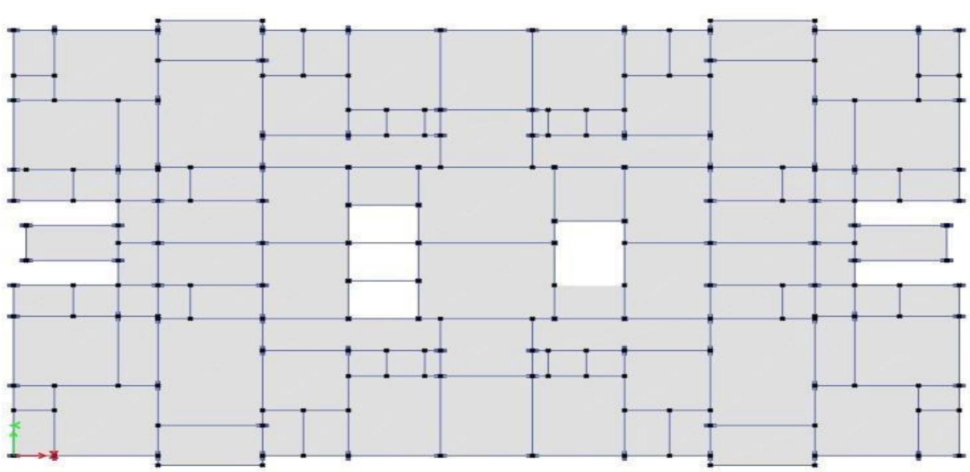

Figure 2 ETABS Model

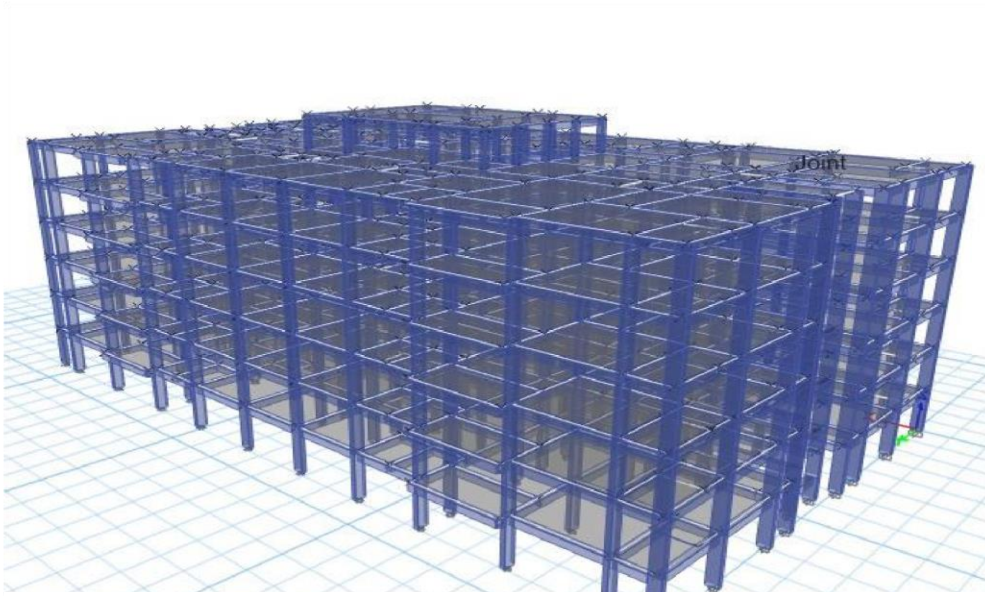

Figure 3 ETABS 3d Model

b) Dual System:

The Plan and 3D views of the MRF system modelled in ETABs are as follows:

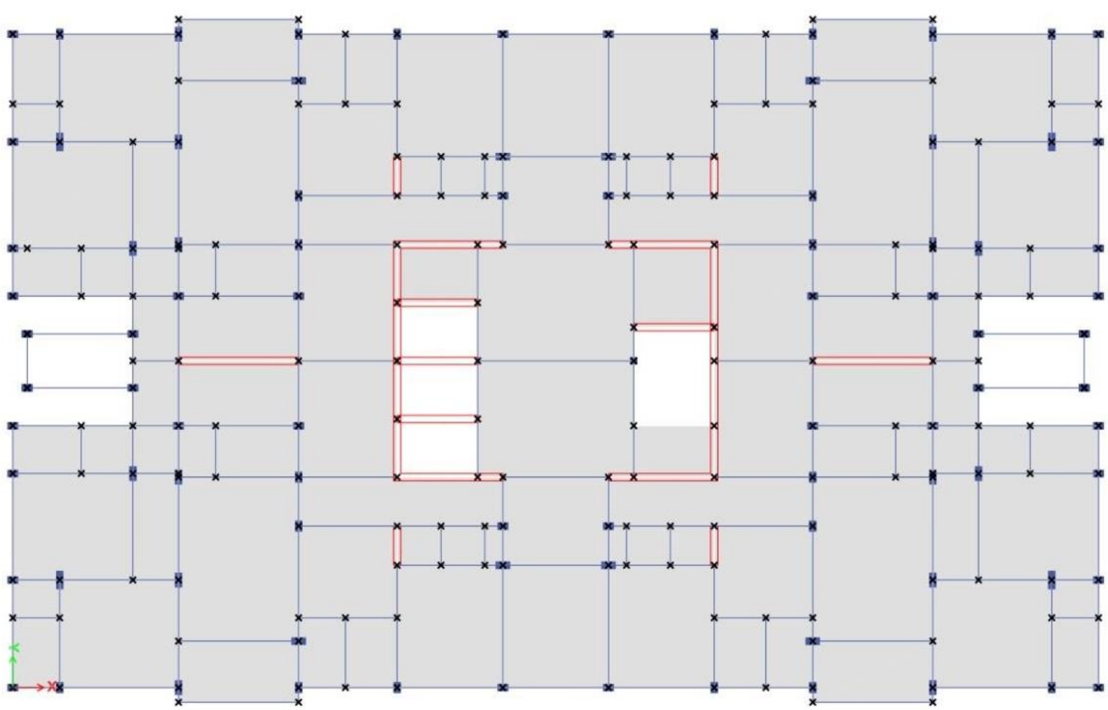

Figure 4 ETABS Model Plan

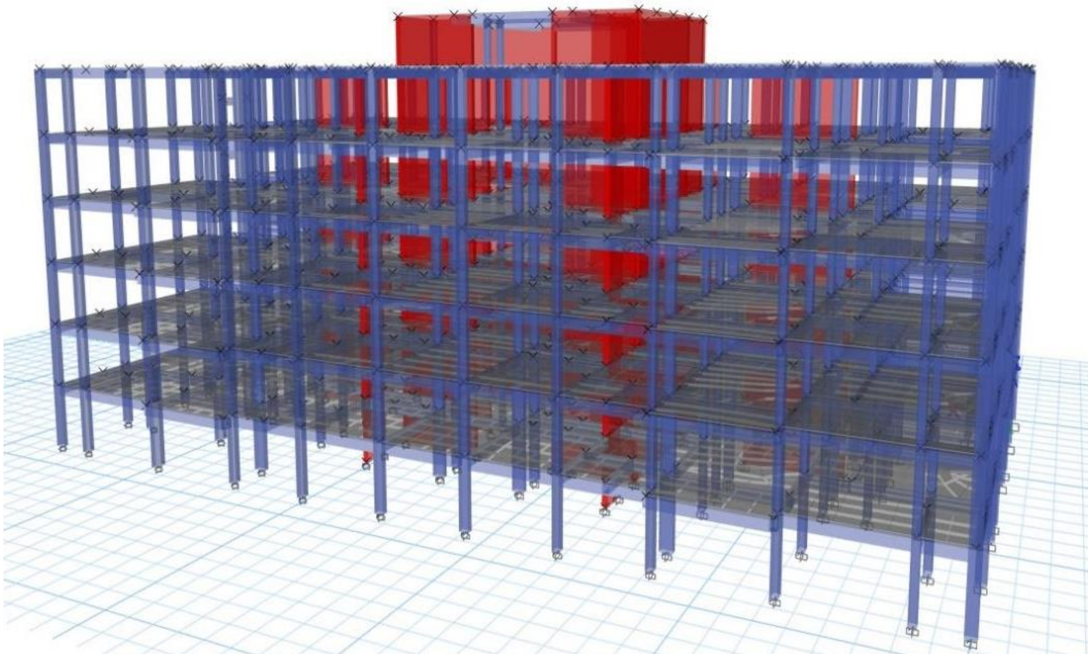

Figure 5 ETABS 3D Model

Special Considerations:

- No Soil Analysis was carried out, so the soil site class 'D' was selected by default for the amplification of the seismic forces.
- Stairs, Mumty, OHT (Water Tank), Partition Walls were not modeled. Rather their dead load was transferred onto the supporting elements.
- Dummy Beams with almost zero properties are assumed and drawn where the partition walls don't have an underlying primary beam for load transfer.
- Sunken Slab is assumed for areas with pipes and ducts (Kitchen, Baths etc.). The sunken slab is modelled at same level as roof slab because both are covered in the depth of the connecting beam.
- However, the weight of the filling material (sand) above the sunken slab is added to the superimposed load on the sunken slab.

Material Properties:

The material properties used in modelling are as follows:

Table 2 Material and Section Properties

Sr. No.	Parameter	
1	Concrete Strength ‘fc’	3000 psi
2	Steel Yield Strength, fy	a) Longitudinal reinforcement ➔ Grade 60 b) Shear reinforcement ➔ Grade 40
3	Slab Size (in)	5”
4	Beam Sizes (in)	Varies
5	Column Sizes (in)	Varies
6	Shear Wall Thickness (in)	12”

5.3.1 Modelling Tools and Challenges:

Detailed 3D finite element models are created which contain shell and frame elements. The modeling, analysis, and design of the building are carried out in CSI ETABS 2020. Section designer tool is used to compare capacity demands of frame elements (beam and columns). PMM interactions curves are used for column design and moment curvature diagrams are used for beam design. Model contains lots of secondary beams which induces torsional loads on supporting beams due to compatibility. In order to capture the real conditions secondary beams are assigned with moment releases at their ends. Stiffness modifiers as prescribed by the code are also used.

5.3.2 Shear Wall Modelling:

The building consists of a combination of Planar and Core shear walls as shown in figure below. Walls are modelled as shell elements and then assigned with piers properties option given by ETABS.

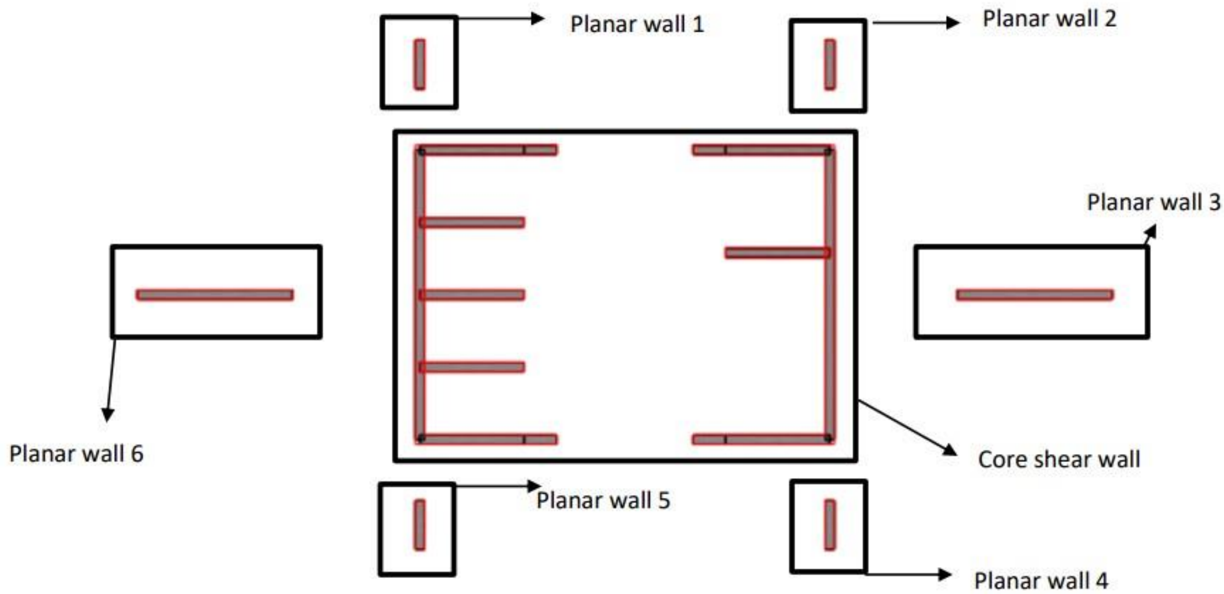

Figure 6 Shear Wall Details

5.3.3 Frame and Shell Elements Modelling:

Beam and columns are modelled as frames elements. The capacities of frame elements frame elements are checked from section designer results. Floors are modelled as shell elements and assigned with rigid floor diaphragms.

Support Modelling:

All the base supports in this model are assigned and fixed supports.

Cases:

Based on the 2 different structural systems under the two codes BCP-21 and BCP-07 for the two locations, a total of 8 different cases are developed.

These cases include the MRF and Dual system models in Islamabad and Abbottabad, designed under BCP-07 and BCP-21. The following is an illustration showing the different cases of building models which were later modelled, analyzed, and designed in ETABS.

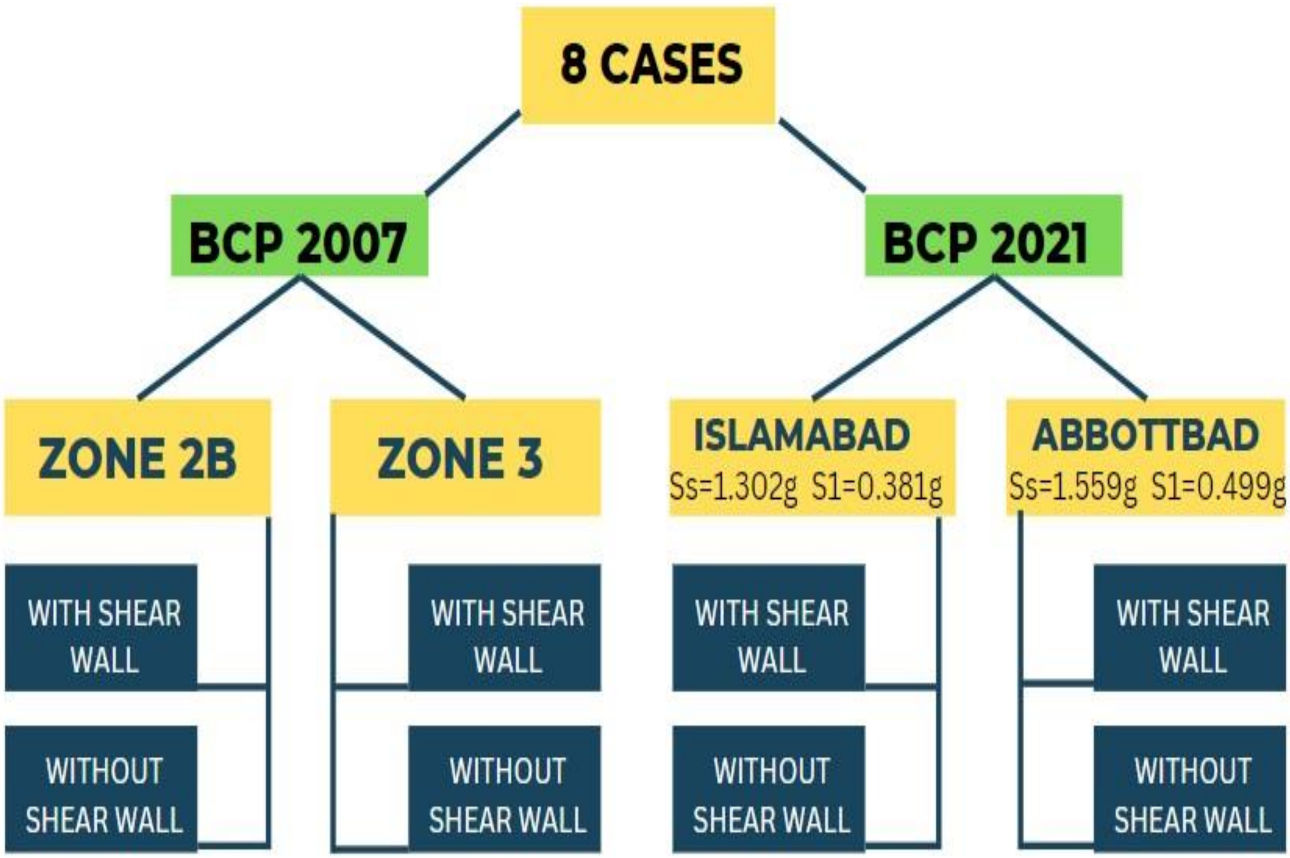

Figure 7 Building Cases

CHAPTER 6

ANALYSIS AND DESIGN OF STRUCTURES:

6.1 Assigning Loads

The building models are analyzed and designed for Gravity and Seismic Loading:

6.1.1 Gravity Load:

It consists of both the dead and live loads. The dead loads of partition walls are calculated and assigned to beams. The dead and live loads for slab are selected for the building type (residential) as per the codes (ASCE 7-16 and UBC-07 respectively). There is no difference in the gravity loads of the two codes.

Seismic Loading:

Equivalent static load procedure is used to apply the seismic load on the building models. The seismic parameters are given below. The seismic demand as per BCP-21 is defined by the Ss and S1 parameters while as per BCP-07, it is defined by the Zones.

Table 3 Seismic Parameters

	Zone (BCP-07)	Spectral Acceleration (BCP-21)	
Location		**Ss (g)**	**S1 (g)**
Islamabad	2B (0.16g-0.24g)	1.302	0.381
Abbottabad	3 (0.24g-0.32g)	1.5596	0.4996

6.2 Load Combinations

The load combinations for both locations under both codes are as follows:

Table 4 Load Combinations for Islamabad

Load Combinations (Zone 2B – Islamabad)		
Sr. No.	**BPC 2007 (UBC 97)**	**BCP 2021 (IBC 2021)**
1	1.2D + 1.6L	1.2D+1.6L
2	1.4D	1.4D
3	1.474D + 0.55L +1.1E	1.3736D + 0.5L+1E
4	1.144 D + 1.1E	1.0736D + 1E

Table 5 Load Combinations for Abbottabad

Load Combinations (Zone 3 – Abbottabad)		
Sr. No.	**BPC 2007 (UBC 97)**	**BCP 2021 (IBC 2021)**
1	1.2D + 1.6L	1.2D+1.6L
2	1.4D	1.4D
3	1.518D + 0.55L +1.1E	1.4079D + 0.5L+1E
4	1.188 D + 1.1E	1.1079D + 1E

Main Differences:

- The combination containing seismic force E is multiplied by 1.1 as per BCP-07 but not as per BCP-21
- The conversion of Ev (Vertical component of seismic force) into dead load D is different as per both codes:

  Ev = 0.5 × Ca × I × D (BCP 2007)
  Ev = 0.2 × SDS × D (BCP 2021)

6.3 Response Modification Factor

Response Modification Factor, which is a measure of the ductility and the overstrength in the system, for both the structural systems under both codes and for both locations is as follows:

Table 6 Response Modification Factors

Parameter	BCP 2007 (UBC-97)	BCP 21 (IBC-21)
Response Modification Factor	IMRF → 5.5 Dual System with IMRF → 6.5 SMRF → 8.5 DUAL SYSTEM WITH SMRF → 8.5	IMRF → 5 Dual System with IMRF → 6.5 SMRF → 8 DUAL SYSTEM WITH SMRF → 7

BCP 2007 only defines Response Modification Factor. However, BCP 2021 defines 2 other factors in addition to Response Modification Factor which are given for the type of lateral resisting system:

- Overstrength Factor, **Ω**
- Deflection Amplification Factor, **Cd**

Overstrength factor is assigned to the brittle members in the model while the deflection amplification factor is used to increase the horizontal deflections in the system back to the original, which initially are reduced because of the reduction in base shear due to response modification factor.

6.4 Analysis of the Structures

Before analysis, the 3D models are checked for following possible error and are removed:

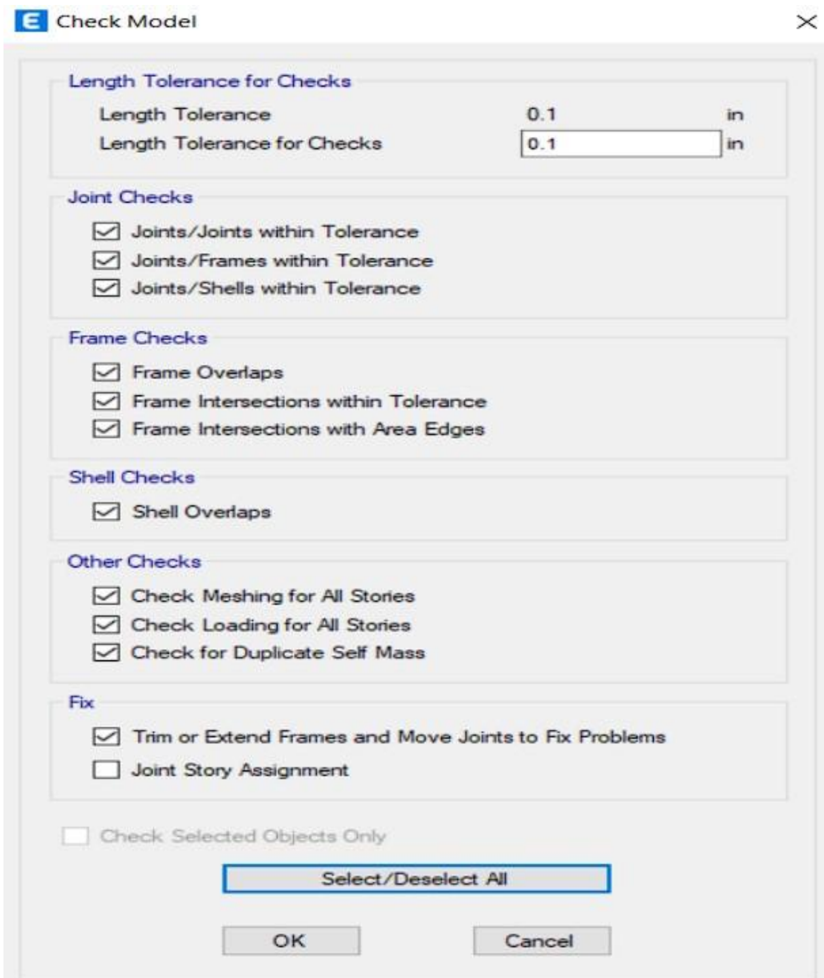

Figure 8 Model Checks

6.4.1 Initial Checks before Linear Design:

Manual checks with the help of Excel sheets are performed to check the linear design serviceability limits. Following limits were confirmed before the design of building:

- Vertical (Gravity) Deflection Check
- Story Displacement and Story Drift Check
- Center of Mass vs Center of Rigidity
- Soft Story Check

The above checks are verified **for all the 8 cases.** For demonstration purpose, the checks have been shown for only the Dual system under both BCP-07 and BCP-21 for Islamabad.

6.4.2 Vertical Deflection Check:

As per the Code, the vertical deflections should be checked against combination of Service Loads i.e 1D+1L while using cracked stiffness modifiers:

Table 7 Stiffness Modifiers

Element	Stiffness Modifier
Beam	0.35I
Column	0.7I
Walls and Slab	0.25I

The deflections should not exceed **L/240** and in case of sensitive equipment or glass portioning, they should not exceed **L/480**.

Moreover, the vertical deflections in the models are **same for both BCP-07 and BCP-21,** so separate checks are not required.

A Slab Panel at Story 6 has been selected which shows the maximum deflection.

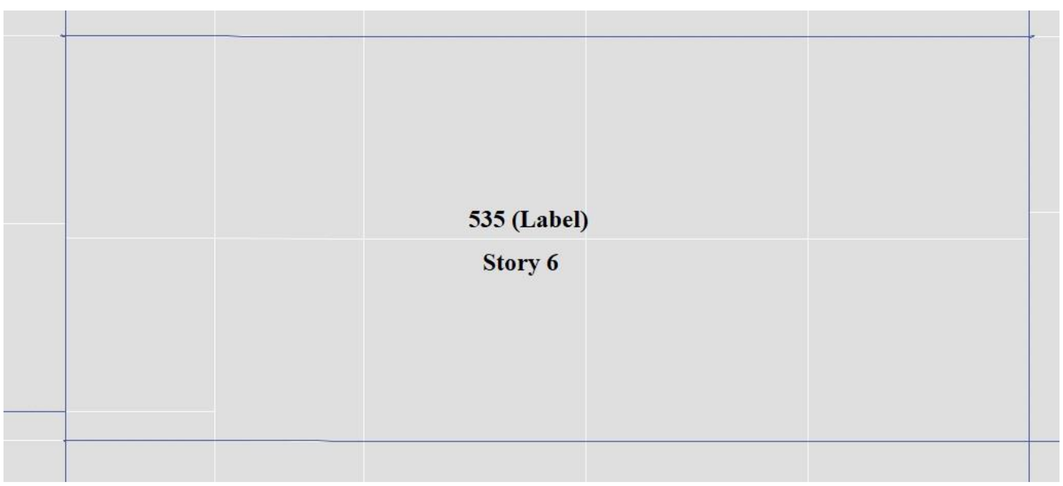

Figure 9 Slab Panel for Maximum Deflection

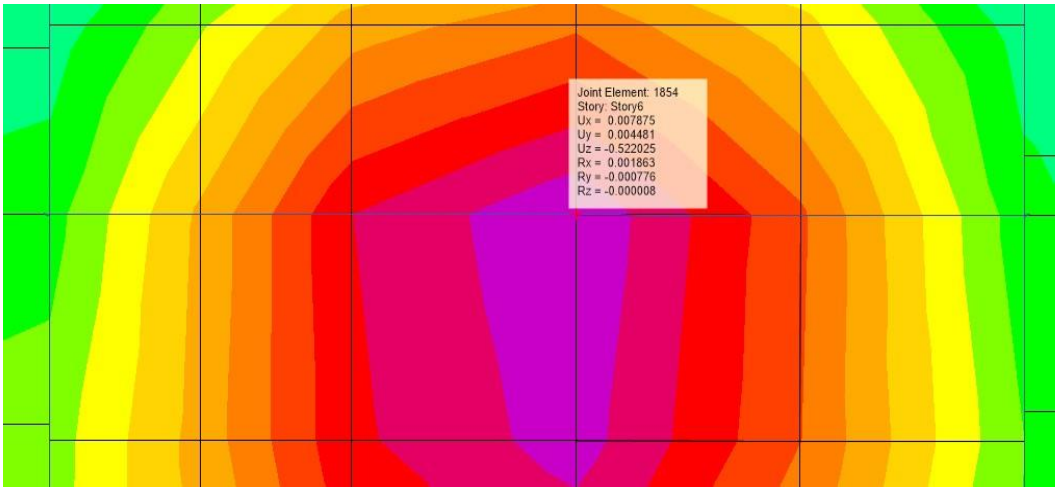

Figure 10 Slab Panel for Maximum Deflection

Table 8 Deflections Check

Maximum Deflection in the Slab Panel	0.55025”
Minimum Slab Dimension	12’ or 144”
Allowable Deflection (L/240)	0.6”
Check	**PASS** (0.55025” < 0.6”)

6.4.3 Story Displacement and Drift Check:

BCP-2021:

The following check is applied as per the BCP-21 for the Dual system in Islamabad. Here, Cd is the Deflection Amplification factor which is taken as 5 here for Dual system having IMRF. I refer to the importance of building which is taken as 1 as it is a residential building. The story drift should not be greater than 2% as per ASCE 7-16 Chapter 12 (Table 12.12-1).

Table 9 Design Checks

Story	H(m)	Elastic Displacement(mm)	Amplified Displacement	Story Drift	Allowable	Check
		Cd	5	I	1	Δa = 0.02
		δ	Δm	Δi	Δa	
Story7	3.2004	24.837	124.185	16.54	64.008	Safe
Story6	3.2004	21.529	107.645	22.005	64.008	Safe
Story5	3.2004	17.128	85.64	23.01	64.008	Safe
Story4	3.2004	12.526	62.63	21.96	64.008	Safe
Story3	3.2004	8.134	40.67	19.25	64.008	Safe
Story2	3.2004	4.284	21.42	14.365	64.008	Safe
Story1	3.2004	1.411	7.055	7.055	64.008	Safe
Base	0	0	0	0	0	Safe

Table 10 Design Checks

Story	Story Drift Ratio	Allowable	Check
	Allowable drift	0.02	
	*Δ	Δa	
Story7	0.005168	0.020000	Safe
Story6	0.006876	0.020000	Safe
Story5	0.007190	0.020000	Safe
Story4	0.006862	0.020000	Safe
Story3	0.006015	0.020000	Safe
Story2	0.004489	0.020000	Safe
Story1	0.002204	0.020000	Safe
Base	0.000000	0.020000	Safe

The elastic displacements of all the 7 stories (i.e including Mumty) were determined from the analysis results in ETABs and copied into our Excel sheet. They were amplified by Cd value of 5. Then the allowable drift was calculated multiplying 0.02 with the height of the story which turns out to be 64.008. The story drifts of all stories are less than 64.008, hence they are within the allowable limit. Similarly, if we find the story drift ratio, the ratios are all less than 0.02 so they are within the limit as well.

BCP-2007:

BCP-07 requires the use of R (Response Modification Factor) and T (Time Period) of the system instead of Cd (Deflection Amplification Factor). The checking criteria is slightly different here as per UBC-97 which is given in Section 1630.10.

Table 11 Design Checks

		R=	6.5	T=	0.738	Sec
Story	**H(m)**	**Elastic Displacement(mm)**	**Story Drift**	**Ratio**	**Allowable**	**Check**
		δ	**Δi**	**Δm**	**Δa**	
Story7	3.2	19.689	2.709	12.32595	64.008	Safe
Story6	3.2	16.98	3.523	16.02965	64.008	Safe
Story5	3.2	13.457	3.652	16.6166	64.008	Safe
Story4	3.2	9.805	3.459	15.73845	64.008	Safe
Story3	3.2	6.346	3.014	13.7137	64.008	Safe
Story2	3.2	3.332	2.237	10.17835	64.008	Safe
Story1	3.2	1.095	1.095	4.98225	64.008	Safe
Base	0	0	0	0	0	Safe

Table 12 Design Checks

$$\Delta i * 0.7 \leq \frac{1}{360}$$

K	360			

Story	Story Drift Ratio		Allowable	Check
	Δi	Δi * 0.7	Δa	
Story7	0.000846	0.000593	0.002778	Safe
Story6	0.001101	0.000771	0.002778	Safe
Story5	0.001141	0.000799	0.002778	Safe
Story4	0.001081	0.000757	0.002778	Safe
Story3	0.000942	0.000659	0.002778	Safe
Story2	0.000699	0.000489	0.002778	Safe
Story1	0.000342	0.000240	0.002778	Safe

Similar procedure is followed for BCP-07 apart from the allowable limit which is different as shown above in the sheet.

6.4.4 Center of Mass vs Center Rigidity Check:

This check is performed to check for the eccentricity between the center of mass of the system and the center of rigidity (stiffness) of the system. The eccentricity should be less than 15% to relative dimension of the building as per ASCE 7-16 Appendix D, Section D.3. Otherwise, the structure will not be symmetric and will be subjected to significant torsion. Same check is performed for both codes:

Table 13 Centre of Mass and Rigidity

the Center of mass and rigidity											
Story	Diaphragms	Mass X	Mass y	C.M		Cumulative x	Cumulative Y	XCCM	YCCm	C.R	
				x_m	y_m					XCR	YCR
Storey 7	D1	12972.68	12972.68	74.8249	44.5859	12972.68	12972.68	74.8249	44.5859	74.6263	44.7696
Storey 6	D1	152462.75	152462.75	75.307	44.5593	165435.43	165435.43	75.2692	44.5614	74.7054	44.7574
Storey 5	D1	145656.39	145656.39	75.2556	44.5627	311091.82	311091.82	75.2628	44.562	74.813	44.7505
Storey 4	D1	145656.39	145656.39	75.2556	44.5627	456748.21	456748.21	75.2605	44.5622	74.9327	44.742
Storey 3	D1	145656.39	145656.39	75.2556	44.5627	602404.59	602404.59	75.2593	44.5623	75.0547	44.7363
Storey 2	D1	145964.09	145964.09	75.2557	44.5626	748368.68	748368.68	75.2586	44.5624	75.1527	44.7453
Storey 1	D1	146355.71	146355.71	75.2559	44.5624	894724.39	894724.39	75.2582	44.5624	75.2061	44.8224

Table 14 Centre of Mass and Rigidity

The Eccentricity							
Eccentricity		Dimension		ex/Dx result		ey/Dy result	
e_x	e_y	Dx	Dy	%		%	
0.20	0.18	150	90	**0.1**	**Ok**	**0.2**	**Ok**
0.60	0.20	150	90	**0.4**	**Ok**	**0.2**	**Ok**
0.44	0.19	150	90	**0.3**	**Ok**	**0.2**	**Ok**
0.32	0.18	150	90	**0.2**	**Ok**	**0.2**	**Ok**
0.20	0.17	150	90	**0.1**	**Ok**	**0.2**	**Ok**
0.10	0.18	150	90	**0.1**	**Ok**	**0.2**	**Ok**
0.05	0.26	150	90	**0.0**	**Ok**	**0.3**	**Ok**

6.4.5 Soft-Story Check:

Soft Story irregularity exists in the story when the lateral stiffness of that story is less than 70% of the lateral stiffness of the story above it or less than 80% of the average lateral stiffness of the 3 stories above it as per ASCE 7-16, Section 12.3-2. Same check has been performed for both codes to avoid soft-story irregularity:

Table 15 Stiffness Irregularity Check X direction

Stiffness Irregularity Check in X-Direction											
		Soft-Story Irregularity Check					Extreme Soft-Story Irregularity Check				
Story	Stiffness X-Direction	K_i / K_{i+1} 0.7	check	$K_{mi} = avg(K_{i+1,i+2,i+3})$	K_i / K_{mi} 0.8	check	K_i / K_{i+1} 0.6	check	$K_{mi} = avg(K_{i+1,i+2,i+3})$	K_i / K_{mi} 0.7	check
Story7	867.7547	-	-				-				
Story6	7559.0191	8.71	Regular				-				
Story5	12887.5905	1.70	Regular				-				
Story4	17781.7876	1.38	Regular	7104.79	2.50	Regular	1.38	Regular	7104.79	2.50	Regular
Story3	24182.6525	1.36	Regular	12742.80	1.90	Regular	1.36	Regular	12742.80	1.90	Regular
Story2	37030.0366	1.53	Regular	18284.01	2.03	Regular	1.53	Regular	18284.01	2.03	Regular
Story1	72358.1935	1.95	Regular	26331.49	2.75	Regular	1.95	Regular	26331.49	2.75	Regular

Table 16 Stiffness Irregularity Check Y direction

Stiffness Irregularity Check in Y-Direction											
		Soft-Story Irregularity Check					Extreme Soft-Story Irregularity Check				
Story	Stiffness Y-Direction	K_i / K_{i+1} 0.7	check	$K_{mi} = avg(K_{i+1,i+2,i+3})$	K_i / K_{mi} 0.8	check	K_i / K_{i+1} 0.6	check	$K_{mi} = avg(K_{i+1,i+2,i+3})$	K_i / K_{mi} 0.7	check
Story7	2727.1136	-	-				-				
Story6	39212.5385	14.38	Regular				-				
Story5	42743.6245	1.09	Regular				-				
Story4	34845.2498	0.82	Regular	28227.76	1.23	Regular	0.82	Regular	28227.76	1.23	Regular
Story3	37281.3421	1.07	Regular	38933.80	0.96	Regular	1.07	Regular	38933.80	0.96	Regular
Story2	41741.4568	1.12	Regular	38290.07	1.09	Regular	1.12	Regular	38290.07	1.09	Regular
Story1	66062.3222	1.58	Regular	37956.02	1.74	Regular	1.58	Regular	37956.02	1.74	Regular

6.5 Design of the Structures:

After satisfying all the analysis checks, next all the models will be designed to determine both the longitudinal and shear reinforcement:

Elements to be Designed:

- Beams
- Columns
- Shear Walls

Slab and Foundation are not designed because there is no difference in the sizes and reinforcements using both BCP-07 and BCP-21. This is because the demand on these elements do not change under both codes.

Design Code:

ACI 318-19 is used for design considerations.

6.5.1 Design Preferences:

a) <u>Concrete Frame Design Preferences</u>:

	Item	Value
01	Design Code	ACI 318-19
02	Multi-Response Case Design	Step-by-Step - All
03	Number of Interaction Curves	24
04	Number of Interaction Points	11
05	Consider Minimum Eccentricity?	Yes
06	Design for B/C Capacity Ratio?	Yes
07	Ignore Beneficial Pu for Beam Design?	Yes
08	Seismic Design Category	D
09	Design System Omega0	2
10	Design System Rho	1
11	Design System Sds	0.5
12	Phi (Tension Controlled)	0.9
13	Phi (Compression Controlled Tied)	0.65
14	Phi (Compression Controlled Spiral)	0.75
15	Phi (Shear and/or Torsion)	0.75
16	Phi (Shear Seismic)	0.6
17	Phi (Joint Shear)	0.85
18	User Defined Allowable PT Stresses?	No

Figure 11 Concrete Frame Design Preferences

b) <u>Concrete Shear Wall Design Preferences:</u>

	Item	Value
01	Design Code	ACI 318-19
02	Multi-Response Case Design	Step-by-Step - All
03	Rebar Material	Grade - 60
04	Rebar Shear Material	Grade - 40
05	Design System Rho	1
06	Design System Sds	0.5
07	Importance Factor	1
08	System Cd	5.5
09	Wall Ductility Type	Special Structural Wall
10	Phi (Tension Controlled)	0.9
11	Phi (Compression Controlled)	0.65
12	Phi (Shear and/or Torsion)	0.75
13	Phi (Shear Seismic)	0.6
14	Pmax Factor	0.8
15	Number of Curves	24
16	Number of Points	11
17	Edge Design PT-Max	0.06
18	Edge Design PC-Max	0.04

Figure 12 Concrete Shear Wall Design Preferences

6.5.2 Design of Elements:

All the elements (Beams, Columns and Shear Walls) are designed using ETABs. The reinforcement for the members is calculated and it is made sure that no member is being overstressed (O/S). Finally, a check is performed to make sure that all the members have passed.

Additionally, manual checks are also performed to verify the results of the software. For demonstration purpose, one of the beams is designed manually with the help of Excel Sheets as follows:

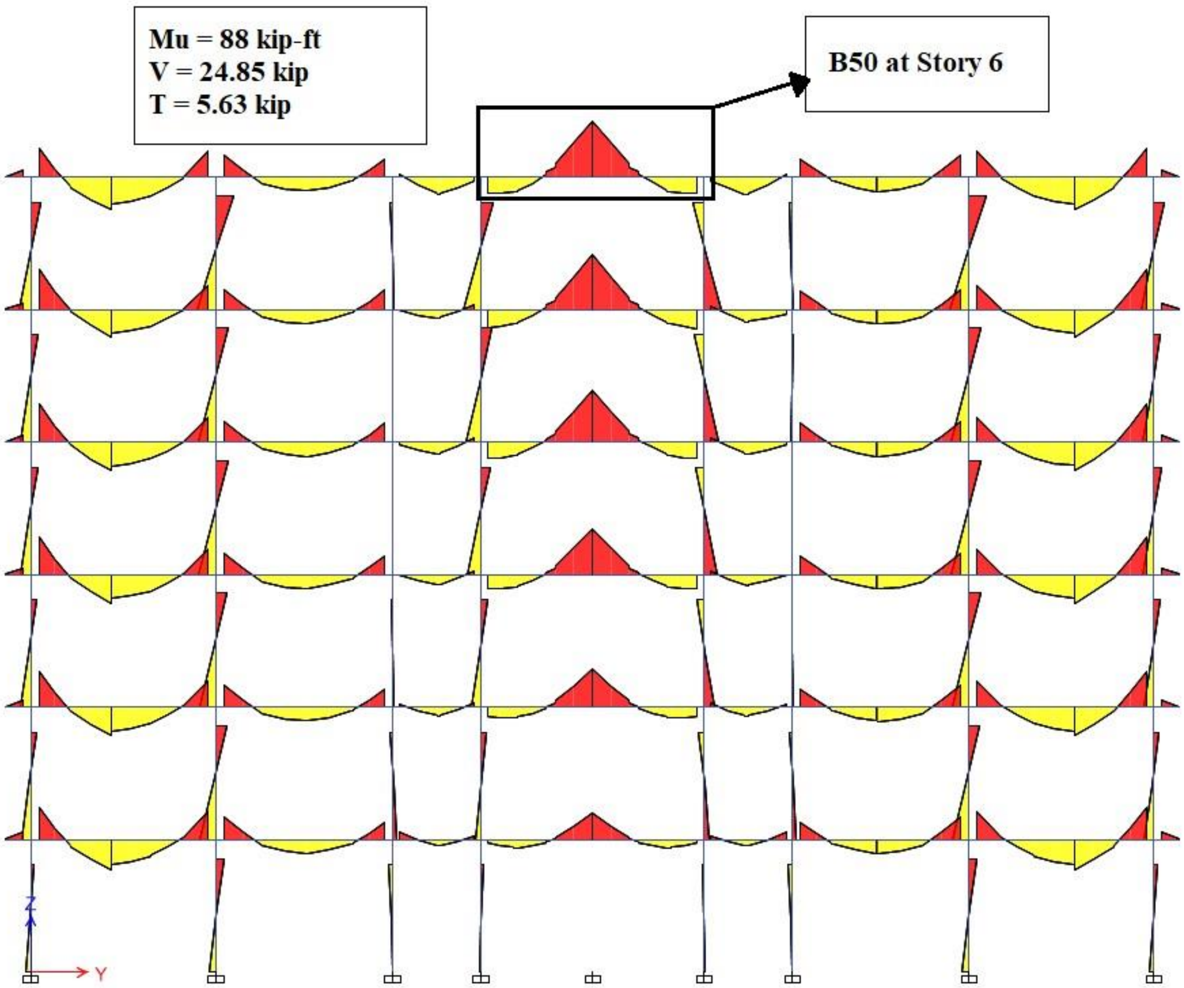

Figure 13 Moment Distribution

a) **Flexure Design:**

Table 17 Flexure Design

Design Moment	M_u	88	k-ft
Beam Width	b	12	inches
Beam Depth	h	18	inches
Steel Yield Strength	f_y	60	ksi
Concrete Cylinder Strength	f_c'	3	ksi
Total Cover to Rebar Centre	c	2.5	inches
Required Area of Steel =		1.38	sq. inch.
Selection of Bars			
No. of Bars	Bar Size (#)		
4	# 6		
+			
0	# 6		
	1.7671	0.00000	
Total Area of Steel =	1.77 sq. inch.	>	1.38 sq. inch.

The result of the excel sheet is compared with that of the software for verification.

b) **<u>Shear and Torsion Design:</u>**

Table 18 Shear and Torsion Design

TORSION & SHEAR DESIGN of Beam			
INPUT DATA			
WIDTH OF BEAM =	(b)	12	in
DEPTH OF BEAM =	(h)	18	in
LENGTH OF BEAM =	(L)	20	ft
NO. OF REINFORCEMENT LAYERS (FLEXURAL)		1	number
STIRRUP BAR		4	# bar
STEEL YIELD STRENGTH =	(fy)	40	ksi
CONCRETE CYLINDER STRENGTH =	(fc')	3	ksi
SHEAR FORCE AT SUPPORT =	(V)	24.85	kips
TORSION AT THE SECTION =	(Tu)	5.63	k-in
OUTPUT DATA			
CHECK OF SECTION =		SECTION IS OK	
STIRRUP SPACING =		# 4 @ 7.75	" c/c
LONGITUDINAL STEEL =		NO STEEL IS REQUIRED	

6.6 Comparison of Responses:

After analysis and design of the models, following responses are compared under both BCP-07 and BCP-21 to determine the possible differences:

- Base Shear
- Story Displacements
- Story Drifts

6.6.1 Base Shear Comparison:

The Base Shear is determined both manually and from the software. The results are displayed in the form of bar graphs for both codes and locations:

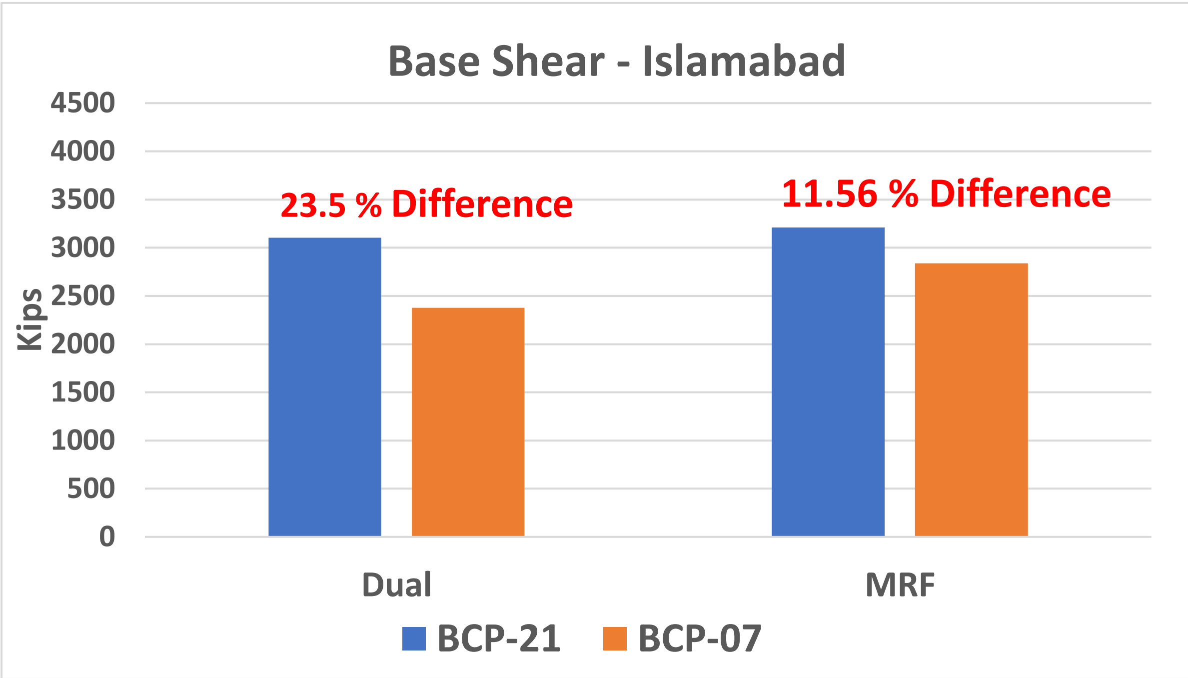

Figure 15 Base Shear for Islamabad

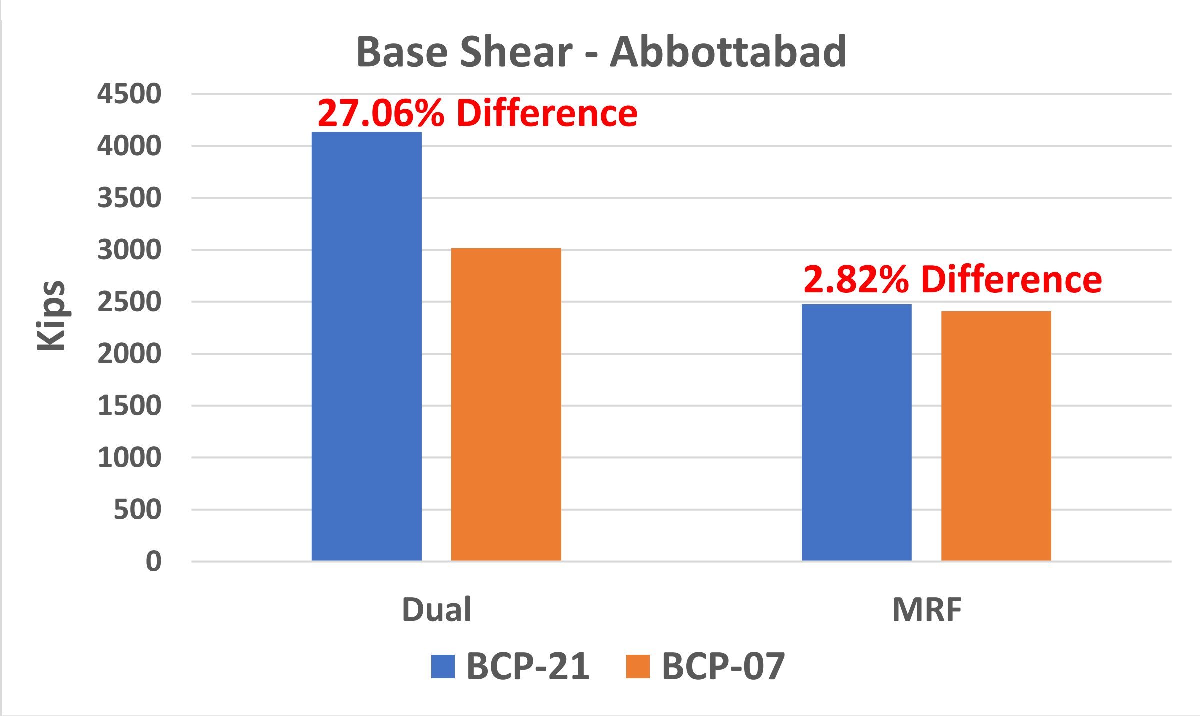

Figure 14 Base Shear for Abbottabad

Conclusions:

- Both systems under BCP-21 show a greater base shear than that under BCP-07 for both locations/zones. This shows that there is an increased seismic demand for both Islamabad and Abbottabad as per the new code of 2021.
- The difference in base shear is more apparent in Dual systems as opposed to MRF. This is because Dual system has greater stiffness due to inclusion of shear walls so they will attract greater lateral forces for the same unit deformation.
- For Zone 2B (Islamabad), the Dual system shows lesser base shear as opposed to the
  IMRF system (**3.22% difference** as per BCP-21 and **16.3% difference** as per BCP-07)
- Zone 3 (Abbottabad) shows a reverse trend i.e., Dual system has more base shear than SMRF system (**40.1% difference** as per BCP-21 and **20.14% difference** as per BCP-07)

6.6.2 Story Displacements:

The maximum story displacements are determined from the software and then plotted in excel sheet to be displayed in the form of a graph:

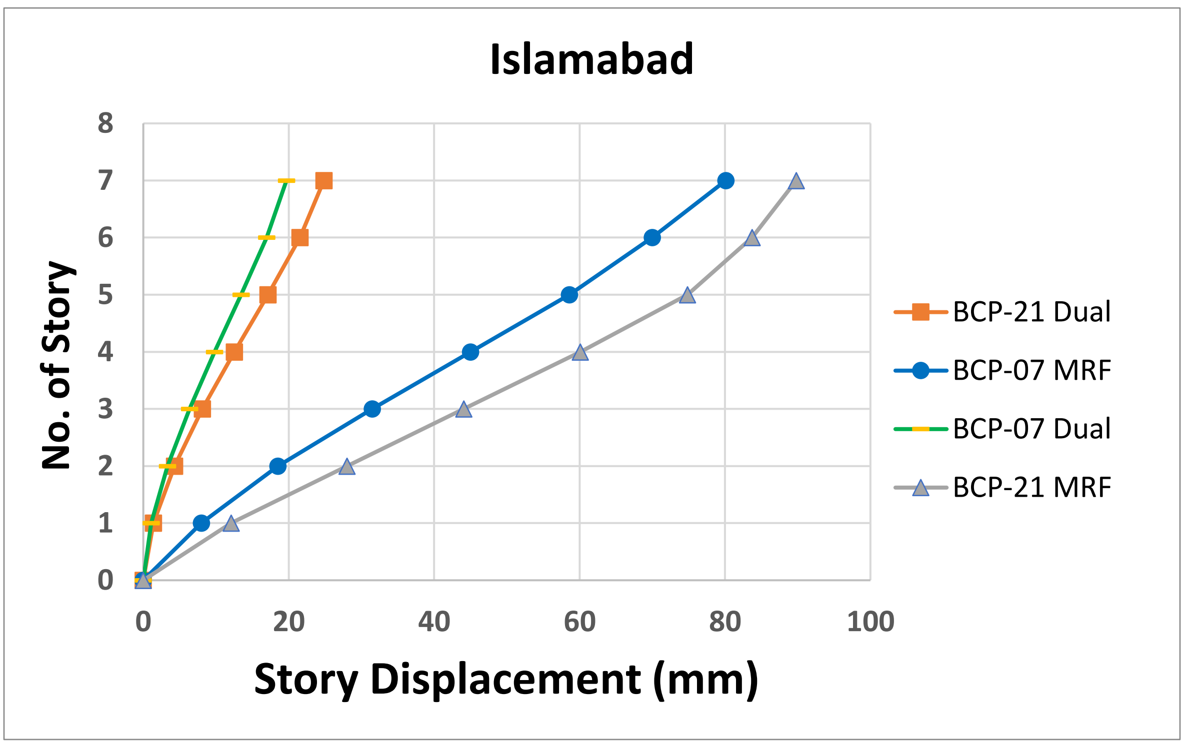

Figure 16 Story Displacement for Islamabad

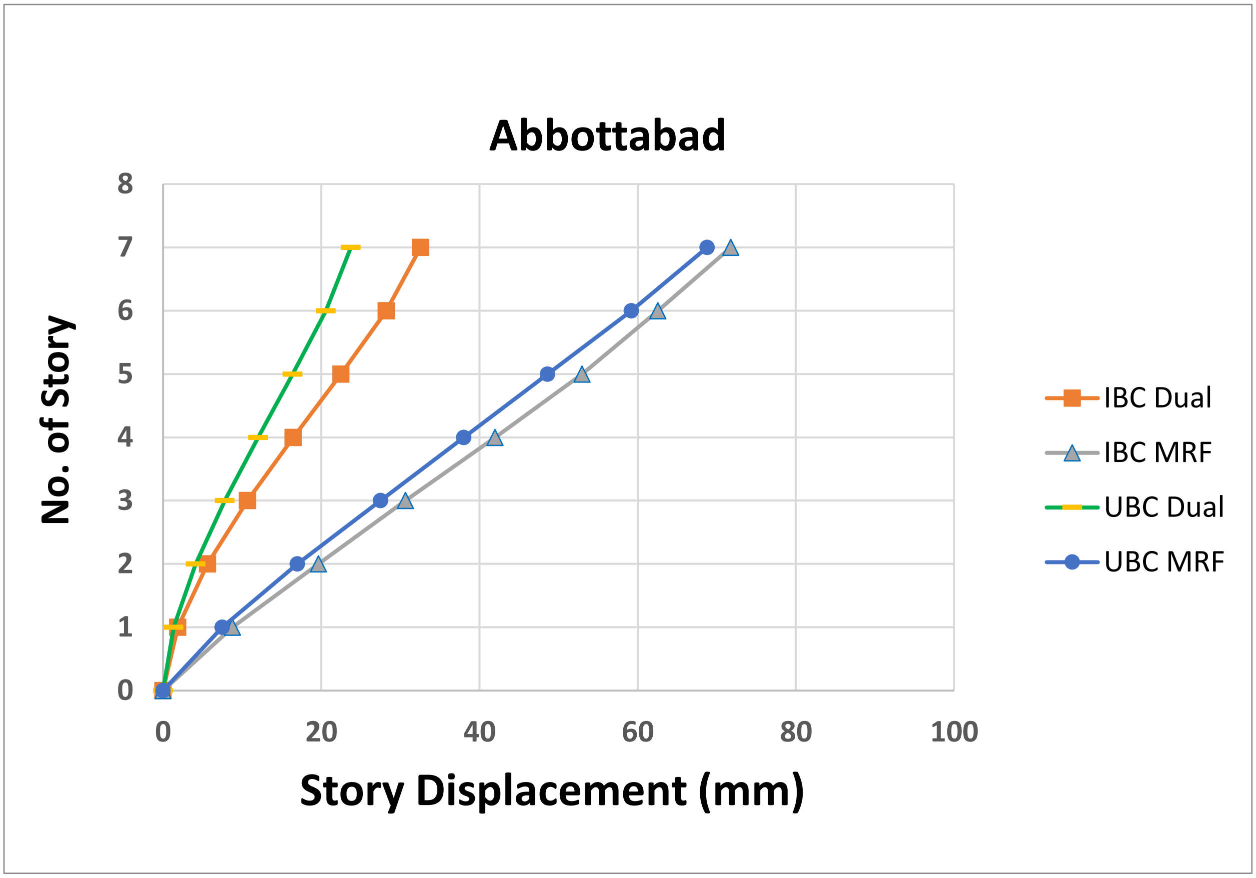

Figure 17 Story Displacement for Abbottabad

Conclusions:

- Both systems under BCP-07 show relatively lesser displacement than that under BCP-21 for both locations. This is in accordance with the difference in base shear. A smaller base shear would displace the system less horizontally.
- Dual systems show far less displacements than MRF systems. This is because Dual systems have greater stiffness than MRF systems so greater forces are required to displace them.
- Similar trend is observed for story drifts as that for story displacements.
- All the story drifts are within the allowable limits.

6.6.3 Story Drifts:

The story drifts are calculated manually with the help of excel sheets from the story displacements and are then plotted in the form of a graph:

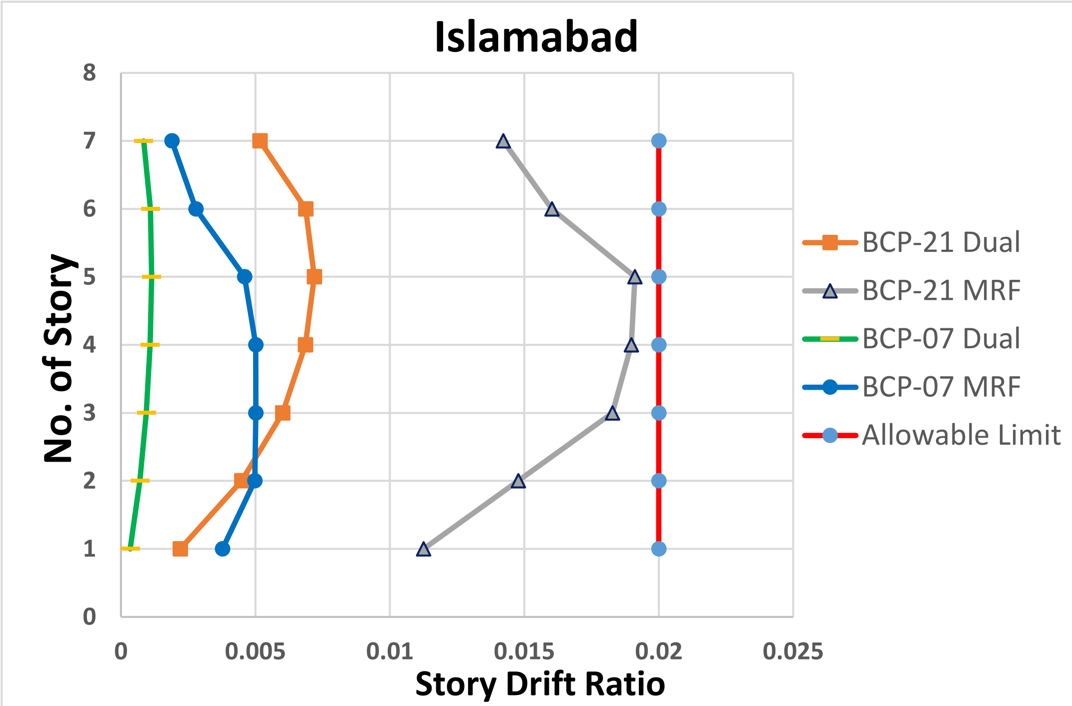

Figure 18 Story Drift Ratio for Islamabad

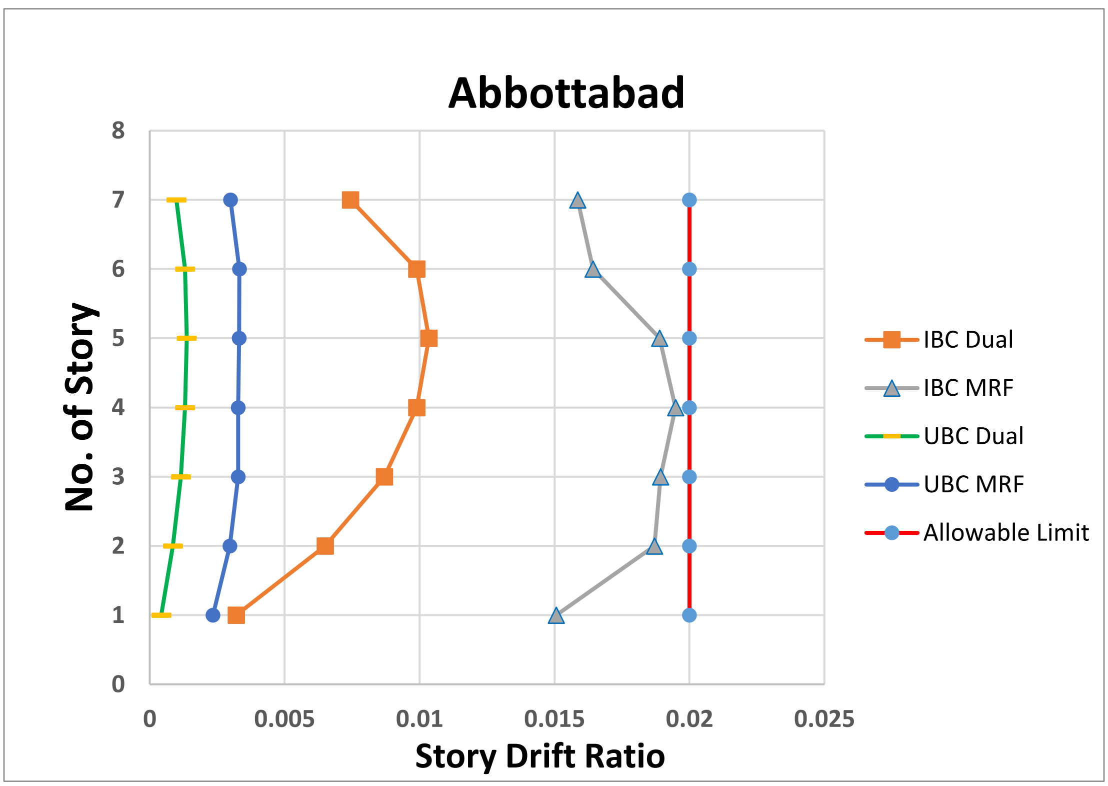

Figure 19 Story Drift Ratio for Abbottabad

CHAPTER 7

Quantity and Cost Estimation

Quantity Estimation of all the 8 models is carried out both manually and also with the help of CSI Detail Software. The Concrete quantities were taken directly from the CSI Detail Software. However, for determining the quantity of reinforcement, manual detailing of the member sections was done after which Steel was calculated in terms of its weight (tons). The detailing requirements for Zone 2B (Islamabad) and Zone 3 (Abbottabad) are different. This is because in Zone 2, the recommended framing system by the code is Intermediate Moment Resisting Frame (IMRF) whereas for Zone 3, a Special Moment Resisting Frame (SMRF) is recommended. Both these framing systems have their own detailing requirements.

MES (Military Engineering Services) Rate System *(MES)* is used to determine the cost of Concrete and Steel in Rs.

The results are plotted in the form of bar graphs for both locations as follows:

7.1 Quantity and Cost Estimation for Islamabad:

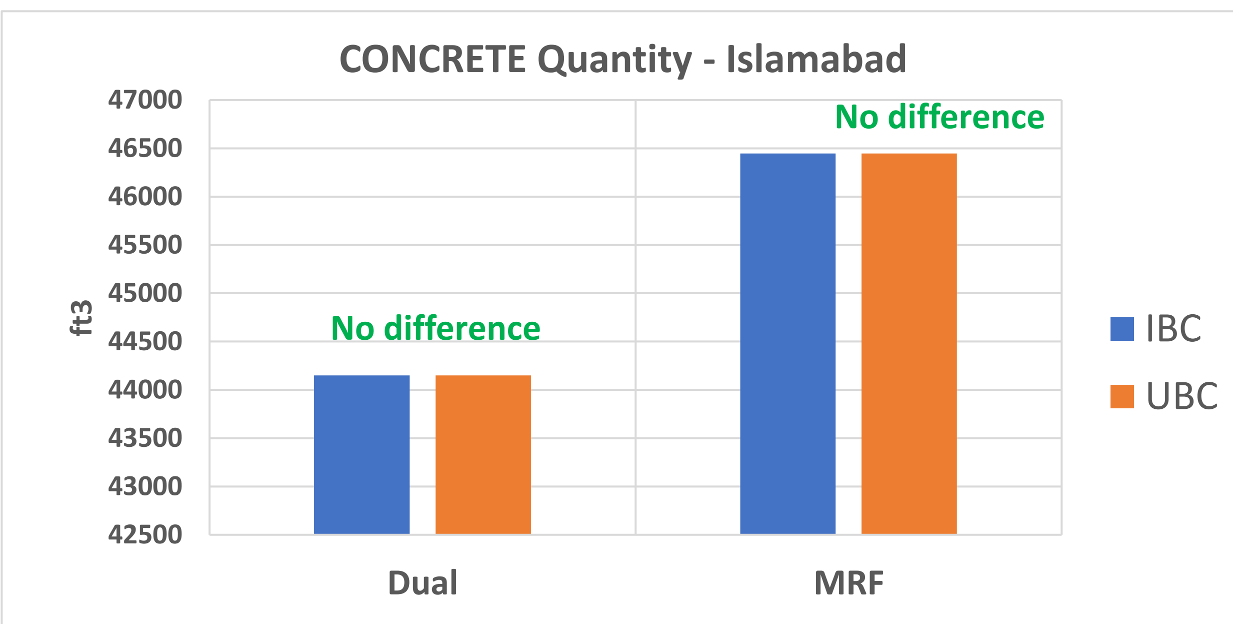

Figure 20 Concrete for Islamabad

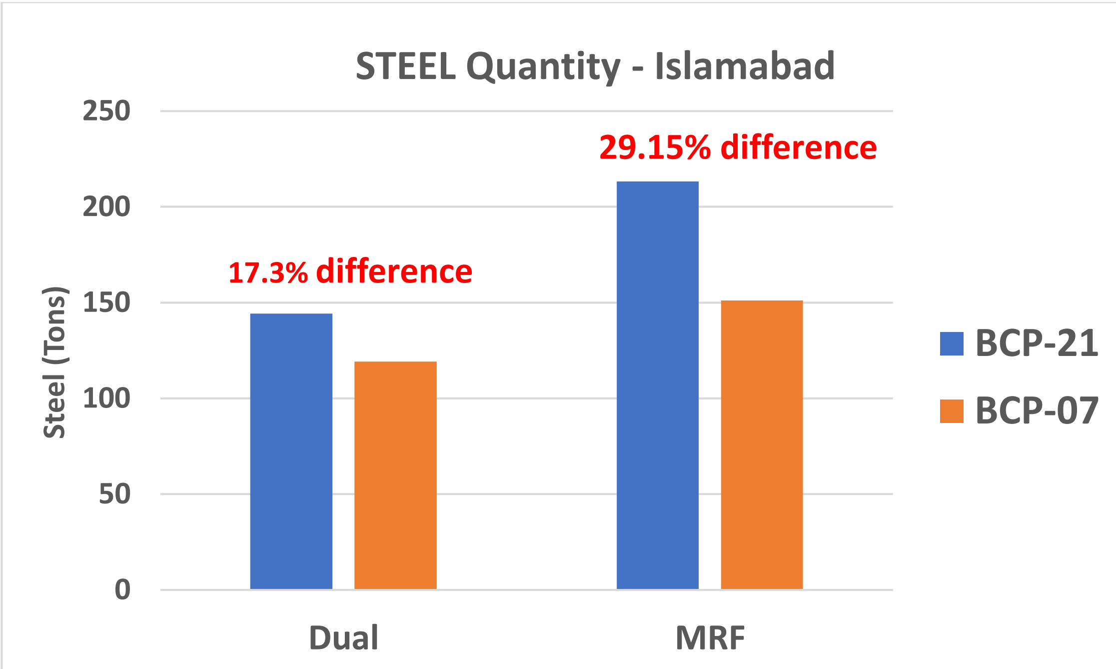

Figure 21 Steel for Islamabad

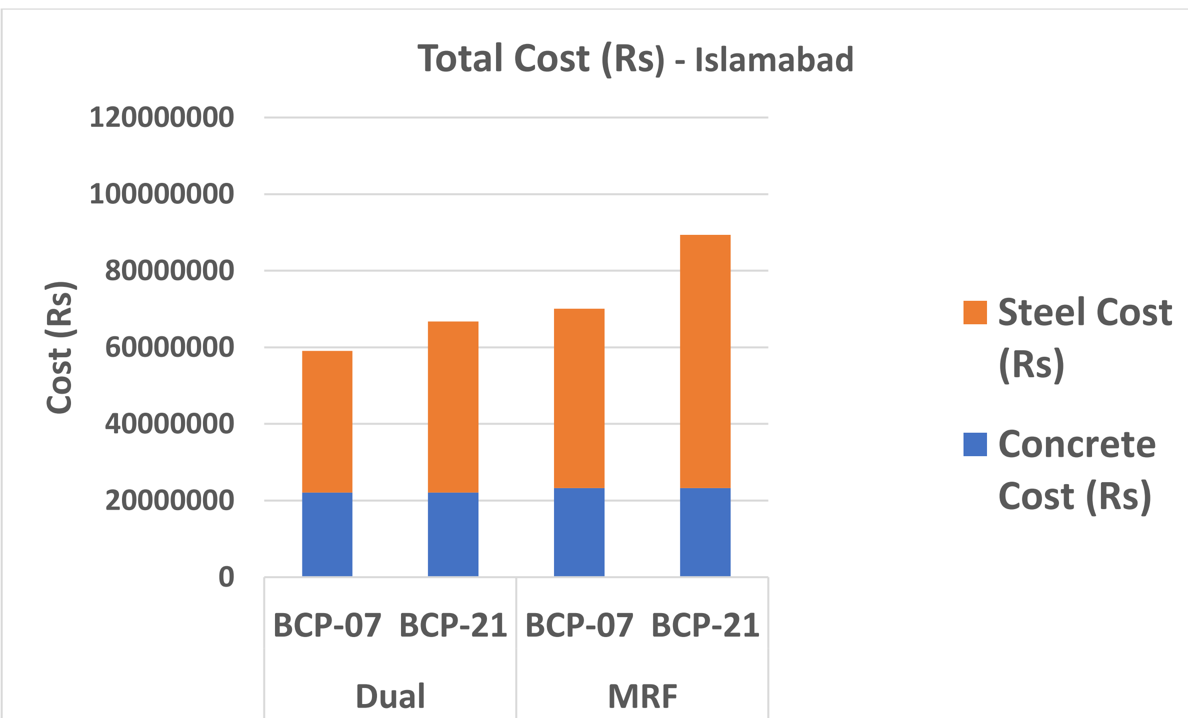

Figure 22 Total Cost for Islamabad

7.2 Quantity and Cost Estimation for Abbottabad:

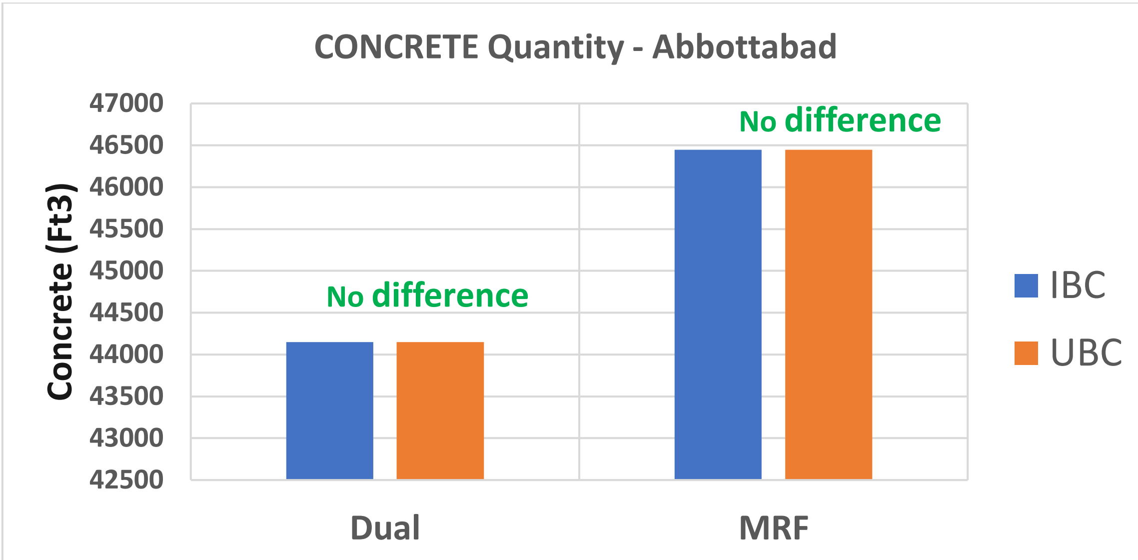

Figure 23 Concrete for Abbottabad

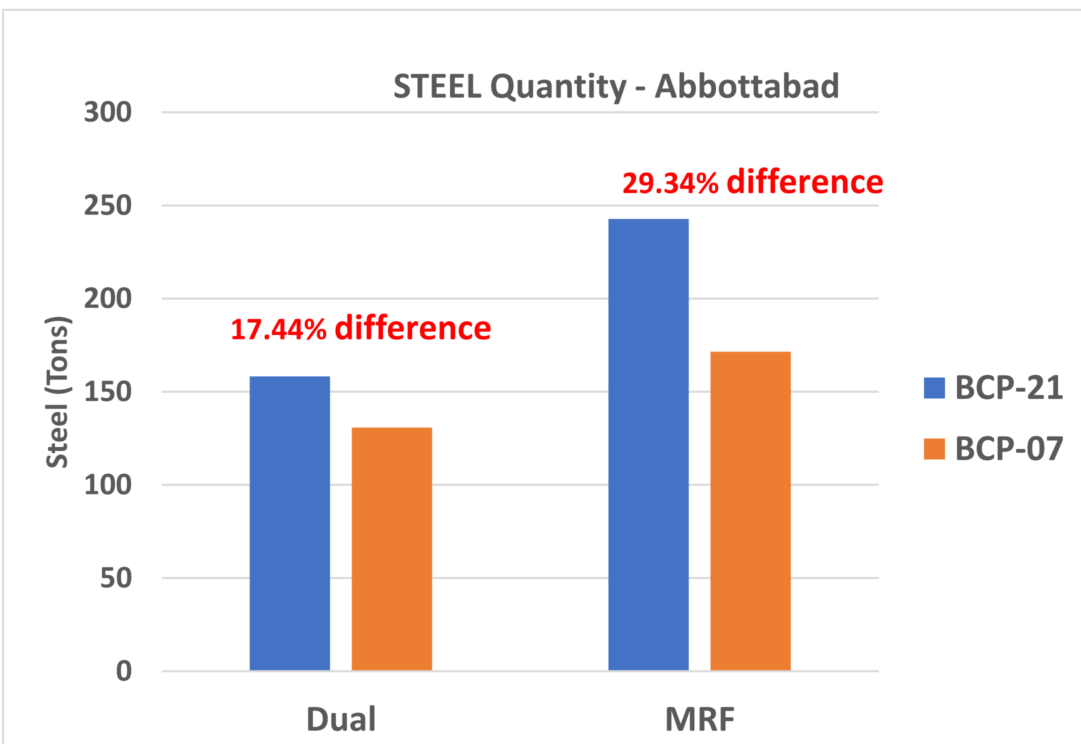

Figure 24 Steel for Abbottabad

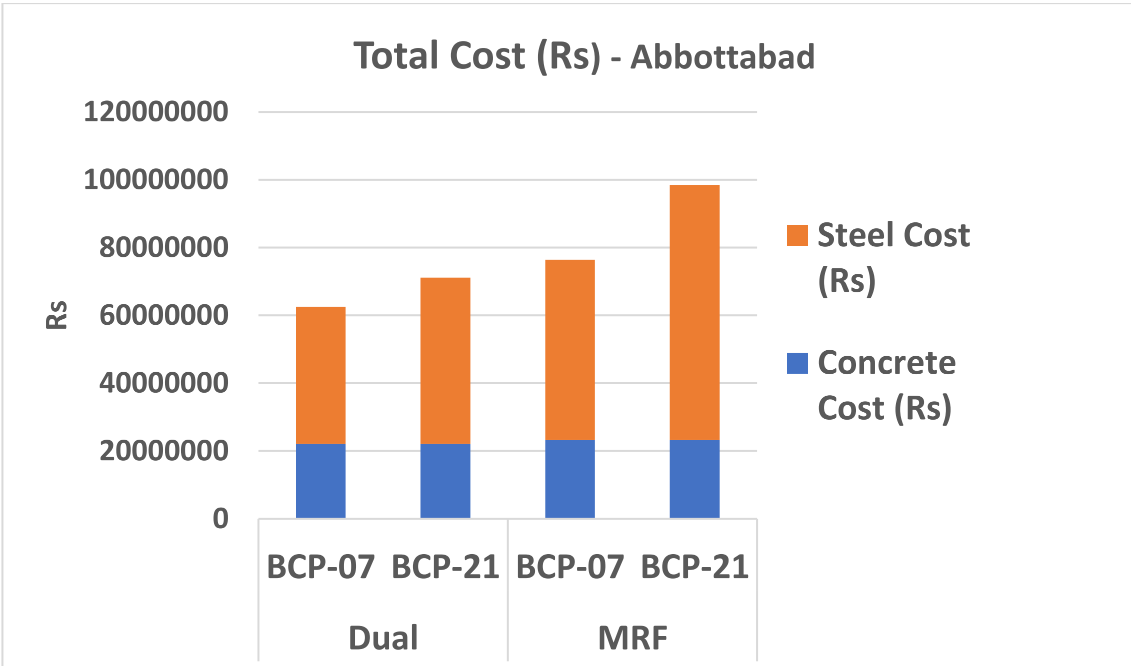

Figure 25 Total Cost for Abbottabad

Conclusions:

- Both systems under BCP-21 show greater quantity of Steel (and hence cost) than under BCP-07. This again verifies that the seismic demand is greater in the new code as compared to the previous
- Dual systems are more economical than MRF systems.
- There is no difference in the quantity of Concrete (and hence the cost) for the same system under both codes for both locations/zones.
- Under any code, the MRF system shows higher Concrete quantity (**4.94% difference**) than the Dual system. This is because shear walls make both the columns and beams relaxed by attracting the seismic forces towards themselves due to greater stiffness and as a result, the columns and beams have smaller sizes.
- Going from Zone 2B (Islamabad) to Zone 3 (Abbottabad) shows a **9.77%** increase in Steel quantity for Dual system and **13.7%** increase in Steel quantity.

CHAPTER 8

NON-LINEAR SEISMIC PERFORMANCE EVALUATION

As discussed earlier, one of the objectives of this research is to study the nonlinear behavior of buildings and assess the performance of buildings beyond the elastic range. This section covers the details regarding nonlinear pushover analysis, its essence and its application to this research.

The name Non-Linear signifies that this analysis involves the non-linear behavior of the building, and the performance of buildings is analyzed beyond the linear range resulting in a more realistic and detailed study of the performance of buildings under real loadings. This thesis involves the non-linear performance assessment of buildings under two variables, the building codes and the structural system used.

To serve this purpose, Static Pushover Analysis is used, and the performance of the buildings is evaluated under the variables mentioned above.

8.1 INTRODUCTION TO PUSHOVER ANALYSIS

A static pushover analysis is a nonlinear static analysis method used to evaluate the seismic performance of buildings. A series of increasing lateral loads is applied to the structure and the corresponding internal forces and deformations are calculated. The results are plotted on a pushover curve, which shows the relationship between the applied loads and the structural response.

The analysis method is based on the principle that the response of a structure to a seismic event is governed by its strength and stiffness properties. By evaluating the structure's response to incremental loads, the pushover analysis method can estimate its capacity to resist lateral loads and identify its weak point as well as its behavior under real seismic loadings.

There are two types of pushover analysis, force controlled, and displacement controlled. In a force-controlled pushover analysis, the external lateral load is incrementally increased until a specified target force level is reached. The structure's response is calculated at each load level, and the internal forces and deformations are plotted on the pushover curve.

Whereas displacement-controlled pushover analysis applies incremental lateral displacement to the structure until a specified target displacement level is reached. The external load is calculated based on the structure's stiffness and the displacement level. The analysis continues until the target displacement level is achieved.

The main results the pushover curve of the building which is studied to assess the behavior of the building. The pushover curve is plotted against base shear and roof displacement. The forces are applied at each story incrementally and the base shear is applied at the base of the building as explained in the figure.

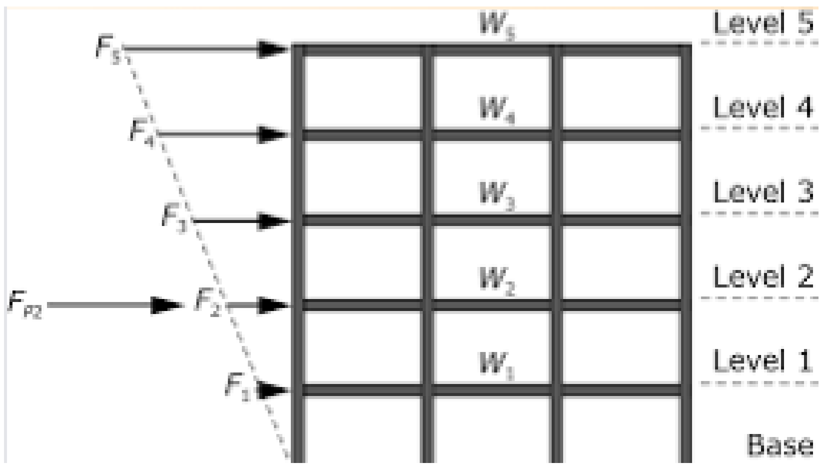

Figure 26 Pushover Load Distribution

8.2 NON-LINEAR MODEL PREPARATION

For Non-Linear Analysis, the original models are simplified. This is because the original models being based on an existing structure had far too many complexities. To simplify the analysis, the model is made much more simplistic in its geometry. Similar no. of stories (6) has been kept for this simplified model and also the same loads have been applied as before. The Non-Linear Analysis has only been done for Zone 2B (Islamabad). Hence, a total of 4 models are prepared and analyzed using the two structural systems under both codes:

1. MRF system under BCP-2007.
2. MRF system under BCP-2021.
3. Dual system under BCP-2007.
4. Dual system under BCP-2021.

The models were linearly designed to finalize the cross-section sizes and the required reinforcement. These cross-section sizes and the design output from the linear design will serve as the input for the non-linear analysis.

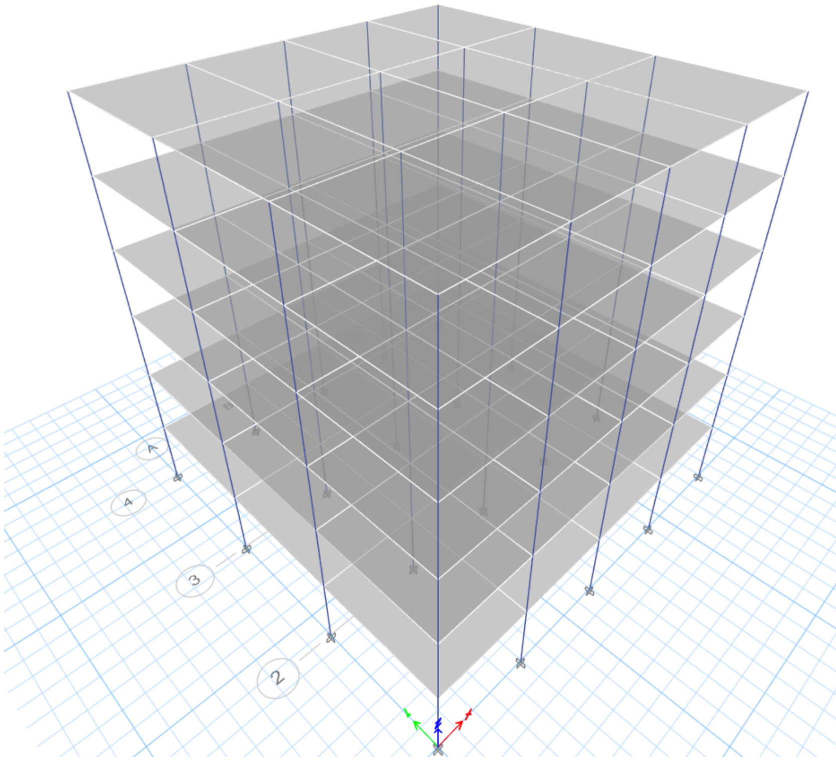

Figure 27 Non-Linear Model MRF

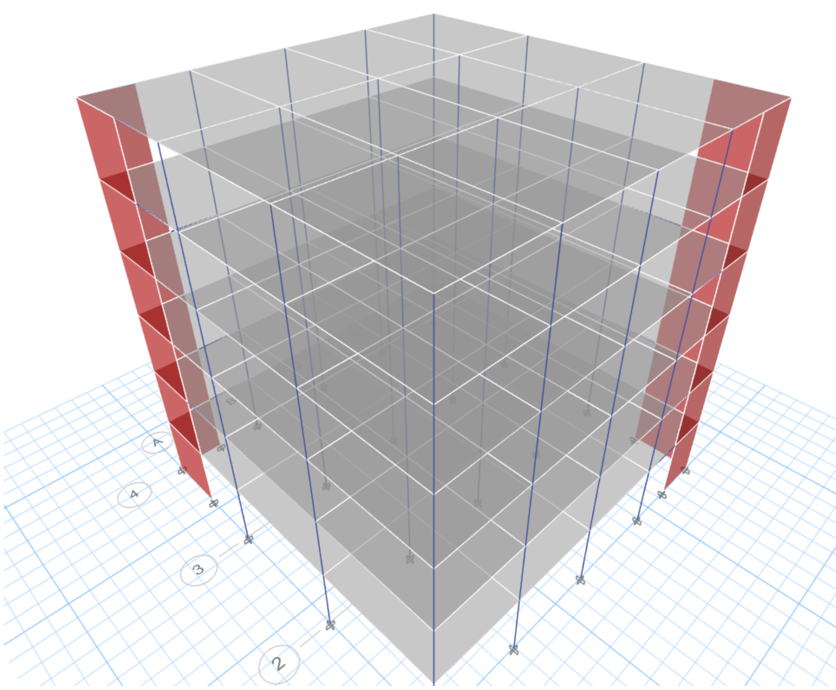

Figure 28 Non-Linear Dual Model

These buildings were first modelled in ETABS software and analyzed and designed to get the cross-sectional requirements and the steel bars to be designed. These models were designed as real buildings and the suitable cross sections with proper reinforcements were selected for beams, columns and shear walls, as per the linear design. This linear design would serve as the input needed to assess the performance through non-linear analysis.

8.3 ASSIGNING NON-LINEARITY AT MATERIAL LEVEL

The first step in making a non-linear model is to assign non-linearity at the material level. This step involves assigning the complete non-linear stress-strain graphs to Concrete and Steel so that the analysis can go beyond the linear graph and allow the material (concrete and steel) to go into the non-linear range. These curves were used from Mender’s Experimental values automatically available in ETABs, based on extensive testing.

The criteria for performance assessment are also assigned to the stress-strain graphs of materials. The performance criteria mainly comprise of

1. IO (Immediate Occupancy)
2. LS (Life Safety)
3. CP (Collapse Prevention)

These performance levels are marked at the stress-strain plots accordingly.

The table below shows the details for Concrete (3000psi).

Table 19 IO, LS, and CP values For Concrete

ACCEPTANCE CRITERIA	DESCRIPTION	STRAIN (in/in)
COMPRESSION		
IO	Onset of compression yielding	0.01
LS	2 times of compression yielding	0.02
CP	5 times of compression yielding	0.05
TENSION		
IO	Onset of tensile yielding	0.00088
LS	3 times of tensile yielding	0.0022
CP	5 times of tensile yielding	0.0036

Following is the stress-strain plot for the concrete used along with the IO, LS and CP criteria marked on the curve.

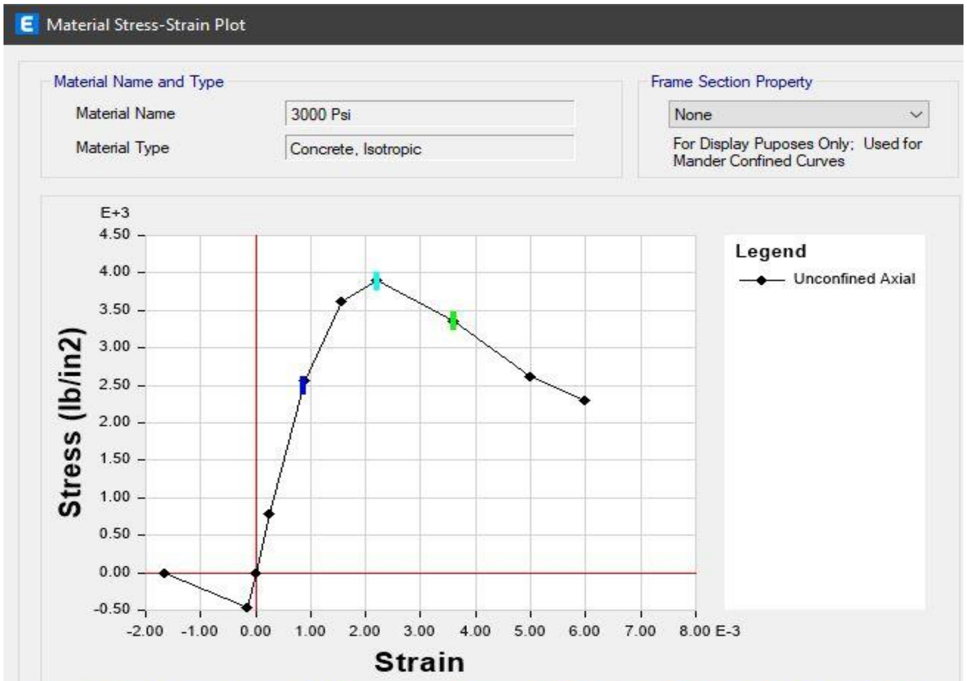

Figure 29 Stress-strain Plot for Concrete

The table below shows the details for Steel (60,000psi).

Table 20 IO, LS, and CP for steel

ACCEPTANCE CRITERIA	DESCRIPTION	STRAIN (in/in)
COMPRESSION		
IO	Onset of compression cracking	0.002276
LS	Onset of Peak stress	0.004552
CP	Onset of significant strength degradation	0.006828
TENSION		
IO	Onset of tensile cracking	0.002276

Following is the stress-strain plot for the steel used along with the IO, LS and CP criteria marked on the curve.

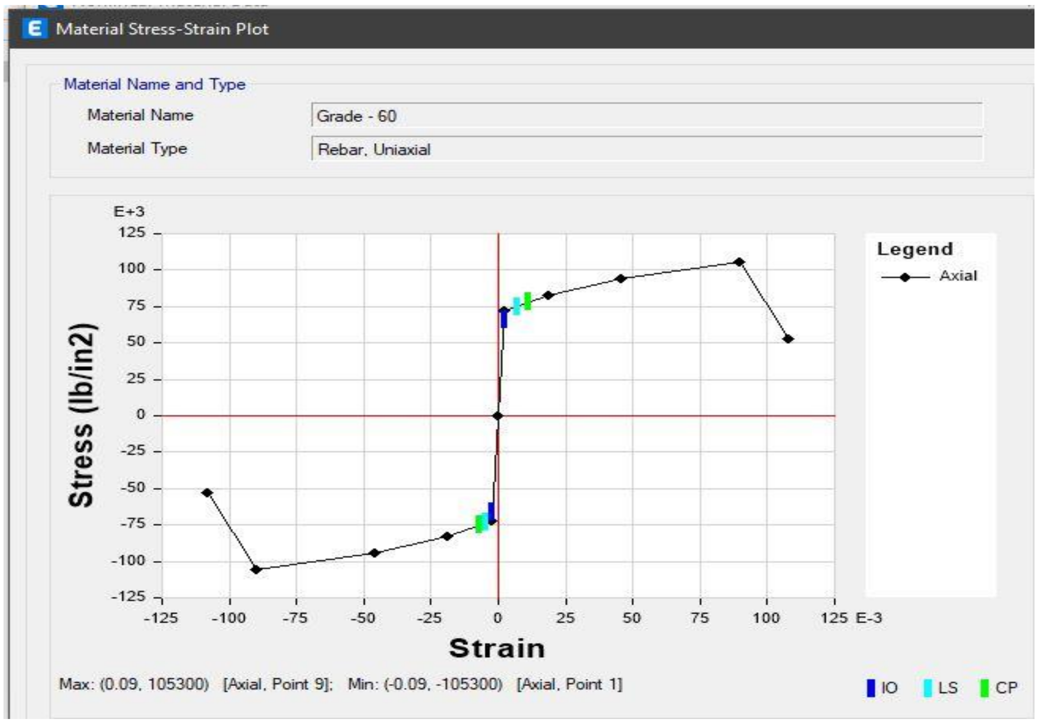

Figure 30 Stress-strain Plot for Steel

8.4 ASSIGNING NON-LINEARITY AT MEMBER LEVEL

The non-linearity is assigned at the members of the model after the material is assigned the stress-strain curves. The members used include columns, beams and shear walls. Rigid Diaphragm was assigned to all the slabs, which means that the slabs will not move relative to each other at a particular floor level.

There are two approaches which are used to assign non-linearity to the members namely, Fiber Modelling Approach and Plastic Hinge Modelling Approach.

8.4.1 FIBER MODELLING APPROACH

The fiber modeling approach is a finite element method that represents the structural system as an assembly of discrete, interconnected fibers which move throughout the length of the member. Each fiber is characterized by its material properties and orientation, and the behavior of the entire system is determined by the interactions between these fibers.

In this approach, the structure is divided into multiple fibers, each of which has its own unique material properties and geometry. The fibers are assigned nonlinear material behavior, and the behavior of the entire element is determined through the integration of the behaviors of the individual fibers.

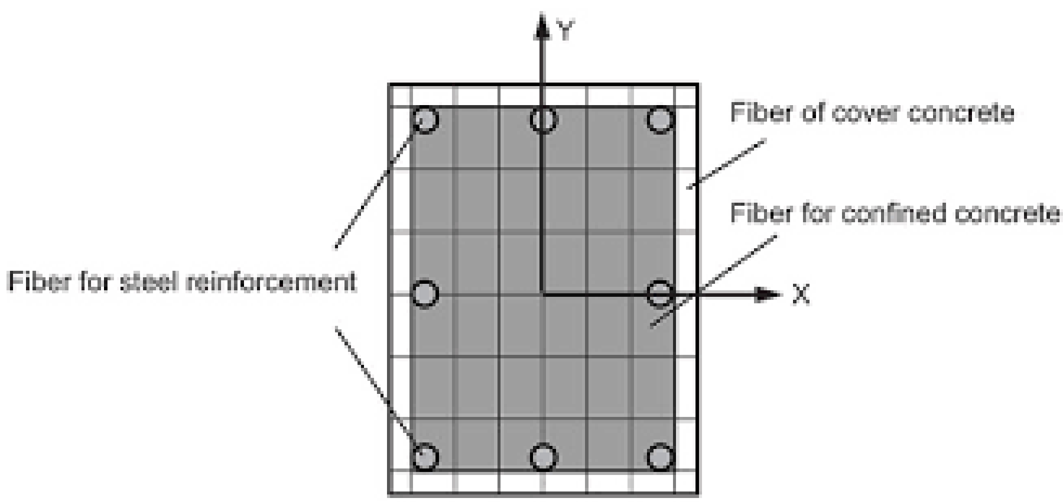

Figure 31 Fiber Hinge

8.4.2 PLASTIC HINGE MODELLING APPROACH

The plastic hinge modeling approach is a simplified method of modeling nonlinear behavior in structural analysis. In this approach, plastic hinges are used to represent regions of a structure where significant plastic deformation occurs, and the remaining part of the member is considered to remain under the linear deformation.

A plastic hinge is a hypothetical point in the structure where the section becomes fully plastic and significant deformation can occur. By modeling plastic hinges, the behavior of the elements during large displacements can be predicted.

8.4.3 ASSIGNING HINGES TO MEMBERS

The cross-sectional size and the number and layout of the steel bars used is needed as an input to assign the fibers to columns and shear walls, and plastic hinges to the beams respectively.

The Fiber Modelling Approach was used for assigning non-linearity to columns and shear walls whereas the Plastic Hinges were assigned to the beams, The Plastic hinges were assigned the non-linear curves and the IO, LS, and CP levels were assigned to the curve.

The Fibers and hinges are assigned up to 10 percent of member length on both sides. This ratio is based on the assumption that the plastic hinge and the non-linearity would develop within the extreme 10% of element and most of the central part would remain in the linear range. The fiber hinges used were P-M2-M3 default hinges and for the beams, M3 default hinges were used as per the instructions in ASCE 41-17 document.

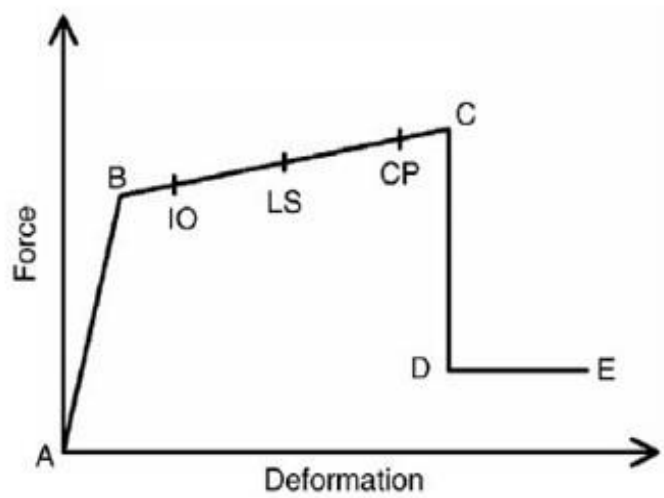

Figure 32 Plastic Hinge

8.5 LOAD CASE FOR PUSHOVER ANALYSIS

After assigning non-linearity to the material and members, the pushover load case was formed to carry out the pushover analysis. Firstly, the deflection of the building is noted in the first two modes, which came out to be y-direction and x-direction in the first and second mode respectively. So, the pushover case was built for these two directions as “Pushover-Y case” and “Pushover-X case”.

The models were made to first undergo gravity loading and at the end of this the pushover case is run and the results are computed as per the first and second mode of the building, obtained from modal analysis of the buildings.

As the pushover analysis is based on the realistic behavior of the members and material, the applied loading is also used realistically. So, the dead load is not amplified and 25% of the live load is used at the time of analysis.

The buildings were pushed in x and y directions and the pushover curves were obtained for both directions. The results are discussed in the later part of thesis.

8.6 PERFORMANCE EVALUATION AT TARGET DISPLACEMENT

The performance of the building is properly evaluated at the performance point. This point represents the stage at which the seismic capacity and the demand of the structure overlap. The seismic demands are governed by the response spectrum curve of the building under the expected earthquake. The capacity of the building is visualized by its bilinear pushover curve, which shows the base shear against the roof displacement.

The performance point and the target displacement are calculated by converting the capacity and demand curves under similar variables and the overlapping point of these two curves is generally considered to be the expected displacement that would be experienced by the structure during a real earthquake, as per the guideline procedures of Capacity Spectrum Method, specified in ATC 40.(ATC-40.)

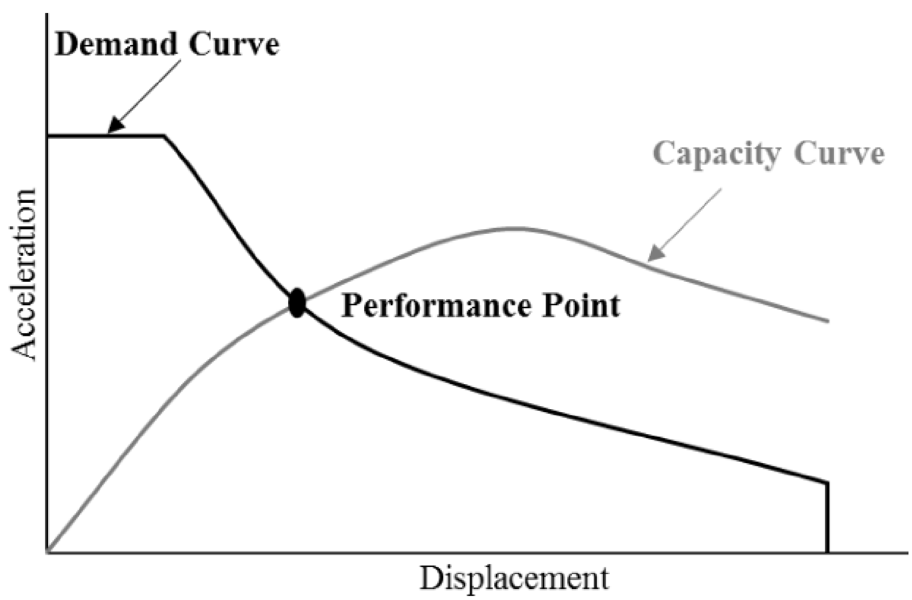

Figure 33 Capacity Spectrum Method

8.7 COMPARISON OF NON-LINEAR PUSHOVER ANALYSIS

The seismic performance beyond the linear range is evaluated by the pushover analysis. The pushover curves are compared. The performance of buildings designed as per BCP-21 is better than those designed as per BCP-07.

The performance can further be evaluated by comparing the overstrength ratio and the ductility of the buildings, using the pushover curves. The Overstrength ratio is the ratio of maximum base shear of a building to the design base shear. It is a measure of overstrength exhibited by buildings in a real earthquake scenario. The table shows the comparison of overstrength in different models.

Table 21 Overstrength Ratios

OVERSTRENGTH RATIO (Ω)		
	MRF SYSTEM	DUAL SYSTEM
BCP-07	1.6	1.97
BCP-21	1.8	2.17
INCREASE	12.5%	10%

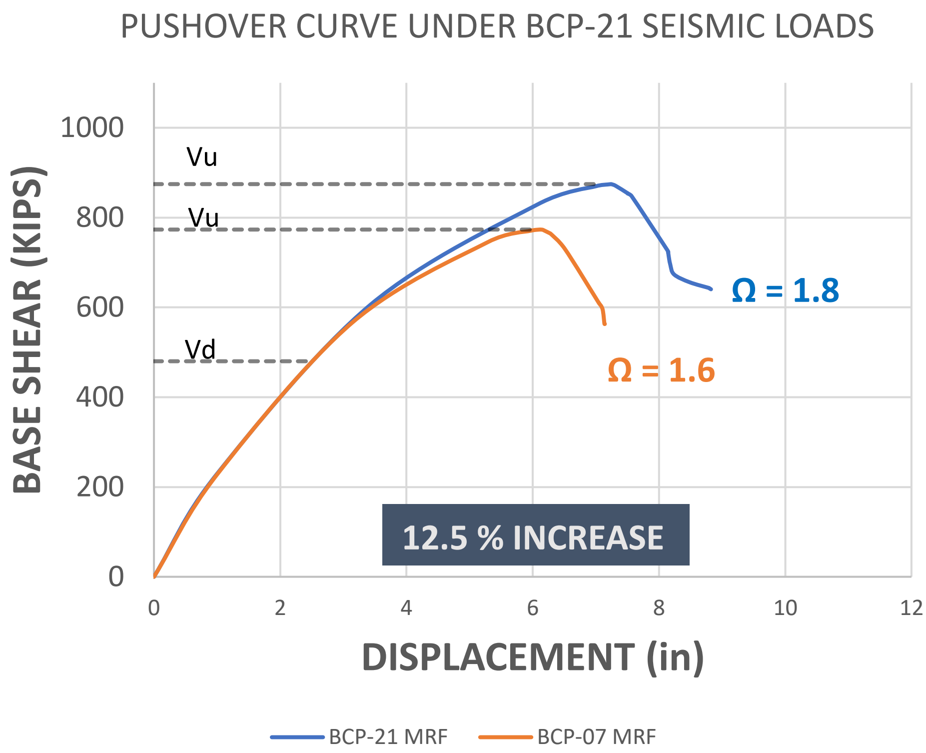

Figure 34 Pushover Curve for MRF System

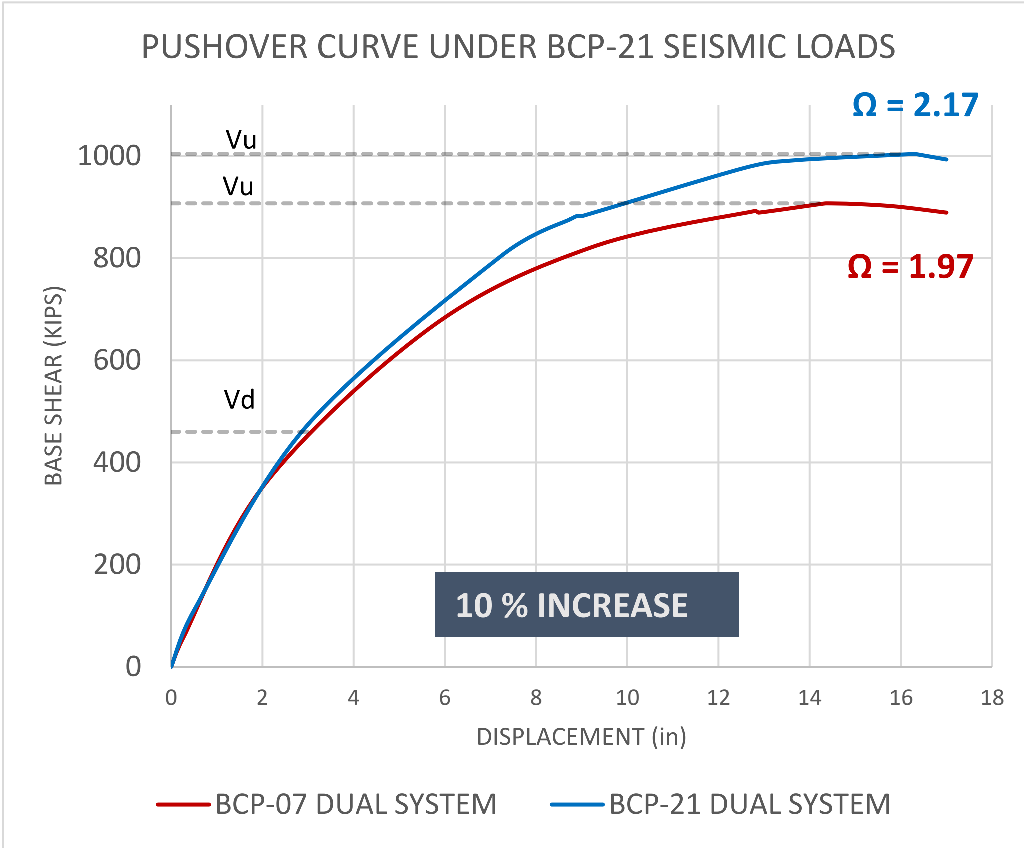

Figure 35 Pushover Curve for Dual System

The ductility is a measure of how the structure will fail. A ductile failure is preferred as compared to a brittle failure, in order to allow the people to evacuate the structure before failure, leading to life safety. The ductility is calculated as a ratio of drift at the maximum base shear, to the drift at design base shear. The ductility of the structures is also compared as illustrated in the table.

Table 24 Ductility Values

DUCTILITY		
	MRF SYSTEM	DUAL SYSTEM
BCP-07	2.47	4.95
BCP-21	2.89	5.62
INCREASE	17%	13.5%

As illustrated above, there was an increase in overstrength ratio and ductility in BCP-21 models as compared to BCP-07 models. The primary reason is the increase in steel requirements. As discussed earlier, an increase of 15-30% is observed in steel quantities, leading to a more ductile and strong structure.

These results imply that the structures designed as per the BCP-21 are more safe and secure, as compared to those designed as per BCP-07. The increase in overstrength and ductility is observed more in MRF as compared to Dual system, which implies that MRF structures face more changes due to the change of code. It also implies that the MF structures built upon BCP-07 can be more vulnerable as per new seismic demands, in comparison to Dual system structures.

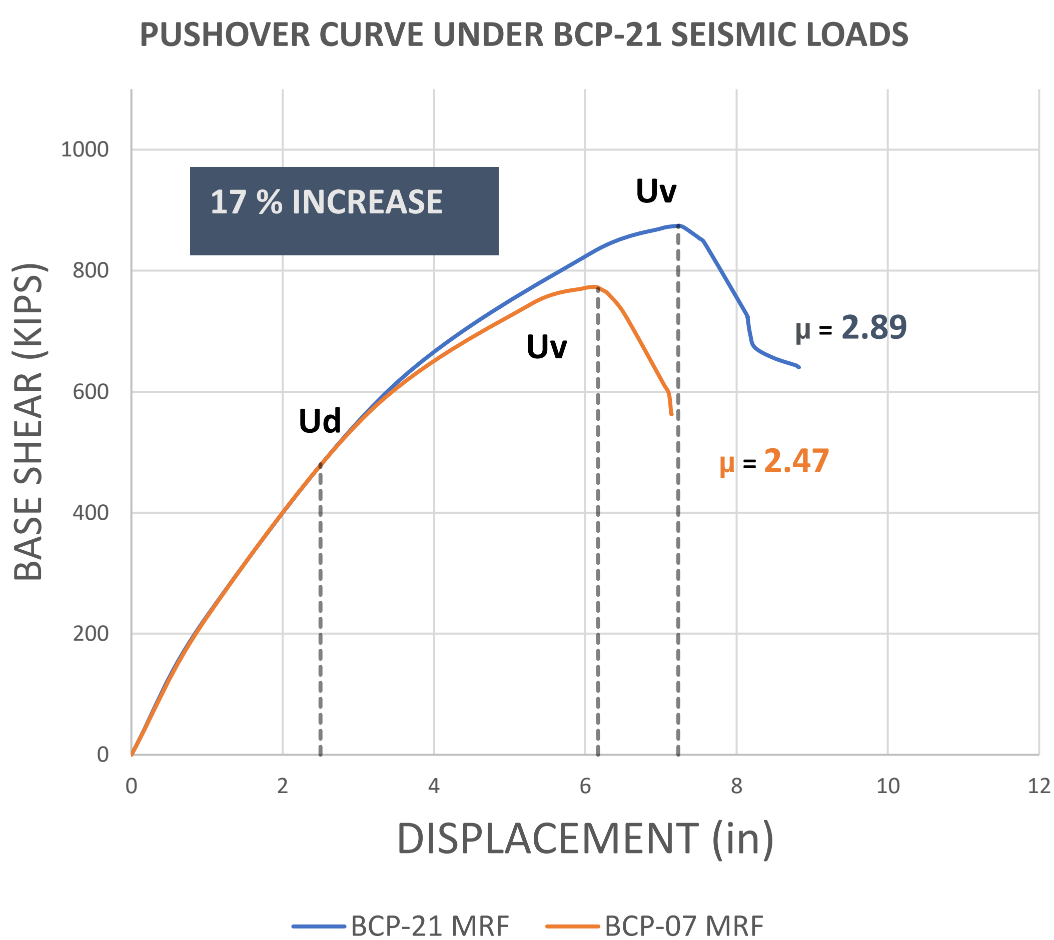

Figure 36 Pushover Curve for MRF System

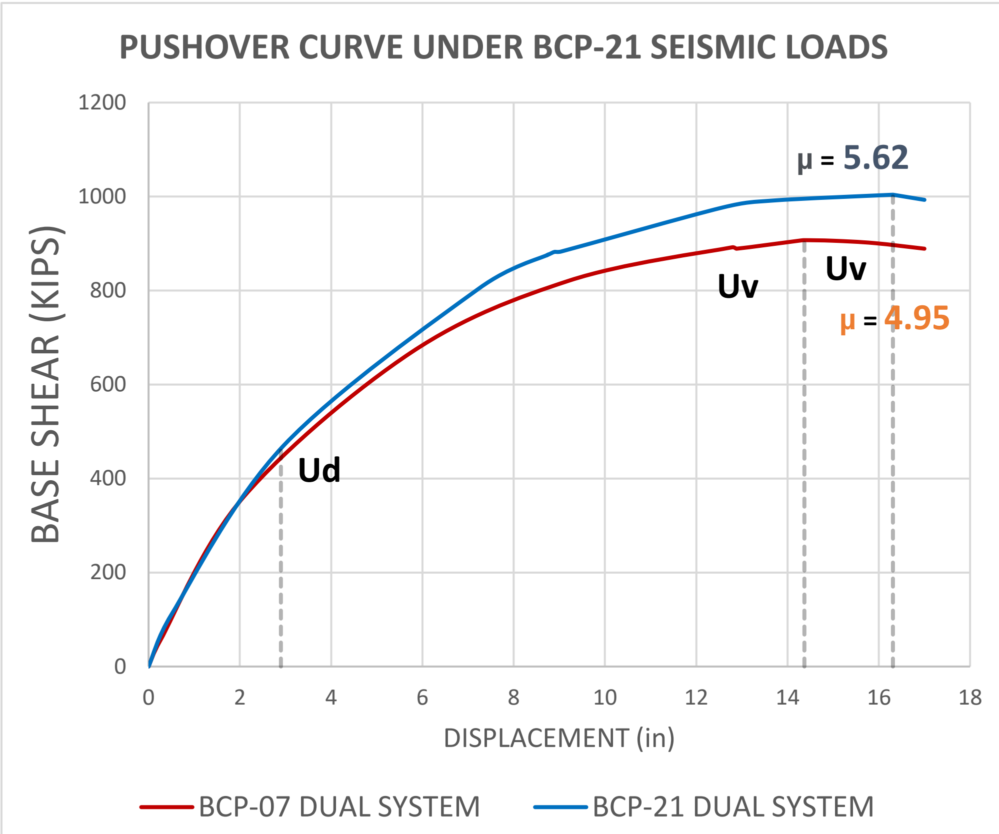

Figure 37 Pushover Curve for Dual System

- The Pushover Analysis shows that the buildings designed as per BCP-21, have more overstrength Ratio, are more ductile and suffer lesser damage, in comparison to BCP-07
- The Pushover Analysis also shows that the MRF structural system exhibits more difference in Overstrength and Ductility, in comparison to Dual structural system, due to change of code. The Overstrength ratio increased by **12.5%** in MRF and **10%** in Dual system respectively, when shifted from BCP-07 to BCP-21. Whereas the ductility increased by **17%** in MRF and **13.5%** in Dual system respectively, when shifted from BCP-07 to BCP-21.

Target displacements:

The following table shows the target displacements of the models.The plastic hinges developed at the target displacement, for each model are also illustrated below.

Table 22 Target Displacements

	BCP-07 MRF	BCP-21 MRF	BCP-07 DUAL	BCP-21 DUAL
Target Displacement (in)	7.2	7.54	8.35	8.48

Table 23 Number of Hinges In IO, LS, CP at Target Displacement

Number Of Hinges In IO, LS, CP at Target Displacement				
	<IO	IO-LS	LS-CP	CP<
BCP-07 MRF	246	110	156	90
BCP-21 MRF	414	80	88	33
BCP-07 DUAL	394	85	96	37
BCP-21 DUAL	395	88	96	30

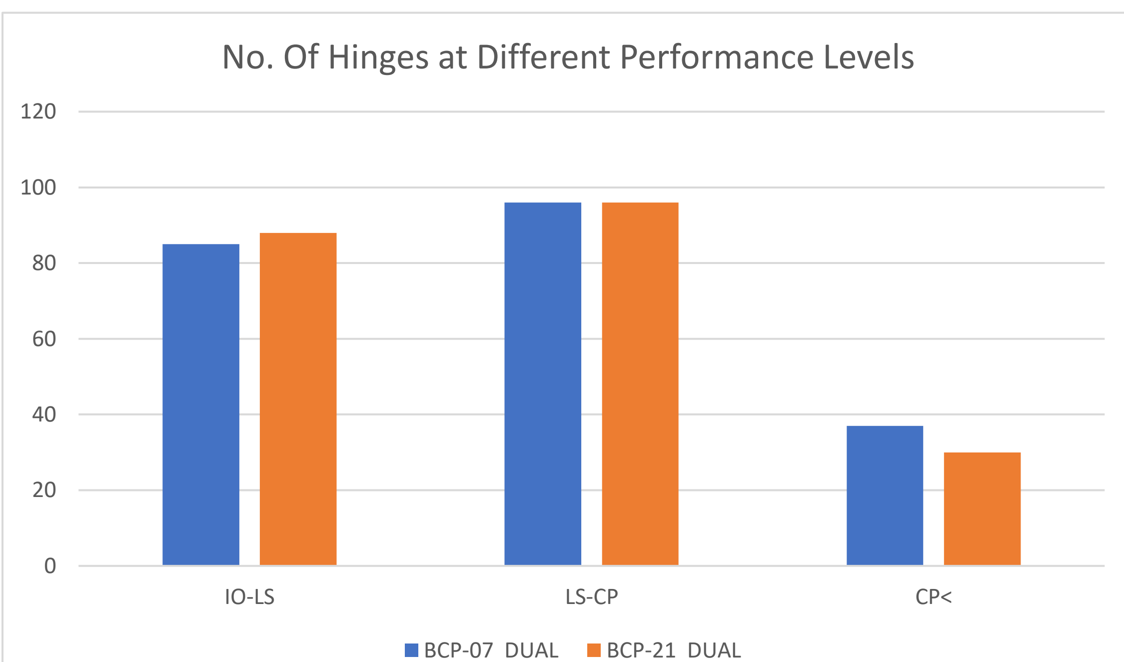

Figure 38 No. of Hinges at different Performance Levels for MRF System

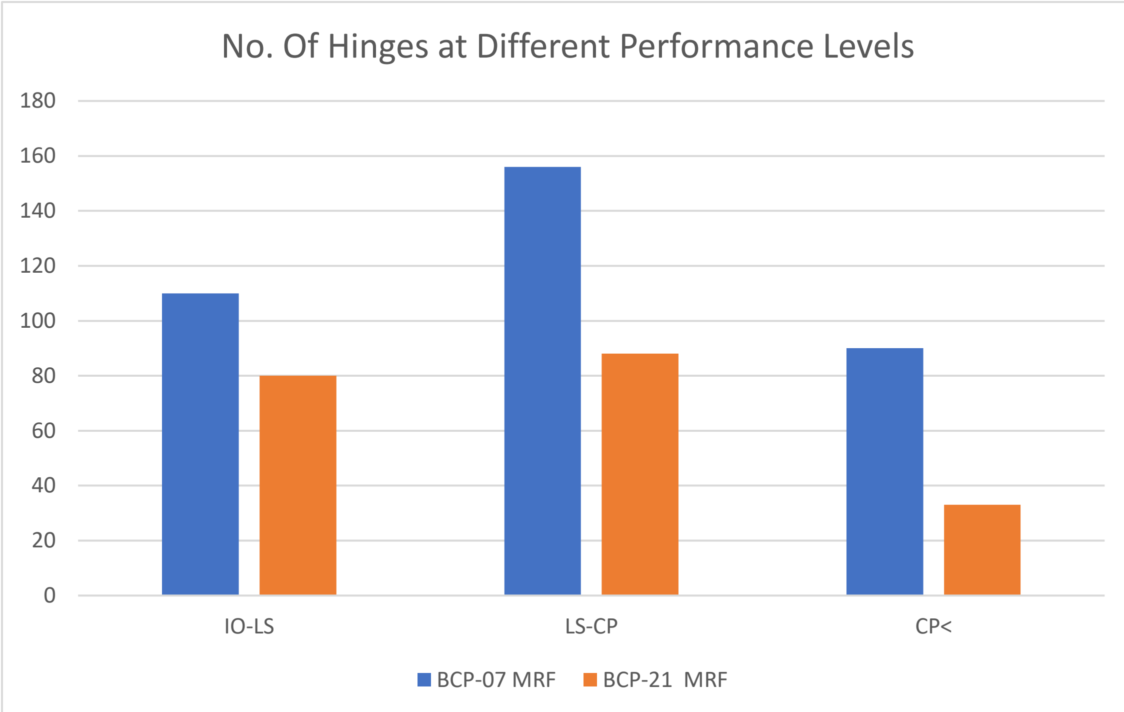

Figure 39 No. of Hinges at different Performance Levels for Dual System

The number of hinges in different performance levels at target level shows that the BCP-07 MRF model is the most damaged at the performance point. It can also be deduced that MRF has more difference in damage as compared to dual system, as a result of change of code.

CHAPTER 9

CONCLUSIONS:

- Both systems under BCP-21 show a greater base shear and displacements than that under BCP-07 for both locations/zones. This shows that there is an increased seismic demand for both Islamabad and Abbottabad as per the new code of 2021.
- The difference in base shear is more apparent in Dual systems as opposed to MRF.
- Dual systems show far less displacements than MRF systems. This is because Dual systems have greater stiffness than MRF systems so greater forces are required to displace them.
- Both systems under BCP-21 show greater quantity of steel (and hence cost) than under BCP-07. This again verifies that the seismic demand is greater in the new code as compared to the previous
- Dual systems are more economical than MRF systems.
- There is no difference in the quantity of concrete (and hence the cost) for the same system under both codes for both locations/zones.
- Under any code, the MRF system shows higher concrete quantity than the Dual system. This is because shear walls make both the columns and beams relaxed by attracting the seismic forces towards themselves due to greater stiffness and as a result, the columns and beams have smaller sizes.
- The Pushover Analysis shows that the buildings designed as per BCP-21, have more overstrength Ratio, are more ductile and suffer lesser damage, in comparison to BCP-07
- The Pushover Analysis also shows that the MRF structural system exhibits more difference in Overstrength and Ductility, in comparison to Dual structural system, due to change of code.

RECOMMENDATIONS

Following are some recommendations that can be helpful in extending this research:

1. The effect of addition of Bracers can also be checked in comparison with MRF and Dual system.
2. The analysis can be done for more zones and locations to obtain even more detailed results.
3. The results can further be verified through Dynamic Analysis.
4. The effect of change of code can be compared in low-rise and high-rise buildings.

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