Seismic Vulnerability Assessment of Partially Completed RC Structure in Horizontal Direction

FINAL YEAR PROJECT UG-2018

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2018

This is to Certify that the

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Has been accepted towards the

requirements For the undergraduatedegree

In

CIVIL ENGINEERING

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ABSTRACT

Pakistan is still striving for improvements in the construction industry. Major construction in the private sector is carried out as non-engineered; there are very few projects that are properly designed for gravity and lateral loads, which is the main cause behind deaths in major earthquakes. Severe earthquakes, when near inhabited districts, have caused extensive loss of life and property. For example, Kashmir-Hazara (2005) earthquake caused the deaths of 85,000 people. Nevertheless, after the Kashmir-Hazara (2005) earthquake, the government and engineering commission stressed the execution of a seismic code. By constructing seismic resisting structures losses can be reduced. The aim of this study was to compare the seismic vulnerability of partially completed and fully completed RC structures in horizontal direction using two different approaches, empirical and analytical. Our main goal is whether the vulnerability assessment of partially completed buildings is necessary or not and to compare the vulnerability of partially and fully completed buildings. In the empirical approach, the RVS method was used while pushover analysis was used in the analytical approach to calculate the seismic vulnerability of structures.

ACKNOWLEDGEMENT

This research was made possible due to the dedicated input of our Research Supervisor, Engr. Arslan Mushtaq, who remained calm, humble and helpful throughout our research tenure. In fact, it is not out of place to mention here that, Lecturer Arslan Mushtaq has been an excellent mentor and proved himself more than a supervisor. Apart from that our group members Mr. Awais Khalid Butt, Mr. Muhammad Talha and Mr. Murtaza Hassan have played key roles in the completion of research and compilation of results. Being students of engineering, we thank the administration of NICE, NUST which provided us with the resources and offered their continuous support.

Regards,

Awais Khalid Butt

Muhammad Talha

Murtaza Hassan

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CHAPTER 1

INTRODUCTION

Human casualties and economic losses caused by natural disasters have dramatically increased in the last couple of decades. In the recent past, many devastating earthquake events occurred. Some of them occurring throughout the world are Bhuj in India (2001), Bam in Iran (2003), and Kashmir in Pakistan with a magnitude of 7.6 (Shahzada et al.2011; Maqsood and Shwarz (2011), China (2010) and Indonesia (2010). Kashmir-Hazara (2005) earthquake caused the deaths of 85,000 people. Nevertheless, in Pakistan, after the Kashmir-Hazara (2005) earthquake, the government and engineering commission stressed the execution of a seismic code. Generally, different parameters can affect assessment procedures. These parameters have different values based on the structural system, seismic capacity, soil conditions and irregularities in plane and elevation. Many methods for seismic risk assessment were proposed by researchers as part of loss prediction which was classified into two major groups: empirical and analytical methods.

1.1a Empirical assessment approach

Rapid Visual Screening (RVS) can be used on a large building to estimate the seismic vulnerability of the structures. In this technique observations are made from the exterior of building. This may take up to 30 minutes. Based on

FEMA 154 the street screening method is known as the Rapid Visual Screening Method. This approach is applied before going into detailed procedure and classifying buildings based on their material and structural system. The performance score is calculated based on the building features, such as in FEMA 154.

1.1b Analytical assessment approach

The analytical procedures for determining the seismic vulnerability of structures may also be named the theoretical approaches, since, in contrast to the empirical approach, which is based on observations, they rather focus on simulating the strong ground motions. Designing structures exposed to seismic action according to seismic regulations or performance based design is trending. Non-linear method is used to get accurate results.

Non-Linear static analysis - Pushover analysis:

Due to its simplicity non-linear static analysis approach has become quite popular. It becomes an active engineering tool for estimating structural safety against earthquake-induced collapse. The non-linear static analysis refers to the pushover analysis that will result in a well-known curve identified as the "Capacity Curve". The goal of this approach is to obtain the structure's dynamic properties such as stiffness, strength, and ductility under seismic loading.

In the non-linear static pushover analysis procedure, the constructed model of the structure will consider explicitly the non-linear force and displacement behavior of its structural elements. A relation between base shear and displacement (V vs. Δ) is formed via exposing the structure to lateral forces monotonically increasing until the displacement of the model exceeded or reached the allowable displacement that described predefined structural damage. This allowable displacement is called target displacement.

1.2 Objectives of the research

Our main objective is to draw a comparison between the seismic vulnerability of partially and fully completed buildings. Empirical and analytical methods of seismic assessment will be used to calculate the seismic vulnerability of RC structures. Improvement in the design practices regarding seismic analysis of partially completed buildings is our objective. The danger of an earthquake can never be ignored and if not catered for, it can prove to be dangerous and tragic like the Kashmir Hazara earthquake where the loss was devastating. In the meantime, it is an absolute necessity to make structures safer and better utilizable. The overall purpose of our work is to investigate and improve the behavior of partially completed RC structures against earthquake forces.

The specific objectives of this study are:

- Selecting an Area
- Locating partially completed buildings
- Empirical vulnerability assessment procedure, i.e., RVS method

- Analytical vulnerability assessment procedure, i.e., Non-linear static pushover analysis
- Getting capacity curves
- Comparing empirical and analytical methods results
- Comparing vulnerability of partially and fully completed buildings.

1.3 Background

Pakistan is a developing country and the construction industry is always in motion. But due to various factors, construction works have several breaks in between which can extend from a few months to years. As a result, there are a lot of buildings which are left partially completed. Seismic vulnerability assessment of these partially completed buildings is not done in common practice, which results in buildings being prone to earthquake forces. There are different techniques used to estimate the seismic vulnerability of structures. We have FEMA forms which are updated regularly over the years, RVS method is applied which comes under empirical approaches and is only accurate to some extent. There are several other more accurate and advanced methods, such as pushover analysis and time history analysis. These non-linear analysis methods come in the category of analytical methods. Structures are modelled and analyzed in ETABS. This method can take a long time but is very accurate and shows the real response of structures under seismic action.

1.4 Problem Statement

There is a common trend in Pakistan to leave buildings for future extensions in the horizontal direction. Seismic vulnerability assessment of such partially completed structures is not performed and they are designed only considering gravity loads. Such buildings are stable in the case of vertical loads but are very prone to lateral loadings due to earthquakes. Therefore, it is very necessary to conduct seismic vulnerability of buildings as well. Seismic vulnerability can be calculated by either of two approaches: The empirical and Analytical methods. We used the RVS method for determining vulnerability scores of partially completed buildings which is an estimative technique and offers less accurate results. Further, we performed a vulnerability assessment of buildings through non-linear static pushover analysis using ETABS, firstly for partially completed structures, and then for completed versions of the same buildings.

CHAPTER 2

Literature Review

The literature shows the considerable work and study on seismic vulnerability assessment. Several experimental and numerical analyses were performed on the matter by various authors. These works are reviewed keeping in view the methodology, principles and various aspects and behavior

of structures under the earthquake forces. Given below are some of the related works.

Mustafa Mufeed Kaseem estimated the seismic vulnerability of different types of buildings masonry, RC and wooden structures by using an empirical Malaysian approach in October 2021.

There is a study focused on masonry structures performed in Tawang (India) which used the American approach to perform a seismic vulnerability assessment.

Ashwin Prabhu T. in May 2013, performed a Seismic Evaluation of a 4-Story RC Structure using an analytical approach by Pushover Analysis

Riza Ainul Hakim in November 2013, worked on Seismic vulnerability assessment of RC structures using non-linear static Pushover Analysis.

In January 2011, Khan Shahzada studied vulnerability assessment of typical buildings in Pakistan by taking Abbottabad, one of the most affected cities during the 2005 Kashmir earthquake, as a case study.

Sameh A.El-Betar in September 2016, investigated the seismic vulnerability of existing R.C. buildings in Egypt. In this paper, suggestions are made for a suitable procedure for seismic evaluation of existing R.C. buildings in Egypt.

Svetlana Brzev in December 2017, assessed the seismic vulnerability of low-rise reinforced concrete buildings affected by the 2015 Gorkha, Nepal, Earthquake.

S. A. Elkholy in March 2012, worked on the seismic vulnerability assessment of existing multi-story reinforced concrete buildings in Egypt.

CHAPTER 3

METHODLOGY

To assess the seismic vulnerability of partially completed buildings of Islamabad two approaches were used. First empirical approach in which rapid visual screening technique using FEMA 154 was adopted. Second was analytical approach for which pushover analysis of buildings was done using ETABS 18.

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 experimental work to come.

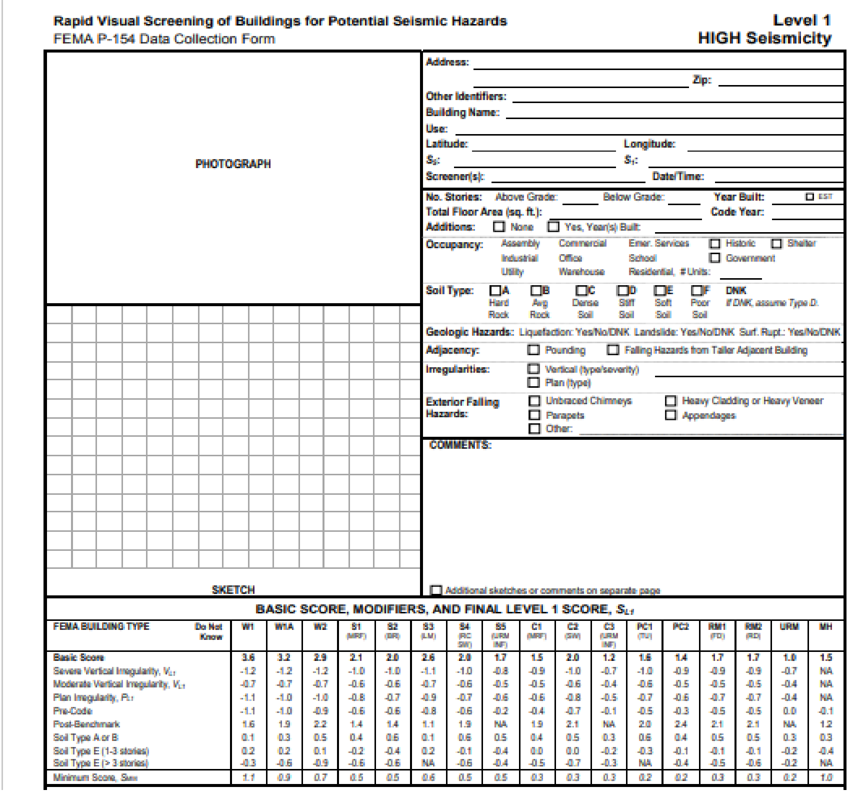
3. First of all, partially completed buildings left for future extension in horizontal direction were located.
4. Buildings were visited and rapid visual screening was done.
5. FEMA 154 form was used to assess the seismic vulnerability of the buildings.
6. FEMA 154 forms were filled to get vulnerability score.
7. Second approach that was used to assess the seismic vulnerability was push over analysis of the buildings.
8. Modeling of buildings was being done using ETABS 18.
9. Pushover analysis of partially completed buildings was being done.
10. Base share, spectral acceleration and damage index curves were obtained after running pushover analysis.
11. Then complete models of buildings were made.
12. Pushover analysis of completed models was being done.
13. Results of partially completed and fully completed buildings were compared to check which type of building is more vulnerable in case of earthquake.
14. Evaluation of results.
15. Writing thesis

CHAPTER 4

RAPID VISUAL SCREENING (FEMA 154)

4.1. Introduction of Rapid Visual Screening.

The rapid visual screening (RVS) procedure is a method which is used to check the seismic vulnerability of buildings. Such buildings are further checked using analytical approach to check if the building will hold under earthquake of specific intensity depending upon specific zone. The Rapid Visual Screening method uses a methodology which is based on Data Collection Form and a sidewalk survey of a building. A survey is conducted, and building is observed from outside and also from inside if the building owner or management allows you to enter. For this two-page Data Collection Form is used that includes space for documenting building identification information, its size and use, a photograph of the building, sketches, and documentation of pertinent data related to seismic performance. Data is collected by survey on the basis of which, a score is calculated that provides an indication of the expected seismic performance of the building. FEMA 154 form has score modifiers which are related to observed performance attributes and are then they are added or subtracted from the Basic Score to get a Final Score.


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
HIGH Seismicity

PHOTOGRAPH

Address:
Zip:
Other Identifiers:
Building Name:
Use:
Latitude: Longitude:
S_S: S_1:
Screener(s): Date/Time:

No. Stories: Above Grade: Below Grade: Year Built: ☐ EST
Total Floor Area (sq. ft.): Code Year:
Additions: ☐ None ☐ Yes, Year(s) Built:
Occupancy: Assembly Commercial Emer. Services ☐ Historic ☐ Shelter Industrial Office School ☐ Government Utility Warehouse Residential, # Units:
Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil DNK *If DNK, assume Type D.*
Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity) ☐ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other:

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score		3.6	3.2	2.9	2.1	2.0	2.6	2.0	1.7	1.5	2.0	1.2	1.6	1.4	1.7	1.7	1.0	1.5
Severe Vertical Irregularity, V_{L1}		-1.2	-1.2	-1.2	-1.0	-1.0	-1.1	-1.0	-0.8	-0.9	-1.0	-0.7	-1.0	-0.9	-0.9	-0.9	-0.7	NA
Moderate Vertical Irregularity, V_{L1}		-0.7	-0.7	-0.7	-0.6	-0.6	-0.7	-0.6	-0.5	-0.5	-0.6	-0.4	-0.6	-0.5	-0.5	-0.5	-0.4	NA
Plan Irregularity, P_{L1}		-1.1	-1.0	-1.0	-0.8	-0.7	-0.9	-0.7	-0.6	-0.6	-0.8	-0.5	-0.7	-0.6	-0.7	-0.7	-0.4	NA
Pre-Code		-1.1	-1.0	-0.9	-0.6	-0.6	-0.8	-0.6	-0.2	-0.4	-0.7	-0.1	-0.5	-0.3	-0.5	-0.5	0.0	-0.1
Post-Benchmark		1.6	1.9	2.2	1.4	1.4	1.1	1.9	NA	1.9	2.1	NA	2.0	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.1	0.3	0.5	0.4	0.6	0.1	0.6	0.5	0.4	0.5	0.3	0.6	0.4	0.5	0.5	0.3	0.3
Soil Type E (1-3 stories)		0.2	0.2	0.1	-0.2	-0.4	0.2	-0.1	-0.4	0.0	0.0	-0.2	-0.3	-0.1	-0.1	-0.1	-0.2	-0.4
Soil Type E (> 3 stories)		-0.3	-0.6	-0.9	-0.6	-0.6	NA	-0.6	-0.4	-0.5	-0.7	-0.3	NA	-0.4	-0.5	-0.6	-0.2	NA
Minimum Score, S_{MIN}		1.1	0.9	0.7	0.5	0.5	0.6	0.5	0.5	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.2	1.0

4.2. Identifying the locations of buildings:

There are not too many partially completed buildings that are left for future extension, in Islamabad. After consulting our adviser and taking the help of internet we got the location of buildings. We surveyed 4 buildings that are in G 12 and F 17. Google map locations of buildings are shown in figure 4-1.

Figure 4-1

4.3. Sidewalk survey:

We visited above mentioned location and did a survey to fill our FEMA 154 forms. Most of the buildings were visited from outside because could not permission to enter the building. We also faced visibility issues due to confinement of buildings.

F 17 Building

G 12 Building 1

G 12 Building 2

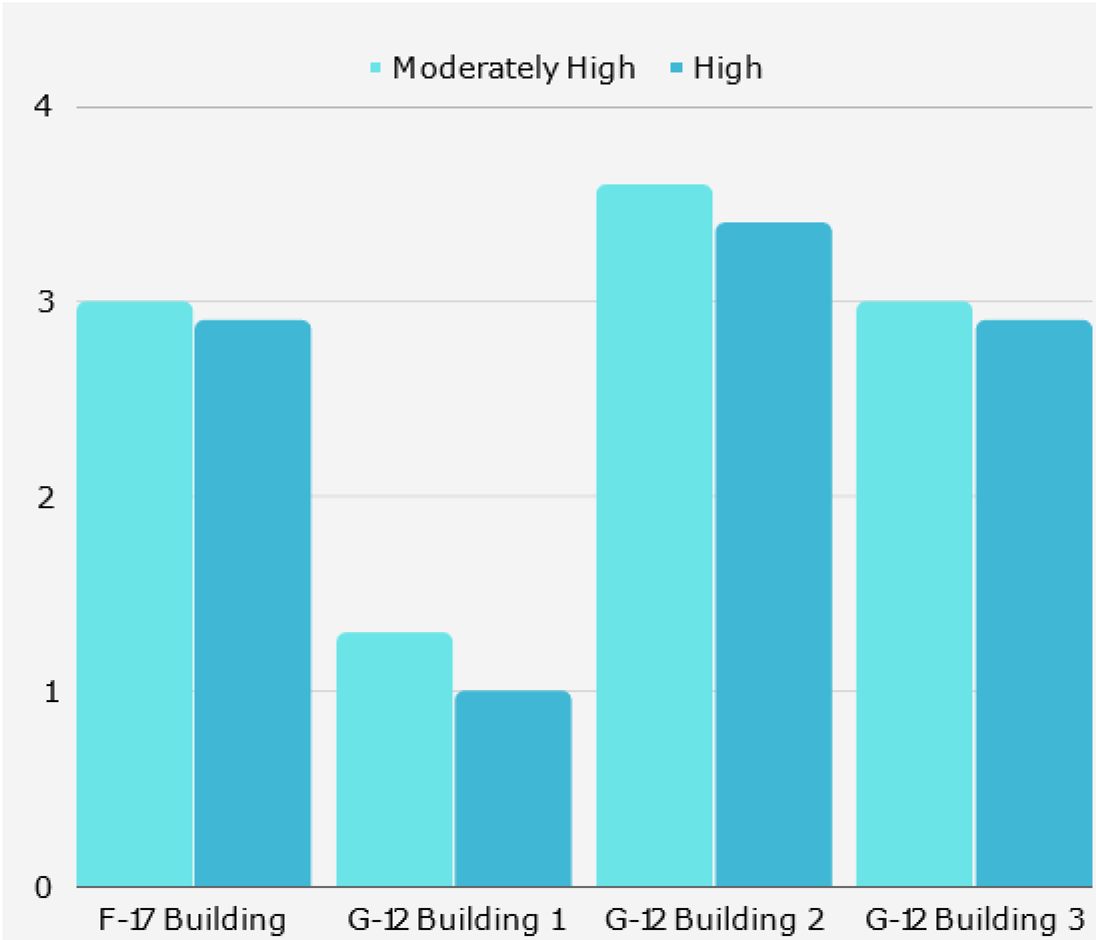
G 12 building 3

4.4. FEMA 154 score of buildings:

After survey we got this score of buildings on the basis of which defined the seismic vulnerability of buildings.

Vulnerability Scores

Building Name	FEMA Score (Moderately High)	FEMA Score (High)	Damage State Classification
F-17 Building	3	2.9	D1-D2
G-12 Building 1	1.3	1	D2-D3
G-12 Building 2	3.6	3.4	D0-D1
G-12 Building 3	3	2.9	D1-D2


Moderately High
High
4
3
2
1
0
F-17 Building
G-12 Building 1
G-12 Building 2
G-12 Building 3

CHAPTER 5

MODELING OF STRUCTURES

5.1. Introduction of ETABS 2018

"ETABS is an engineering software product that is helpful in design and analysis of multi-story structures. ETABS have built in modeling tools and templates, predefined loads and its types, analysis methods and solution techniques, all are helpful with the grid-like geometry specific for a certain type of structure. The advanced and revolutionary new ETABS is the ultimate integrated software package for the analysis and design of structures."

Figure 5-1

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 plate

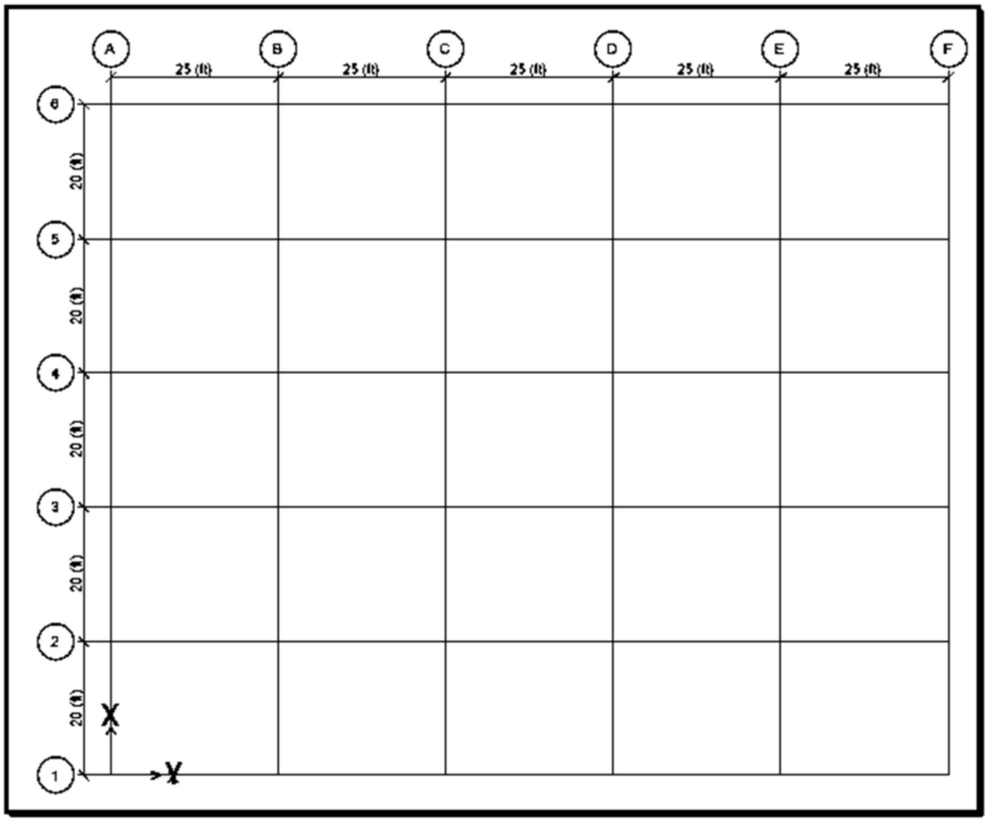
ETABS 2018 has incorporated with functions of Peform-3D and has following new features:

1. Results are directly visible on the modelled structure.
2. Comprehensive reports are available for all analysis and design output,
3. Engineering drawings of plans, scheduling, detailing, and cross-sections can be generated for concrete and steel structure.

5.2 Modeling in ETABS

1. All Structures were modeled in CSI ETABS 2018. In every structure only one type of columns and beams were used.
2. The first step was to define the grids.

3. By defining grid we mean that assigning coordinates or positions.
4. After that the next step was to define materials which were given in building characteristics.
5. Next step was to define the frame sections. Frame sections consists of beams and columns.
6. The concrete reinforcements were added in columns and beams.
7. 1% steel was given in beam and column section because we could not get structural drawings of buildings.
8. Concrete cover for beams and columns was taken “1.5 inches. The remaining values were set to default.
9. Loads were defined and the loads that were used for pushover analysis were Gravity nonlinear, Pushover X and Pushover Y.
10. The next step after defining area sections was to assign the loads to the structure. We assigned live load of 40 psf for slabs.
11. First of all, it was checked if the model has no error.
12. Except gravity nonlinear, pushover X and Pushover Y every load was set to run.
13. Then Pushover analysis was being done.



Models and structural details the of buildings are shown in following figures

BUILDINGS DESCRIPTION

F-17 BUILDING

Items	Completed	Partial
Beams	856	440
Columns	476	254
Height	48 ft	48 ft
No. of Storeys	4	4

G-12 BUILDING 1

Items	Completed	Partial
Beams	180	336
Columns	112	196
Height	44 ft	44 ft
No. of Storeys	4	4

G-12 BUILDING 2

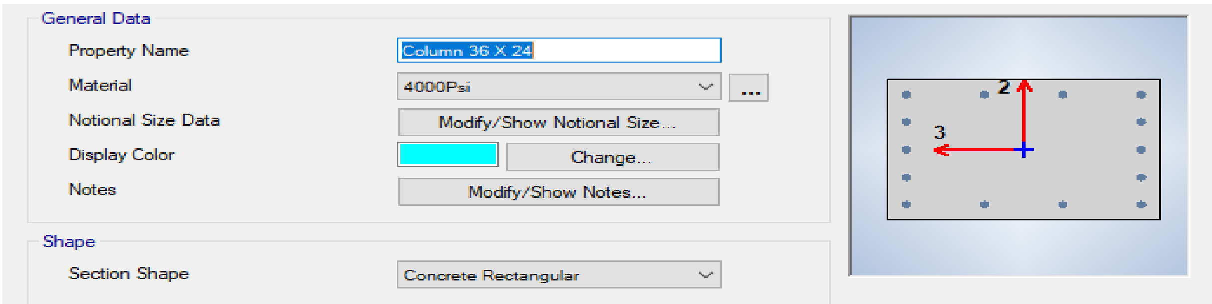
Items	Completed	Partial
Beams	135	72
Columns	84	48
Height	30 ft	30 ft
No. of Storeys	3	3

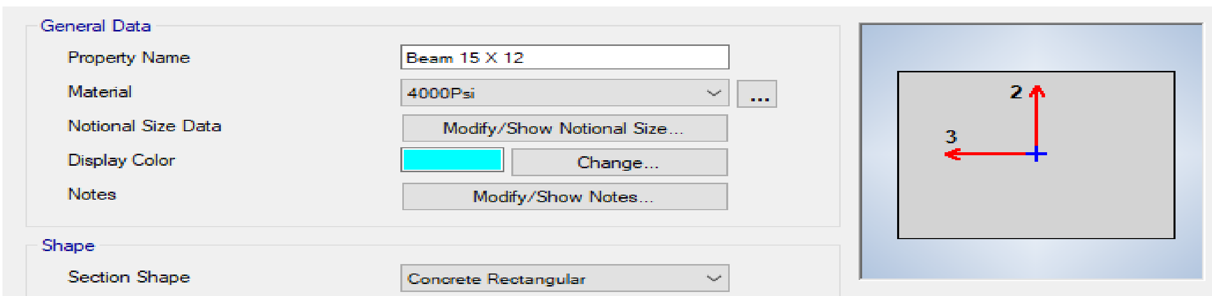
G-12 BUILDING 3

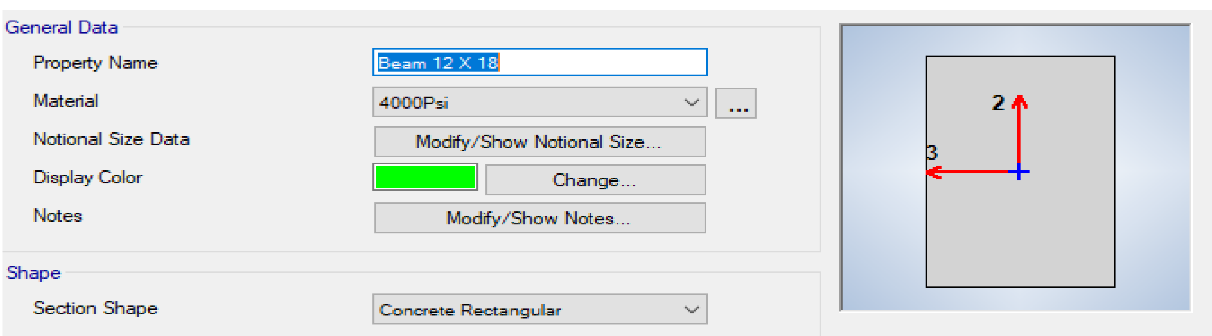
Items	Completed	Partial
Beams	180	96
Columns	112	64
Height	40 ft	40 ft
No. of Storeys	4	4

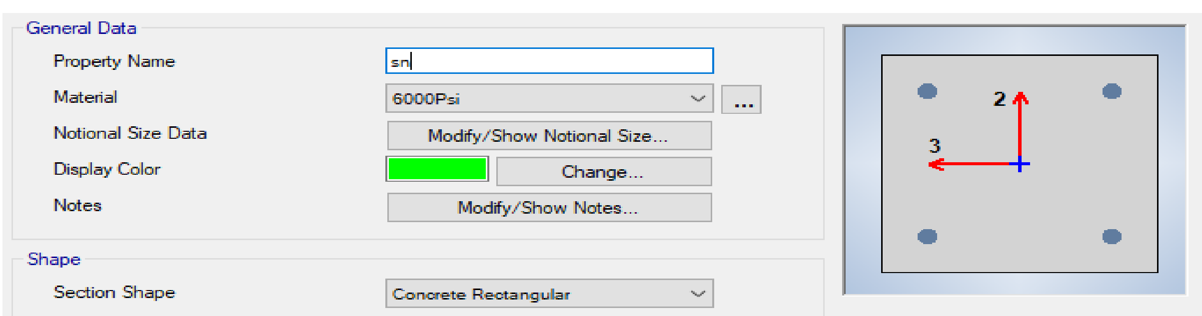
Figure 5-2

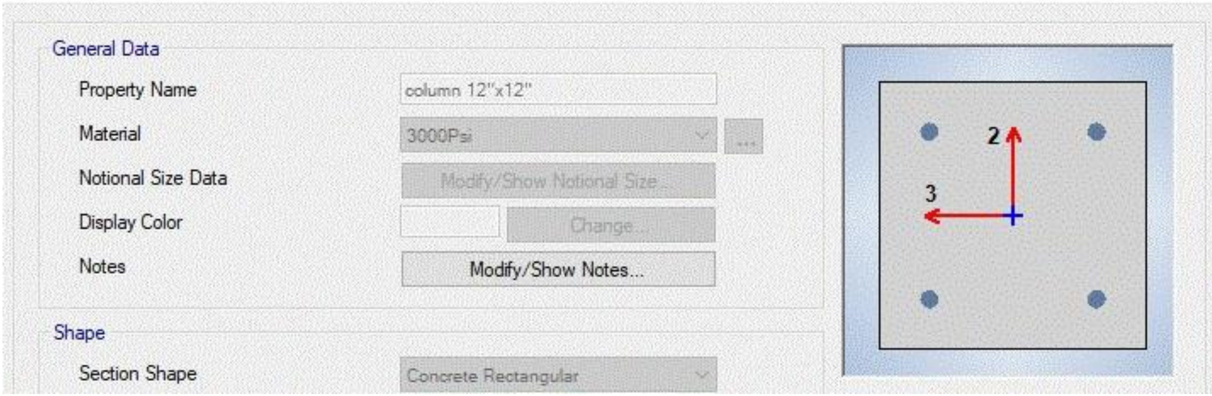
Beam and Column sections used in modeling

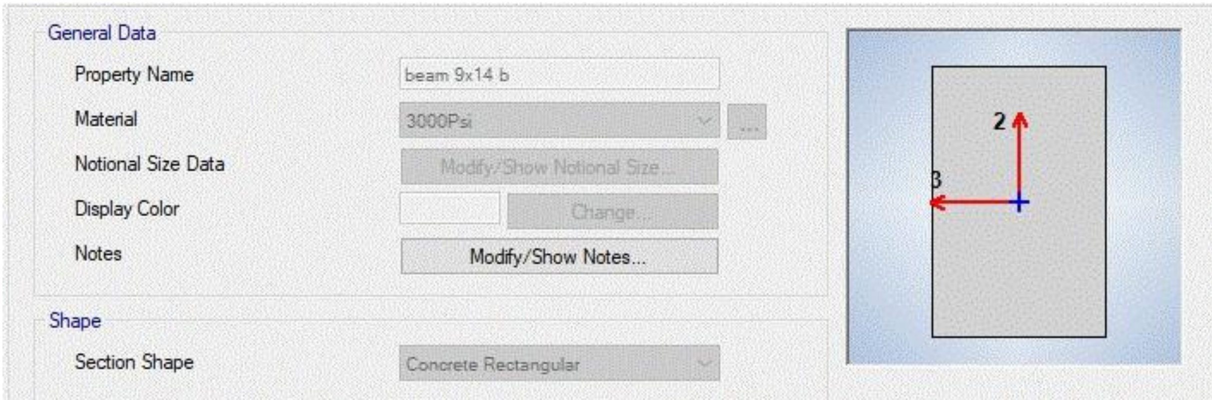









General Data
Property Name
column 12"x12"
Material
3000Psi
Notional Size Data
Modify/Show Notional Size...
Display Color
Change...
Notes
Modify/Show Notes...
Shape
Section Shape
Concrete Rectangular
2
3


General Data
Property Name
beam 9x14 b
Material
3000Psi
Notional Size Data
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Change...
Notes
Modify/Show Notes...
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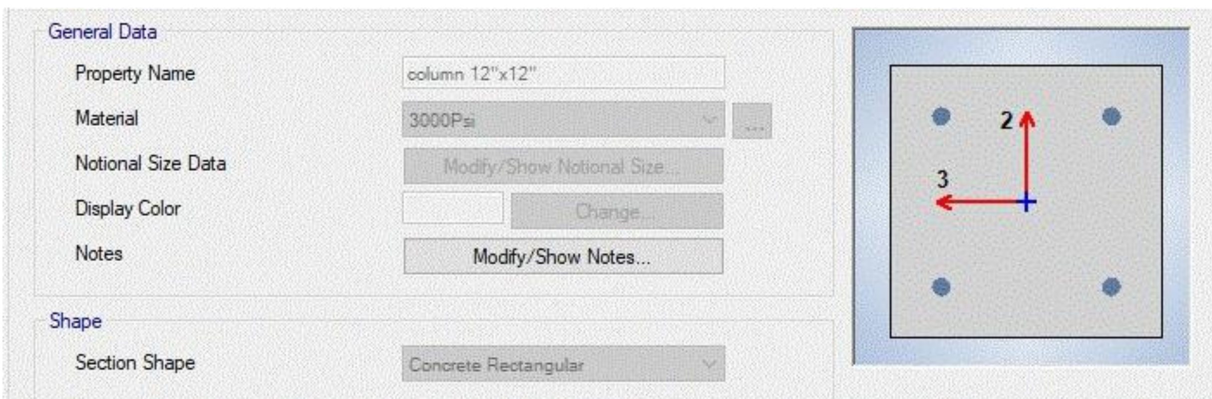
Section Shape
Concrete Rectangular
2
3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Concrete Rectangular
2
3

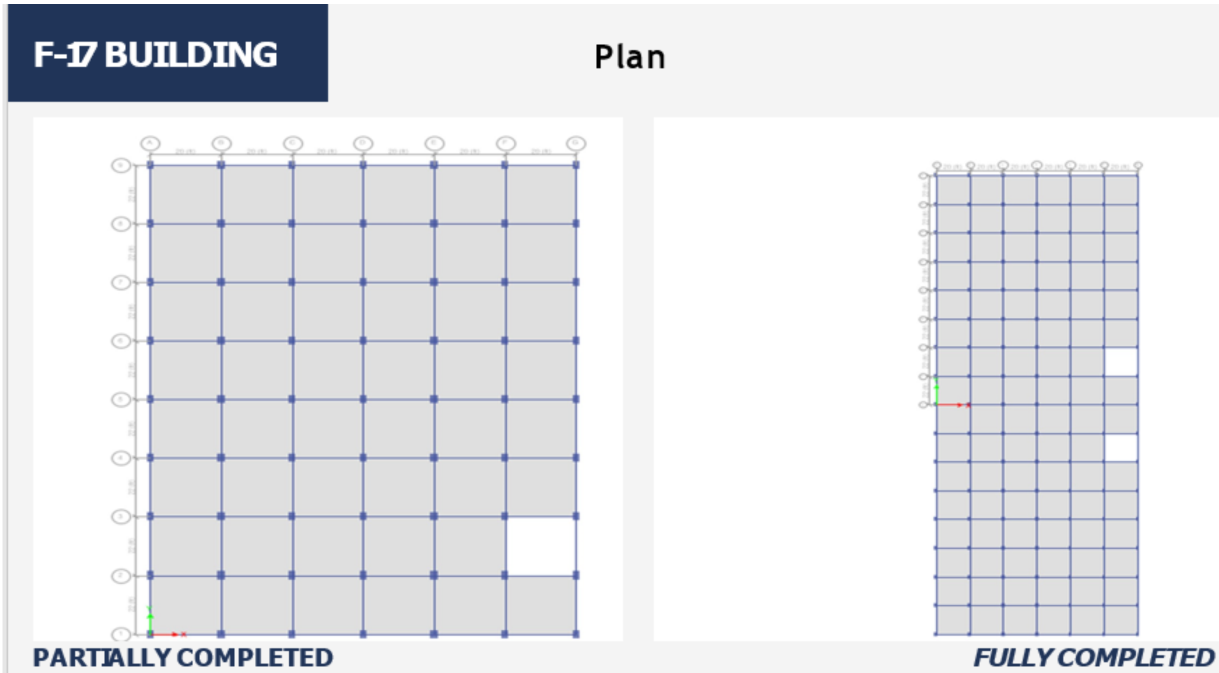


Figure 5-3

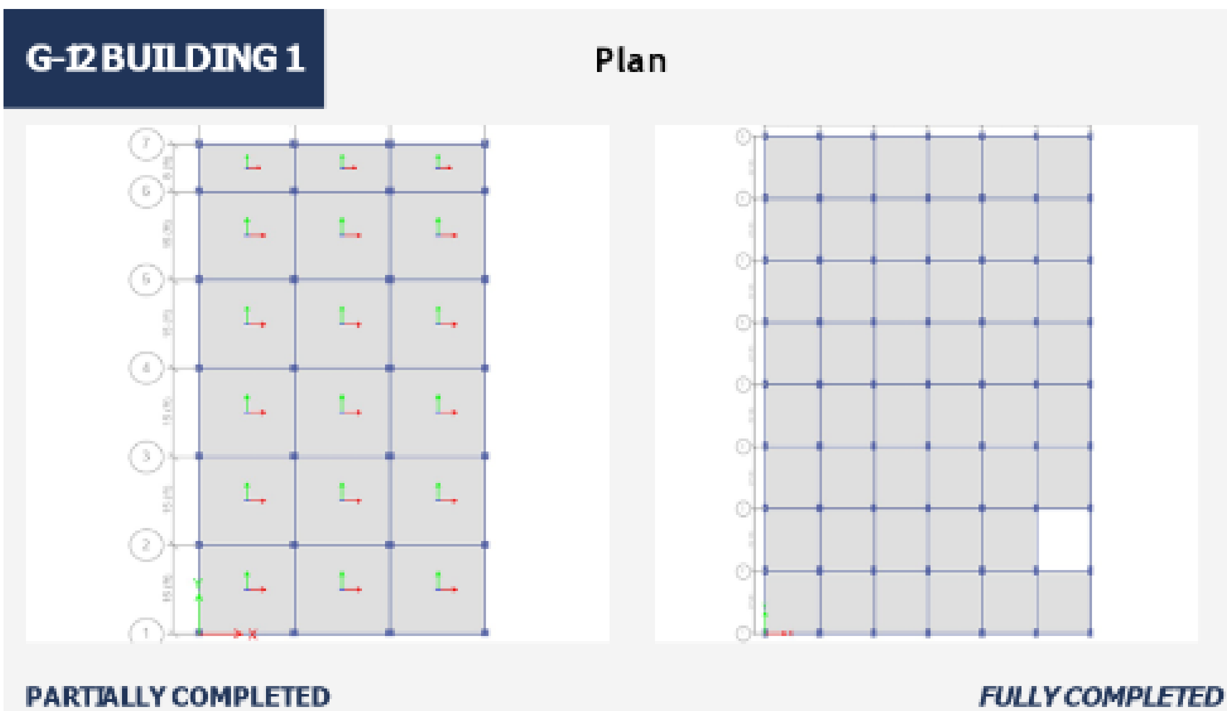


Figure 5-4

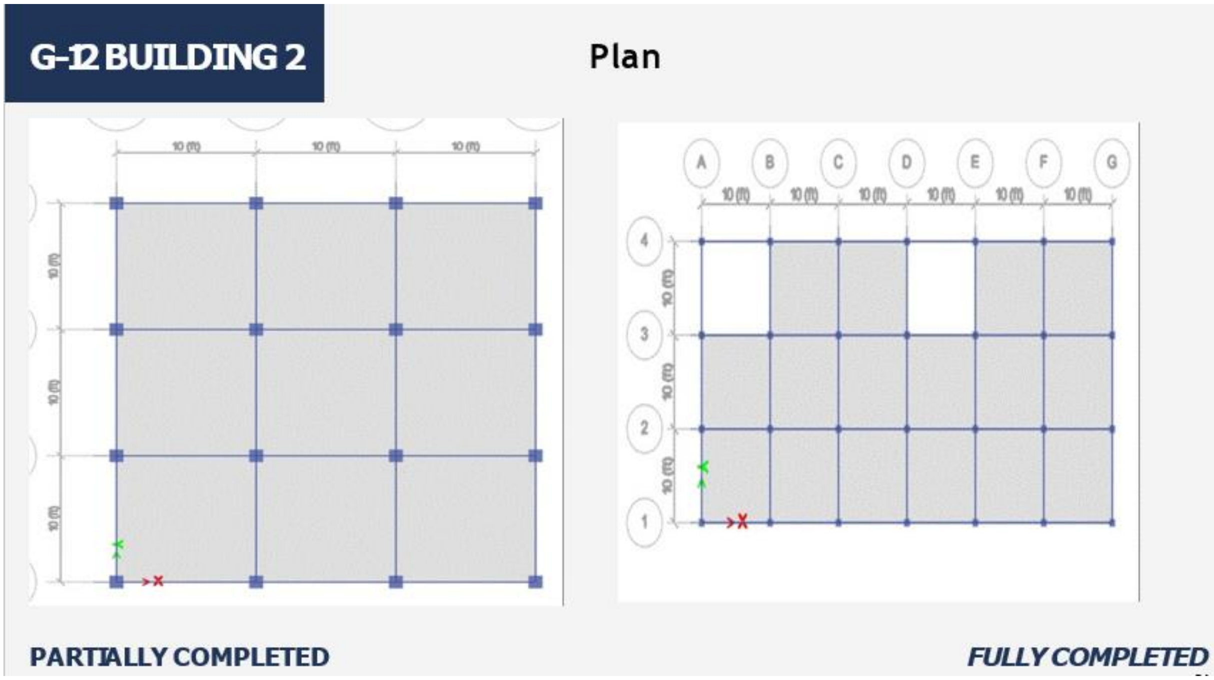


Figure 5-5

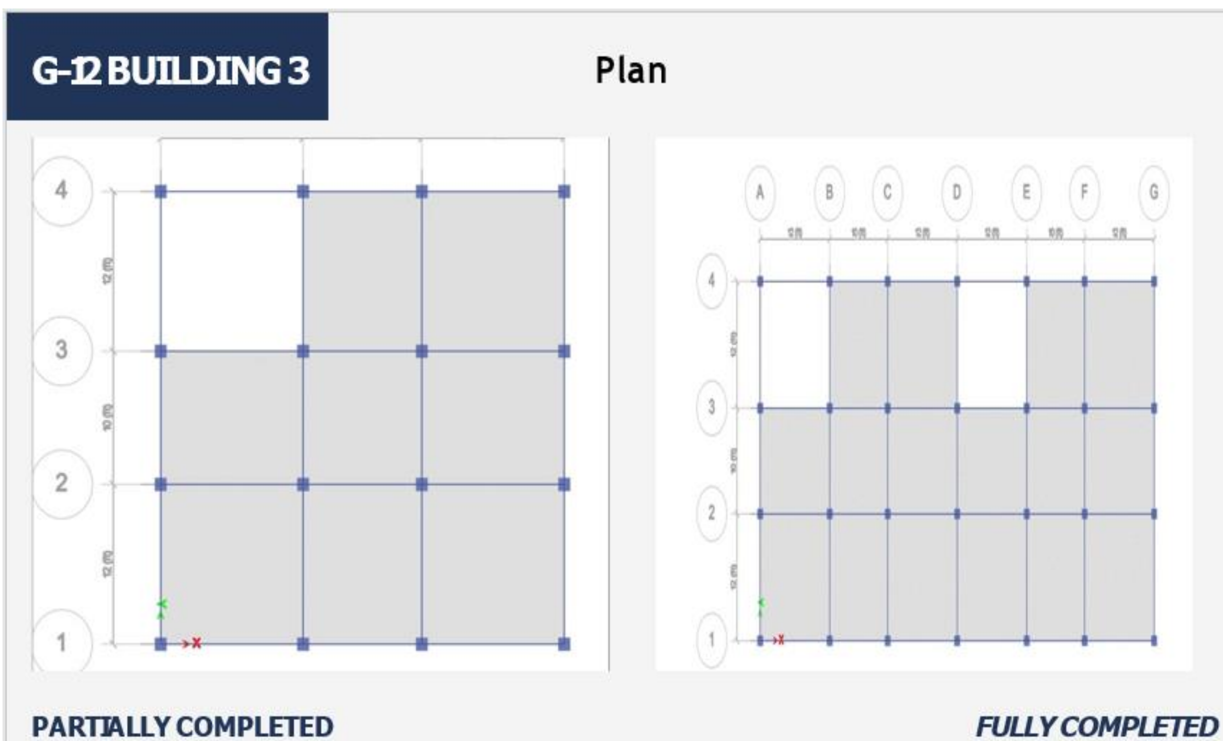


Figure 5-6

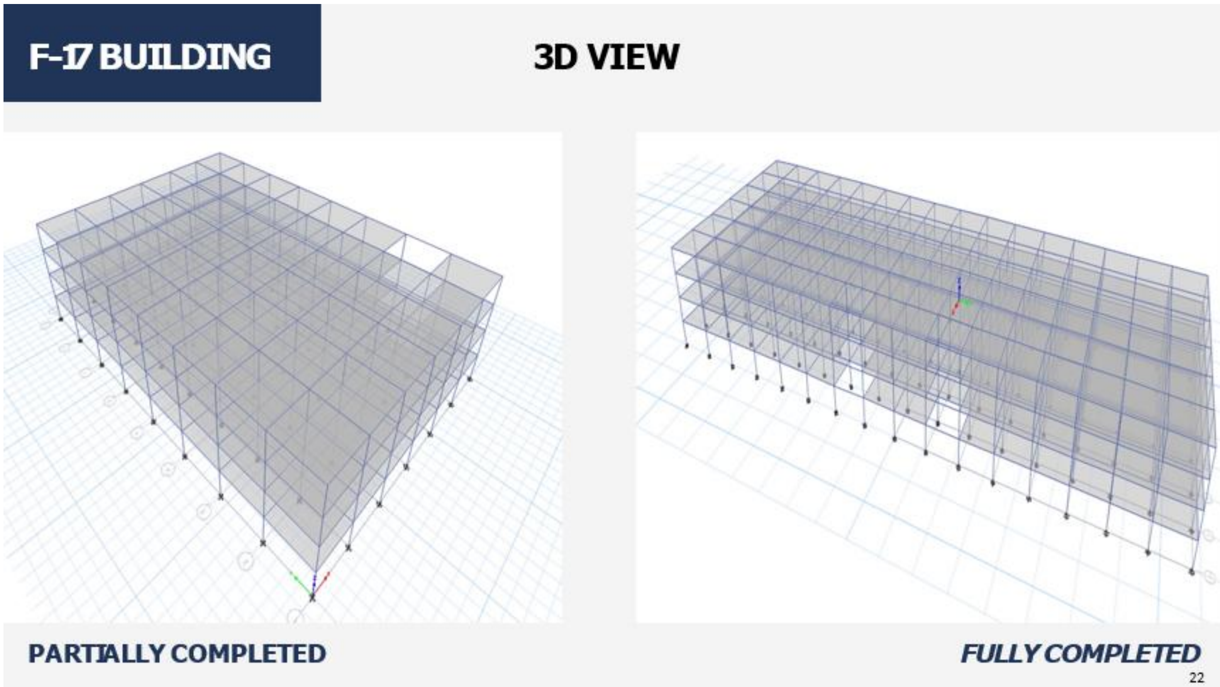


Figure 5-7

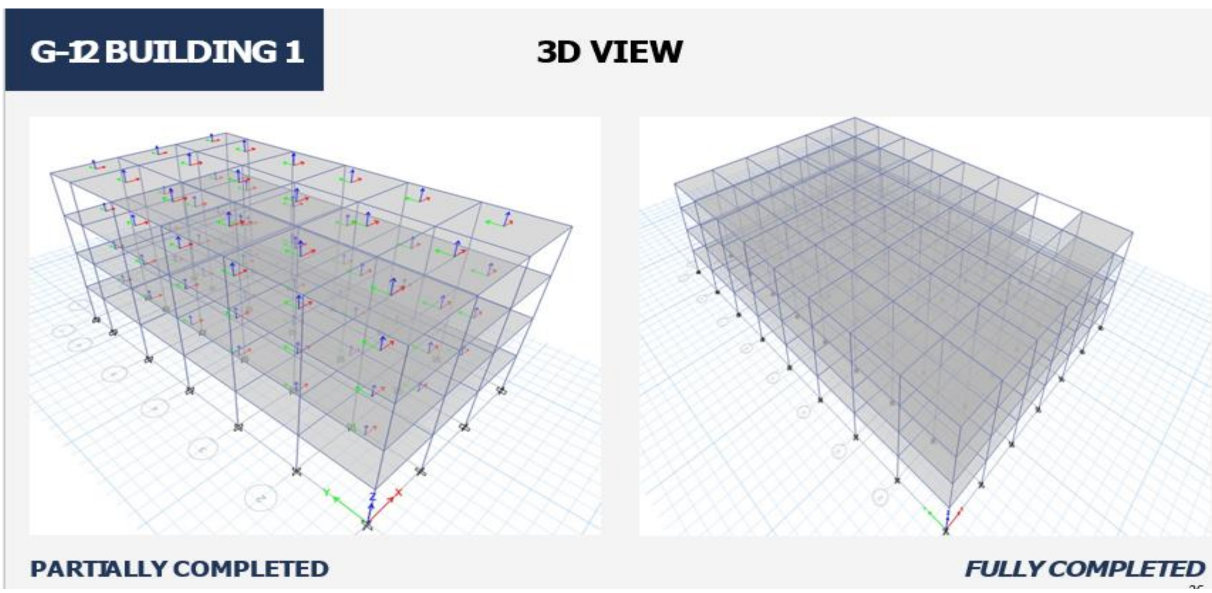


Figure 5-8

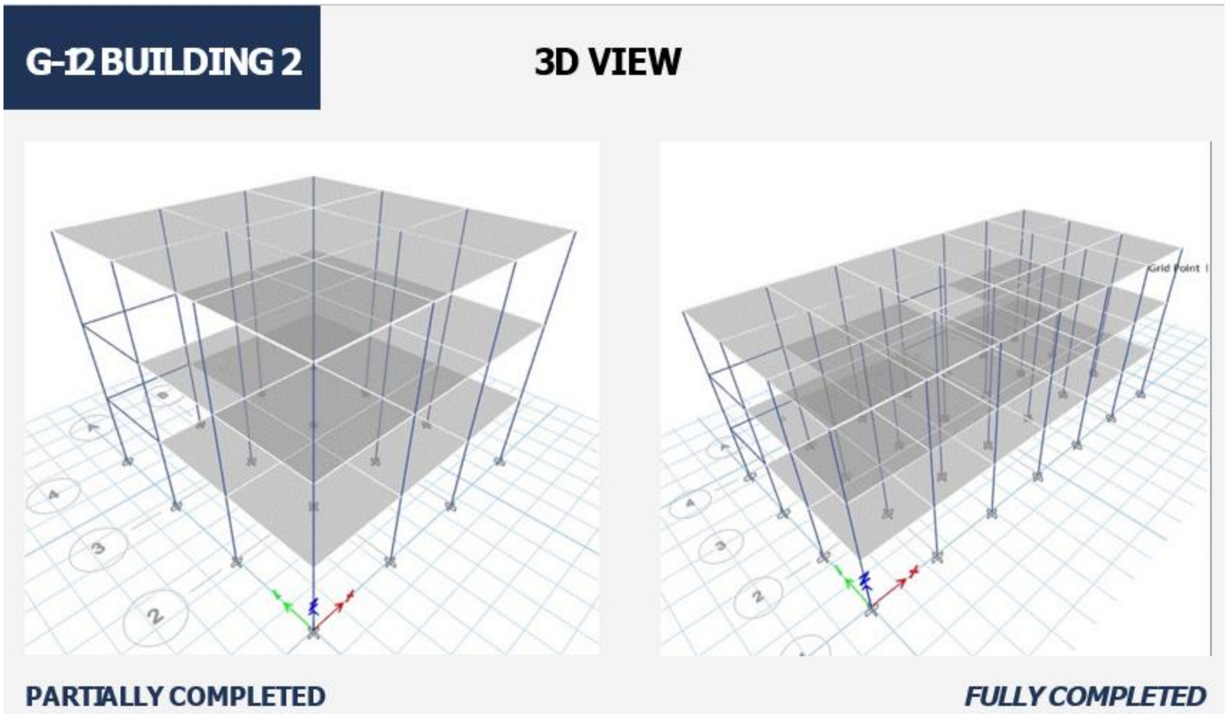


Figure 5-9

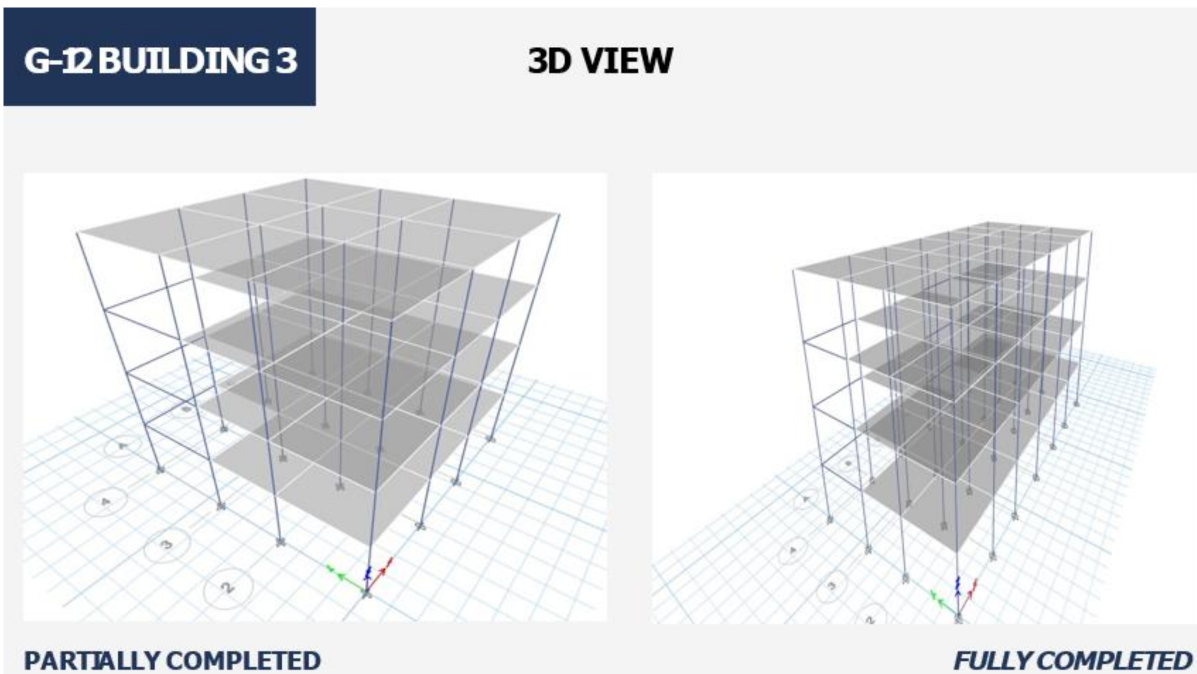


Figure 5-10

5.3.Gravity design of Structures

Sections and slabs were designed in ETABS on basis of ASCE 7-16 code. After analyzing the structure under gravity loads concrete design (check of sections) was started. Passing of the structure under gravity loading means that the structure must be safe within the allowable limits under gravity loading. By gravity loading it is meant that load acting due to force of gravity that is the vertical forces. Gravity load includes the weight of the structure itself, human and other things occupancy load and snow load imposed on the structure.

Chapter 6

6.1. Pushover Analysis

Pushover analysis is a procedure through which seismic structural deformations are estimated through a simplified nonlinear static procedure. Structure is subjected to lateral loads which are monotonically increased until the point of target displacement is reached. A mathematical model of building is generated which includes load-deformation curves of all the lateral force resisting elements. Initially, gravity loads are applied and then a predefined lateral load pattern is applied which is distributed along the building height.

It is nonlinear static analysis method in which gravity and displacement controlled lateral loads are applied which are increased step by step until the structure ceases to resist and fails.

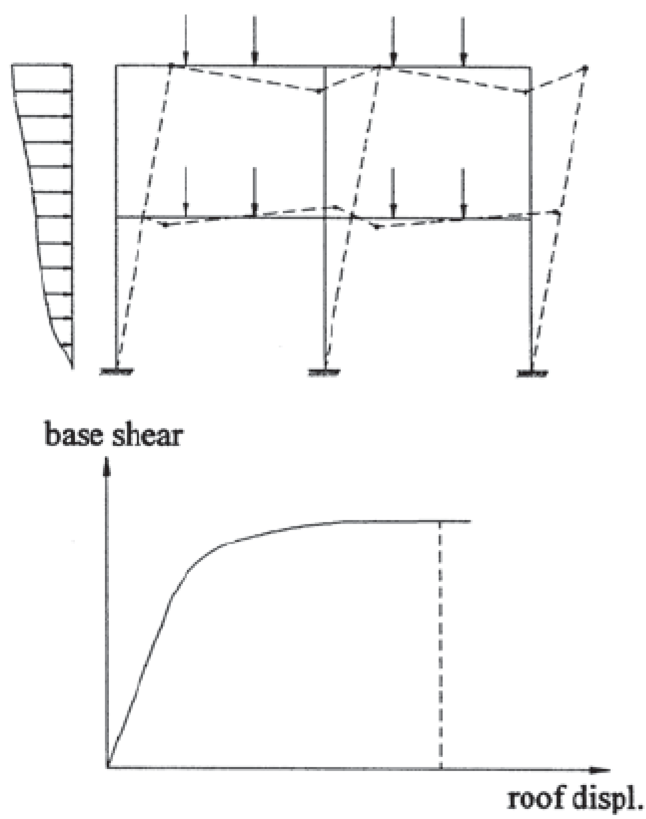


Figure 6-1

Plastic hinge approach was used. CSI ETABS 2018 built in plastic hinges were used in the structure. In frame structure, P-M2-M3 hinges were defined for columns and M3 hinges were defined for the beams.

6.2. Types of Pushover Analysis

There are two types of pushover analysis:

- Force Controlled method
- Displacement control method

In Force controlled method, the loading is known while in Displacement controlled method the applied displacement in known while the loading is unknown. Different loads are applied on the structure to get different displacement until a specific target displacement is reached and the structure fails at this target displacement. Generally, displacement of slab is considered control displacement. At a specific displacement, Internal forces and deformations give inelastic strength and displacement demand which are used to find a performance point. For gravity loading, force-based method is used and for earthquake loading displacement-controlled method is used.

6.3. Limitations of Pushover Analysis

Though for elastic analysis techniques pushover analysis has its advantages. But it has some limitations that must be identified for better results. The selection of transverse loading patterns, approximation of target displacement and failure due to greater modes of vibration are a specific problem that are a reason of inaccurate results produced by pushover analysis. The properties of equivalent SDOF system are obtained by shape vector demonstrating the deformed shape of MDOF system. With the amplitude of seismic loading and time the distribution of inertia forces differs but in pushover analysis throughout similar transverse loading pattern is used. The product of story mass and displacement obtained by shape vector is directly proportional transverse loading pattern obtained through pushover analysis. Generally uniform, elastic force mode, code distributed and a single transverse loading at the top of structure are used as transverse loading patterns. Due to middle and upper story mechanism triggered by higher mode effects, the similar throughout lateral loading pattern cannot expect possible failure means. If higher mode effects are not insignificant, constant loading pattern can provide better estimates. These limitations have led many limitations to recommend adaptive loading patterns which consider the variation in inertial forces with level of inelasticity, But the adaptive loading pattern make the pushover analysis conceptually complex and computationally challenging.

6.4. Input parameters of pushover analysis

For pushover analysis, plastic hinge approach was used. Plastic hinges can be assigned to beams, columns, and shear walls at any location and in both x and y directions. Hinges can be defined for moment M2 and M3, torsion T, shear force V2 and V3 and axial force P. For columns, there is a coupled P-M2-M3 hinge for axial load changes under lateral loading which yields based on interaction of bending moment and axial force at hinge location. Three types of hinge properties are considered by ETABS. More than one type of hinge can be assigned at a point. The default built in hinge properties are assigned using the ASCE 41-17 code for concrete and steel members. We have defined the default hinges based on ASCE 41-17. For beams, we have assigned hinges at a relative distance of 0.1 and 0.9. For columns we have assigned hinge only on base. Then the hinge overwrites were also given. For checking the formation of hinges at different level hinge assignment step is also necessary. Different performance levels are shown by hinges which are as follows:

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

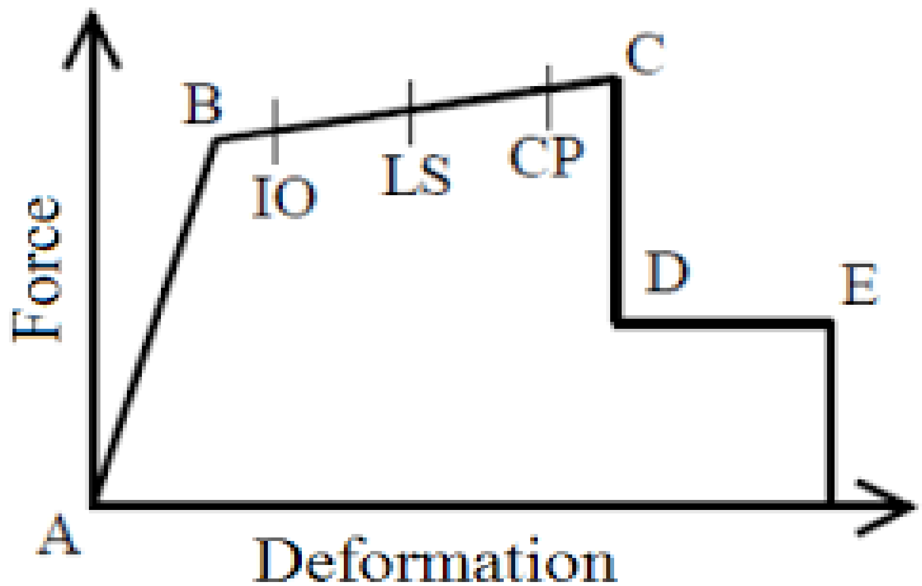


Figure 6-2

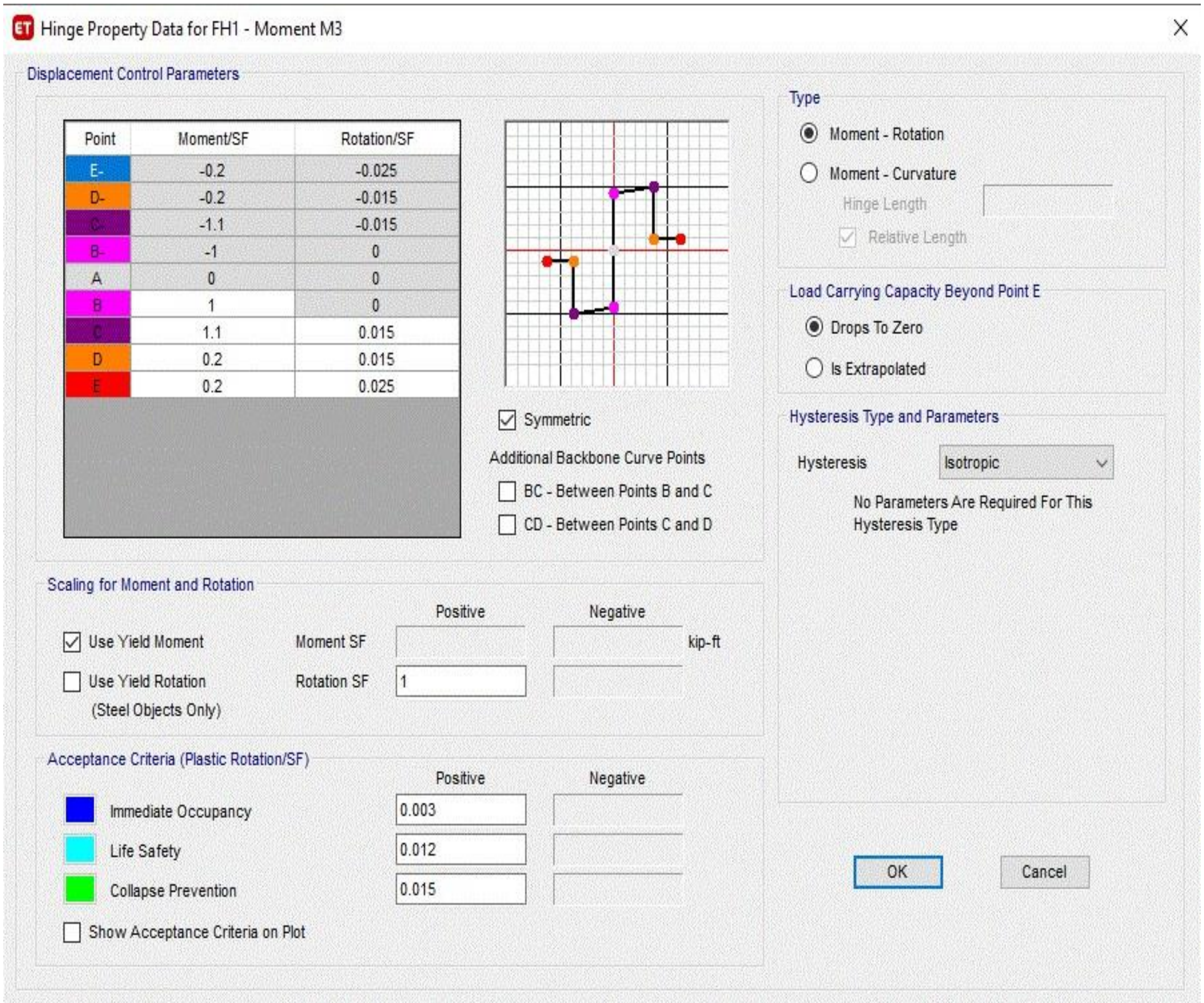

Hinge Property Data for FH1 - Moment M3
Displacement Control Parameters
Point | Moment/SF | Rotation/SF
E- | -0.2 | -0.025
D- | -0.2 | -0.015
C- | -1.1 | -0.015
B- | -1 | 0
A | 0 | 0
B | 1 | 0
C | 1.1 | 0.015
D | 0.2 | 0.015
E | 0.2 | 0.025
Symmetric
Additional Backbone Curve Points
BC - Between Points B and C
CD - Between Points C and D
Type
Moment - Rotation
Moment - Curvature
Hinge Length
Relative Length
Load Carrying Capacity Beyond Point E
Drops To Zero
Is Extrapolated
Hysteresis Type and Parameters
Hysteresis
Isotropic
No Parameters Are Required For This Hysteresis Type
Scaling for Moment and Rotation
Positive
Negative
Use Yield Moment
Moment SF
kip-ft
Use Yield Rotation
(Steel Objects Only)
Rotation SF
1
Acceptance Criteria (Plastic Rotation/SF)
Positive
Negative
Immediate Occupancy
0.003
Life Safety
0.012
Collapse Prevention
0.015
Show Acceptance Criteria on Plot
OK
Cancel

Figure 6-3

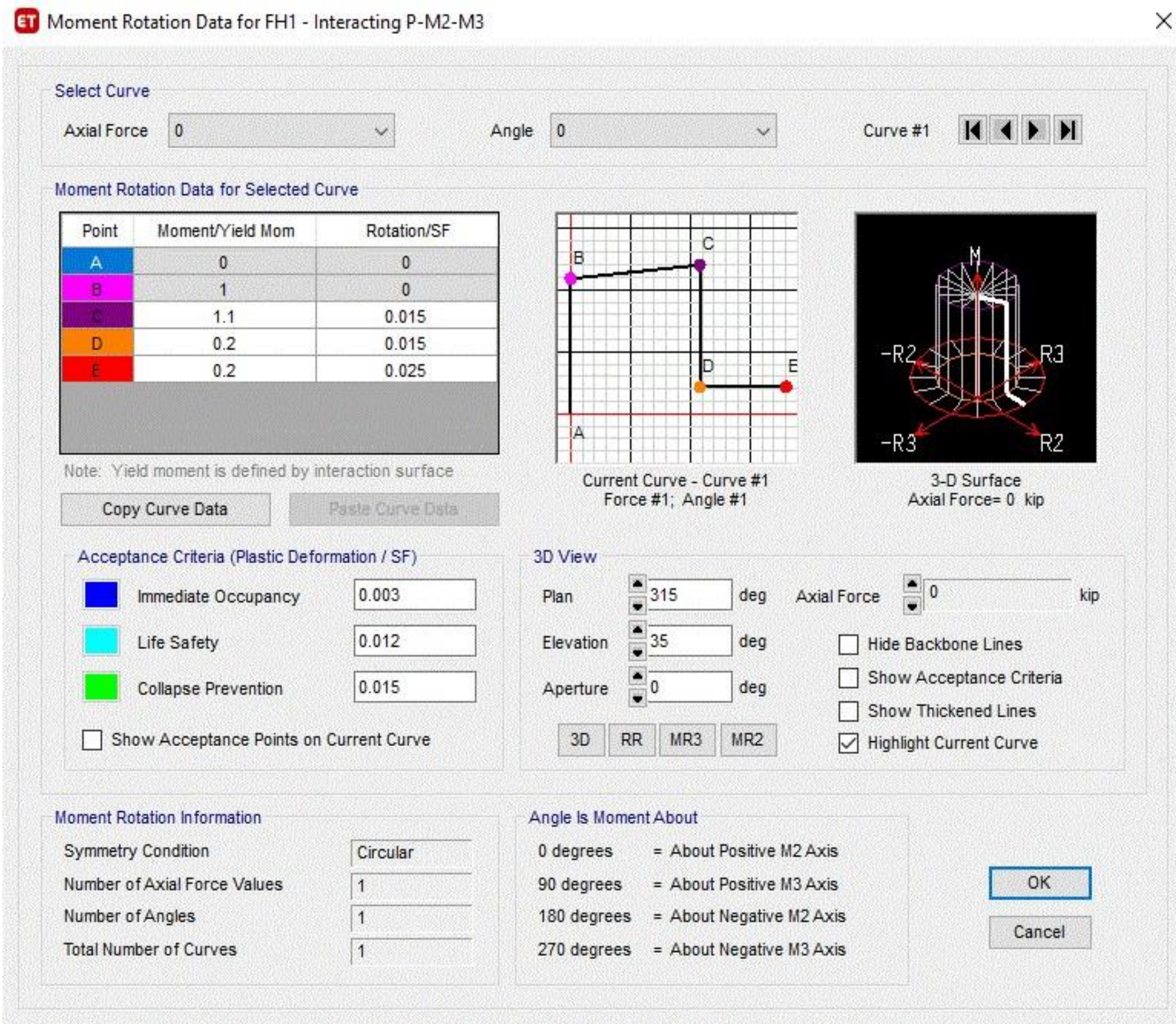


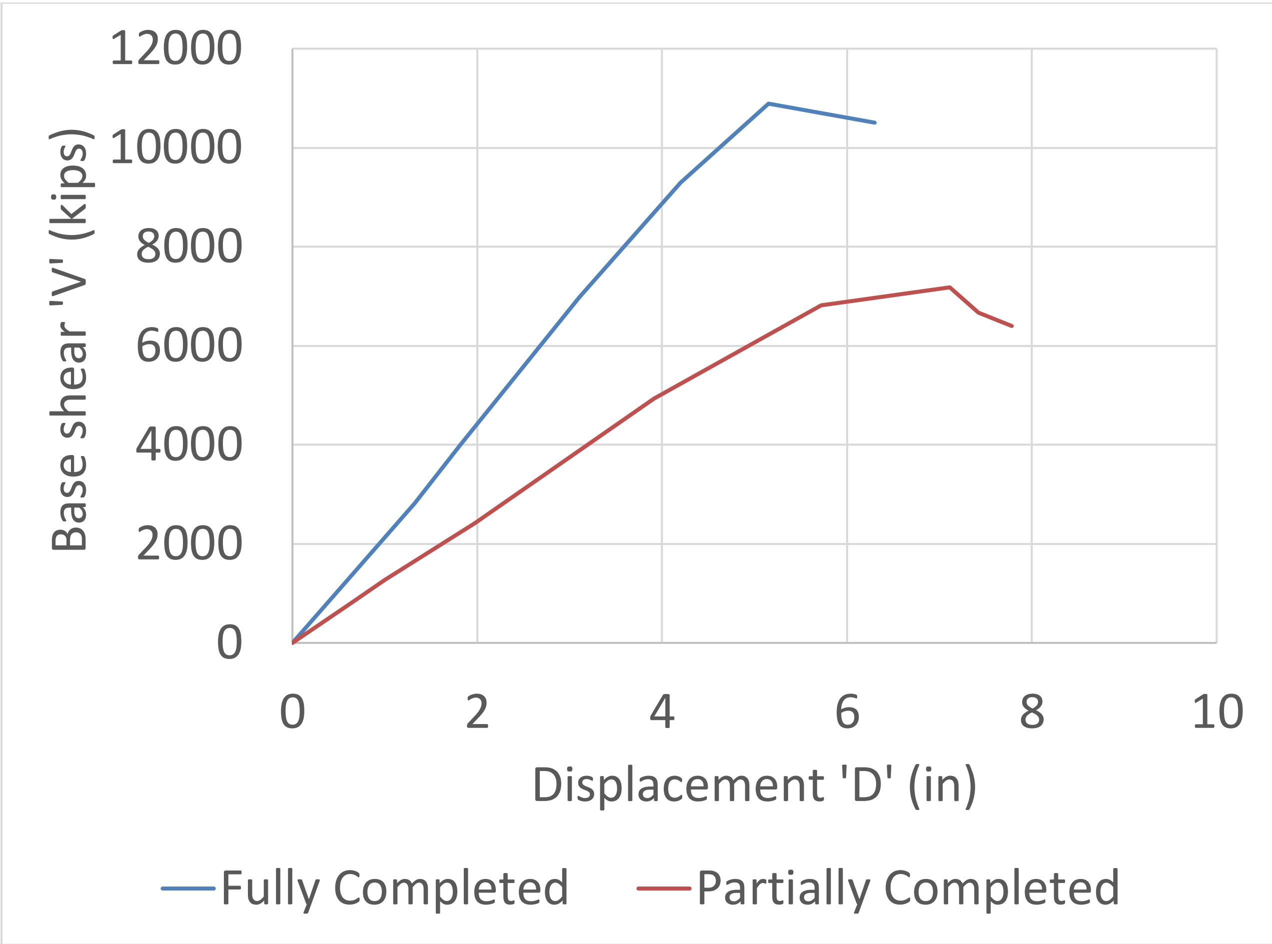
Figure 6-4

6.5. Pushover Analysis Results

Pushover analysis gave result in the form of pushover curve. We used curves for load case PAX AND PAY. Curve from vulnerable side is used. We added two types of pushover curves. One is base shear V vs displacement d curve, and the other is spectral acceleration Sa vs spectral displacement Sd. The pushover analysis was performed both partially and completed models. The partially completed buildings displaced more and resisted less base shear than completed buildings. In terms of spectral acceleration and spectral displacement, the partially completed building gave more spectral displacement and resisted less spectral acceleration. The curves for base shear vs displacement and spectral acceleration vs spectral displacement are as follows:

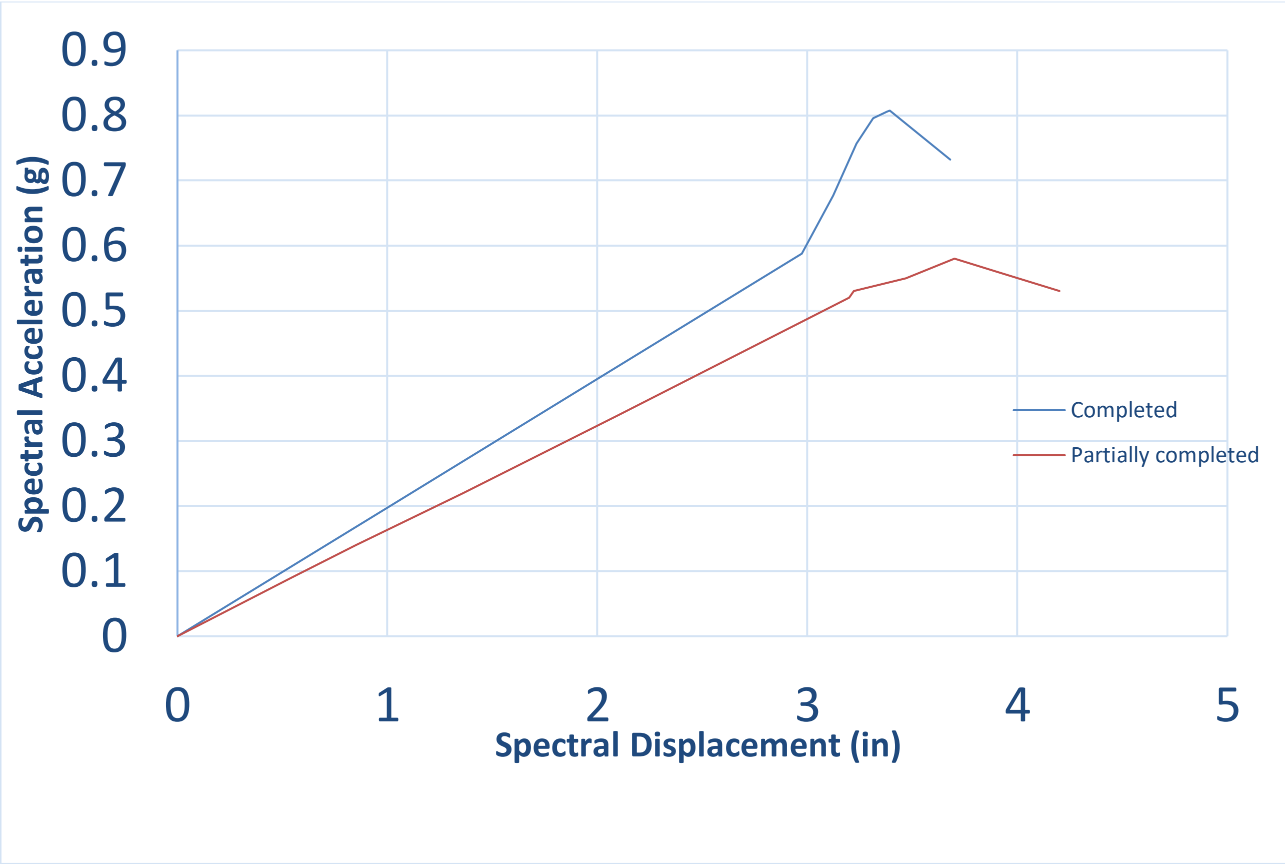
F-17 Building

Base Shear vs Displacement



The orange line shows the curve for partially completed building and the blue line shows the curve for completed building. As you can see the completed building resist more base shear and has less displacement then partially completed building. Which shows that partially completed building is more vulnerable than the completed building. Though the partially completed show more displacement and is ductile but still it is more vulnerable because it resists less base shear.

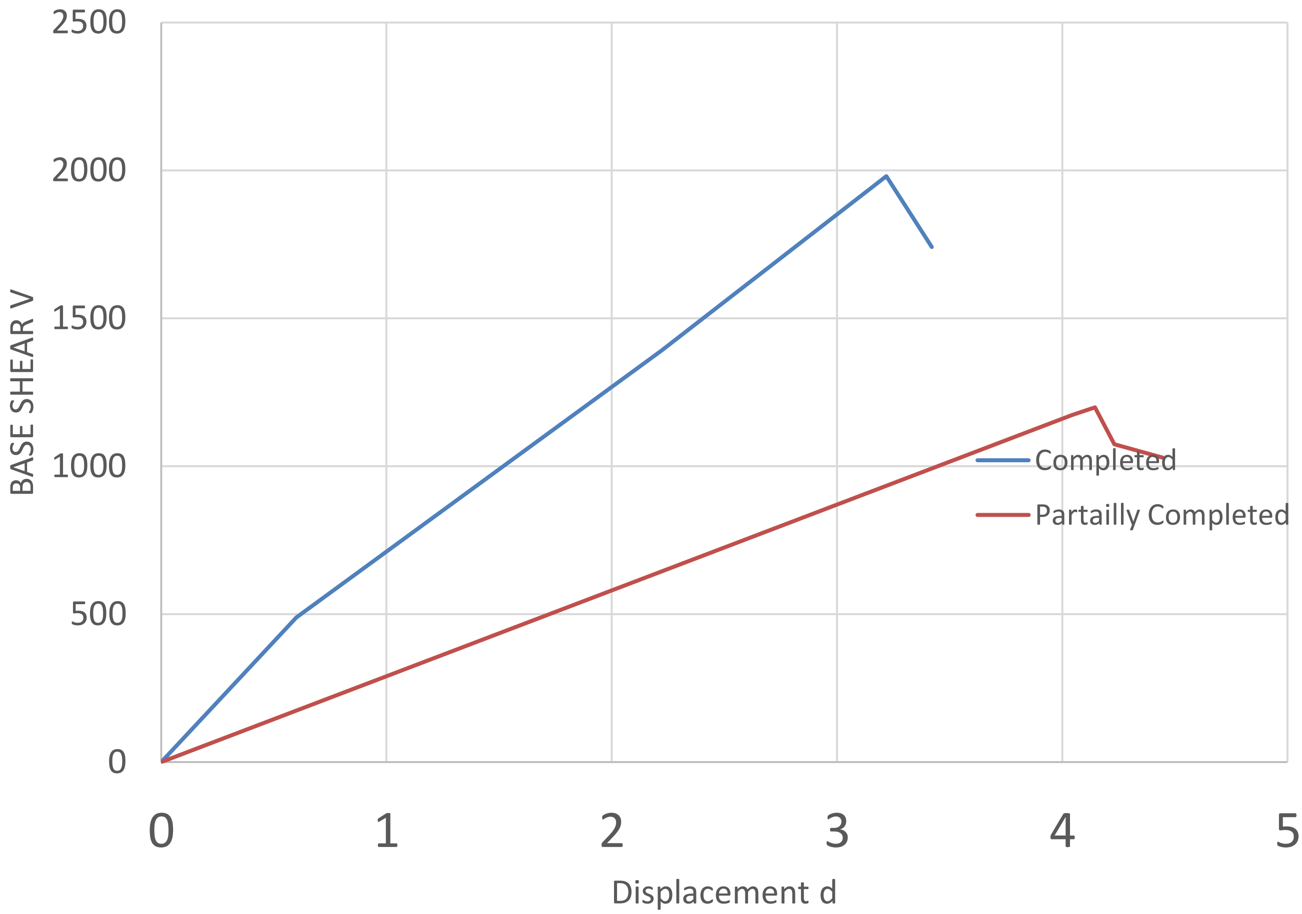
Spectral acceleration vs Spectral displacement



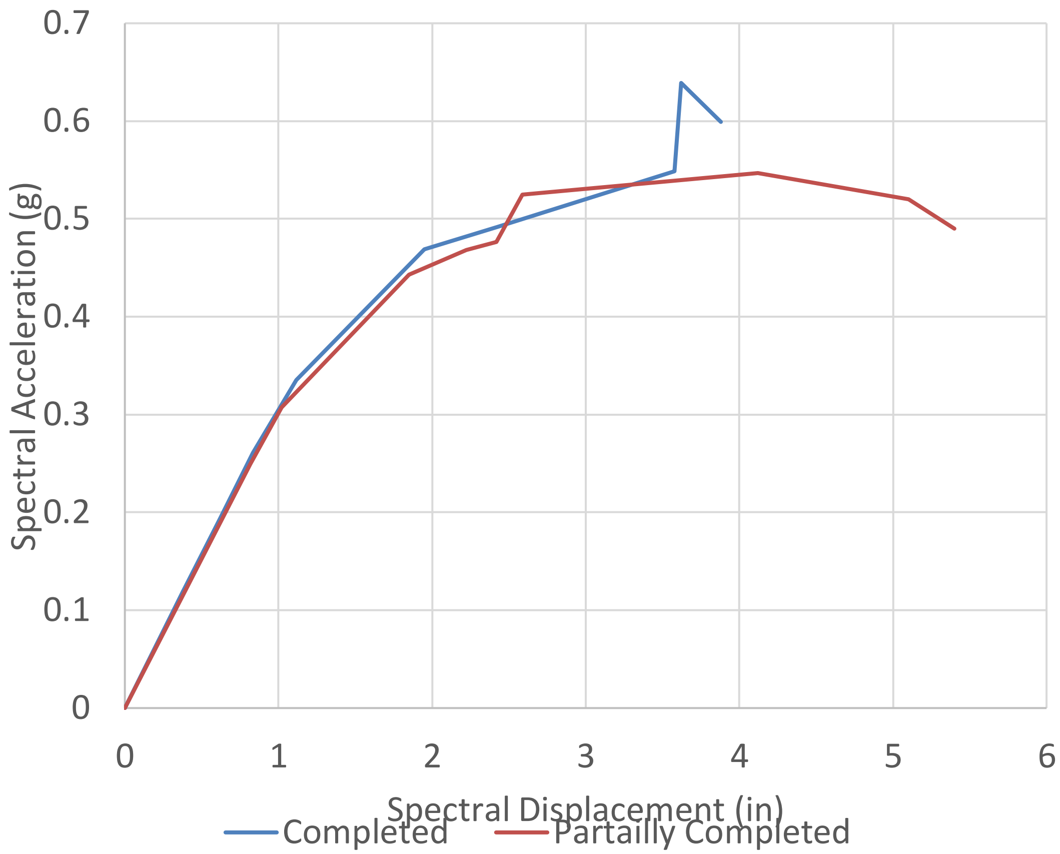
The orange line shows the curve for partially completed building and the blue line shows the curve for completed building. As you can see the completed building resist more spectral acceleration and has less spectral displacement then partially completed building. Which shows that partially completed building is more vulnerable than the completed building. Though the partially completed show more spectral displacement and is ductile but still it is more vulnerable because it resists less spectral acceleration.

G-12 Building 1

Base shear vs Displacement



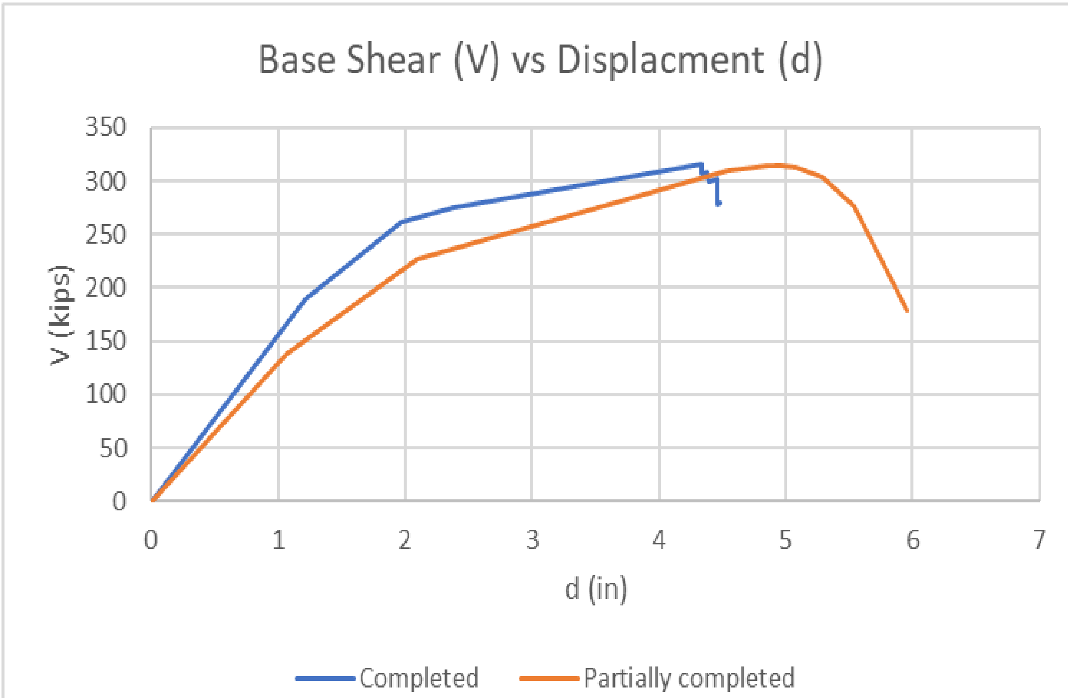
Spectral acceleration vs Spectral displacement



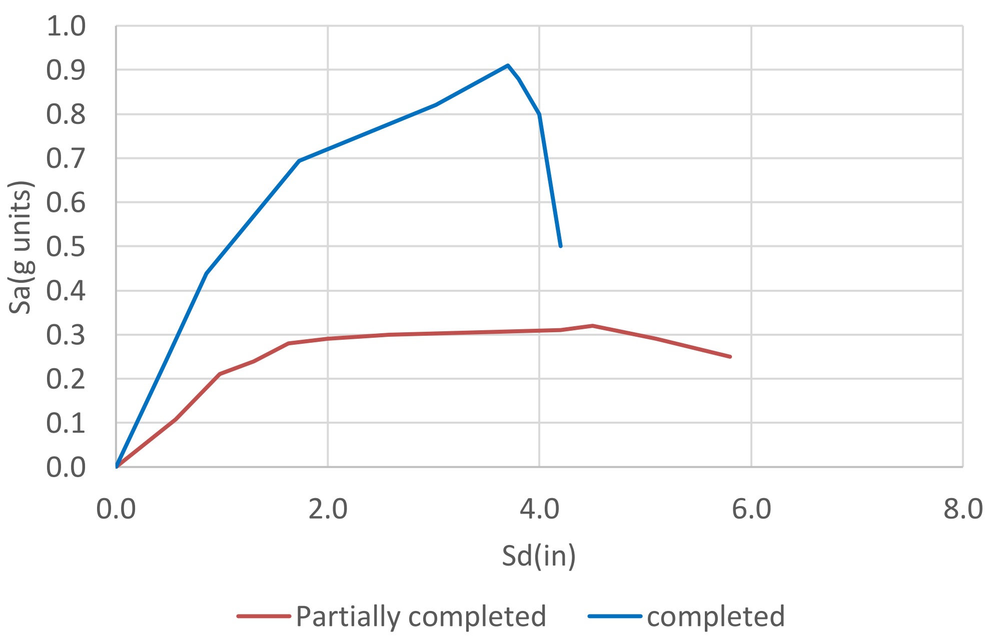
Similarly, the G-12 building gives the same result as F-17. As you can see the partially completed building is more vulnerable than the completed one.

G-12 Building 2

Base shear vs Displacement

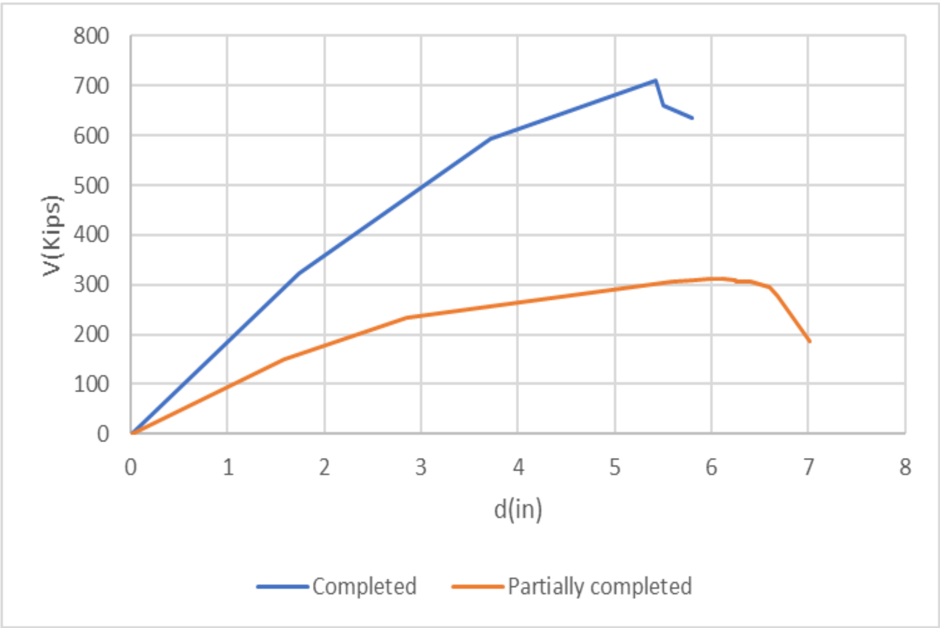


Spectral acceleration vs Spectral displacement

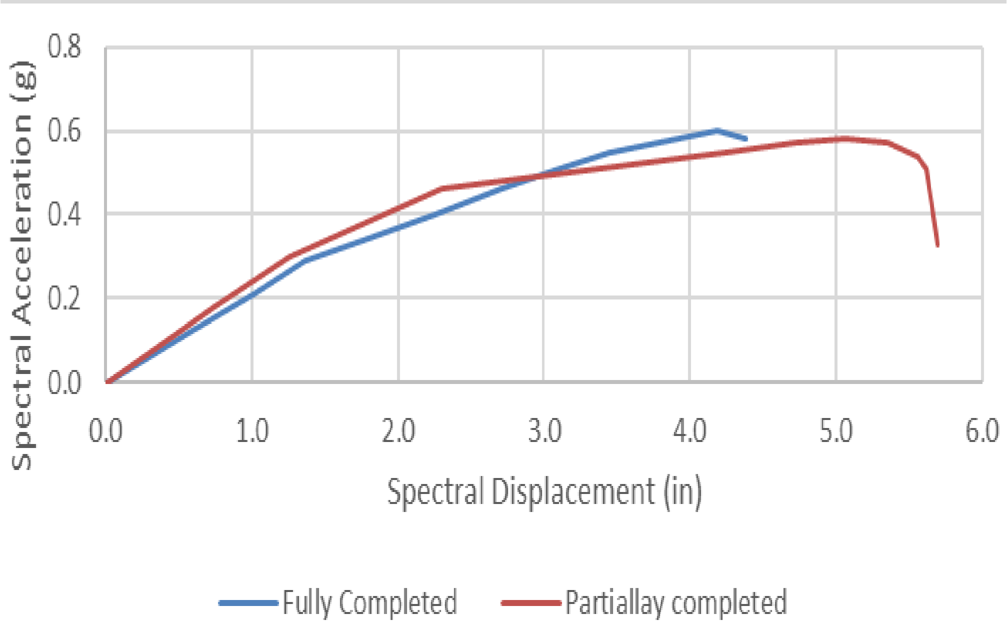


G-12 Building 3

Base shear vs Displacement



Spectral acceleration vs Spectral displacement



Chapter 7

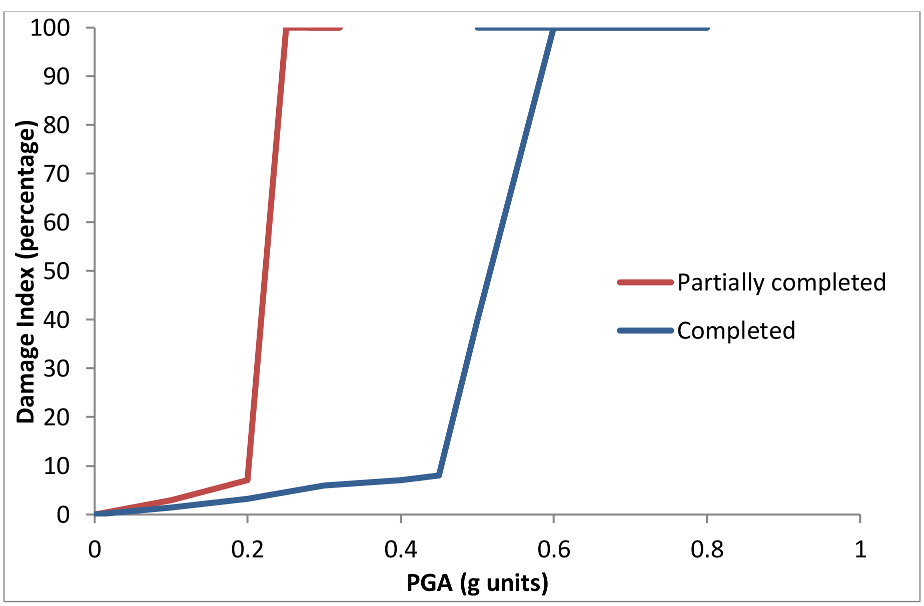
7.1. Capacity spectrum method

Capacity spectrum method is an approximate method which helps to describe efficiently the seismic performance of the structure and helps to analyze the seismic response of structure in terms of forces and displacement. Thus, the capacity spectrum method helps to analyze the seismic response of structure with a nonlinear static procedure. We get a pushover from pushover analysis which is taken as capacity curve. Both the capacity and demand curves are plotted. The point where both curves meet is called performance point. There are many variations of capacity spectrum method. We performed capacity spectrum method on excel sheet. The capacity spectrum gave the performance of structure at each point of the pushover curve and gave results in the form of Peak ground acceleration (PGA) vs Damage index (DI).

ss7.2. Capacity spectrum method Results

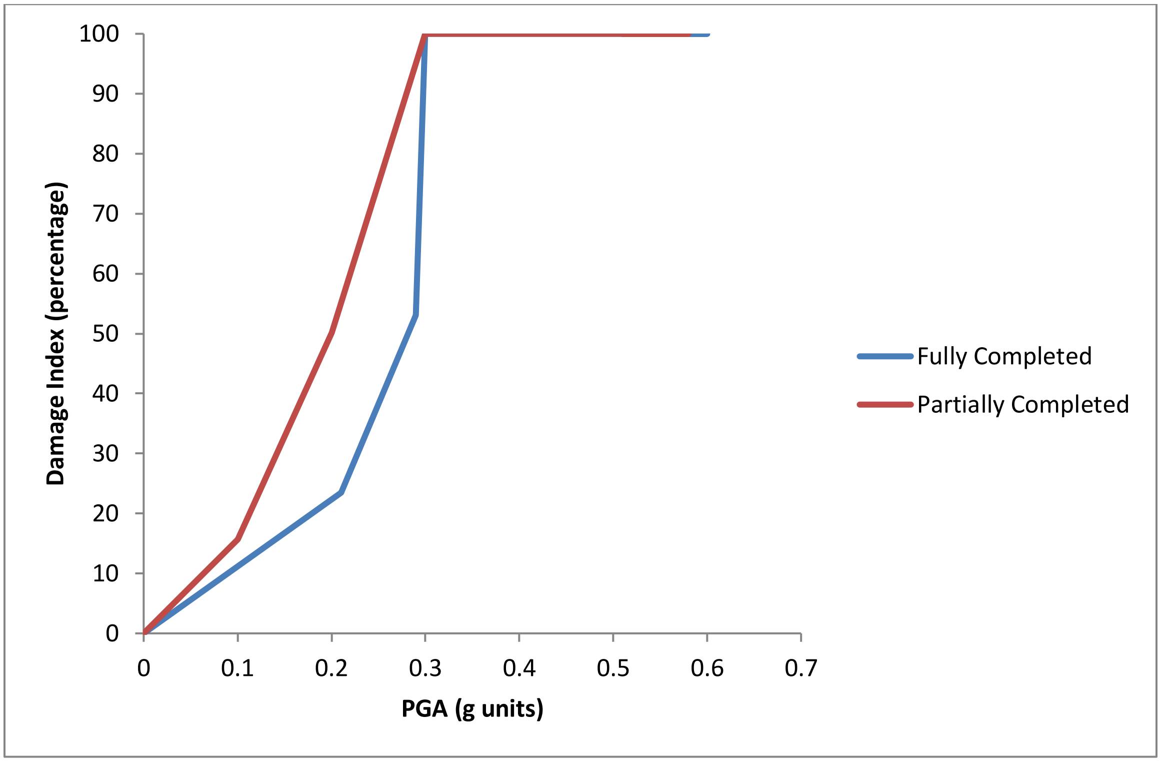
G-12 building 2

PGA VS DI



The orange line shows the result of partially completed building and blue line shows the result of completed building. Partially completed building has more damage at a specific PGA. So, it confirms that partially completed model is vulnerable than completed one.

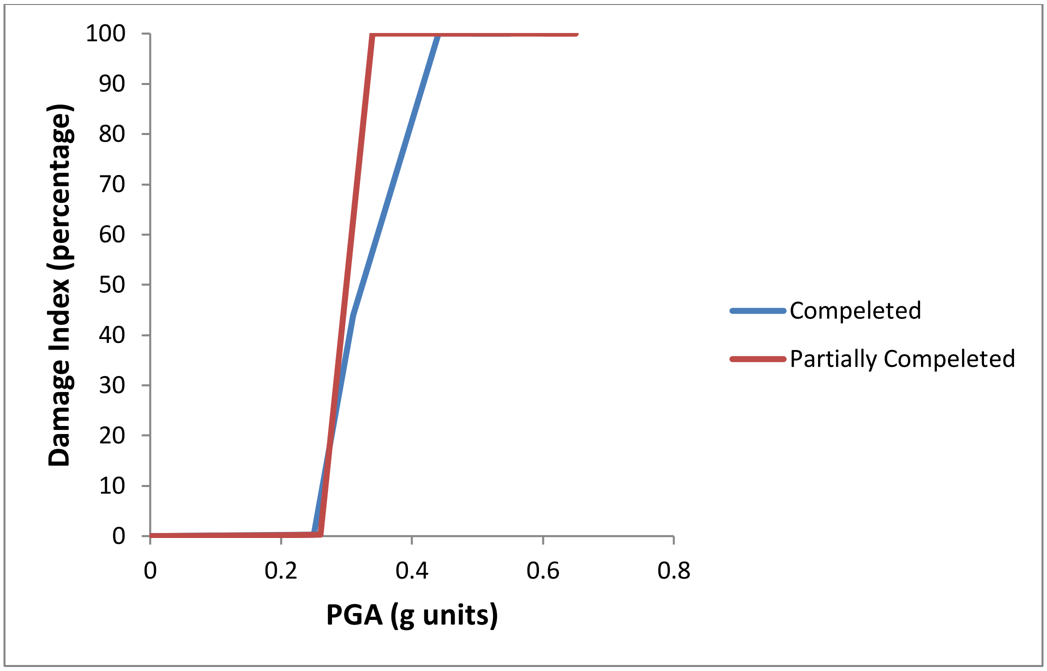
G-12 building 3



Here again for G-12 building 3 the result is same. Partially completed buildings are vulnerable than completed.

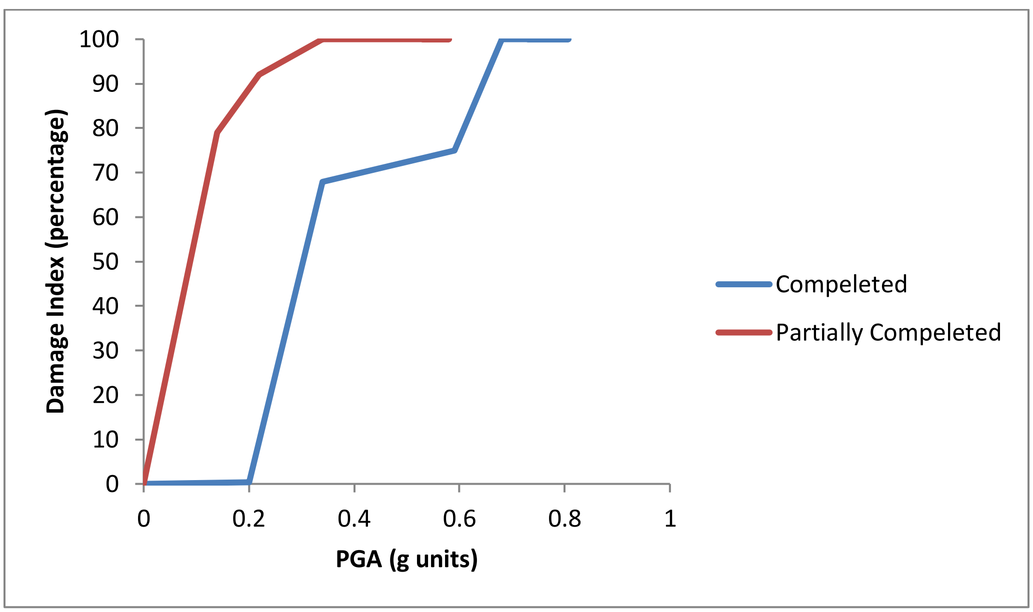
G-12 Building 1

PGA VS DI



F-17 Building

PGA vs DI



Chapter 8

8. Conclusion and Recommendation

8.1 Conclusion

The results from FEMA-154 show that:

Building Name	FEMA SCORE (MODERATLY HIGH)	FEMA SCORE (HIGH)	Damage classification
F-17 Building	3	2.9	D1-D2
G-12 Building 1	1.3	1	D2-D3
G-12 Building 2	3.6	3.4	D0-D1
G-12 Building 3	3	2.9	D1-D2

These results conclude that the G-12 building 1 is the most vulnerable building among the given building. But FEMA-154 doesn't give detailed and accurate results. They don't give results in terms of seismicity parameters. These results just give rough idea so vulnerability assessment should be done by analytical methods.

The results from pushover analysis and capacity spectrum method show that:

Building Name	PGA at 100% Damage Index (DI)	Building Name	PGA at 100% Damage Index (DI)
F-17 Building (Partially completed)	0.35 g	**G-12 Building 2 (Partially completed)**	0.25 g
F-17 Building (Completed)	0.68 g	**G-12 Building2 (Completed)**	0.6 g
G-12 building 1 (Partially completed)	0.34 g	**G-12 building 3 (Partially completed)**	0.28 g
G-12 building 1 (Completed)	0.47 g	**G-12 building 3 (Completed)**	0.3 g

The results from the table show that partially completed fail at a lesser PGA than the completed building. So, partially completed Building is more vulnerable than the completed building and take more damage at a lesser PGA.

From the results of Pushover analysis, we conclude that:

- Partially completed displace more than completed building so they are more ductile and fully completed buildings are more brittle.
- Partially completed building take more damage at a specific PGA so they are more vulnerable than completed one.
- So, vulnerability assessment of partially completed buildings should be necessary.
- Analytical methods of vulnerability assessment give more detailed, accurate, and meaning full results than the empirical methods.
- So empirical methods should only be used for rough estimate before detailed modelling.

8.2. Recommendation

In future, vulnerability assessment could be done for building which are unsymmetrical, have complicated designs, have much greater heights and stories more than 4. Other recommendation is that dynamic analysis could be performed like response spectrum and Time history analysis.

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