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INSTITUTE OF GRADUATE STUDIES

NONLINEAR BEHAVIOR OF 3D IRREGULAR RCC STRUCTURES

Masters of Applied Science Thesis

WALEED MOHAMMADI

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Department: Civil Engineering

Program: Structural Engineering

Supervisor: Prof. Dr. HÜSEYİN FARUK KARADOĞAN

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Dr. Öğr. Üyesi Erdal Coşkun

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APRIL 2021

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In the name of ALLA, the most gracious and the most merciful

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ABSTRACT

Earthquakes are very common in every part of the world which is very dangerous and unpredictable forces in the nature. Resisting of structures against seismic forces are always an area of concern and requires special attention from structural designers. Recently most of the architects are trying to make very complicated plan of buildings. So in this case irregularity in plan and elevation may exist, Therefore, plan and vertical irregularities further complicates the seismic behavior of the structures and also make the structures more vulnerable to seismic forces. Therefore, to resist the structures from the severe motions many analysis methods were developed. Pushover analysis which is nonlinear static analysis is an important method in term of determining the capacity of existing and new structure and the seismic vulnerability of structures.

This research paper deals with nonlinear static analysis (pushover analysis), buckling analysis and p-delta analysis of 3, 9 and 15 story irregular RCC buildings which are located in zone IV. ETABS2016 software is used to perform the analysis. IS 456:2000 and IS1893 part 1 are used for design of structural members and calculation of earthquake load.

From result of pushover analysis for all three structures, a pushover curve for each structure generated which include capacity spectrum, demand spectrum and performance point. The obtained pushover curves describe the global behavior of structures individually. A table also generated from result of pushover analysis which represent the coordinates of each step of the pushover curve and explain in detail the number of hinges formed in each step of pushover analysis at different state (for example, between IO, LS, CP, or between B, C, D and E).

Seismic load induces lateral load which cause lateral displacement of structures. The effect of gravity load on the laterally displaced structure which is known as P-delta effect also considered in this study. From the result of analysis, it is observed that the effect of geometric nonlinearity is more for high rise buildings as compare to low rise buildings. Due to applying lateral load to the structures and performing nonlinear static analysis, the crack appeared (plastic hinges form) at different part of structural elements which reduce the stiffness of structural members and effect on buckling safety. From result of buckling analysis for 2D frame it is obvious that the buckling safety decrease when formation of plastic hinges increase at the end of structural members.

Keywords - Capacity curve, Demand curve, Pushover analysis, performance level, buckling safety, geometric nonlinearity and the Status of formed hinges.

ÖZET

Doğada çok tehlikeli ve öngörülemeyen kuvvetler olan depremler dünyanın her yerinde çok yaygındır. Yapıların sismik kuvvetlere karşı direnci her zaman bir endişe konusudur ve yapı tasarımcılarının özel ilgi göstermesini gerektirir. Son zamanlarda mimarların çoğu çok karmaşık bina planları yapmaya çalışıyor. Dolayısıyla bu durumda planda ve kotta düzensizlik olabilir, Bu nedenle plan ve düşey düzensizlikler yapıların sismik davranışını daha da karmaşık hale getirir ve ayrıca yapıları sismik kuvvetlere karşı daha savunmasız hale getirir. Bu nedenle, yapıları şiddetli hareketlerden korumak için birçok analiz yöntemi geliştirilmiştir. Doğrusal olmayan statik analiz olan itme analizi, mevcut ve yeni yapının kapasitesini ve yapıların depreme karşı kırılganlığını belirlemesi açısından önemli bir yöntemdir.

Bu araştırma makalesi, IV. bölgede yer alan 3, 9 ve 15 katlı düzensiz RCC binaların doğrusal olmayan statik analizi (pushover analizi), burkulma analizi ve p-delta analizi ile ilgilidir. Analizi gerçekleştirmek için ETABS2016 yazılımı kullanılmıştır. IS 456:2000 ve IS1893 bölüm 1, yapı elemanlarının tasarımı ve deprem yükünün hesaplanması için kullanılır.

Her üç yapı için de itme analizi sonucunda, kapasite spektrumu, talep spektrumu ve performans noktasını içeren her yapı için bir itme eğrisi oluşturulmuştur. Elde edilen itme eğrileri, yapıların küresel davranışını tek tek tanımlar. Ayrıca, itme eğrisinin her adımının koordinatlarını temsil eden ve farklı durumda (örneğin, IO, LS, CP veya arasında) itme analizinin her adımında oluşturulan menteşelerin sayısını ayrıntılı olarak açıklayan itme analizinin sonucundan oluşturulan bir tablo. B, C, D ve E arasında).

Sismik yük, yapıların yanal yer değiştirmesine neden olan yanal yüke neden olur. P-delta etkisi olarak bilinen yanal yer değiştirmiş yapı üzerindeki yerçekimi yükünün etkisi de bu çalışmada ele alınmıştır. Analiz sonucunda, yüksek katlı binalarda geometrik doğrusalsızlığın etkisinin az katlı binalara göre daha fazla olduğu gözlemlenmiştir. Yapılara yanal yük uygulanması ve doğrusal olmayan statik analiz yapılması nedeniyle, yapı elemanlarının farklı yerlerinde çatlaklar (plastik mafsallar oluşur) ortaya çıkmış, bu da yapı elemanlarının rijitliğini ve burkulma emniyetini azaltmıştır. 2D çerçeve için yapılan burkulma analizi sonucunda, yapısal elemanların sonunda plastik mafsal oluşumu arttığında burkulma güvenliğinin azaldığı açıktır.

Anahtar Sözcükler - Kapasite eğrisi, Talep eğrisi, İtme analizi, performans seviyesi, burkulma güvenliği, geometrik doğrusal olmama ve oluşturulmuş mafsalların durumu.

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LIST OF ABBREVIATIONS

ASCE: American Society of Civil Engineering

ATC: Applied Technology Council

FEMA: Federal Emergency Management Agency

EC8: Eurocode 8

IS 1893 part 1: Indian Standard for seismic force

IS 456:2000: Indian Standard for plain and reinforced concrete

RCC: Reinforced cement concrete

DOF: Degree of Freedom

PA: Pushover Analysis

LS: Life safety

IO: Immediate Occupancy

CP: Collapse Prevention

SDOF: Single Degree of Freedom

MDOF: Multiple Degree of Freedom

CHAPTER ONE

1. INTRODUCTION

1.1 Introduction of Pushover Analysis

Nonlinear static analysis also known as pushover analysis is the most suitable method in term of timing and has been developed in recent two decades and has become the most suitable approach to examine the performance of existing and new structures under earthquake loads. Although nonlinear time history or nonlinear dynamic analysis is the most complete method for structural analysis and seismic evaluation of buildings, but it is too complicated and takes too much time to finish the analysis, that is why its use is limited.

Pushover analysis is an estimated analysis method which can predict the degradation in the structure stiffness, strength and the formation and locations of plastic hinges and also recognize members likely to reach critical states during an earthquake and finally evaluate the overall performance of the structure to the specified earthquake.

This approach is determined as a step-up from the use of linear analysis, because they are more accurate for estimation of the distributed yielding within a structure, rather than an assumed, uniform ductility. As result of pushover analysis, pushover curve gives information regarding inelastic behavior of the structure under lateral load. However, it is very important to know that that pushover analysis method have no powerful theoretical basis, and can be wrong if the applied load distribution is incorrect.

1.2 Introduction to irregularity of buildings

According to the structural configuration, structures must be specified that whether its regular or irregular structure and its define in the below.

- Regular Structure: in regular structures there is no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems.
- Irregular Structures: Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems.

Irregularity exist in plan or elevation or in both of structural configuration of irregular structures.

Regular and Irregular Configuration of buildings according to IS 1893 part 1

When a structure performs well in an earthquake, this structure should possess four main attributes, namely simple and regular configuration, and adequate lateral strength, stiffness and ductility. Structures with simple and regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation, suffer much less damage than buildings with irregular configurations. A building shall be considered as irregular for the purposes of this standard, if at least one of the conditions given in the blow is applicable.

a) Torsion Irregularity

Torsional irregularity is considered when there is rigidity in floor diaphragms in their own plan in relation to the vertical structural elements that resist the lateral forces. According to IS 1893 part 1, when the maximum story drift, considered with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure, then torsional irregularity exist.

b) Re-entrant Corners

There is Re-entrant corners in Plan configurations of a structure and its lateral forces resisting system, when both projections of the structure beyond the re-entrant corner are greater than 15 percent of its plan dimension in the given direction.

c) Diaphragm Discontinuity

When there is cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one story to the next then it can be say that there is variation in stiffness or diaphragm discontinuity, Therefore, the structure is irregular.

d) Out-of-Plane Offsets

Irregularity exist when there be discontinuities in a lateral force resistance path, such as out-of-plane offsets of vertical elements.

e) Non-parallel Systems

When the vertical elements resisting the lateral force are not parallel to or symmetric about the major orthogonal axes or the lateral force resisting elements then the structure is irregular.

f) Stiffness Irregularity — Soft Story

A soft story is one in which the lateral stiffness is less than 70 percent of that in the story above or less than 80 percent of the average lateral stiffness of the three stories above.

g) Stiffness Irregularity — Extreme Soft Story

When the lateral stiffness of one story is less than 60 percent of that in the story above or less than 70 percent of the average stiffness of the three stories above then the story is extremely soft. For example, buildings on STILTS will fall under this category.

h) Mass Irregularity

When the seismic weight of any story is more than 200 percent of that of its adjacent stories, then it can be say that mass irregularity exist in the structure.

Vertical Geometric Irregularity

When the horizontal dimension of the lateral force resisting system in any story is more than 150 percent of that in its adjacent story, then there is Vertical geometric irregularity in the structure.

i) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force

Irregularity exist when an in-plane offset of the lateral force resisting elements be greater than the length of those elements.

j) Discontinuity in Capacity — Weak Story

If the lateral strength of one story is less than 80 percent of that in the story above, then it can be say that the story is weak. The lateral strength of a story is the total strength of all seismic force resisting elements sharing the story shear in the considered direction.

1.3 Introduction to Geometric Nonlinearity

In case of linear analysis the lateral deformation is assumed to be small. Therefore, the deflected geometry is same as the original geometry of structure. But when the structure deforms considerably due to applied gravity load then geometric nonlinearity must be taking account. P-delta effect also known as geometric nonlinearity occurs when the vertical load is applied on the laterally deformed structure which have very significant effect on the stiffness of lateral resisting system and stability of structure.

1.4 Introduction to Material Nonlinearity

stress-strain relationship of material is linear when it is in the elastic range. Beyond this limit it is no more linear and it can be say that nonlinearity in material occurs when the stress-strain relationship of that material cross the elastic range to inelastic range. For example, steel is a ductile material and at low strain value it has linear stress-strain relationship, but when the strain increases the material yield and goes from linear to nonlinear range. The below figure represents the stress-strain curve for ductile material when it is used for tensile test.

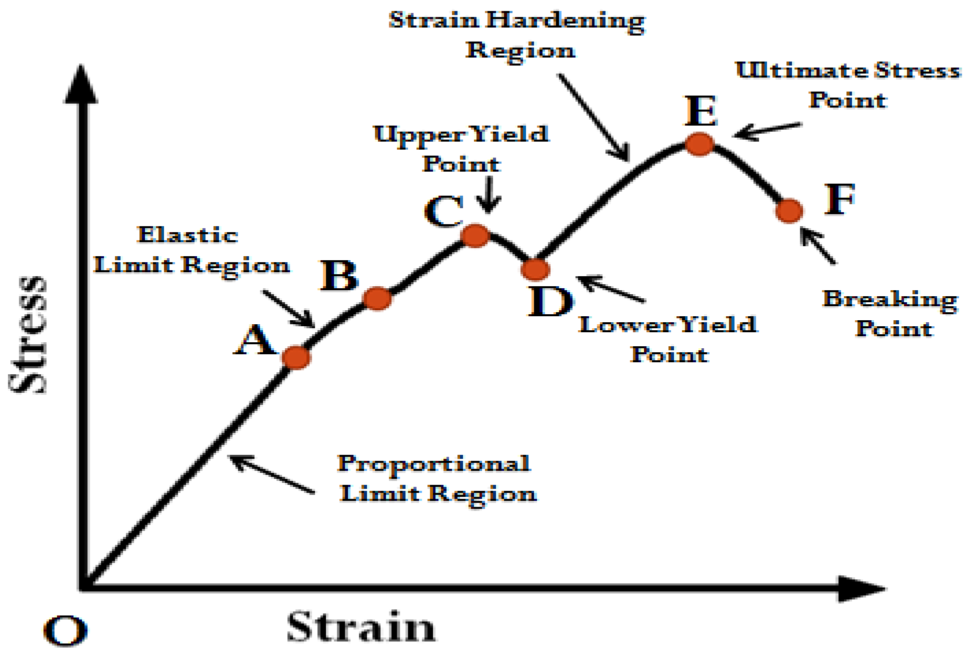


Figure 1.1: Stress-strain curve for ductile material

Material nonlinearity depends on the nonlinear behavior of component of structure. The nonlinear behavior can be characterized by force-deformation relationship which is known as backbone curve. So it is used to identify the strength and rotational deformation. There are various F-D relationship to determine the material nonlinearity such as Monotonic curve, Hysteretic cycle and interaction surface. The monotonic curve is based on the incrementally applied load to component or system in a way that the deformation parameter increases to ultimate condition. Pushover analysis produce monotonic curve, where the P-M2-M3 hinges are used to the structural elements. The relationship between Stress-strain (Axial), moment-curvature (flexural) and plastic-hinging (rotation|) are example of monotonic Force-Deformation relationship. The figure below shows the monotonic backbone curve.

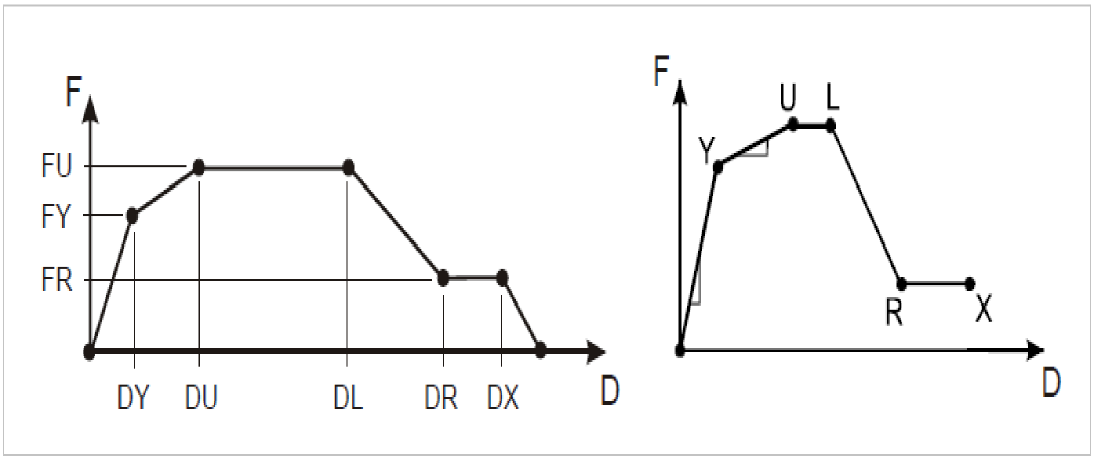


Figure 1.2: Monotonic Curve

1.5 Scope of Study

Nonlinear static analysis is very important to determine the capacity of the buildings as well as to predict potential weak elements in the structure. Due to its easiness in the assumption, it has some restrictions. Nonlinear static analysis is preferred over elastic procedures in assessment of seismic performance of the building in various researches. This thesis aims to:

a) Create a computer model of the buildings in modern structural analysis software like ETABS;
b) Use the principles of pushover analysis to analyze irregular RCC buildings and study their performance under seismic loading;
c) To investigate performance of multistoried frame structures with plan and vertical irregularity under seismic loads;

d) To study and investigate various seismic assessment parameters such as: pushover curve, capacity spectrum, demand spectrum, performance point, displacement ductility, plastic hinge formation;
e) To perform second order analysis (taking into account geometric nonlinearity) and compare its result with first order analysis of individual structures;
f) To perform buckling analysis of structures while considering geometric nonlinearity;
g) To check buckling safety of the frame after generating plastic hinges at different elements due to pushover analysis and compare the result with buckling safety of original structure.

In this study, nonlinear static analysis, P-delta analysis and buckling analysis of four buildings with different story heights (3, 9 and 15 story rcc buildings) are performed by using ETABS2016 and default hinges are assigned at the end of columns and beams.IS 1893 part 1 which deals with earthquake loadings and IS 456:2000 deals with design of structural members like column, beam, slab and foundation are used. performance of the structures under lateral loadings are identified. Nonlinear static analysis is used to predict the potential weak elements in the building that collapsed during seismic event.

1.6 Methodology

Following steps of methods are adopted in this project:
Step-1: Selection of the structures and seismic zone
Step-2: Collection and study of literatures
Step-3: Modelling of structures in ETABS2016
Step-5: Assigning of loads and load combinations as per IS 1893 part 1
Step-6: Linear static analysis and design of structural members
Step-7: Defining how the nonlinearity is determined
Step-8: Defining the nonlinear load cases
Step-9: Defining the hinge properties
Step-10: Buckling and p-delta analysis
Step-11: Nonlinear static pushover analysis
Step-12: Interpretation of results.

CHAPTER 2

LITERATURE

2.1 General

There have been many published research papers regarding to the nonlinear static analysis of different structures and in this section a short review of literatures is presented in brief summarizing the work done by different scholars and researchers on pushover analysis of building structures.

2.2 Literature Review on Pushover Analysis

A) Samir A.B. Jabbar Al-jassim1, Mohanned Abdul Husssain2 (2018) conducted a study on nonlinear static analysis (Pushover analysis) based on ATC40 capacity spectrum method is employed to analyze an existing G+5 stories reinforced concrete building. The building is analyzed in three cases, (regular, irregular in plan and irregular in height) and for more verification of the results a comparison with the FEMA356, FEMA440 displacement coefficient methods and FEMA440 spectrum method are done. The lateral load distributions used in this nonlinear static analysis are usually proportional to the height raised to the power of k (where k can be between 0 for uniform load distribution, 1 for triangular load distribution and 2 for parabolic distribution). FEMA356 requires k to be based on the time period of the structure T (k = 1 for T less or equal 0.5 seconds, k = 2 for T greater or equal 2.5 seconds and interpolated for intermediate values). ATC40 requires at least two different load patterns to be used in the pushover analysis and result envelope to be used. A plot of lateral load virsus roof displacement is then drawn which represent the capacity curve of the structure(pushover curve).

SAP2000 V18 program is used for the analysis. Default plastic hinged are applied at end of columns and beams. After the analysis they concluded that The three buildings analyzed showed an over design behavior and expected to perform well (approximately linearly) when subjected to an earthquake less or equal to the design one.

B) Nzapfakumunsi Alexis and Ass. Prof. Dr. Necati Mert(may 2018) performed the 3D pushover analysis for Seismic Design Evaluation of T Shaped Irregular RC

Building . This study shows that how Turkish Seismic Code 2007 is efficient in providing the immediate occupancy(IO), Life Safety (LS) and Performance Level (PL) of T shaped of RCC buildings with plan irregularities. For this purpose, a set of 12 multi-story residential buildings: 3- rectangular plans as reference and their respective 9- different T shaped plans of 3-, 6- and 8- stories were considered in the North Anatolian Fault Zone (NAFZ) Turkey and were designed based on the Turkish code. Then, a modal and a non-linear static pushover analysis were conducted for all buildings. from the analysis result it can be observed that in both rectangular and T shaped residential buildings the expected performance level which is LS has been overreached and also in some cases the structures reach the collapse prevention(CP) level. This overreach can be mainly due to the fact that the models used in this study neglect foundation flexibility (and many other elements that contribute to the strength of the entire buildings like infilled walls) as many of the observed points in the collapse prevention level can be found on the fixed bottom end of ground stories' columns. Based on this, the researchers think that code provisions still need improvement, particularly on the flexibility of numbers of elements and their locations that can reach collapse prevention level without preventing the performance of the entire building from being in the Life Safety zone.

C) Kancharla Srimukha1, Ramesh Bantupalli2(August 2016) performed nonlinear static analysis of multi-story RCC building with vertical and plan irregularities. The aim of this study is to evaluate the performance of G+9 RCC building against earthquake load. The building is located in zone III and sap2000 is used for modelling and analysis of structures. Comparison of seismic response of the building in terms of base shear and displacement along with the location of the plastic hinges at the performance point of all the models are considered. A RCC structure with G+9 story of dimension 20mx 20m, considered for this analysis. Five different models of structure including different irregularities are considered for this study. First building is regular, second building is with stiffness irregularity, third building is with mass irregularity, fourth building is with vertical geometric irregularity and model fifth building is combined irregularities i.e. stiffness, mass, vertical geometric irregularity. 3D models are created for all the considered building structures and material properties, frame sections, load cases are defined and assigned. Gravity analysis and linear static analysis is carried out as per IS 456-2000 and IS 1893-2002.For beams default hinge (PM3) is assigned and for columns default hinges of axial force and bending moment (PM2-M3) is assigned. Hinges are assigned both for end beams and columns. Two static pushover cases are defined. Initially gravity load is applied to the structure and then lateral load along longitudinal direction is applied to the structure and nonlinear static analysis is carried out using SAP2000 software. From the result of analysis it can be observed that, in the structure with mass irregularity the lateral load capacity is more as compare to other models, it is due to placing heavy mass along X-X and Y-Y in the structure. For the structure with stiffness irregularity the lateral load capacity is less as compare to other models in longitudinal and transverse directions but the lateral displacement is more. The base force acts more in longitudinal direction than in transverse direction and displacement decreased when base force increased.

D) Mr. Suraj S. Shinde, Dr. Nagesh L. Shelke, Prof. Manoj Deosarkar and Pro. Vishwajeet Kadlag(July 2020) published research paper regarding nonlinear static analysis(pushover analysis) of G+12 rcc building. In this study a residential building of 12 story with 3m story height and 13.5m X 10.5m base dimension have been considered. Four types of models have been prepared. First model is without shear wall, in the second model shear wall is provided at three periphery of lift. in the third model shear wall is provided at middle along periphery of structure and shear wall is placed at corner along periphery of structure in L shape in the fourth model. SAP2000 software is used to perform linear static and nonlinear static analysis of all four types of buildings. IS 456:2000 is used for designing of structural members and the code which is used for calculation of lateral load and distribution of it to each floor is IS 1893 part 1.

From the analysis it can be observed that the model three shows the best performance as compare to other three models.

E) Neethu K. N. and Saji K. P.(2013) worked on a research paper regarding pushover analysis of an existing asymmetric-plan building. The structure is a four storied unsymmetrical building frame which is constructed with moment resisting frame of reinforced concrete. This building is located in zone III (zone factor 0.16). Response reduction factor is considered 3 and important factor is 1.5 because it is an educational building. In this study the frame structure has been designed according to IS 456:2000 and IS 1893 part 1 and detailed as per IS 13920:1993. The main objective of this study is to evaluate the seismic capacities of an existing building which is asymmetric in plan.

The software which is used for linearly analyzed and design of building and also for performing nonlinear static analysis of this existing building is SAP2000.

Pushover analysis have been performed in X and Y direction. from the result of analysis it is seen that the performance point base shear is greater than the design base shear, therefore we can say that the building is safe under earthquake loading. The structure has good resistance and good behavior, because both pushover curve in X and y direction show no decline in the load carrying capacity and also demand curve intersect the capacity curve near to elastic range.

F) Nikunj Mangukia, Arpit Ravani, yash Miyani and Mehul Bhavsar (March 2016) performed p-delta analysis of 25 story RCC building with plan dimension of 15m X 28m. The building is located in zone III and IS 2893 part 1 is used in this study. ETABS software is used to perform linear static analysis and p-delta analysis in the present work. From the analysis result it is obvious that the model period of structure with p-delta effect is more than without p-delta effect. There are 12-20 % variation in lateral displacement and 5% to 20 % variation in bending moment for specified load combination while considering geometric nonlinearity. From the research its understood that geometric nonlinearity should be considered for analysis and design of high rise buildings.

CHAPTER 3

NONLINEAR STATIC ANALYSIS OF STRUCTURES

3.1 Pushover Analysis Foundation

In recent years Applications of nonlinear static analysis for evaluating performance of buildings have become increasingly prevalent. Whereas nonlinear static (pushover) analysis was at the forefront of engineering practice in the mid- to late-1990s and still it is one of the most appropriate method for capacity assessment of new or existing buildings. Pushover analysis is mostly used for seismic design of irregular or high rise buildings. If a realistic nonlinear static analysis of a concrete structure can be carried out, the safety of the structure is increased and the cost can frequently be reduced.
There is no theoretical foundation behind the nonlinear static analysis. It assumes that the response of the building is determined by the first mode of vibration and mode shape of the equivalent single degree of freedom (SDOF) system. The shape of the first mode is constant throughout the analysis. The SDOF idealization can be basic concept of the pushover analysis. A structure with a number of joints and mass is represented by the lumped mass of the structure at the top of the single degree of freedom (SDOF) system with a strut supporting. Although pushover analysis is based on assumptions, but still it led to the excellent prediction of the seismic response of the multiple degrees of freedom system.

3.2 Purpose of Pushover Analysis

The main purpose of pushover analysis is to evaluate the durability and capacity of structures against demand (earthquake motions). After linear analysis and design of structure, pushover analysis is carrying out. When the analysis is completed, to insure that whether the structure is safe or not, different parameters are checking out like, base share vs roof displacement, capacity curve, demand curve, performance point, inter-story drift and moment curvature for formation of different hinges at the end of beams and columns. Pushover analysis can be performed to estimate the earthquake loading versus lateral deformation demands. It is an approximate manner in case of redistribution of internal forces which is unable to be endured in elastic range.

Some data about response characteristics may not be given by linear static or linear dynamic analysis, but from pushover analysis it is obtained easily. The examples of this kind of response characteristic are as follows

- Elements in critical condition can be specified when the deformation demand are high.
- Strength degradation for each elements of buildings in which structural system behaved.
- It can predict the inter-story drifts that consider for discontinuity of strength or stiffness which can be used to prevent the damages and to assess P-Delta effects.
- To specify the integrity and suitability of the load path, while accounting all components, connection and nonstructural components of significant strength.

In addition, nonlinear static pushover analysis is the best way to determine the overall performance of new and existing structures against the most devastating natural force(earthquake). A structure built earlier may be seismically inadequate due to the recent upgrade of the various seismic codes or in some cases due to the omission of seismic design at the time of building the structure. In such cases, the non-linear static analysis is helpful for prediction of the buildings such that those buildings can be nearly retrofitted to meet the recent seismic demands.

3.3 Seismic Load Distribution

In order to perform a nonlinear static pushover analysis a load pattern which is equivalent to the seismic force is required. This force is applied laterally to the structure by increment. There are number of guidelines and methods available to distribute lateral load on structure.

3.3.1 Lateral Load Distribution According to FEMA

According to FEMA 273 and FEMA 356 documents at least two vertical distributions of lateral load shall be applied to the structure. It is recommended that the first pattern should be a uniform pattern which is based on lateral forces that are proportional to the total mass at each floor level and the second lateral load distribution pattern is Equivalent Lateral force distribution if more than 75% of the total mass participates in the fundamental mode in the direction under consideration. These lateral load pattern are uniform distribution over the height of building but gradually increasing values until a target roof displacement is obtained.

The uniform distribution can be calculated by the equation $F_i = m_i / \sum m_j$

Where mi is the story mass and mj is the overall story mass of building.

The below formula shows how the equivalent lateral force can be calculated in FEMA documents.

$$C_{vx} = W_x h^k_x / \sum W_i h^k_i$$

C_{vx} = Vertical distribution factor

W_x = portion of the total building weight located on floor x

h_x = The measured height from the base to floor level x

W_i = Portion of the total building weight located on floor i

h_i = The measured height from the base to floor level i

k = 2.0 for 2.5 seconds $\leq$T

k = 1.0 for 0.5seconds $\leq$ T

3.3.2 Lateral Load Distribution According to IS 1893 part 1

The lateral load induced at any level h_i as per IS 1893 part 1 can be determined by,

$Q_i = V_B (W_i h_i^2) / (\sum W_j h_j^2)$

Q_i = Design lateral force at floor i

V_B = Design base share

W_i = Seismic weight of floor i

h_i = Height of floor i which is measured from base

W_j = Total seismic weight of building

h_j = Total height of building

the lateral distribution loads which are used for nonlinear static pushover analysis should be applied at the center of mass of individual floor.

3.4 Load Deformation Behavior of Elements

To perform the nonlinear static analysis, the nonlinear load - deformation behavior for each element should be modelled. The hinges which are assigned at the end of structural members like beams and columns must represent the moment against rotation and shear force against shear deformation. The rotation of the moment hinges for each column could be calculated for the vertical load which is generated from the gravity load analysis. The columns should be modelled with axial load versus axial deformation hinges, because columns are always under compression

The given curve in the below describes the status of plastic hinges generated at each element due to nonlinear analysis.

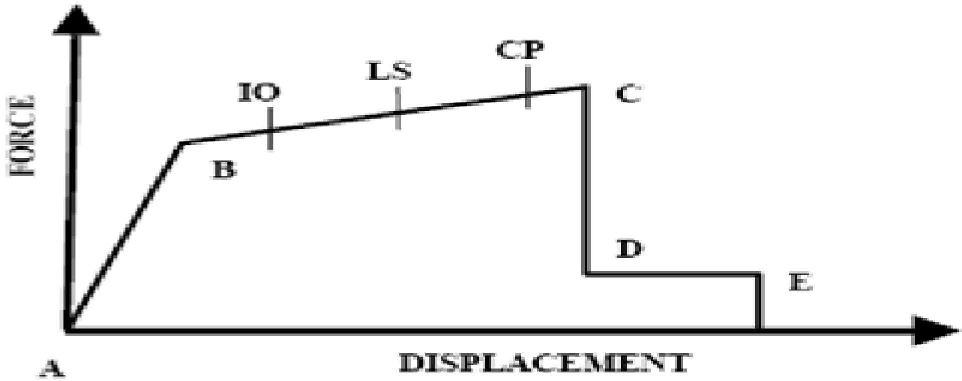


Figure 3.1: Pushover curve

- Point A is the starting point of load-deformation curve
- Point B is the yielding point. After this point the structure goes from elastic range inelastic range.
- Point C represent the ultimate strength. It means that after point C structure lose the lateral strength against earthquake force.
- Point D shows the residual strength. At this point structure will lose almost 80% of its strength and structure should be redesigned again, because according to some guidelines like FEMA 356, structural engineers should design the structure appropriately and the load-deformation curve for each element should not cross point C.
- Point E illustrate the largest deformation capacity. After this point the structure will fail completely.

These five points (A, B, C, D and E) describe the hinge rotation behavior of RC members according to FEMA. Three more points Immediate Occupancy (IO), Life Safety (LS) and (Collapse Prevention) CP which are between point B and C used to define the acceptance criteria for the hinge.

a) Immediate occupancy level: In this performance level after earthquake happened, there should be very less damage to nonstructural members and there should not be any damage to the structural members (column, beam, slab).

b) Life safety level: In this performance level, there are some damages to structural members and none structural members the damage on building is more as compare to immediate occupancy level, but the risk for threatening the life is still low. In this performance level the building can be repaired, but from economical point of view this may not be appropriate option.

c) Collapse prevention level: in this performance level part of the structure or structure completely on the verge of collapse and it include significant degradation in the stiffness and strength of the lateral load resisting system and large permanent lateral deformation of structure occur. In Collapse prevention level, after the earthquake the building may not be used again and repairing of the building is not appropriate.

3.5 Definitions of Plastic Hinges and its Properties

In nonlinear analysis of structures, a plastic hinge refers to the deformation of a part of beam or column wherever a plastic bending happens. When hinge is applied to a part of structural element, it does not have capacity to resist moment and permit free rotation to the element. Therefore, the concept of hinge is very important in order to check the performance of building and understanding structural failure.
When ETABS is used for pushover analysis, while assigning hinges to the end of beams and columns, there are three options of hinge properties.

- Default hinge properties option
- User-defined hinge properties
- Generated hinge properties

Out of these three types, default hinges and user-defined hinges properties are used to the frame elements. There is no way to modify the default hinge properties. The program cannot define the default hinge properties fully, until the section that they apply to is specified. The effect of default hinge properties can be observed only when the default hinges must be assigned at the end of structural elements and then from result of analysis the generated hinge property should be viewed. ATC-40 and FEMA 273 documents explained the concept behind The built-in default hinge properties. In case of default hinge properties, there are Default-M3, Default-P, Default P-M-M, and Default-V2. For beams Default-M3 which is moment hinge property mostly assigned and for columns Default-P-M-M which is interaction of bending moment and axial force is assigned. In nonlinear static pushover analysis, plastic hinges are mostly applied at the end of beams and columns or at 5-10% of total length of beam or column from ends.

We can use User-defined hinge properties as default properties, but in this case, the properties of different hinges can not be illustrated, it is due to default hinges properties are depending on section and when the User-defined is not based on default properties then the properties of hinge (moment-rotation curve) can be viewed and changed.

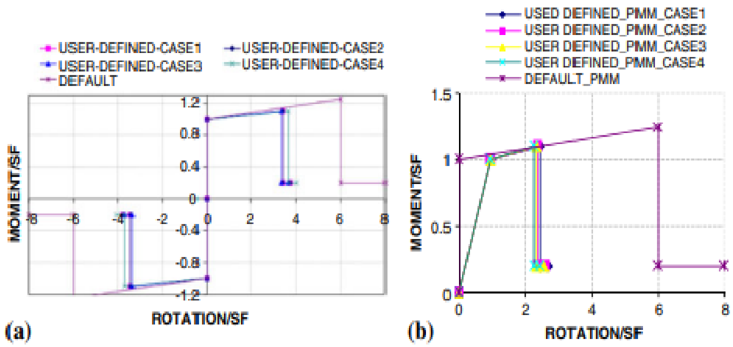


Figure 3.2: (a) Typical user-defined moment–rotation hinge properties (M3)-Beams, (b) Moment vs. Rotation Curves (P-M-M) - Columns.

3.6 Capacity Curve

Capacity curve also known as pushover curve and load-deformation curve, describes the inelastic behavior of a structure. Therefore, the strength and deformation capacities of individual structural components represent the overall capacity of a structure. Pushover capacity curves determine how structure behaves after exceeding the elastic limits. Fig (3.3) shows the capacity curve

3.7 Demand Curve

Due to ground motions during an earthquake there will be horizontal displacement patterns in structure that may change with respect to time. For nonlinear analysis it is suitable and more convenient way to apply a set of lateral displacement as a design condition for a given structure and ground motion, the applied displacement represent the maximum expected response of the building during ground motion. In nonlinear pushover analysis the demand is the earthquake load which is induced to structure to create lateral displacement.

3.8 Performance level

The main outcome of a nonlinear pushover analysis is in terms of response demand versus capacity and the intersection of capacity curve and demand curve is known as performance point. Intersection of demand curve and capacity curve near the elastic range represent that, the structure has good resistance and capacity against earthquake loading. Intersection of demand curve and capacity curve beyond the elastic range with little reserve of strength and deformation capacity, describe how the structure behave poorly during earthquake and retrofitting is needed to avoid future major damage or collapse. After the nonlinear static pushover analysis completed, the pushover curve should be checked and from the result the performance of structure can be observed. None elements should be failed before structure reach the performance point.

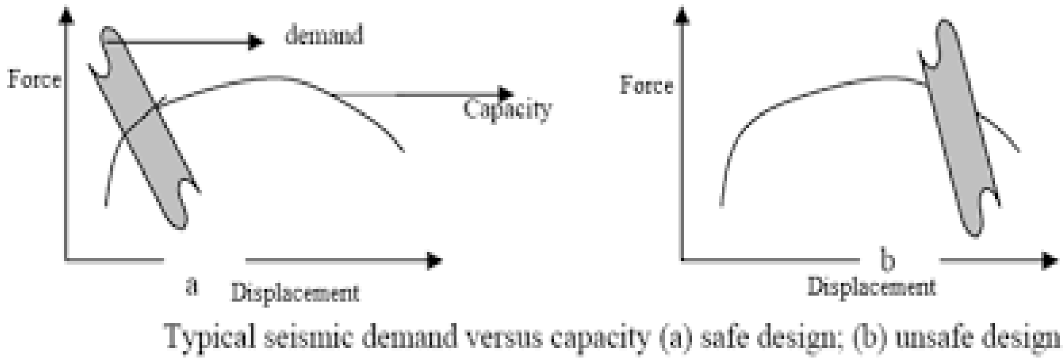


Figure 3.3: Capacity-Demand intersection curve

3.9 Target Displacement

According to FEMA 356 target displacement is the maximum lateral displacement of structure when subjected to the seismic loading. In nonlinear static analysis using ETABS the target displacement can be obtained from result of pushover curve. Formula for calculating the target displacement is given below.

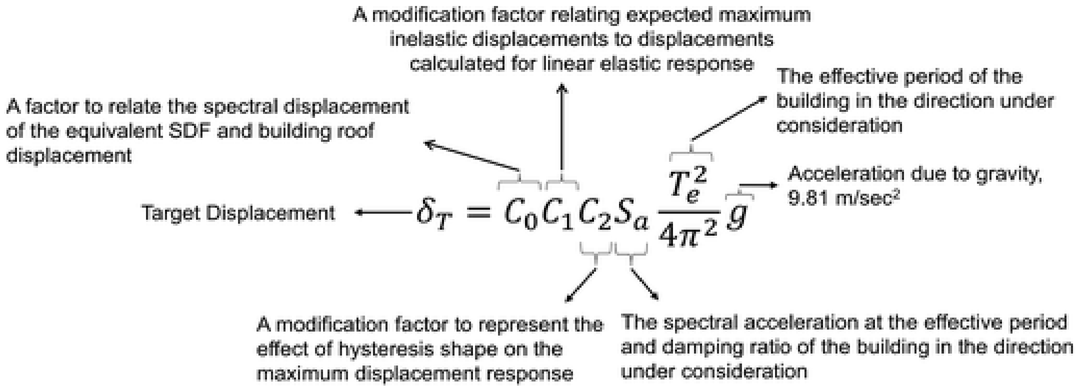


Figure 3.4: Target displacement formula

3.10 P-delta Effect

P-delta effect is also termed as geometric nonlinearity. The structural mass move to a deformed position in the nonlinear analysis of structural system subjected to lateral displacements generates second-order overturning moments that are normally not accounted for in static and dynamic analysis. This second-order behavior is known as the P-delta effect. The magnitude of the P-delta effect can be related to the following points.

- Magnitude of axial load P
- Stiffness/slenderness of the structure as a whole
- Slenderness of individual element

There are two types of p-delta effect. One is P- Δ (large P-delta or big P-delta) and other is P- δ (small P-delta) effects.

a) P- Δ (large p-delta) effect: P-Δ refers to the effects of the vertical loads acting on the laterally displaced structure. Earthquake load or wind load (V) cause a horizontal displacement (Δ) of the structure, while the applied gravity loads (P) are acting vertically on the displaced structure. Due to acting gravity loads on displaced structure, additional moment is generated. This additional moment is known as secondary moment

b) P- δ (small p-delta) effect: P- δ refers to the effects of the axial load in an individual member subject to a deflection (curvature) between its endpoints. The loads which are coming to column due to gravity, wind, and/or seismic forces act on a column that has a curvature because the supported beams are connected to the column. Moments are generated in the member proportional to the axial load P times the member deflection δ. Therefore, axially loaded beams also experience these effects. It is shown in figure.

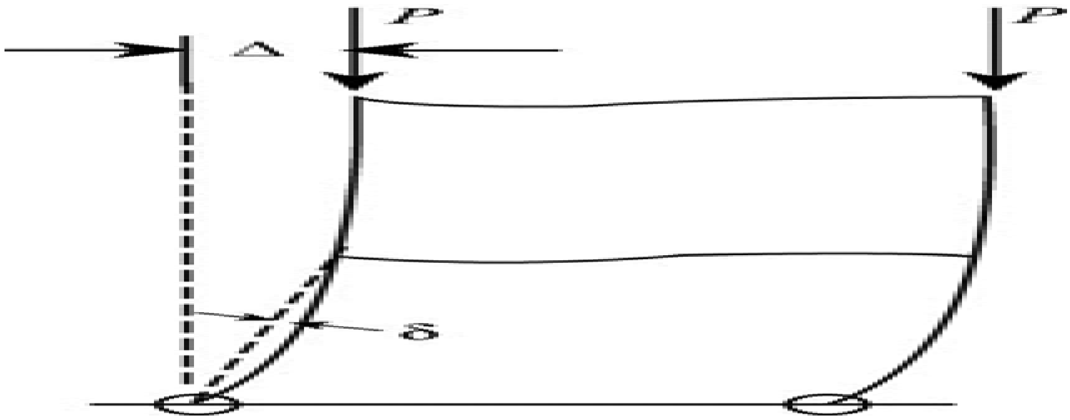


Figure 3.5: Large P-delta effect and small P-delta effect on structure

When linear finite elements program performs first order analysis, it assumes that the properties of the structure are constant and there is no effect due to deformation on the structure behavior. Therefore, in some cases, there will be a geometric second order effect on the behavior of the structure due to the deflection of the structure, which is not taking account by the linear first order analysis. So, this kind of geometric nonlinearity can be analyzed with linear structural analysis program using iterative procedure. The program first run as linear, in which the gravity load and lateral force is applied at the same time. In the second run the software consider P-delta effect, it means that the program consider there is lateral displacement due to lateral load and same vertical load acts on the deflected shape of the building as the input, so this lateral displacement create additional moment. There will be an incremental deflection to the structure due to the second analysis and thus a new deflected shape. This gives a batter evaluation of the deflected shape of the structure, but may still contain unbalanced internal forces if the output shape is still not equal to the input shape. The program repeats the analysis of structure by revising deflected shape until it matches the input shape. Therefore, the iterative procedure calculate the geometric second order deflection of the structure.

3.11 Stability Coefficient

The absolute value of the geometric stiffness divided by the elastic stiffness is known as stability coefficient.

According to ASCE7-16, P-delta analysis should be performed for each building if the stability coefficient as determined by the given formula in ASCE7-16, page number

104 should be more than 0.10. If the stability coefficient for any structure is equal or less then 0.10, there is no need to perform p-delta analysis. The formula for determining the stability coefficient is shown below.

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \quad , \quad \theta max = \frac{0.5}{\beta C_d} \leq 0.25$$

Figure 3.6: Stability Coefficient Formula

P_x= Total vertical design load, at and above level x(KN)
Δ= Design story drift
I_e= Importance factor
V_x= Seismic shear force acting between level x and x-1(KN)
h_{sx}= Story height below level x in (mm)
C_d= Deflection amplification factor

3.12 Buckling Analysis

The term of buckling also known as instability which cause failure. In case of structural engineering this term of instability is used when there is progressive lateral deformation on the vertical structural members until failure due to high level of compressive loads.

Buckling occurs when there is a sudden change in the shape of vertical structural members under the applied axial or vertical loads. When the structure is subjected to axial loads and if the applied loads are gradually increasing and reach a critical level, the shape of vertical structural members may suddenly change and the structure and its component is said to be buckled or we can say that, when a structure become unstable under a given vertical loading configuration, buckling occurs.

Local buckling which occurs on individual structural elements is related to the stiffness of individual member. The below figure describe how critical buckling load is calculated for member with different end support.

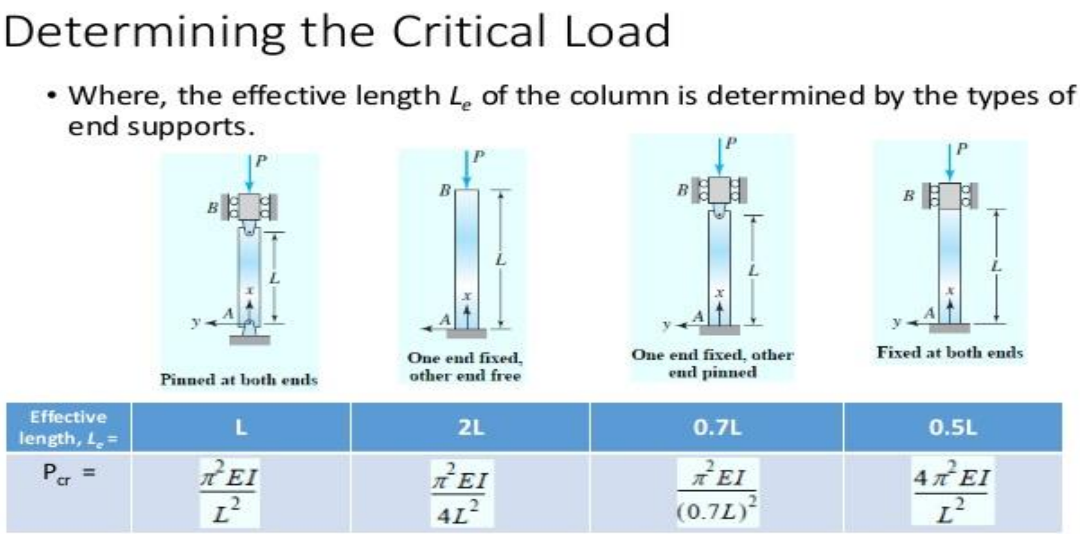
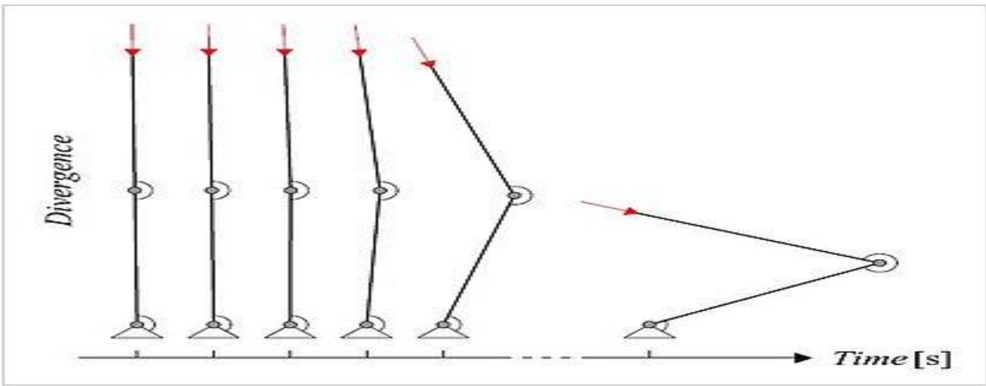


Figure 3.7: Buckling load formula



[1]

Figure 3.8: Buckling of structure

In this study buckling analysis is performed for all four buildings by using ETABS2016. Before the analysis, the buckling load case is defined and then the buckling analysis is performed. When the analysis is completed the buckling factor for each mode corresponding each mode shape is generated and buckling load for each mode is calculated by multiplication of buckling factor of that mode and applied loads. Buckling load= Buckling factor*applied loads (Dead load + live load).

CHAPTER 4

STRUCTURAL MODELLING AND LINEAR ANALYSIS

4.1 General Description of Structures

The structures that considered in this research paper are G+3, G+9 and G+15 irregular RCC buildings. These structures are analyzed linearly according to equivalent lateral load method and response spectrum method and designed according to IS 456-2000 for reinforced concrete and IS 1893-2002 for earthquake forces. The buildings are located in severe seismicity region (ZONE IV). The plan and 3D of the buildings are shown in the given below figures and the software which is used for modelling, analysis and design of buildings is ETABS 2016.

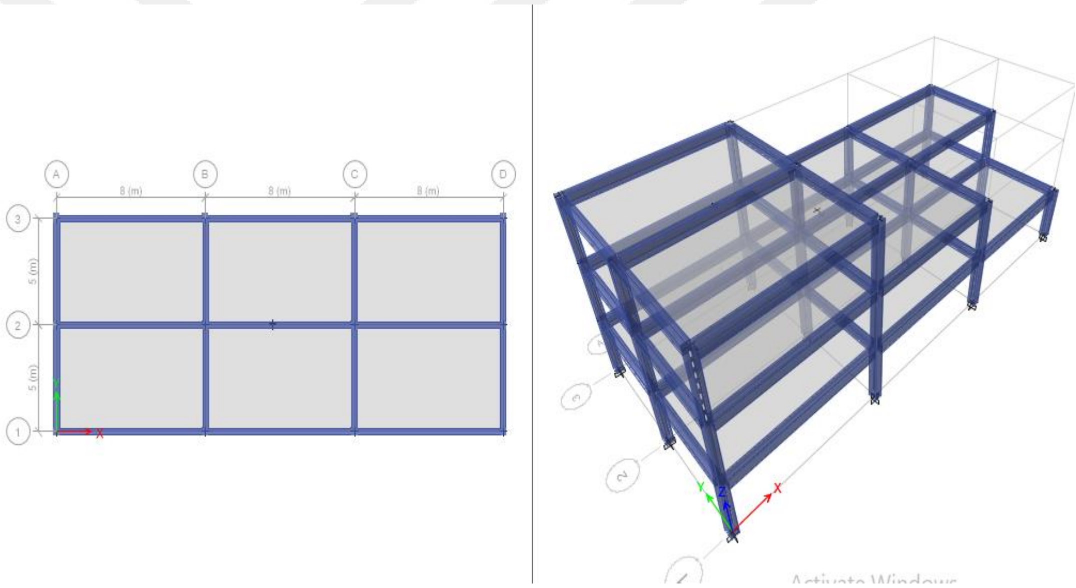


Figure 4.1: First story plan and 3D of 3 story irregular rcc building

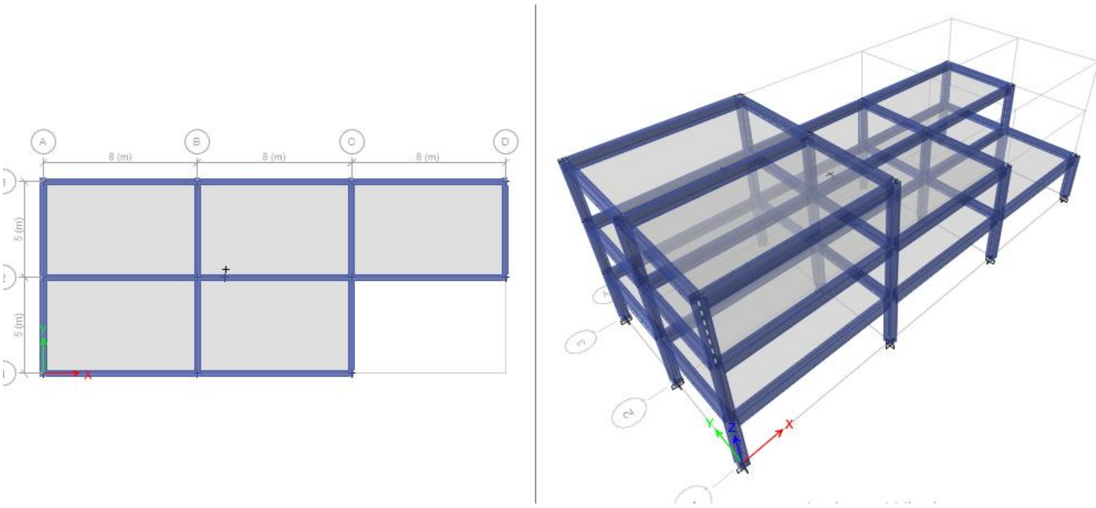


Figure 4.2: Second story plan and 3D of 3 story irregular rcc building

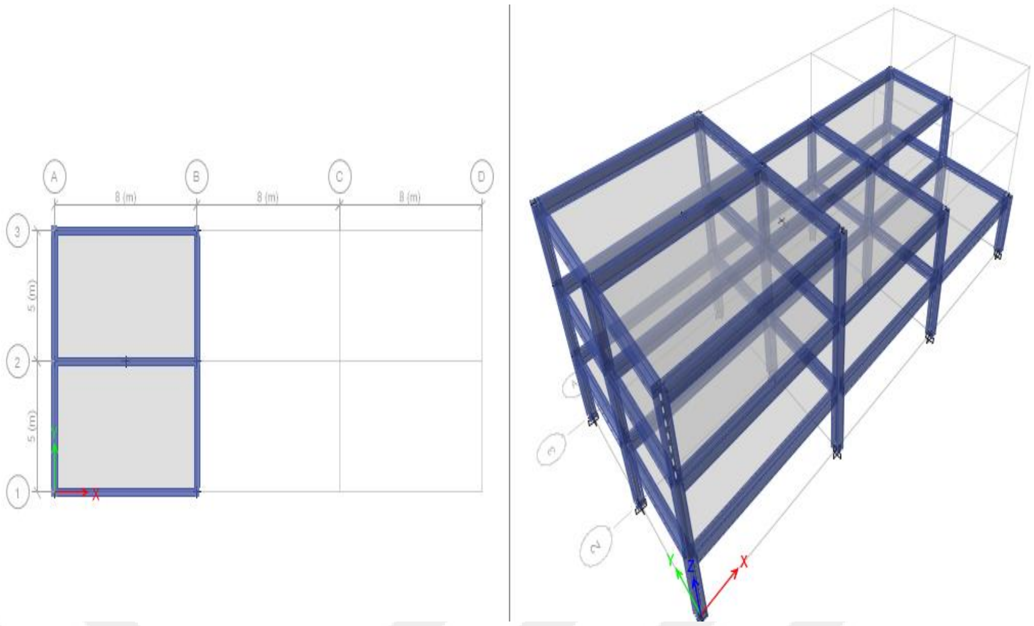


Figure 4.3: Third story plan and 3D of 3 story irregular rcc building

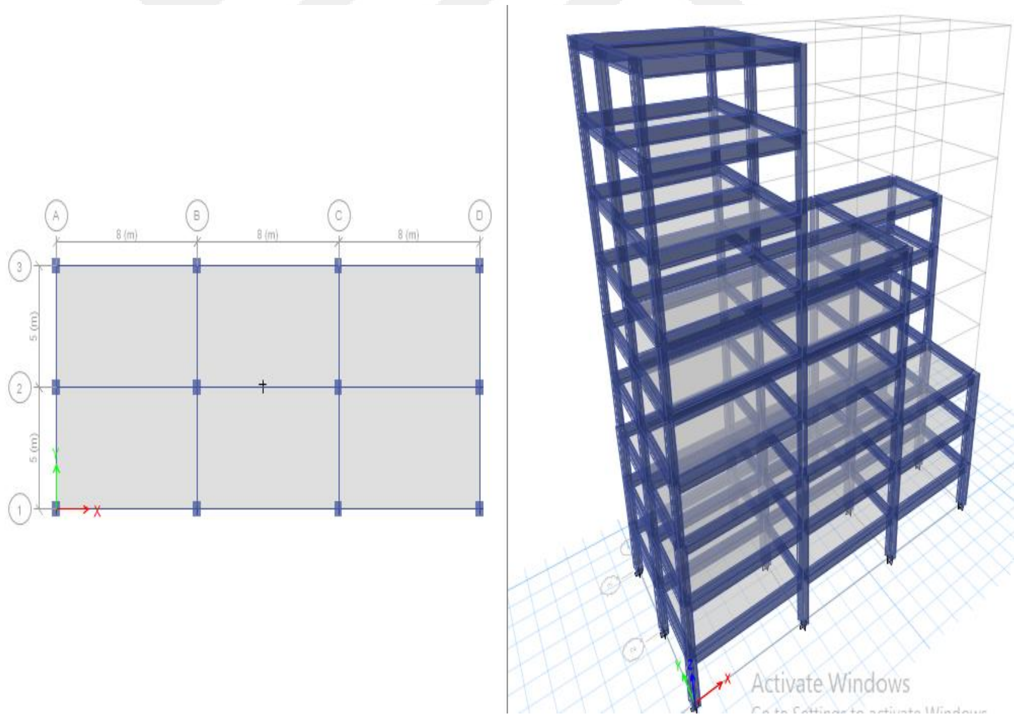


Figure 4.4: First to third story plan and 3D of 9 story irregular rcc building

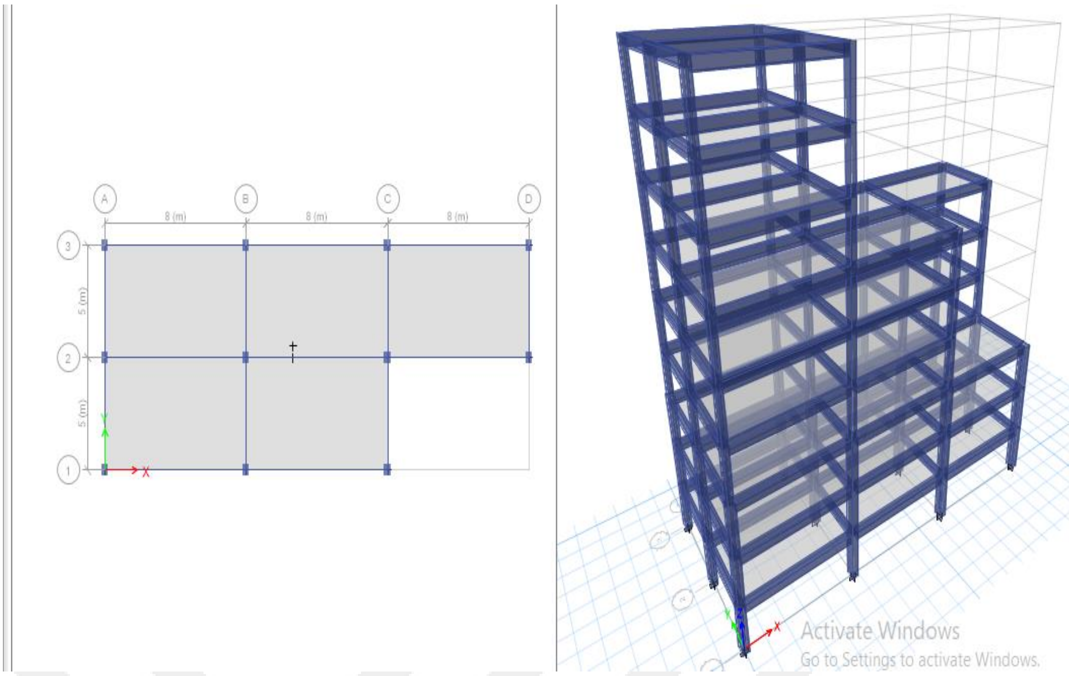


Figure 4.5: Fourth to sixth story plan and 3D of 9 story irregular rcc building

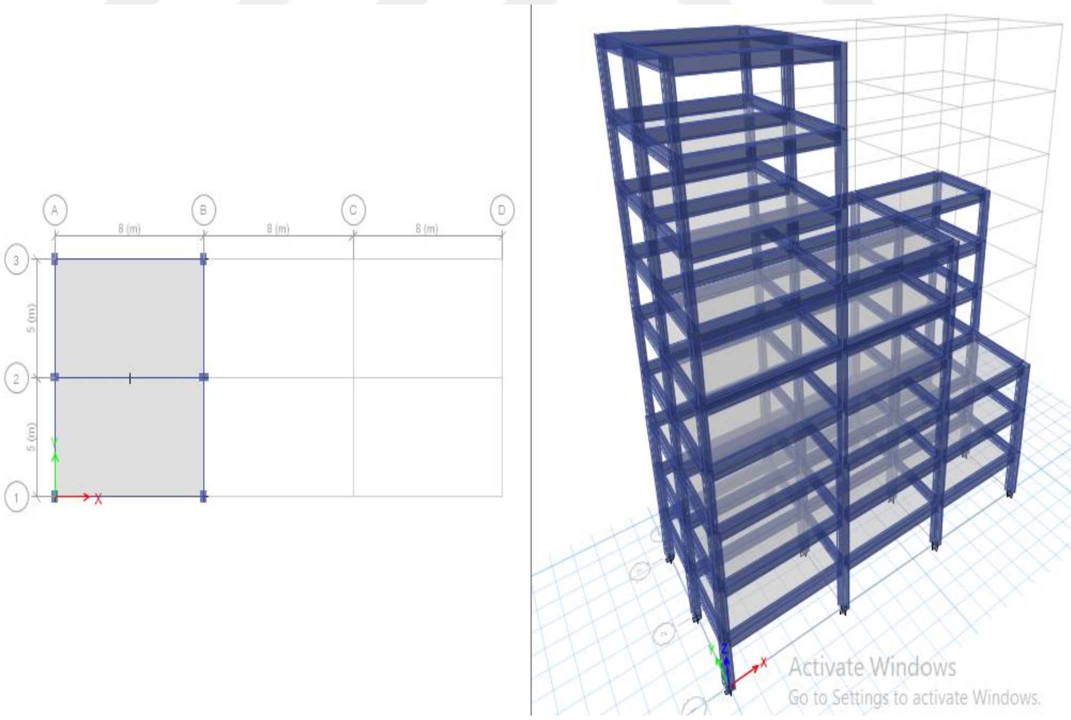


Figure 4.6: Seventh to ninth story plan and 3D of 9 story irregular rcc building

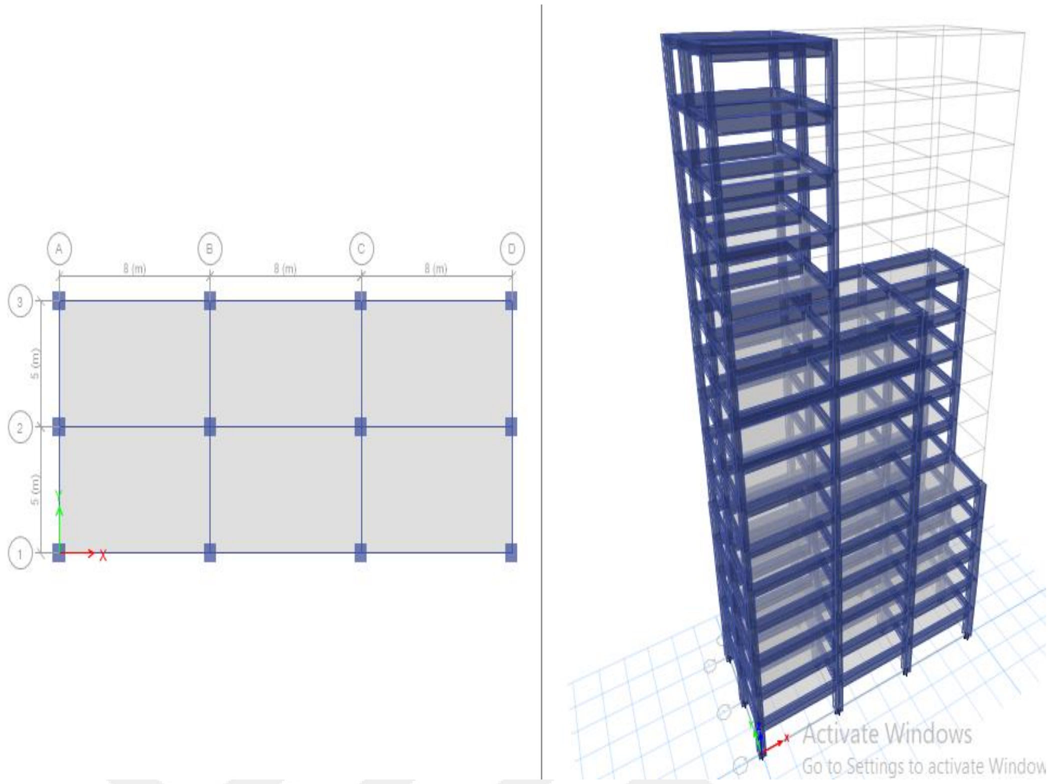


Figure 4.7: First to fifth story plan and 3D of 15 story irregular rcc building

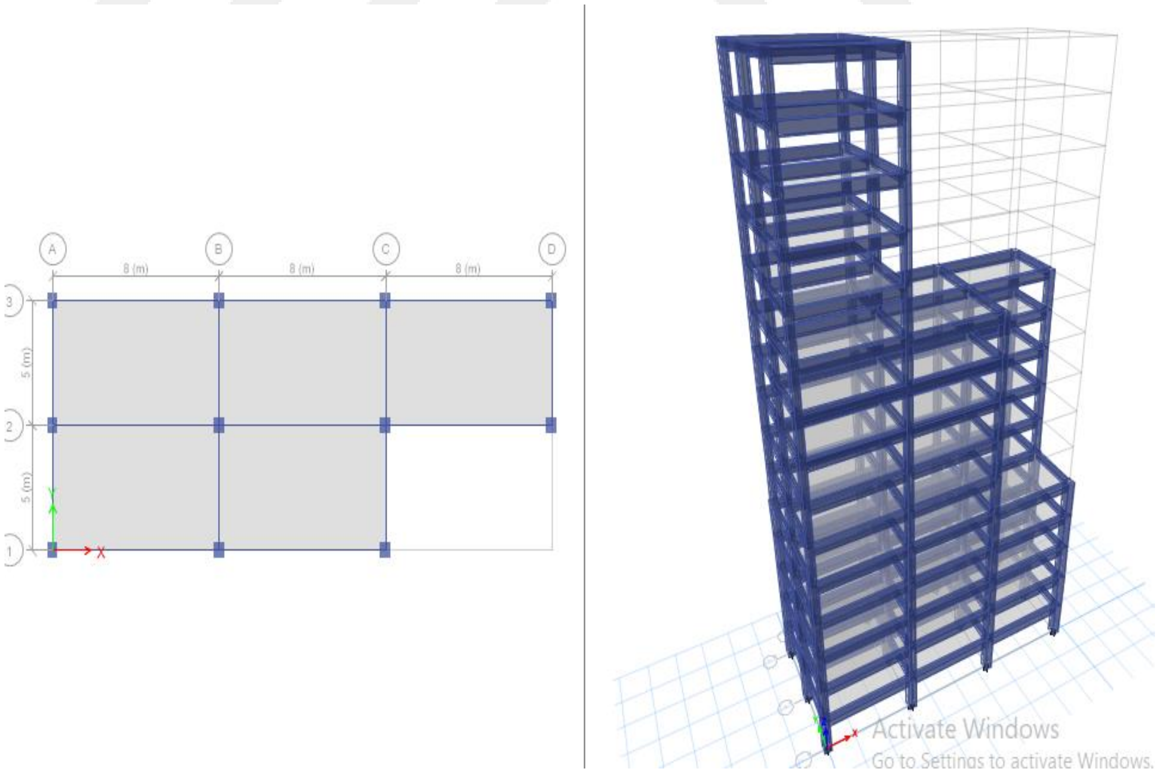


Figure 4.8: Sixth to tenth story plan and 3D of 15 story irregular rcc building

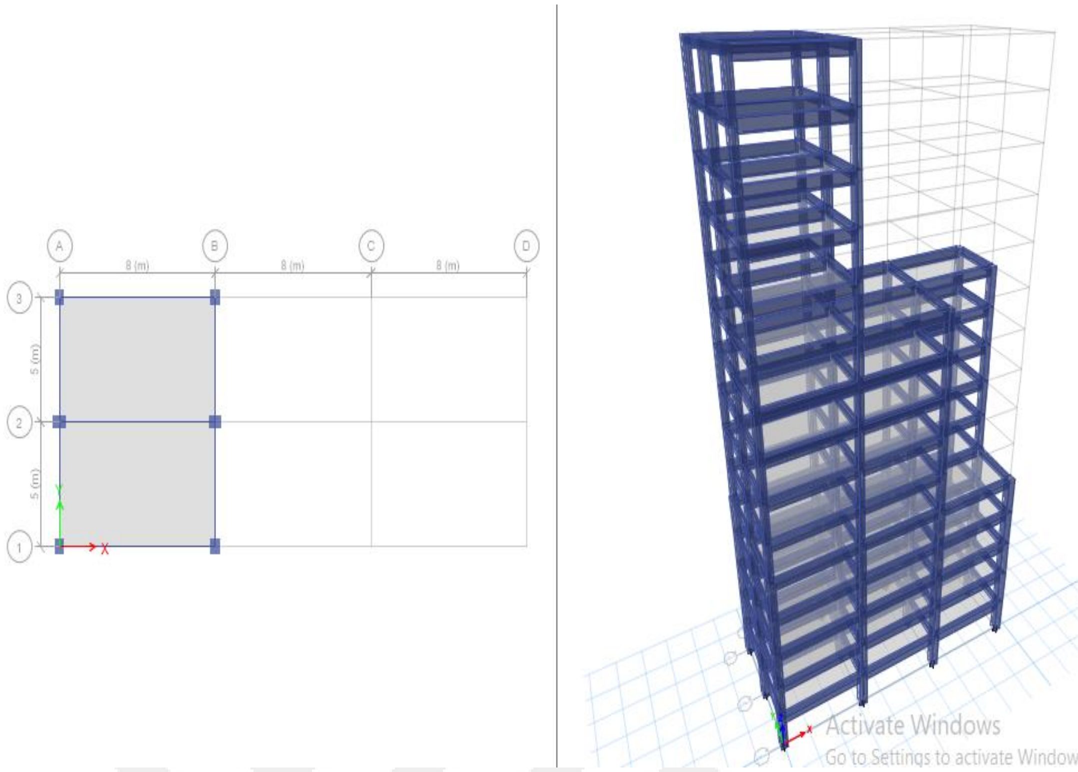


Figure 4.9: Eleventh to fifteenth story plan and 3D of 15 story irregular RCC building

4.2 Member Properties

a) for 3 story building

- Size of columns for first story building is 450mmx350mm
- Size of columns for second and third story building is 400mmx300mm
- Size of beams in x direction is 500mmx300mm
- Size of beams in y direction is 400mmx300mm
- Size of slab is 140mm

b) for 9 story building

- size of columns from first to third story building is 650mmx450mm
- size of columns from fourth to ninth story building is 550mmx400mm
- size of beams in x direction is 550mmx450mm
- size of beams in y direction is 450mmx350mm

c) for 15 story building

- size of columns from first to fifth story building is 750mmx650mm
- size of columns from sixth to fifteenth story building is 650mmx550mm

- size of beams in x direction is 700x450mm
- size of beams in y direction is 500mmx350mm

4.3 Material Properties

According to IS.456:2000 the materials used for design of structural members (column, beam, slab) are M20, M25 grade of concrete and Fe415 grade of steel. M25 grade of concrete is used for design of columns and M20 grade of concrete is used for design of beams and slabs.

The stress-strain relationship is used based on IS.456:2000 and the material properties are used as follows:

- Modulus of elasticity of steel, Es=200000Mpa
- Modulus of elasticity of M20 grade of concrete, Ec=22360.68Mpa
- Modulus of elasticity of M25 grade of concrete, Ec=25000Mpa
- Characteristic strength of M20, fck=20Mpa
- Characteristic strength of M25, fck=25Mpa
- Yield stress for steel, fy=415Mpa
- Ultimate strain in bending is 0.0035

4.4 Modelling Geometry

The structures which are used in this analysis are three, nine and fifteen story rcc buildings with two bay along x-direction and three bay along y-direction. Information regarding modelling of structures in ETABS software are given as:

- Number of stories=3, 9, 15
- Number of bays in X-direction=2
- Number of bays in Y-direction=3
- Story height =3m
- Bay width in X-direction=8m
- Bay width in Y-direction=5m

4.5 Member Loading

Different types of loads assigned to the structures are given as:

- Self-weight of the structures
- Wall load=10.35 KN/m

- Parapet wall load=4.05KN/m
- Surface finish load =0.48KN/m^2 according to specified code
- Live load=2KN/m^2 according to specified code
- Earthquake loading according to IS 1893-2000 part 1

4.6 Stiffness Modifiers

Stiffness modifiers are used to change the properties of reinforced cement concrete structural members. In general stiffness modifiers are used to decrease the stiffness of concrete sections to design the section for cracked behavior. In ETABS software the sections are designed according to the forces obtained from the linear analysis of the building which are related to the stiffness of components of structures. Stiffness is the property of material to attract axial forces, moment and shear. In structural engineering stiffer structural members absorb more forces and more reinforcement is needed to design it.

Concrete is strong in compression but in tensile it is weak and tensile strength of concrete is assumed to be 7-10% of compressive strength. Therefore, crack of concrete reduces the stiffness of member and also reduce the ability to attract moments. For example, moments which were present at cracked section (beams) transferred to un cracked sections (columns). The un cracked section also crack when the concrete reach its tensile capacity limit. The table below shows the value of stiffness modifier for structural members. In this study all three structures are designed according to ultimate condition.

Sr.No.	Structural Member	Service condition	Ultimate condition
1	Columns	$1.00E_cI_{gross}$	$0.70E_cI_{gross}$
2	Beams	$0.50E_cI_{gross}$	$0.35E_cI_{gross}$
3	Slabs	$0.35E_cI_{gross}$	$0.25E_cI_{gross}$

Table 4.1: Stiffness modifier for structural members

4.7 Step by step procedure for modelling and linear static analysis in Finite Element Software(ETABS)

The first step for modelling of structures in ETABS 2016 is model initialization. In this step the codes used for design of structural members are defined. As its obvious from the given figure, IS 800:2007 is for steel design code and IS 456:2000 is for concrete design.

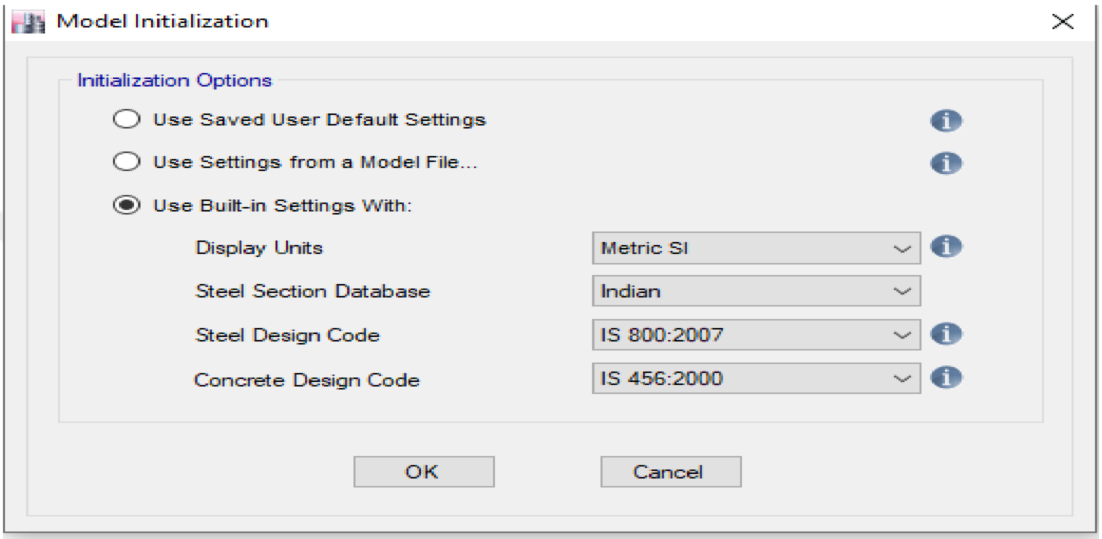


Figure 4.10: Model initialization

After defining the specific codes for design of structural members (Columns, Beams and Slabs) the second step is creation of grid with the help of plan of structures. The below figure shows how grid systems in X-direction and Y-direction in ETABS software has been defined.

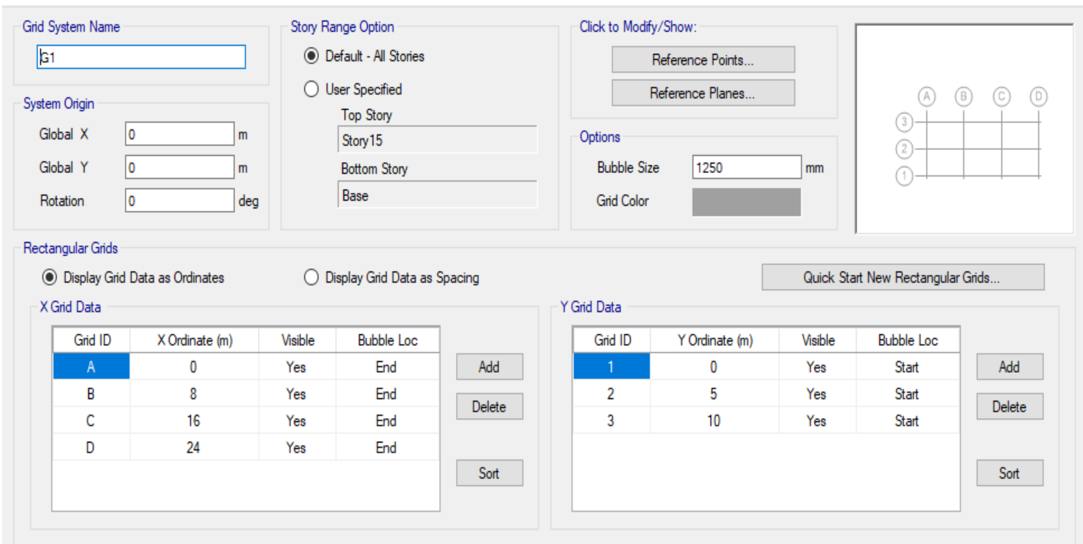


Figure 4.11: Defining grid system

The third step for modelling of the structures is defining of material properties and section properties. As its showing in the below figure the materials which are defined are M20, M25 grade of concrete and HYSD415 grade of steel.

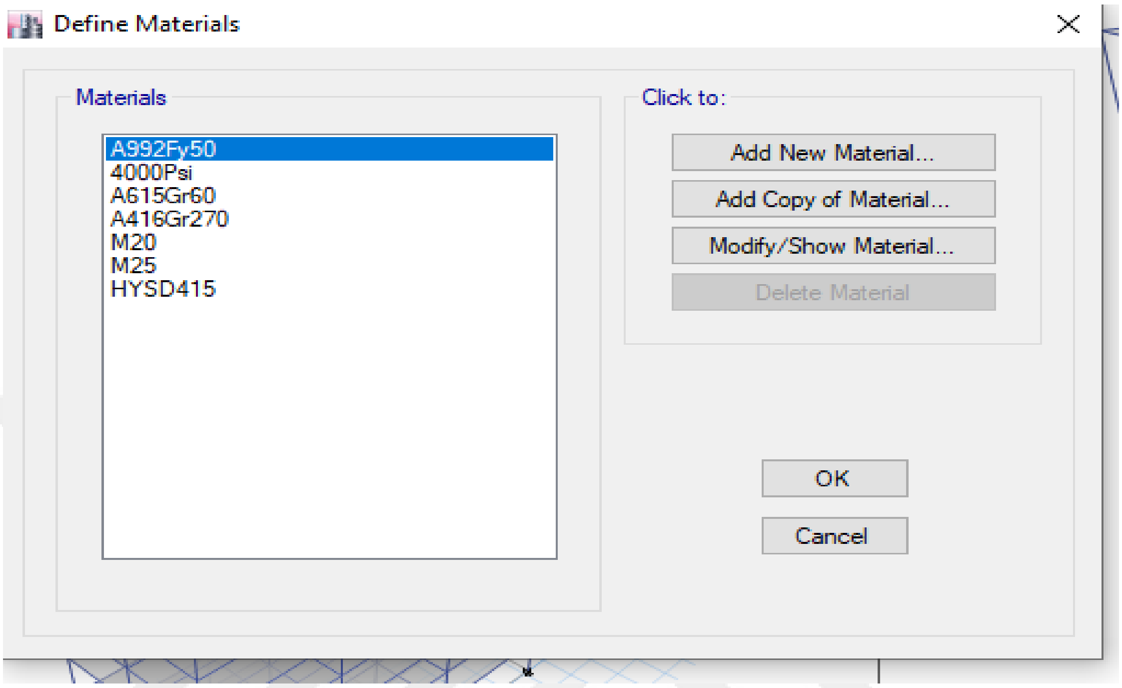


Figure 4.12: Defining material properties

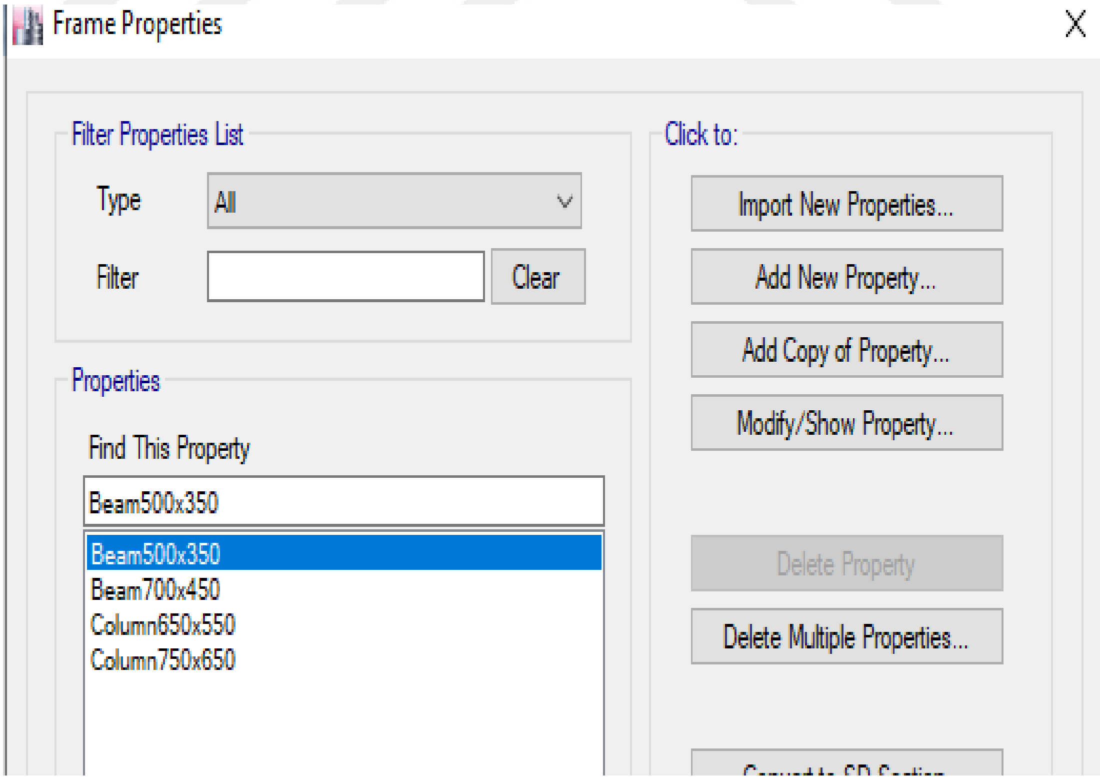


Figure 4.13: Defining section properties

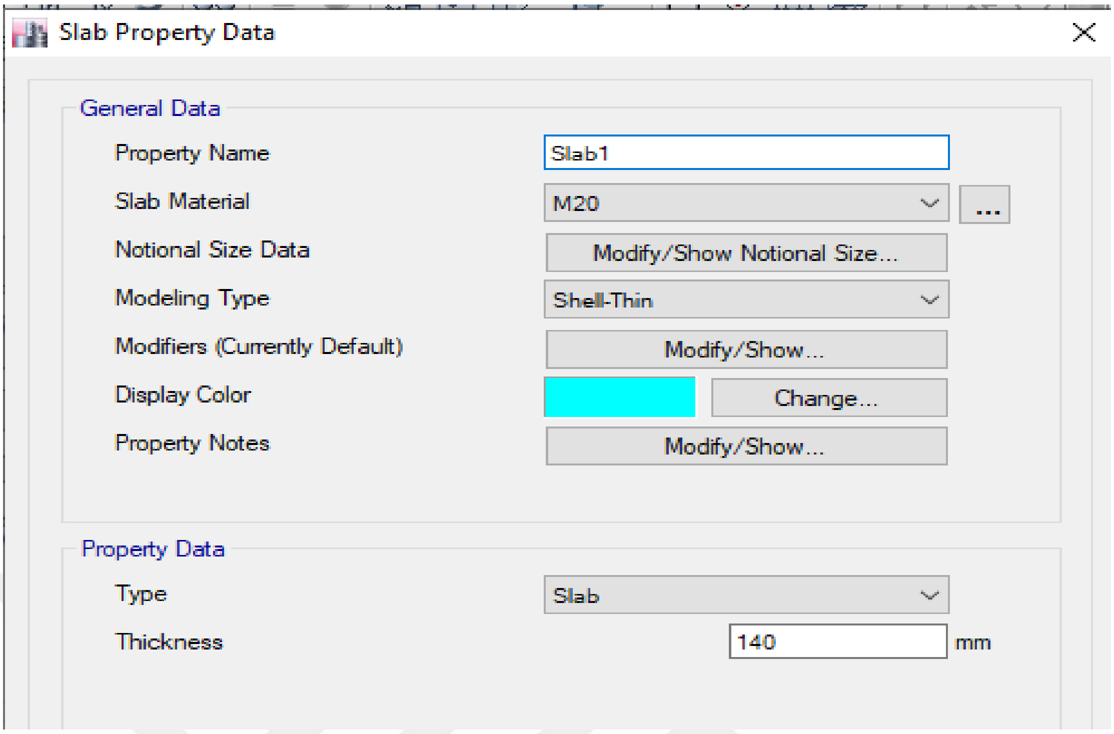


Figure 4.14: Defining slab properties

After assigning the material properties and section properties to the grid system, the plan and 3D of structures can be viewed in above figure.

After defining the material properties and section properties in step four load pattern should be defined. As the given Figure in the below shows different types of loads which include self-weight of structures, wall lad, surface finish load, live load, equivalent lateral loads according to IS 1893:2000 part 1 and pushover loads in X and Y direction which is used in nonlinear analysis. ETABS it-self calculate the self-weight of structures, therefore there is no need to calculate the seismic weight of structure by hand. The seismic zone in this analysis is selected as severe zone(IV).

According to IS 1893, India divided into four seismic zones (Zone II, III, IV and V)

- Zone II has seismic intensity of 0.10 is low seismic zone
- Zone III has seismic intensity of 0.16 is moderate seismic zone
- Zone IV has seismic intensity of 0.24 is severe seismic zone
- Zone V has seismic intensity of 0.36 is very severe seismic zone

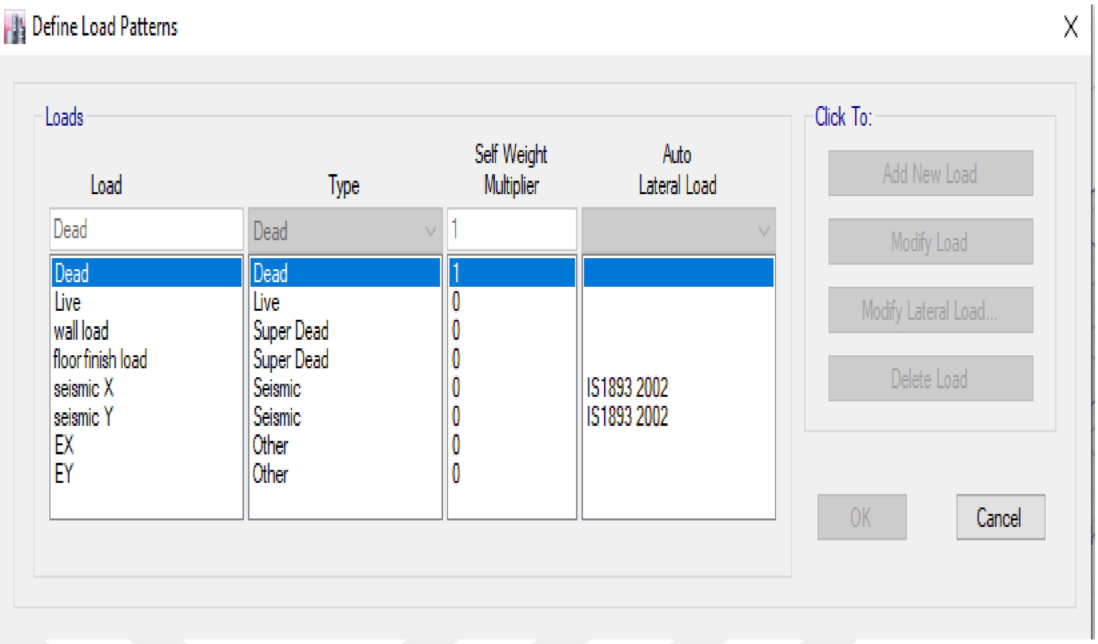


Figure 4.15: Defining load pattern

Now in step five when different loads are applied to the structures, mass source should be defined. According to Indian code the mass source can be defined as 100 percent of dead load plus a percentage of live load. According to code when the applied live load is less than 3 KN/m^2 ,30 percent of live load should be used for defining of mass source. If the applied live load is more than 3KN/m^2 the percentage of live load should be 50 percent. Here 30 percent of live load is used for defining of mass source, because the applied live load is 2KN.

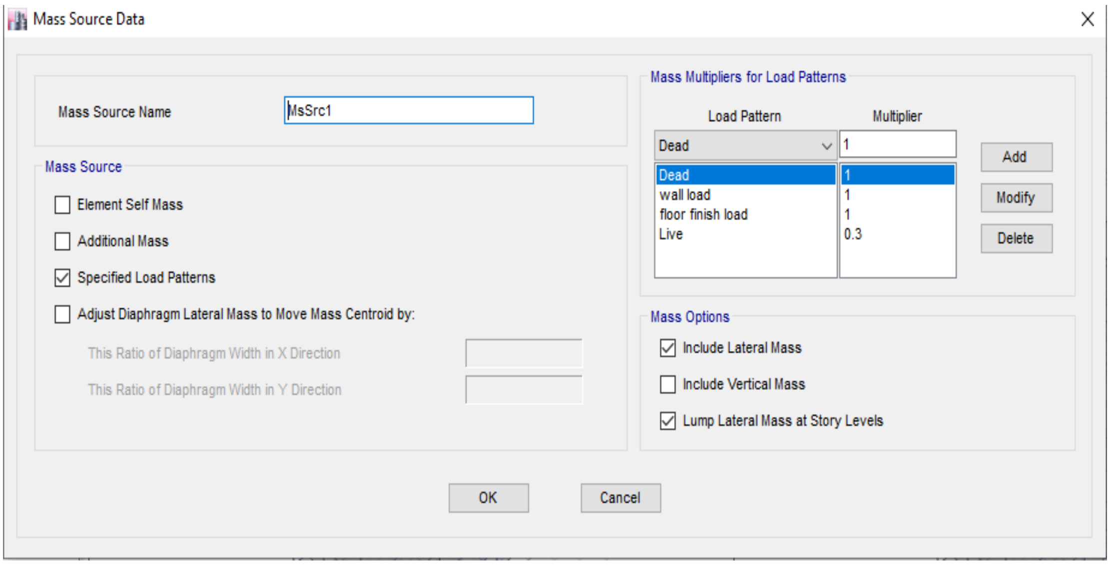


Figure 4.16: Defining mass source

Step six is load combinations which is the last step before running the software for linear analysis. The below Figure shows the load combinations in ETABS software according to IS 1893:2000 part 1. There are 14 load combinations in code for performing linear static analysis.

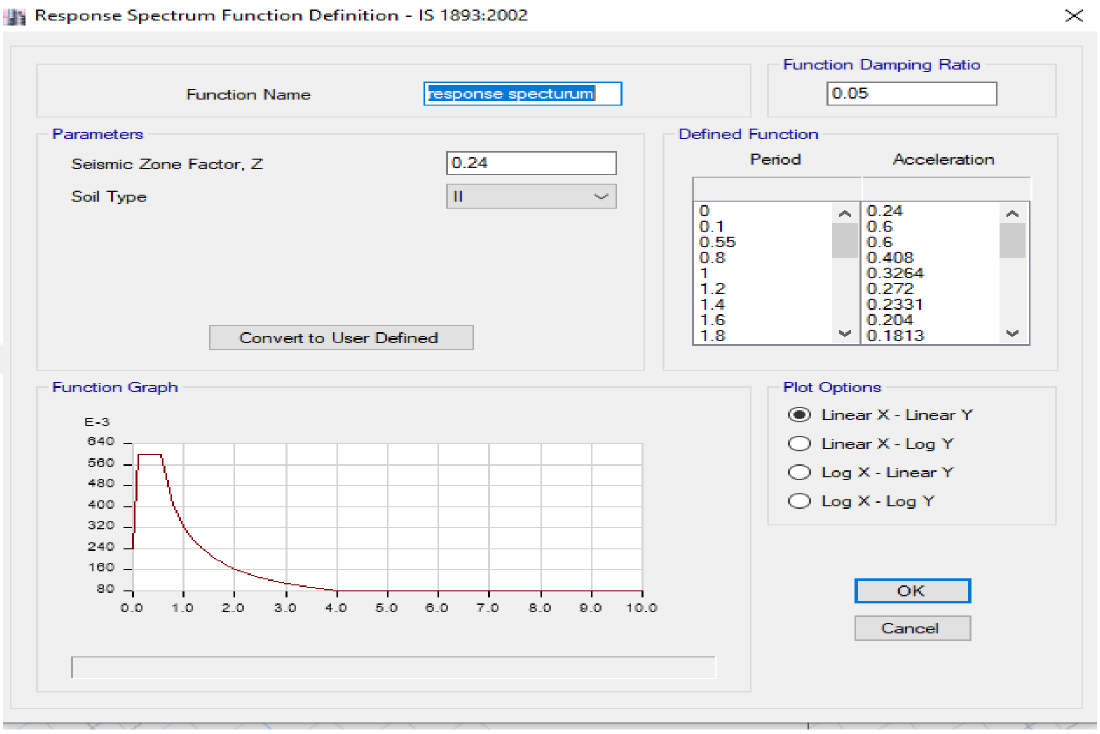


Figure 4.17: Defining response spectrum function

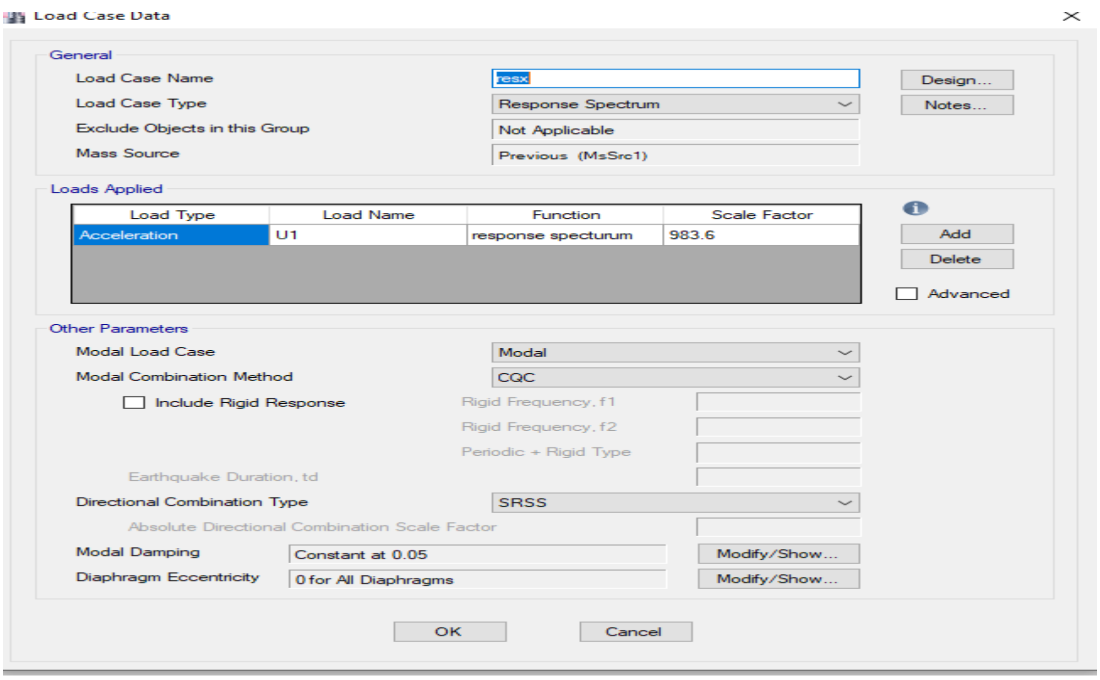


Figure 4.18: Defining response spectrum case in X direction

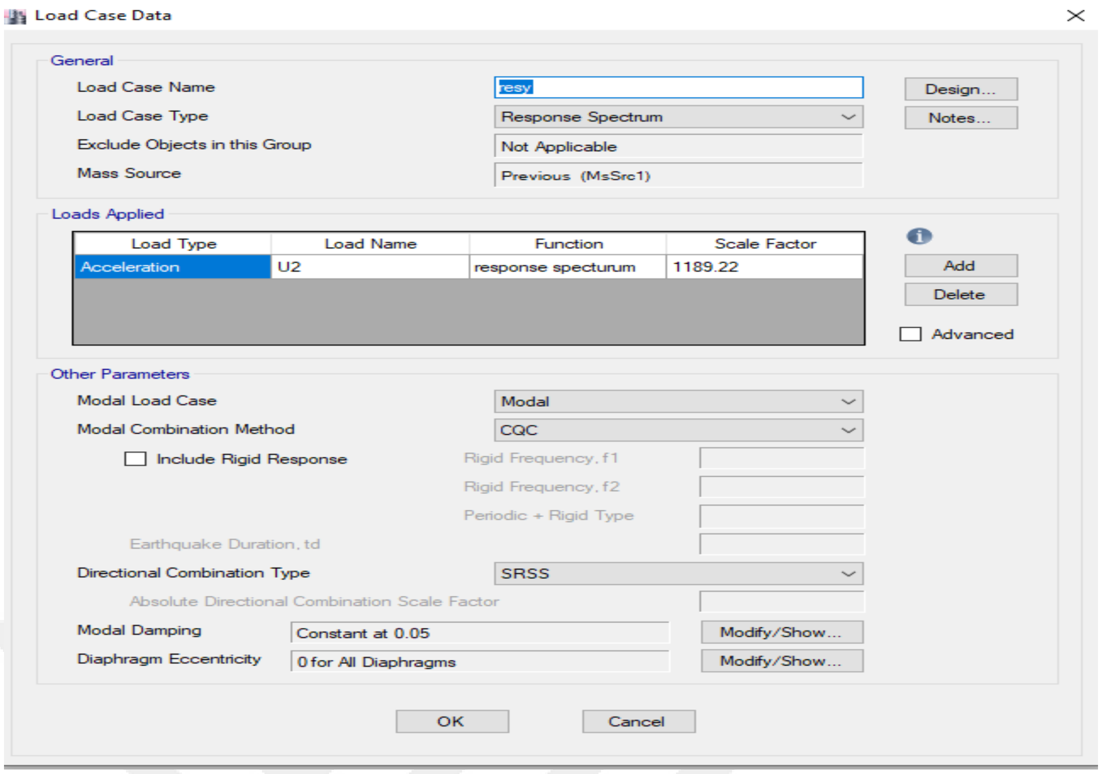


Figure 4.19: Defining response spectrum case in Y direction

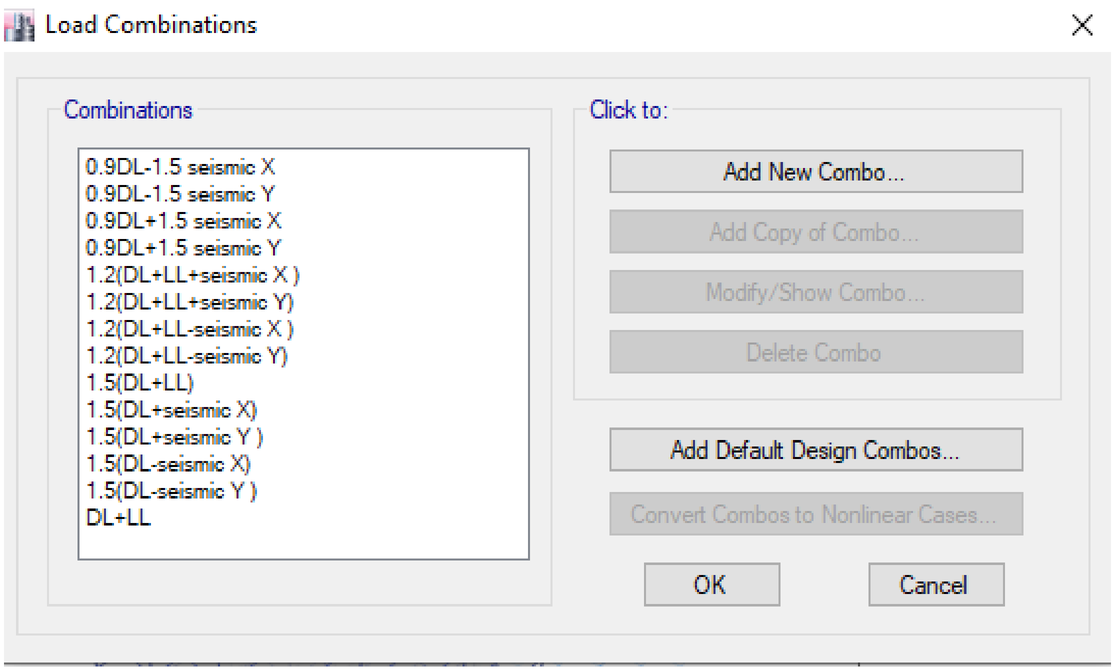


Figure 4.20: Defining load combination

After performing linear static analysis, structures are properly designed according to the specified codes and nonlinear static analysis have been performed.

CHAPTER 5

NONLINEAR STATIC ANALYSIS OF RCC FRAME STRUCTURES USING ETABS 2016

5.1 Description of Nonlinear Static Analysis in ETABS

Nonlinear static pushover analysis can be performed in ETABS when the structures are linearly analyzed and then the structural members are designed properly according to the specified code. In this study, the equivalent lateral load analysis and response spectrum analysis have been performed for all three buildings. Before performing pushover analysis of buildings in ETABS, all the structural members should be checked out, whether it pass the design conditions or not. If all structural members pass the design conditions and there is no failure on any structural member and the percentage of rebar in beams and columns are within the limit as specified in the code then the pushover analysis can be performed, but if there is some failure on members or percentage of steel in beams and columns are not within the specified limit as mentioned in the Indian code, then the sections should be redesigned again and the size of failed members should be changed before running the models for nonlinear analysis in case of new buildings.

5.2 Nonlinear Load Case

The first step for performing pushover analysis of buildings in ETABS is defining the nonlinear load case. Three nonlinear load cases are defined as given below:

- Nonlinear gravity load case. Which is defined as dead load plus 30 percent of live load
- Nonlinear pushover load case in X-direction
- Nonlinear pushover load case in Y-direction

The governing loads for nonlinear pushover loads in X and Y directions is lateral load which can be defined from FEMA-273 document (Building Seismic Safety Council; 1997) and IS 1893 part 1. Each of these documents describe the pushover analysis procedures by applying a lateral load pattern which is a uniform distribution over height but gradually increasing values until a target roof displacement is obtained. According to FEMA there are three lateral load distributions: 1. Uniform distribution. 2. Equivalent Lateral force distribution. 3. SRSS distribution. In this study equivalent lateral lad according to IS 1893 part 1 is defined as pushover load.

5.2.1 Equivalent lateral load as per IS 1893 part 1

A) Equivalent lateral load for three story building

Story	Elevation	location	EX	EY
	m	Top	KN	KN
Story3	9	Top	80.4488	78.80605
Story2	6	Top	102.1165	100.03128
Story1	3	Top	34.28	33.58058
Base	0	Top	0	0

Table 5.1: Lateral load for each story of three story building

B) Equivalent lateral load for nine story building

Story	Elevation	location	EX	EY
	m	Top	KN	KN
Story9	27	Top	47.81504	44.08314
Story8	24	Top	55.38445	51.06178
Story7	21	Top	42.40372	39.09417
Story6	18	Top	59.9701	55.28960
Story5	15	Top	50.1582	46.243442
Story4	12	Top	32.101	29.595803
Story3	9	Top	20.506	18.906327
Story2	6	Top	9.559	8.8136206
Story1	3	Top	2.3899	2.203405
Base	0	Top	0	0

Table 5.2: Lateral load for each story of nine story building

C) Equivalent lateral load for fifteen story building

Story	Elevation	location	EX	EY
	m	Top	KN	KN

Story15	45	Top	48.390487804505	34.6317774071207
Story14	42	Top	61.3908923255129	43.9358190897127
Story13	39	Top	52.9339836888351	37.8834358477625
Story12	36	Top	45.1035127289483	32.2793772904012
Story11	33	Top	37.8994794458524	27.1236434176288
Story10	30	Top	60.3708066055553	43.2057710329029
Story9	27	Top	58.4576806544116	41.8365979764241
Story8	24	Top	46.1887847145968	33.0560774134709
Story7	21	Top	35.3632882971132	25.3085592696887
Story6	18	Top	25.9811914019607	18.5940435450774
Story5	15	Top	20.1794212710025	14.4418718919551
Story4	12	Top	13.6008725215234	9.73378056470372
Story3	9	Top	7.65049079335691	5.47525156764584
Story2	6	Top	3.40021813038085	2.43344514117593
Story1	3	Top	0.850054532595213	0.608361285293983
Base	0	Top	0	0

Table 5.3: Lateral load for each story of fifteen story building

5.2.2 Defining Nonlinear Load Case in ETABS2016

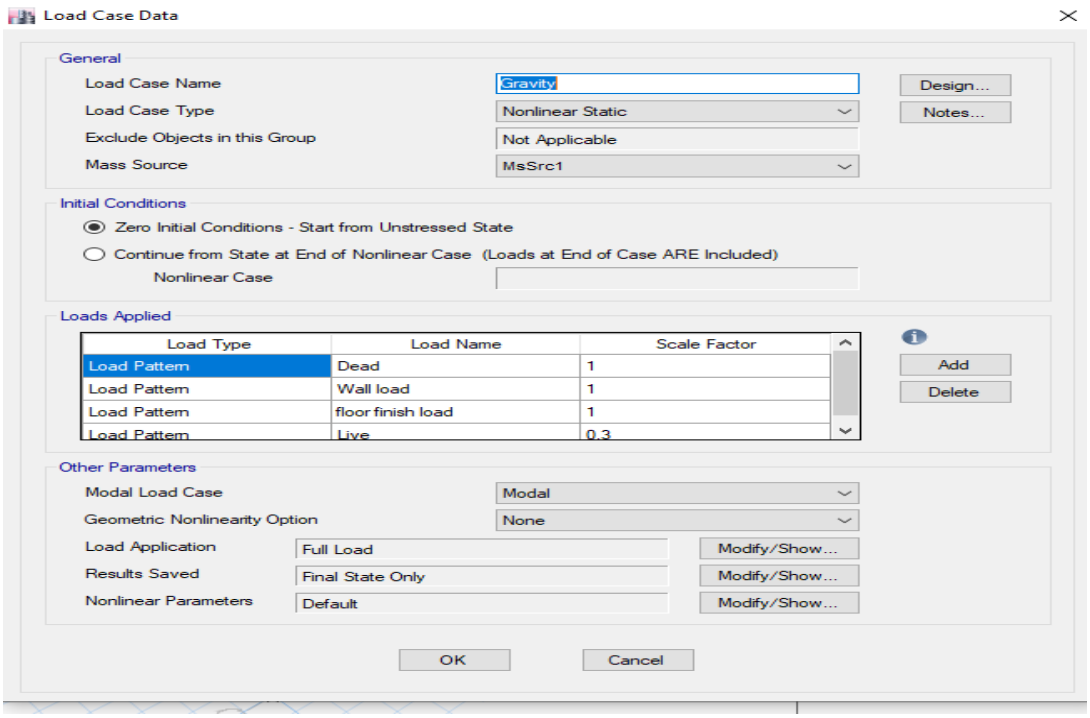


Figure 5.1: Defining nonlinear gravity load case in ETABS

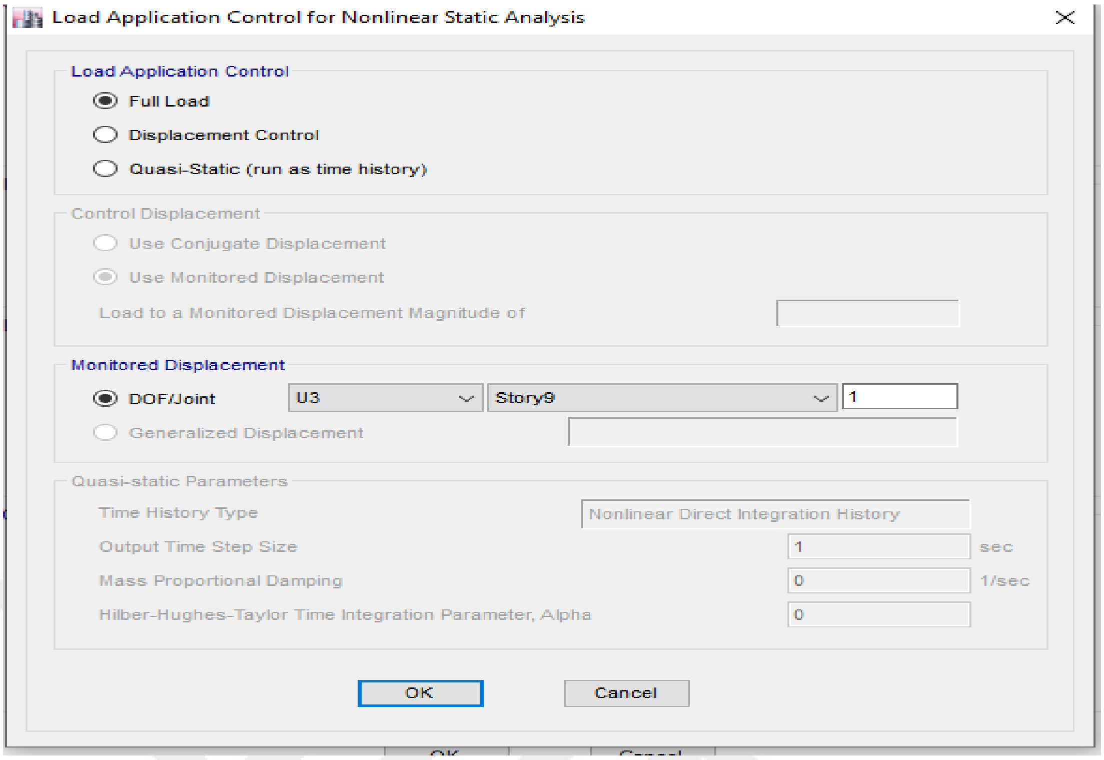


Figure 5.2: Load application control for nonlinear gravity load case

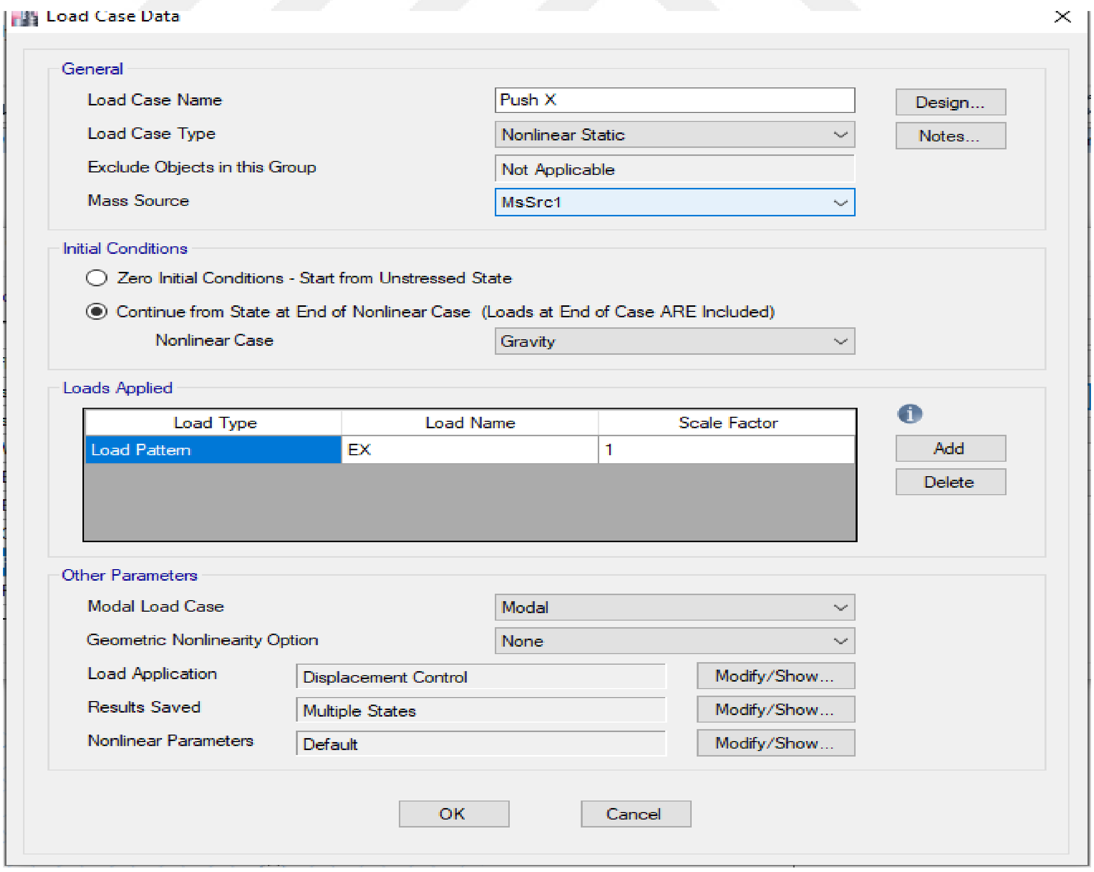


Figure 5.3: Defining pushover load case in X-direction

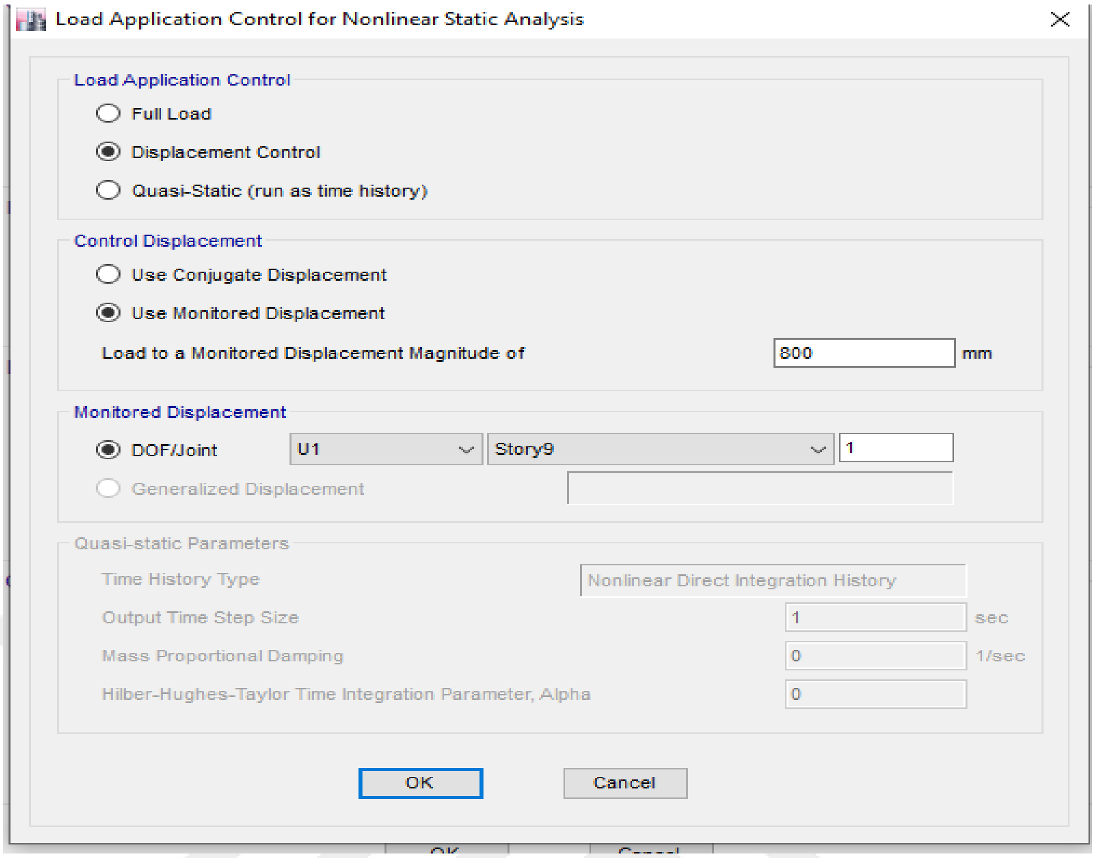


Figure 5.4: Load application control for pushover load case in X-direction

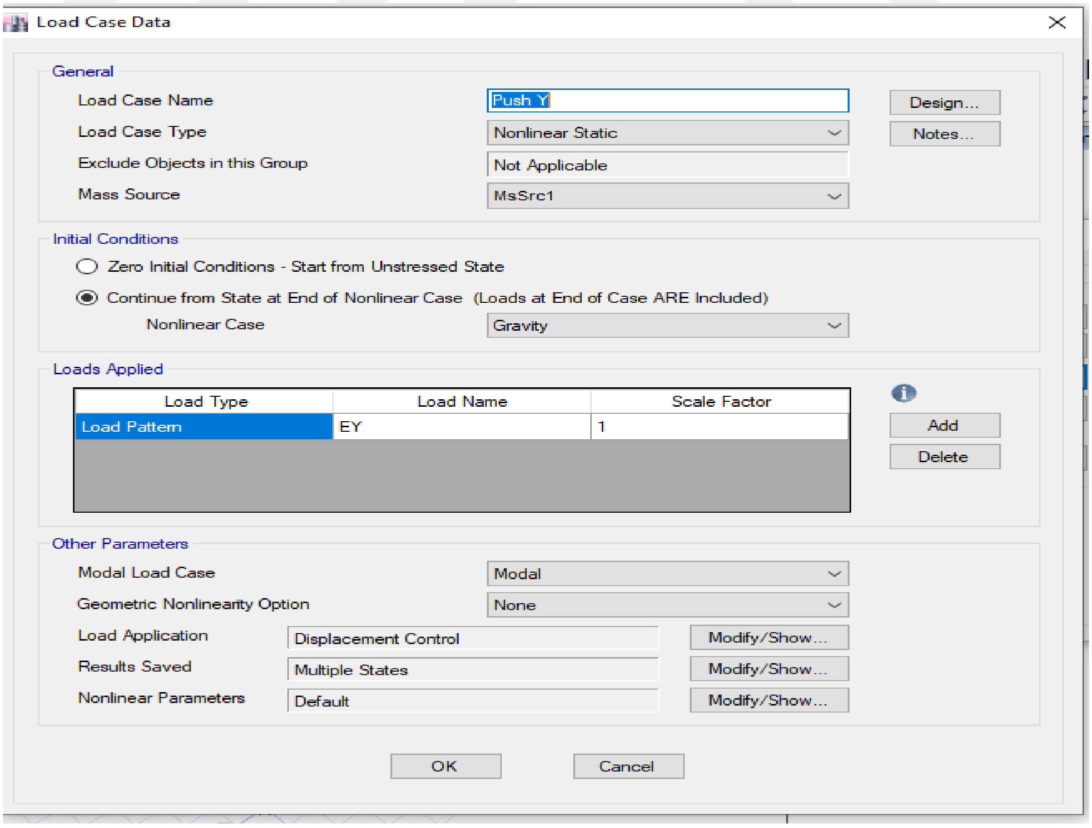


Figure 5.5: Defining pushover load case in Y-direction

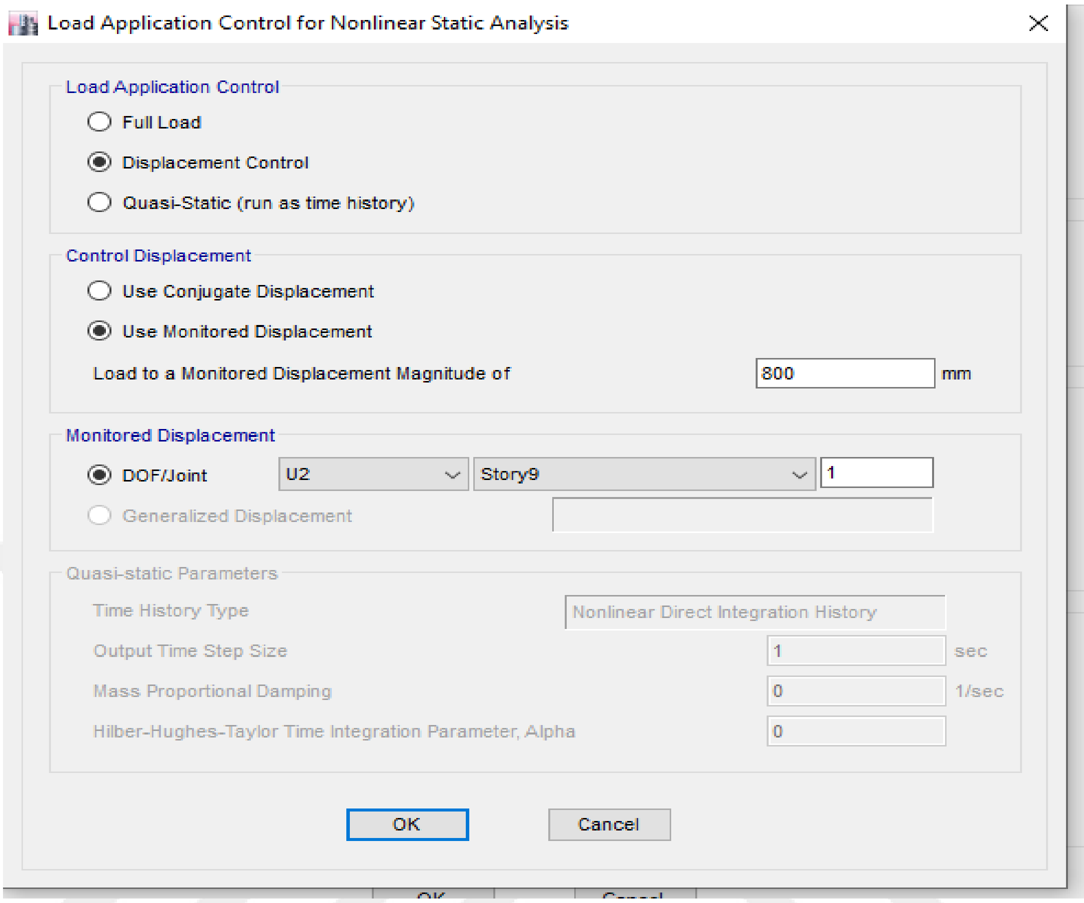


Figure 5.6: Load application control for pushover load case in Y-direction

The above figures show how the nonlinear load cases are defined in ETABS software. Gravity load case is force-controlled (pushed to a specified force level) and pushover load in X and Y direction is displacement-controlled (pushed to a specified displacement).

5.3 Defining Hinge Properties at the End of Columns and Beams

Hinges properties are assigned at the distance of 5 percent of length of beams or columns from end of beams or columns. There are two types of hinges which can be assigned to the end of members, one is user-defined hinge and other is auto hinge type. Auto hinge is used in this analysis. The below Figures show how hinges are defined and assigned to the end of columns and beams.

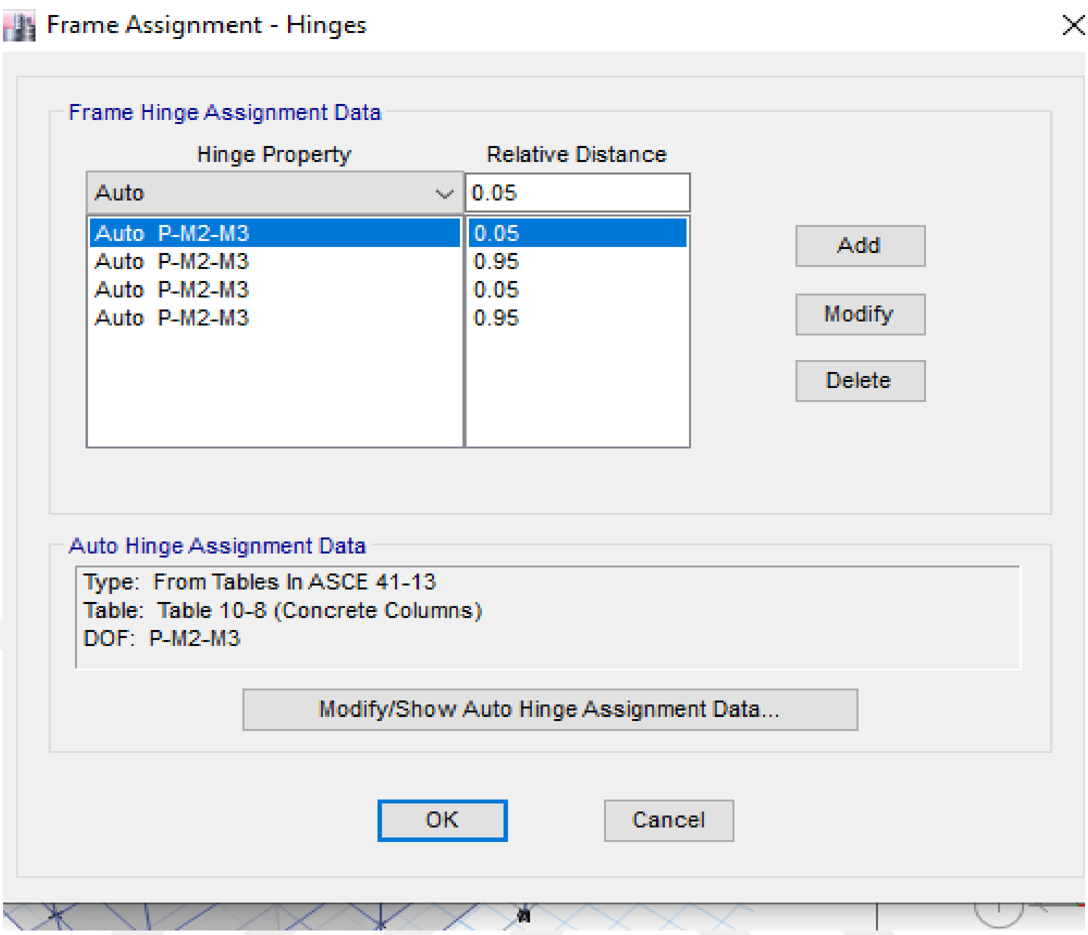


Figure 5.7: Assigning of hinges to the columns

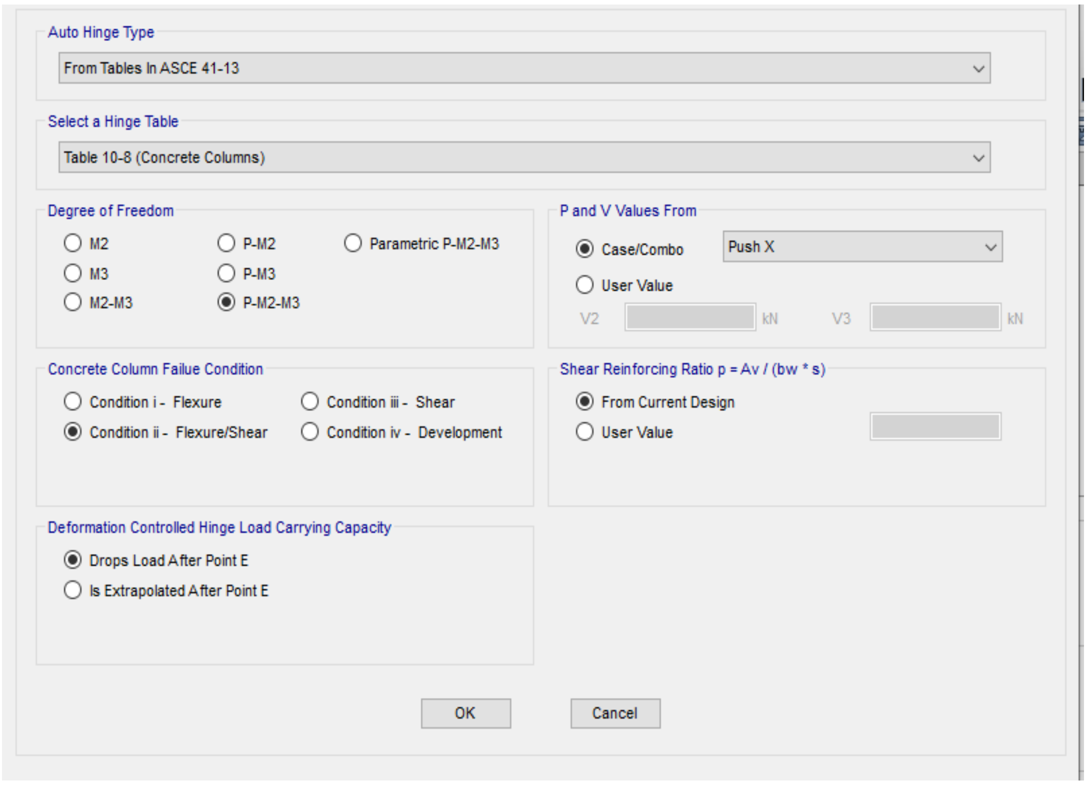


Figure 5.8: Assigning of hinges to the columns for push X load

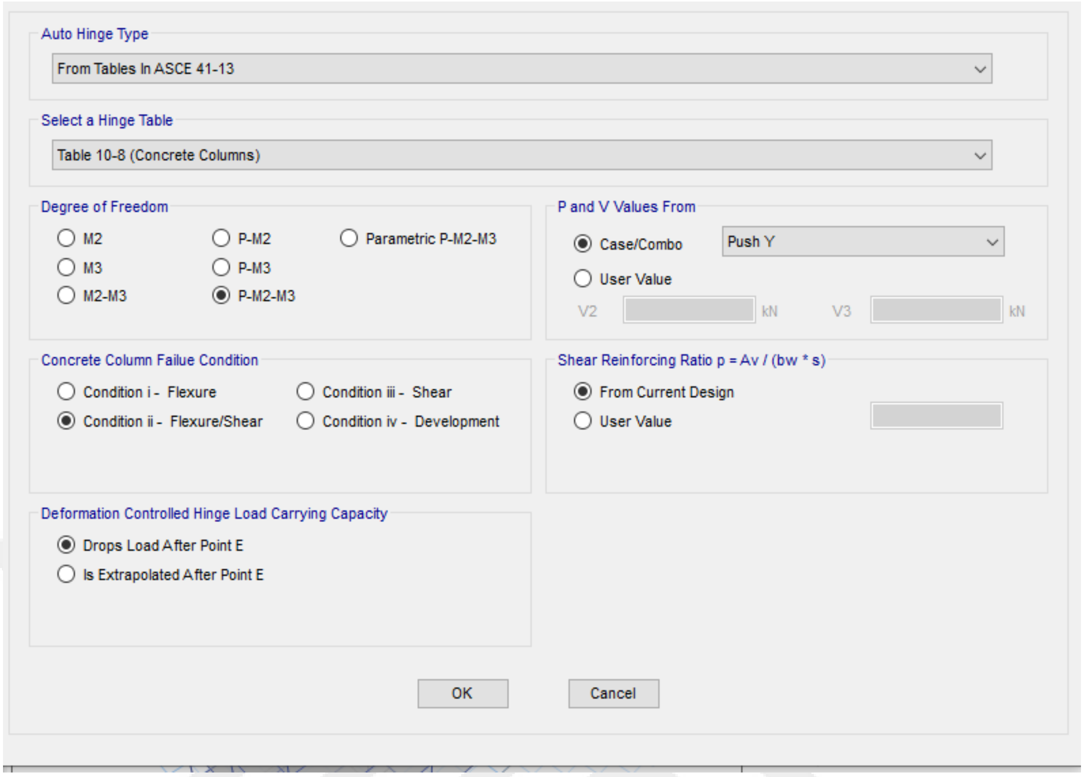


Figure 5.9: Assigning of hinges to the Columns for push Y load

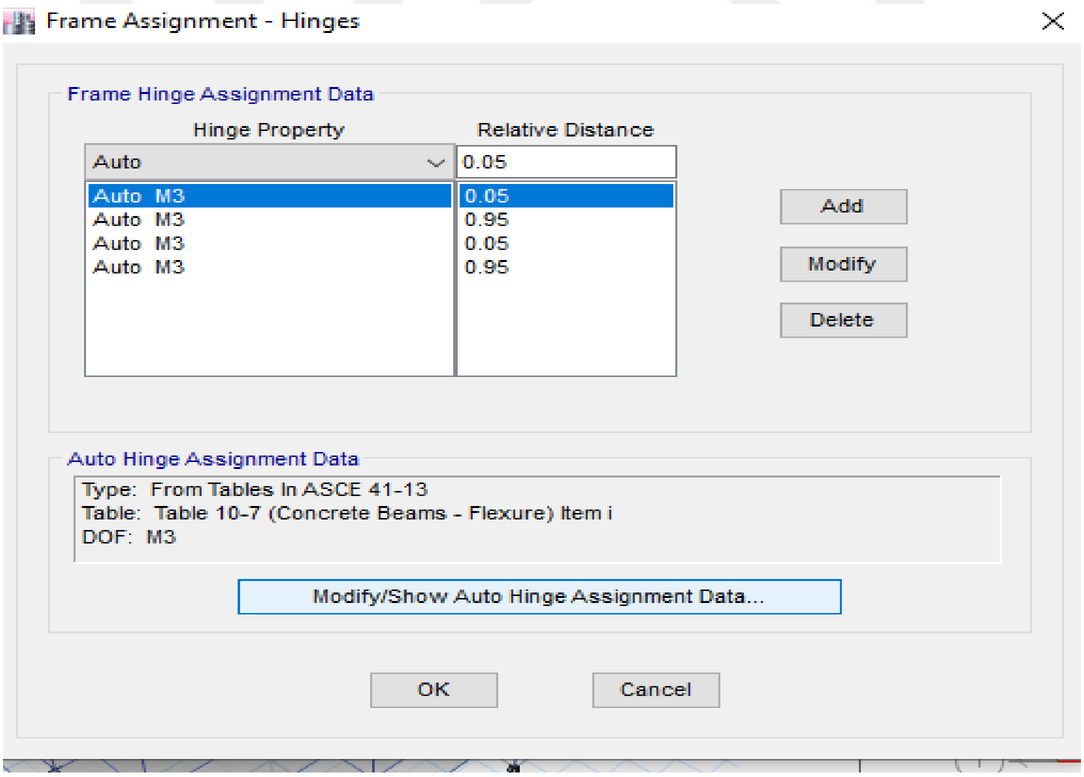


Figure 5.10: Assigning of hinges to the beams

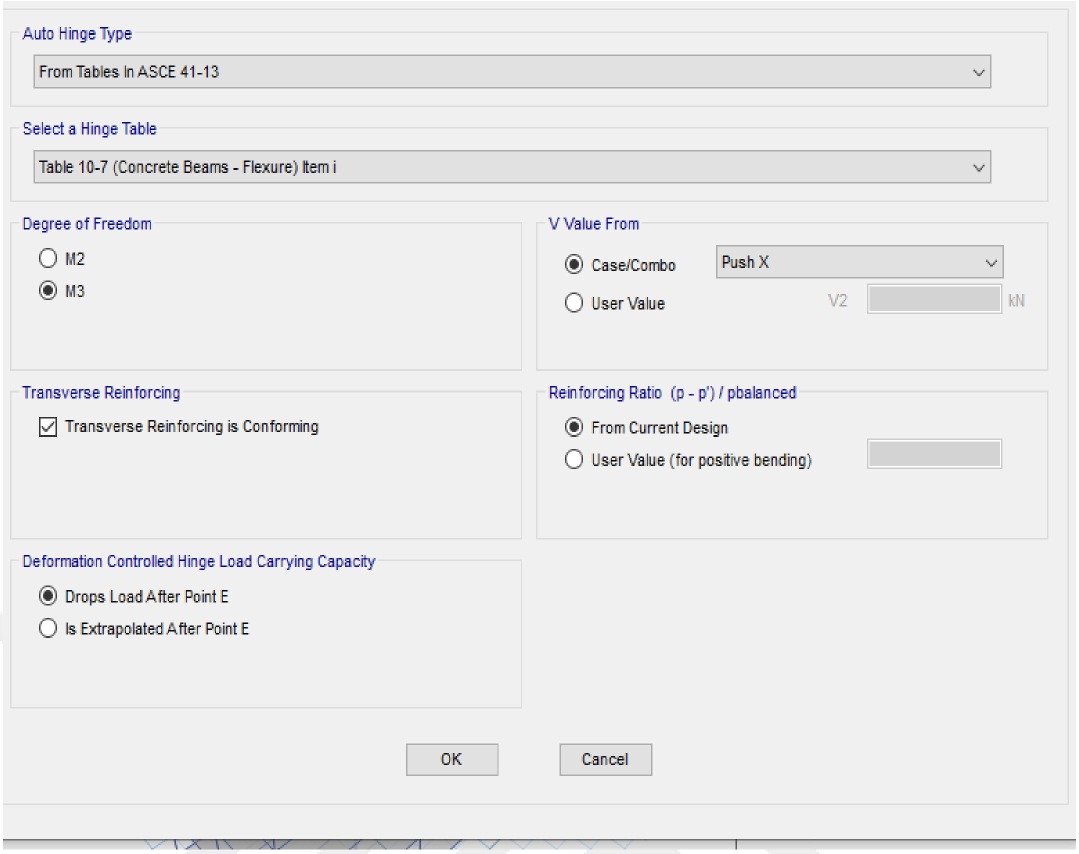


Figure 5.11: Assigning of hinges to the beams for push X load

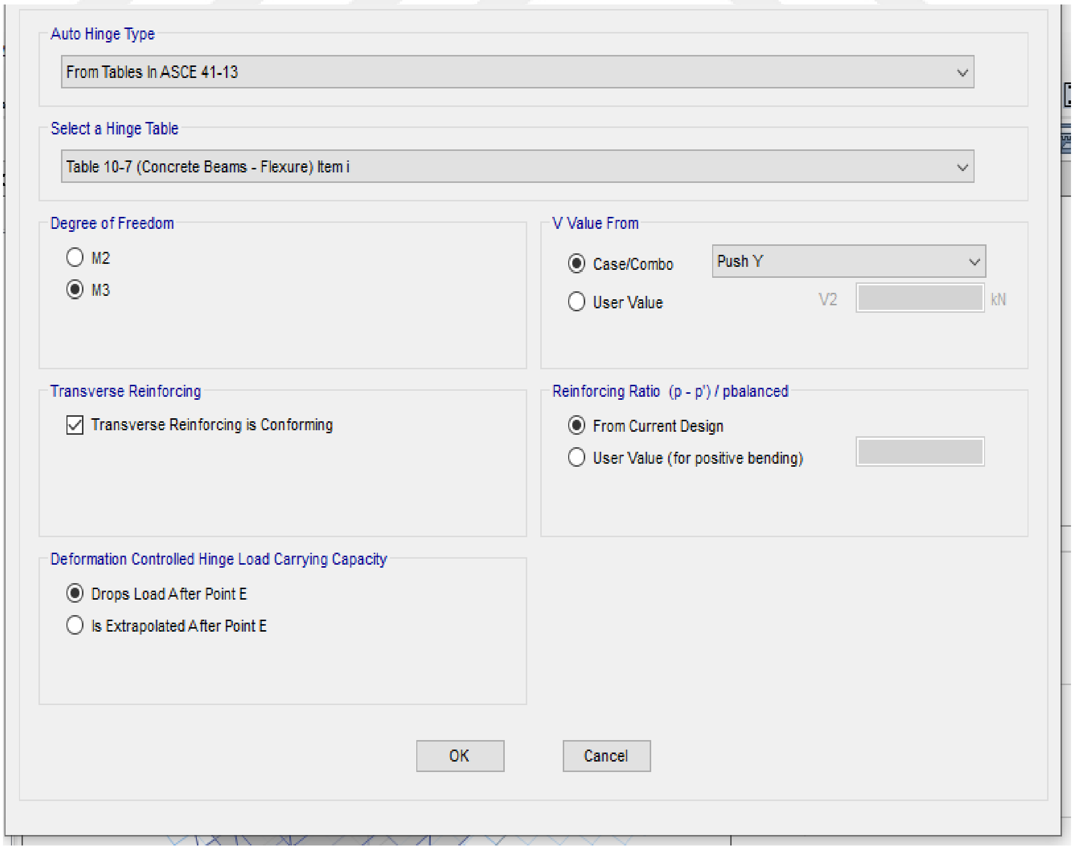


Figure 5.12: Assigning of hinges to the beams for push y load

When the nonlinear load cases are defined and hinge properties are assigned at the end of beams and columns, the structures run for nonlinear pushover analysis.

5.4 Defining Buckling Load Case

In this study buckling analysis is performed for all three buildings by using ETABS2016. Before the analysis, the buckling load case is defined. When the analysis is completed the buckling factor for each mode is generated and buckling load for each mode is calculated by multiplication of buckling factor of that mode and applied loads. Buckling load= Buckling factor*applied loads (Dead load + live load).

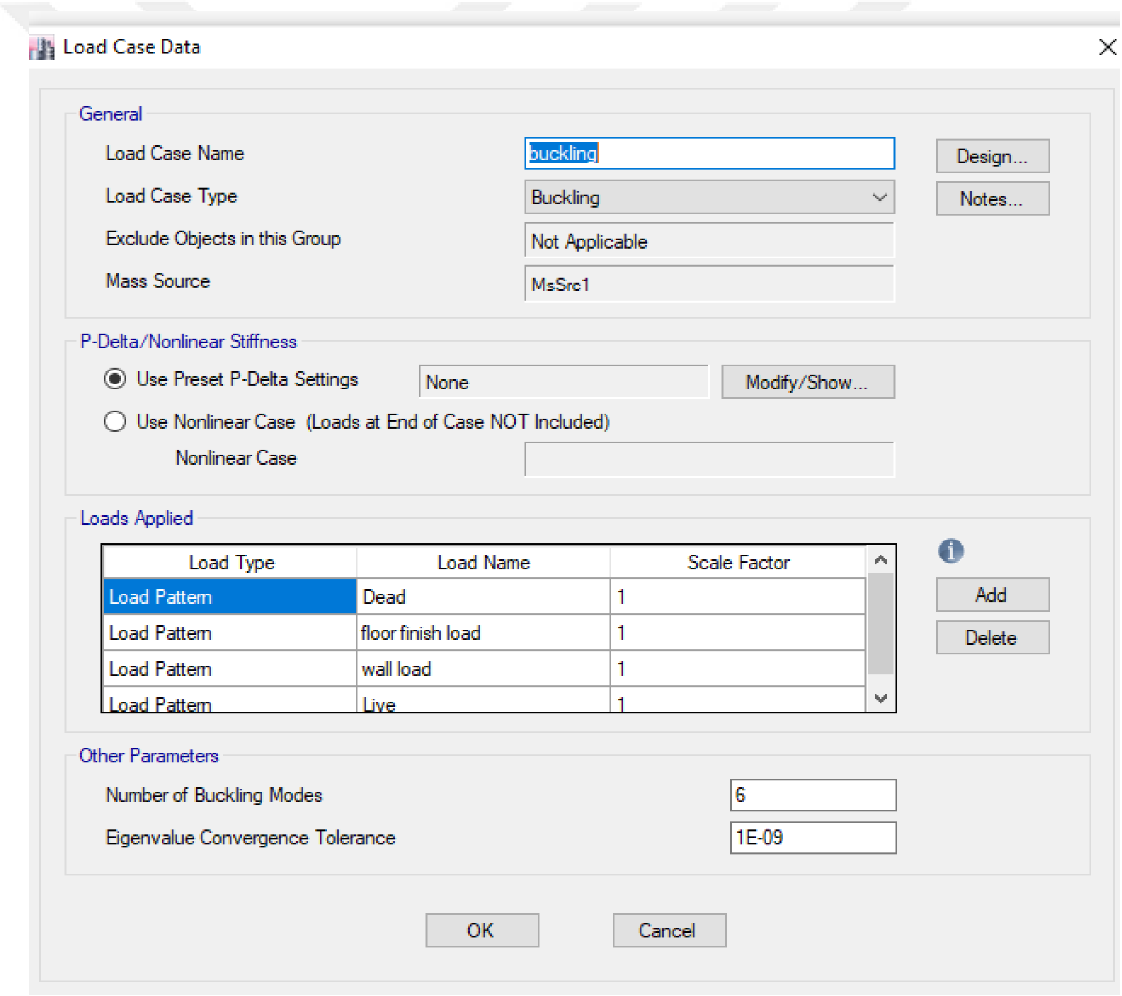


Figure 5.13: Defining of buckling load case

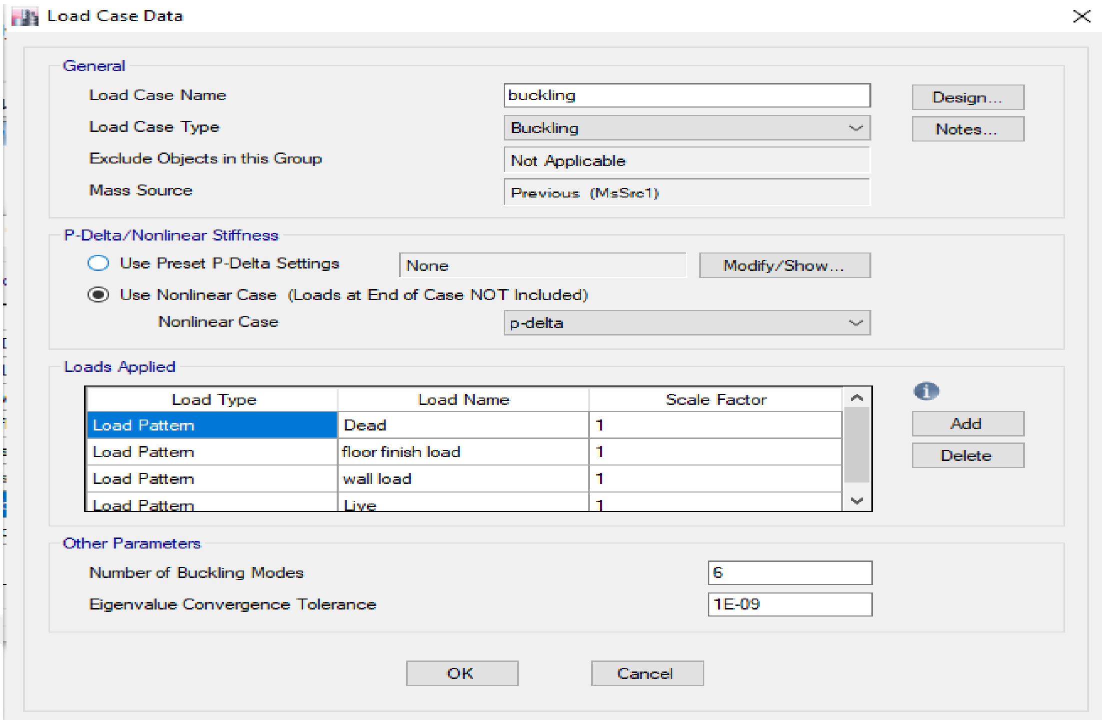


Figure 5.14: Defining of buckling load case considering P-delta effect

The above figures show how the buckling load case is defined in ETABS2016. Here the applied loads are dead load (self-weight of structure, wall load and surface finish load) and live load. The number of buckling modes is six.

5.5 Defining P-delta Load Case

In present study the geometric nonlinear analysis (P-delta Analysis) has been performed for all three RCC buildings (G+3, G+9, and G+15) by using ETABS2016. The aim of this study is to evaluate the effect of geometric nonlinearity for low rise and mid ride buildings. The load combination which is considered in this analysis is dead load + 30 % of live load. Dead load includes self-weight of structure, wall load and surface finish load. The figures below show how P-delta load case is defined in ETABS2016.

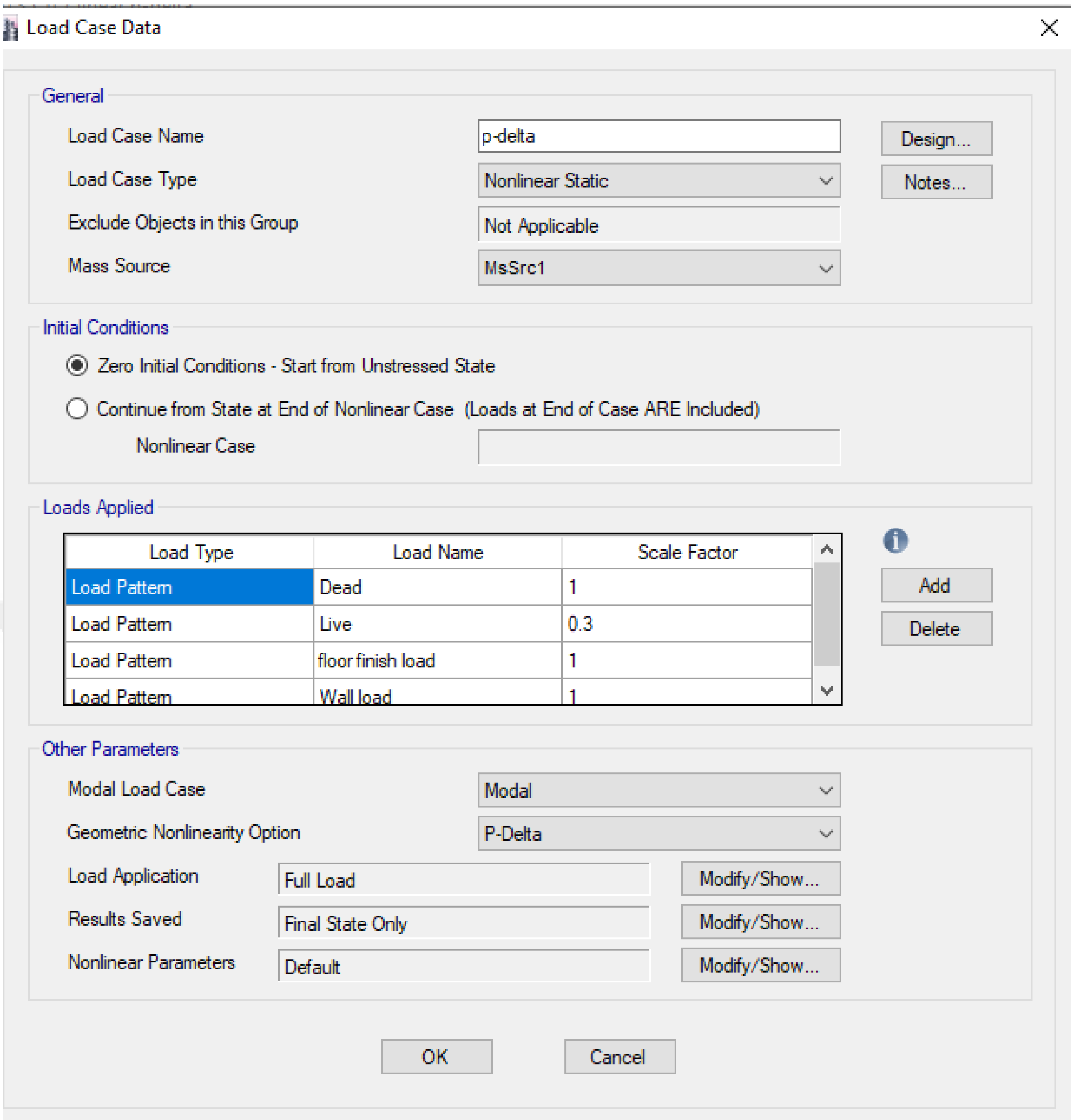


Figure 5.15: Defining P-delta load case

5.6 Example of Pushover and Buckling Analysis of 2D Frame

In case of knowing the basic concept of nonlinear static pushover analysis and buckling analysis of RCC buildings in ETABS, analysis of a simple 2D frame has been done. The columns and beams are selected as reinforced concrete columns and beams with different sizes and different material properties. The 2D frame model is three storied high and each story height is 3m. This model has one bay in the X-direction of 24m and spacing between each column is 8m. the size of column in the first story is 450mmX350mm and in the second and third stories is 400X300mm. The properties of concrete for columns is M25 grade (25N/mm^2) and steel fe415 grade (415N/mm^2). The size of beams in the first story is 500mmX300mm and in the second and third stories is 400mmX300mm. The properties of concrete for beams is M20 grade and of steel fe415. the program it-self consider the dead load of sections, therefore there is no need to calculate the dead load of beams and columns. For this frame the wall load for the first and second stories is 10.35 KN/m and for the third story is 4.05 KN/m because of parapet wall. The frame which is going to be used for this analysis is frame 1 of 3 story RCC building. Therefore, the live load on the slab and the dead load of slabs are transferred to the frame. The live load which comes from slabs to the beams of frame 1 is 5.15KN/m and the dead load of slab is 10.26 KN/m. By defining the grid in ETABS2016 the sections are selected and different loads are applied. The figures below show how different loads are applied to the frame 1.

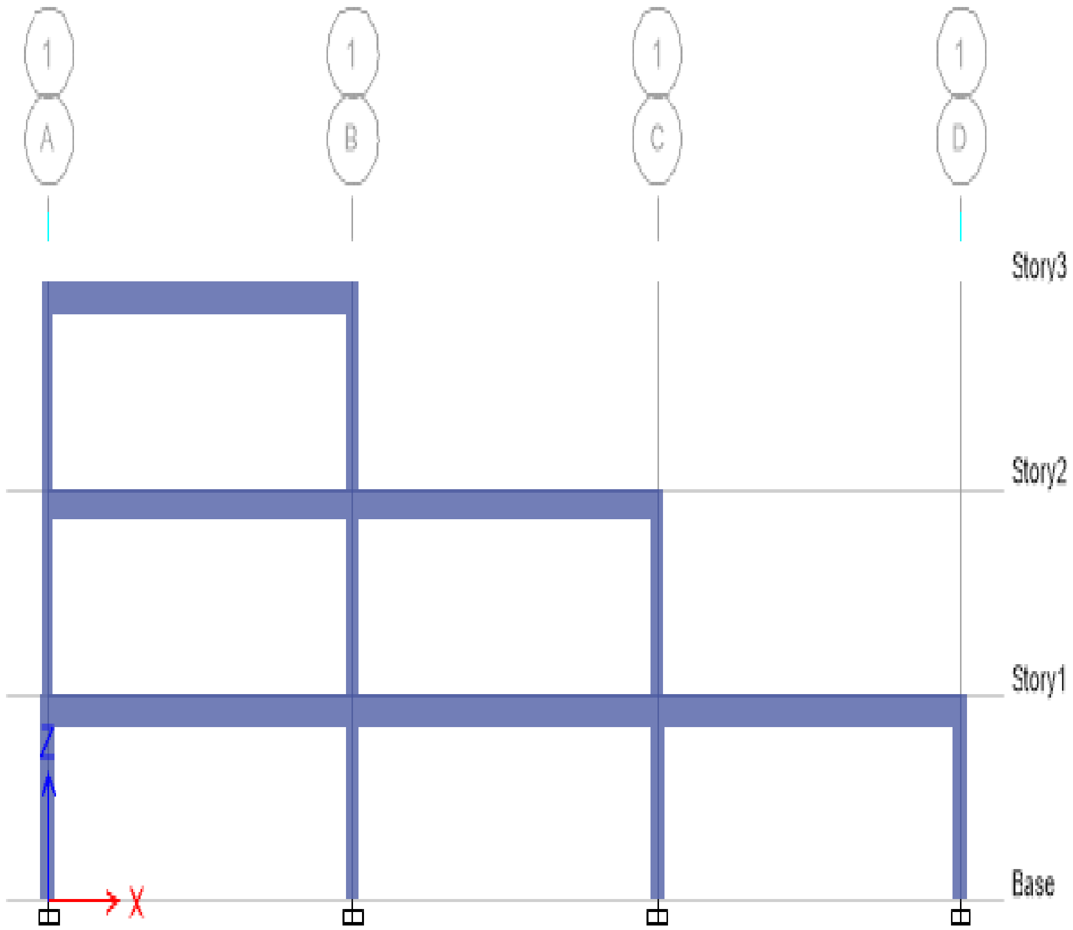


Figure 5.16: Elevation of frame 1

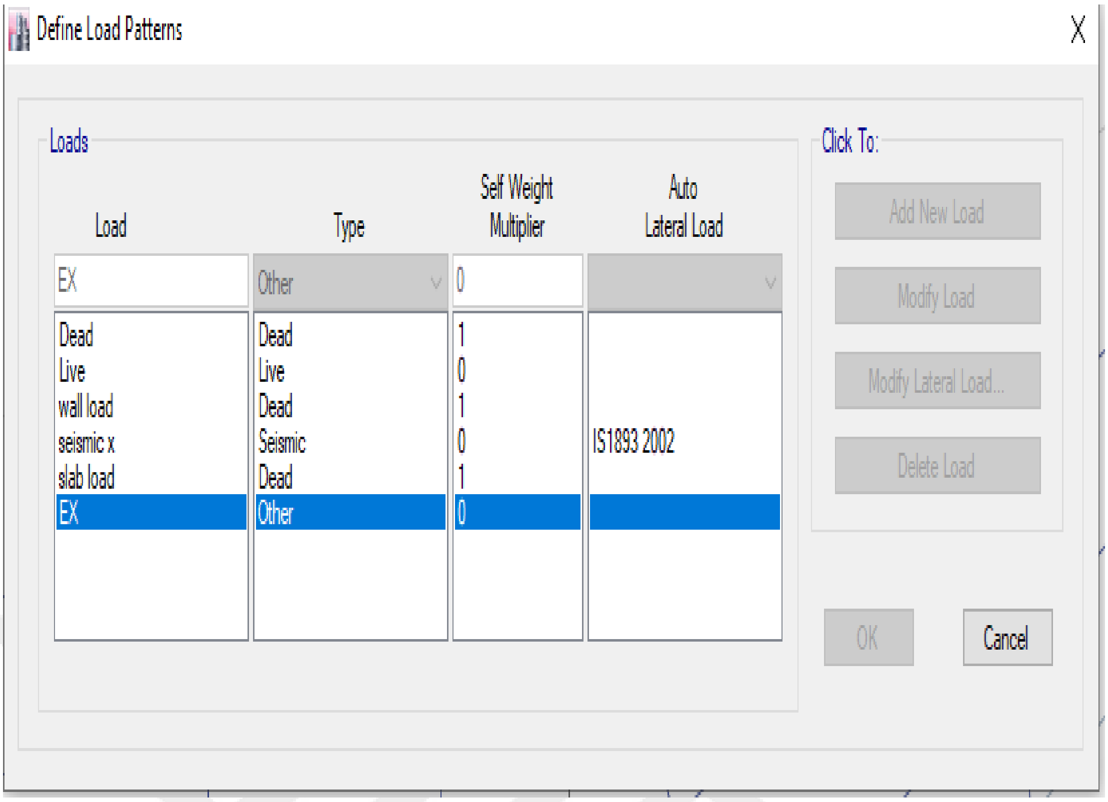


Figure 5.17: Defining load pattern in ETABS

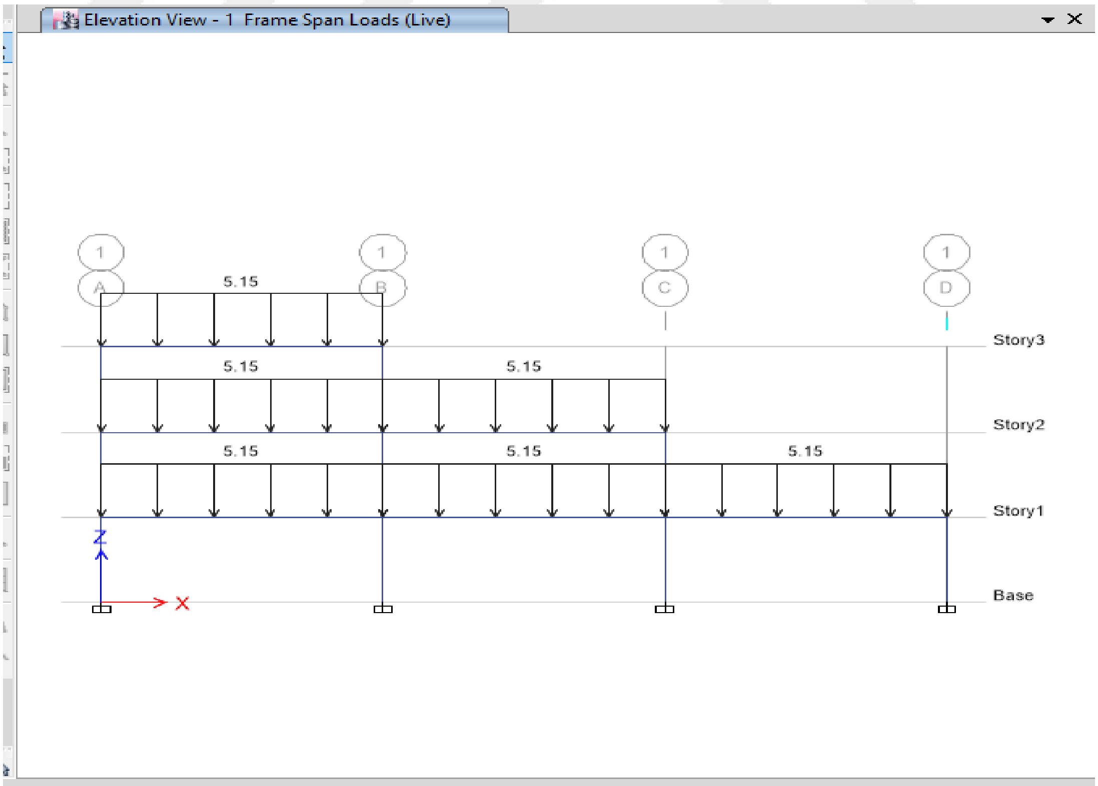


Figure 5.18: Assigning of live load from slab to frame 1 in ETABS

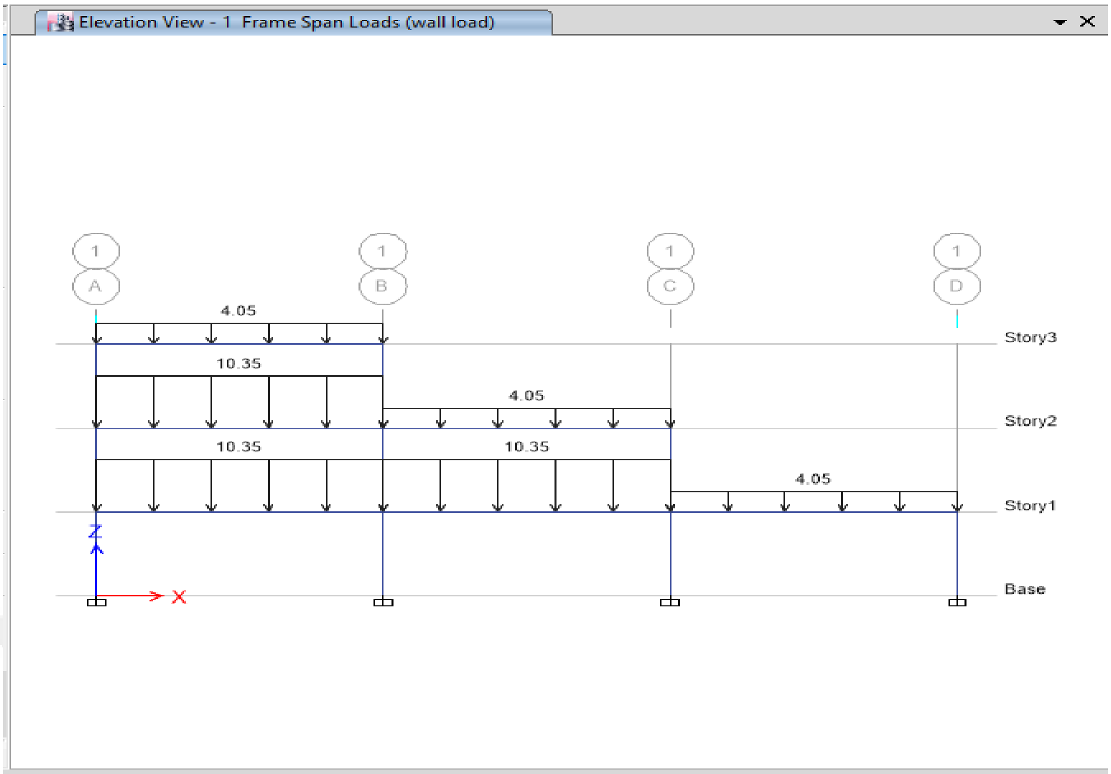


Figure 5.19: Assigning of wall load to frame 1 in ETABS

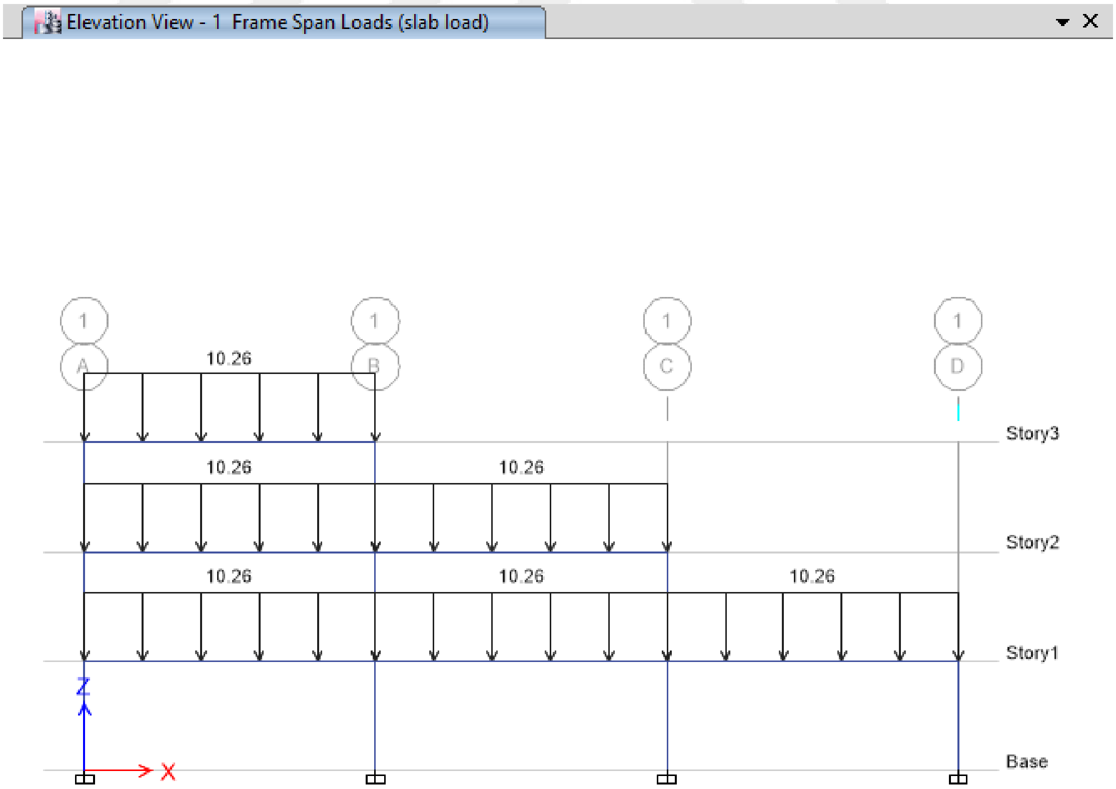


Figure 5.20: Assigning of slab dead load to the frame 1 in ETABS

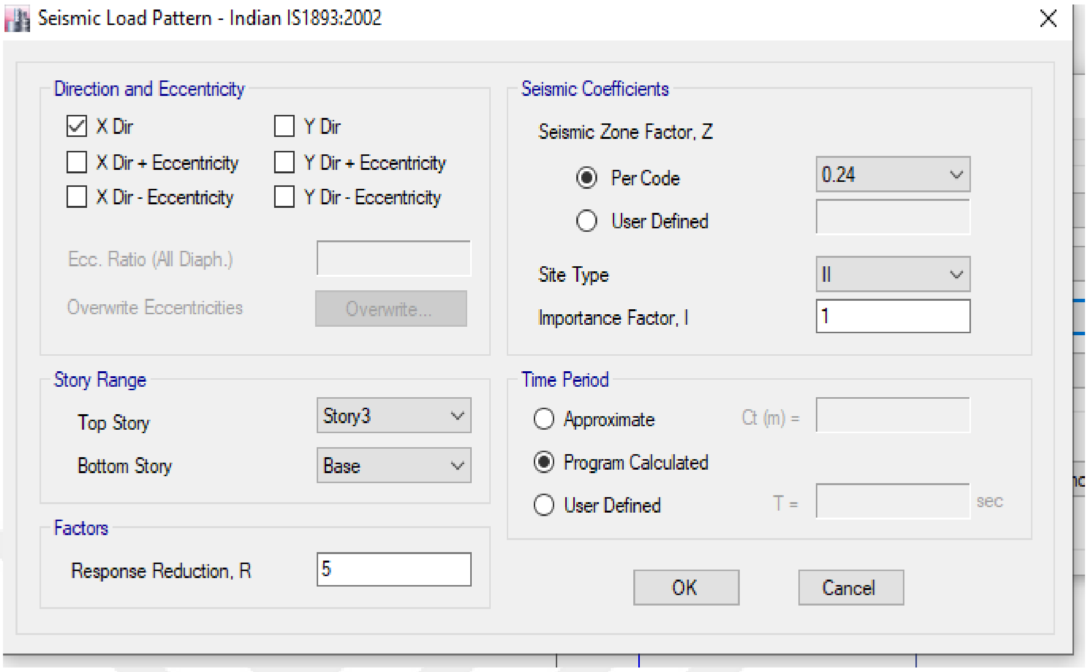


Figure 5.21: Equivalent lateral load pattern according to IS 1893-2000 in ETABS

After selecting the structural members and assigning all loads, the model is run for linear static analysis and design of structural members is done in ETABS2016. In case of nonlinear pushover analysis and buckling load analysis, the nonlinear load cases and buckling load case are defined and the hinge properties are assigned at the 5% distance of length of columns and beams from the ends. ETABS2016 allows the user to assign hinges to the element. For this frame, default hinges based on ASCE 41-13 flexure hinges are assigned to the frame. For the beam element, M3 hinge is assigned, and for the column element, P-M2-M3 hinge is assigned. Geometric nonlinearity (P-delta effects) is considered for the analysis. Pushover analysis can be performed by applying lateral load to the structures. Therefore, FEMA documents describe three methods in this case. One of this method is equivalent lateral load distribution which is used in this analysis. IS1893-2000 part 1 is used to calculate lateral load for each story.

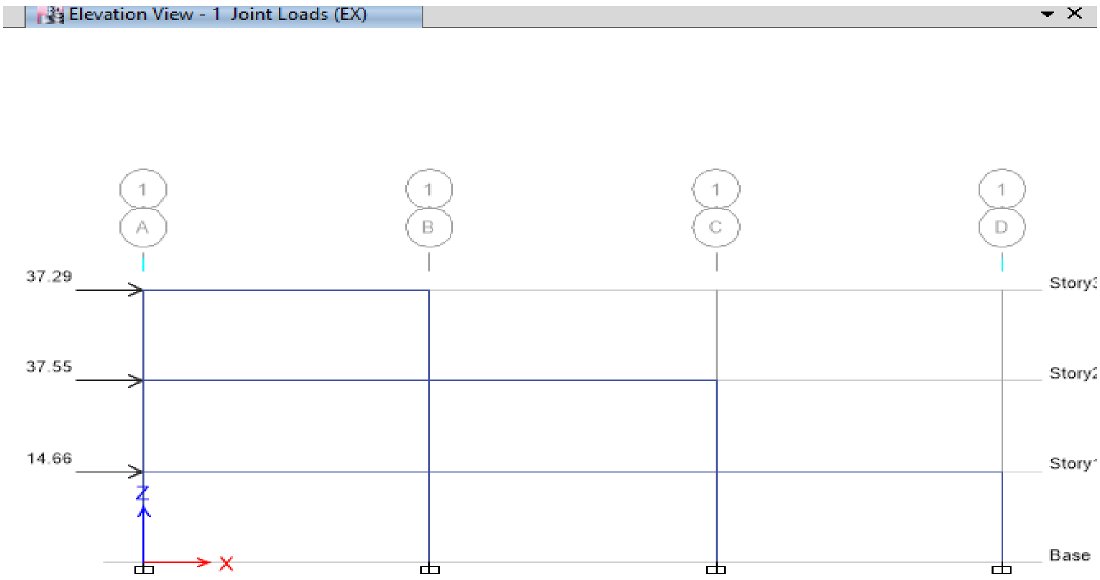


Figure 5.22: Assigning lateral load(KN) to the frame1 in horizontal direction

After defining of nonlinear load cases, buckling load case and assigning of hinge properties at the end of structural members, the frame is run for pushover analysis including geometric nonlinearity and buckling analysis.

Result of pushover analysis for 2D frame

Nonlinear static analysis of 2D frame carried out by using ETABS2016 software. The below figures show formation of plastic hinges and generation of pushover curve from result of pushover analysis for the given frame 1.

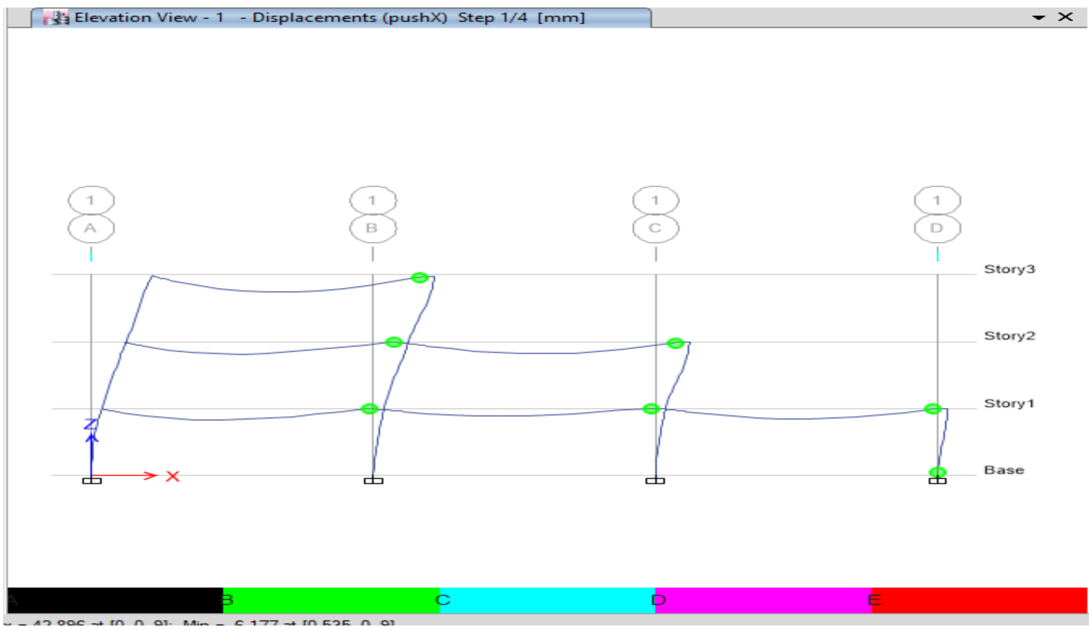


Figure 5.23: Formation of Plastic Hinge at Step 1 of Analysis

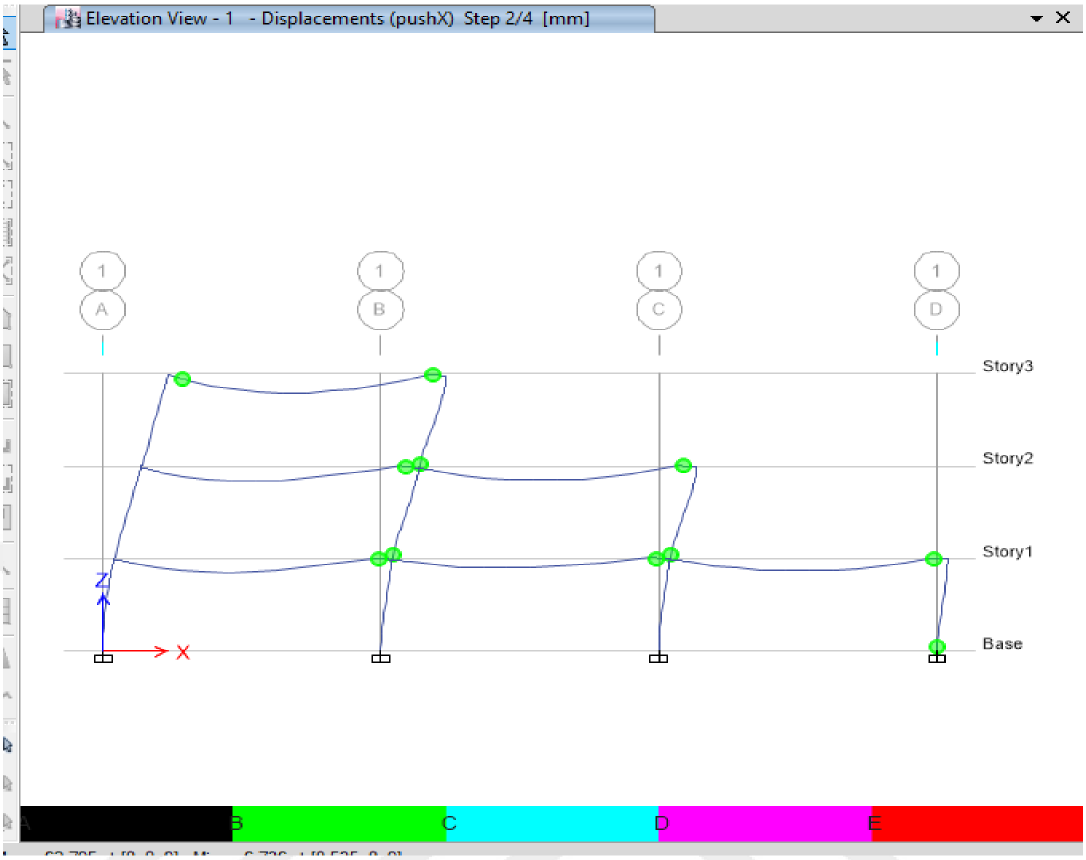


Figure 5.24: Formation of Plastic Hinge at Step 2 of Analysis

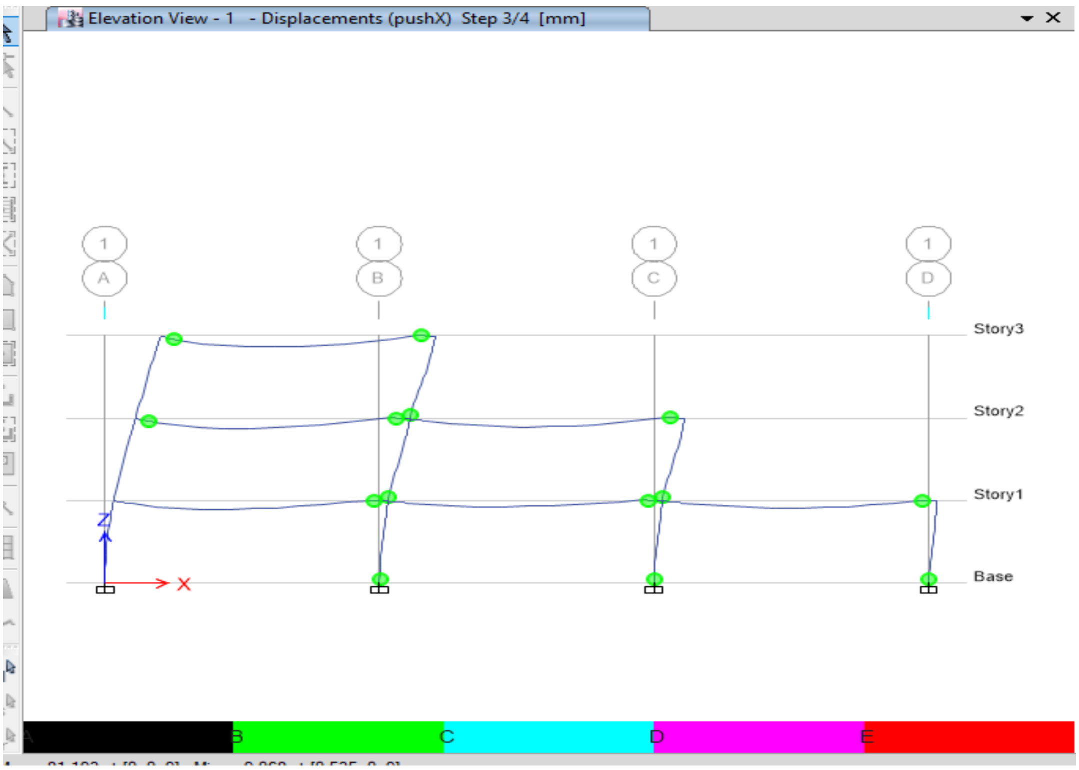


Figure 5.25: Formation of Plastic Hinge at Step 3 of Analysis

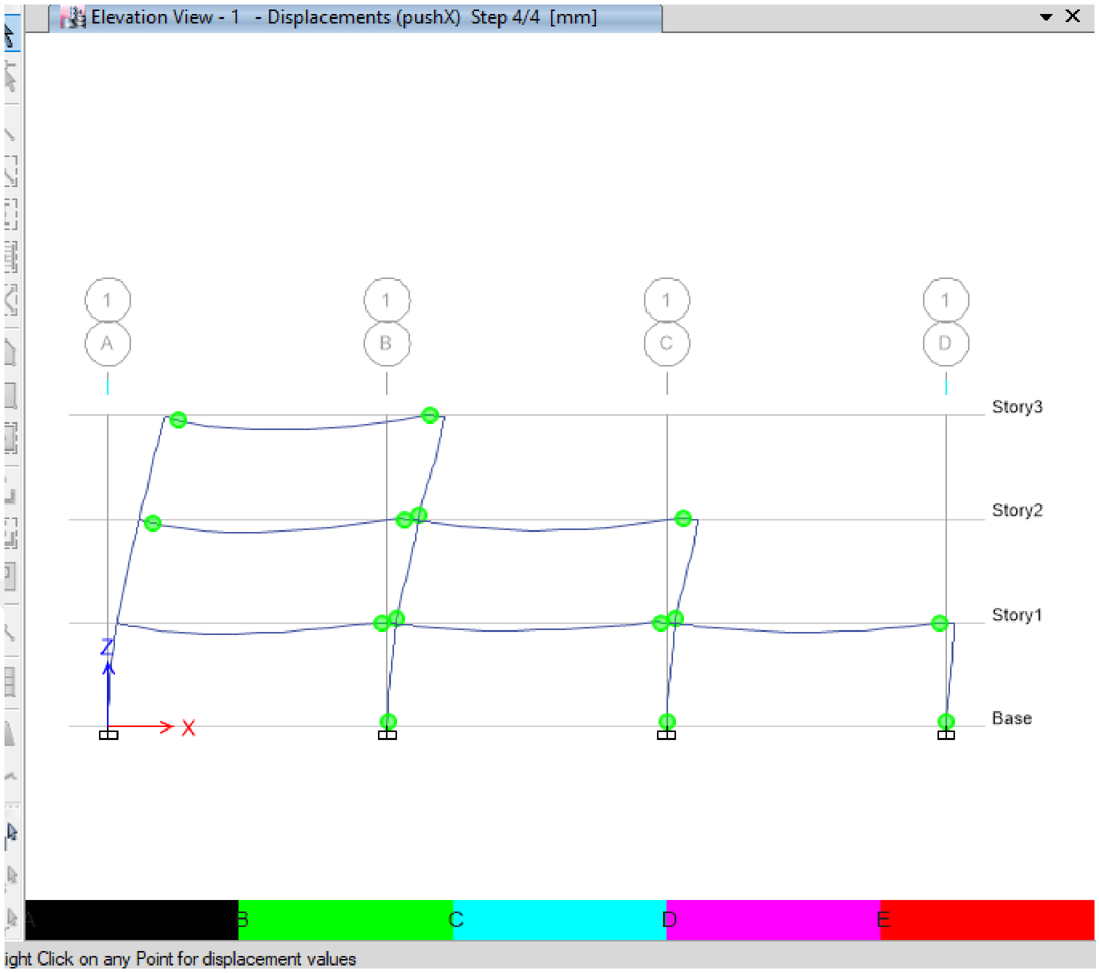


Figure 5.26: Formation of Plastic Hinge at Step 4 of Analysis

As its obvious from figures, the first yielding occurred at step one of the analysis on the beams only. More elements began to yield and more plastic hinges were formed as the frame was pushed monotonically. At step two plastic hinges appeared on some columns and beams and it appear even more on other ends of columns and beams at step three and four. All formed hinges are between point B and C. It means there is no failure member for this analysis and the frame is safe for the expected earthquake load. From the result pushover curve is obtained by plotting the base shear vs lateral displacement at various steps of analysis.

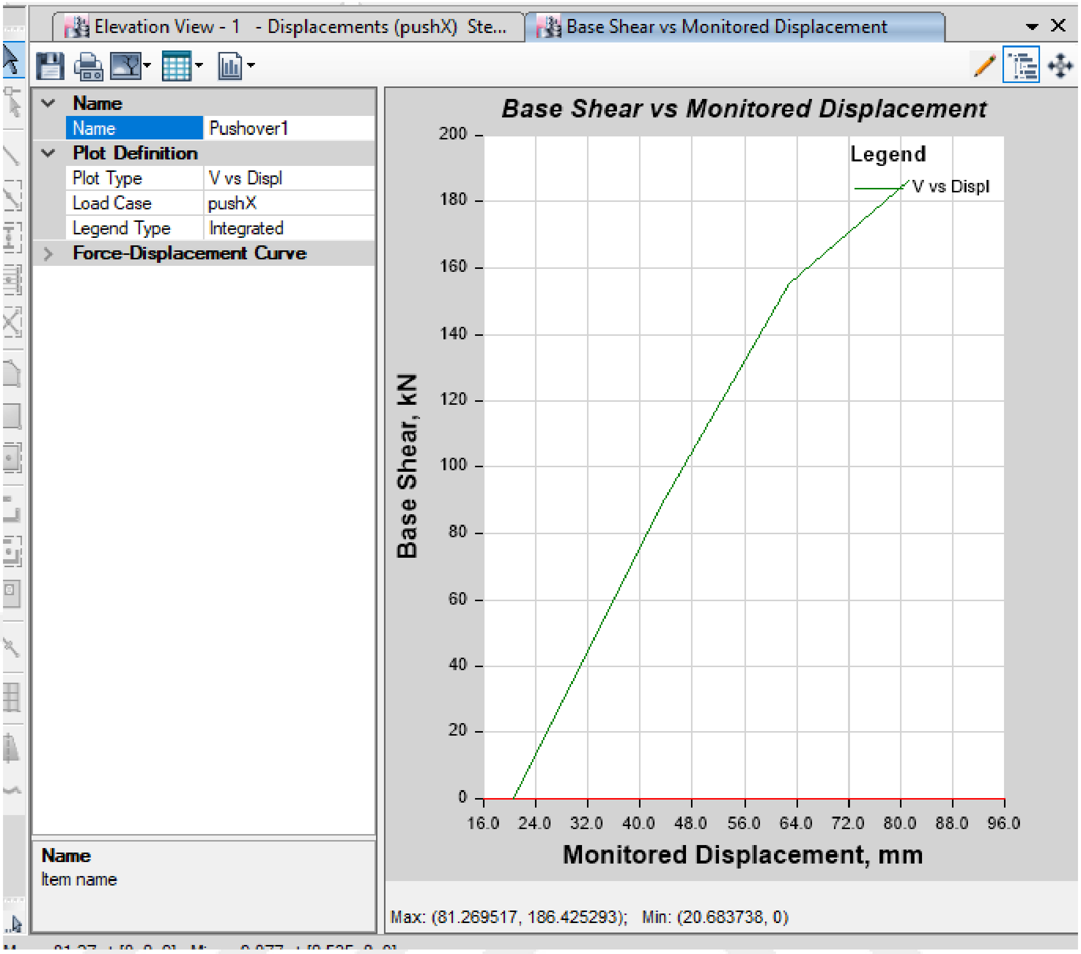


Figure 5.27: Pushover curve

Base Shear vs Monitored Displacement

Step	Monitored Displ mm	Base Force kN	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	20.68373...	0	24	6	0	0	0	30	0	0	0	30
1	42.89565...	87.26714...	23	7	0	0	0	30	0	0	0	30
2	62.79536...	155.2271...	19	11	0	0	0	27	3	0	0	30
3	81.19346...	186.3676...	16	14	0	0	0	24	6	0	0	30
4	81.26951...	186.4252...	16	14	0	0	0	24	6	0	0	30

Figure 5.28: Base shear vs Lateral displacement

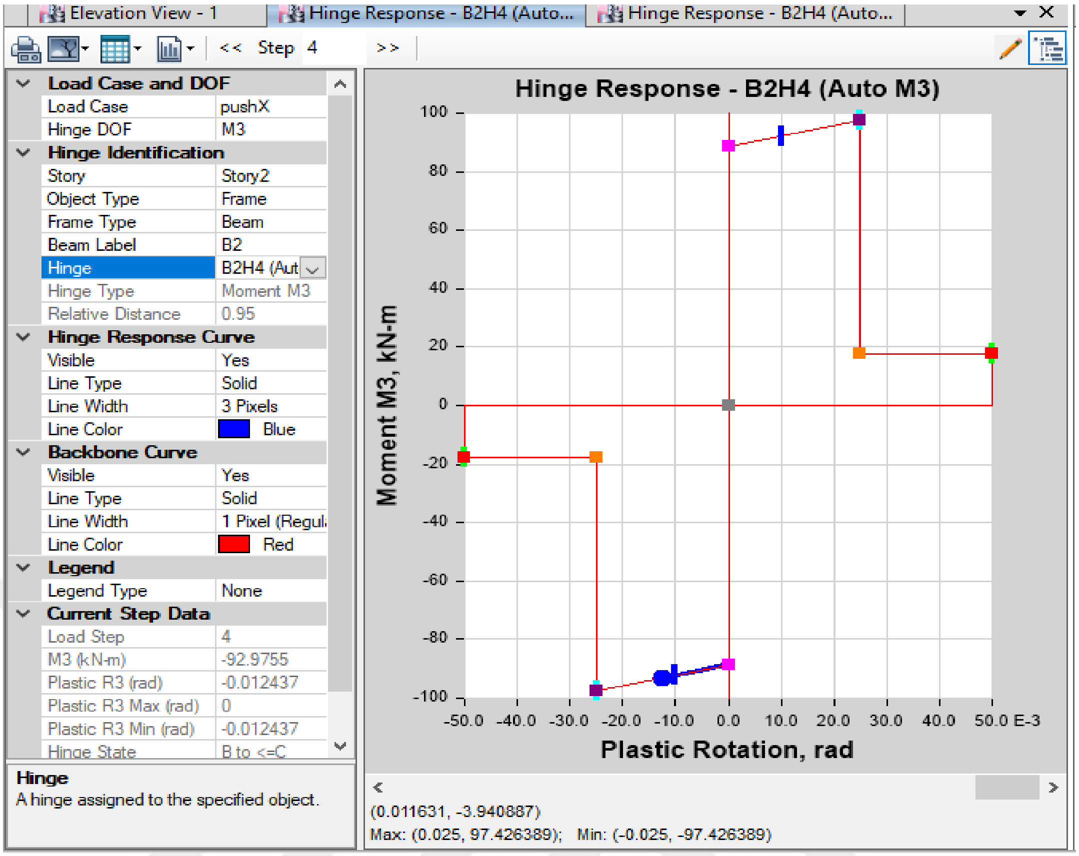


Figure 5.29: Moment vs Plastic rotation for beam (B2) second floor

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Response Values

Hinge Response Values

Step	M3 kN	R3 rad	R3 Max rad	R3 Min rad	State	Status
0	-88.7969	-0.000642	0	-0.000642	B to <=C	A to <=IO
1	-90.5594	-0.005617	0	-0.005617	B to <=C	A to <=IO
2	-92.071	-0.009884	0	-0.009884	B to <=C	A to <=IO
3	-92.9718	-0.012426	0	-0.012426	B to <=C	IO to <=LS
4	-92.9755	-0.012437	0	-0.012437	B to <=C	IO to <=LS

Figure 5.30: Moment vs Plastic rotation details for beam (B2) second floor

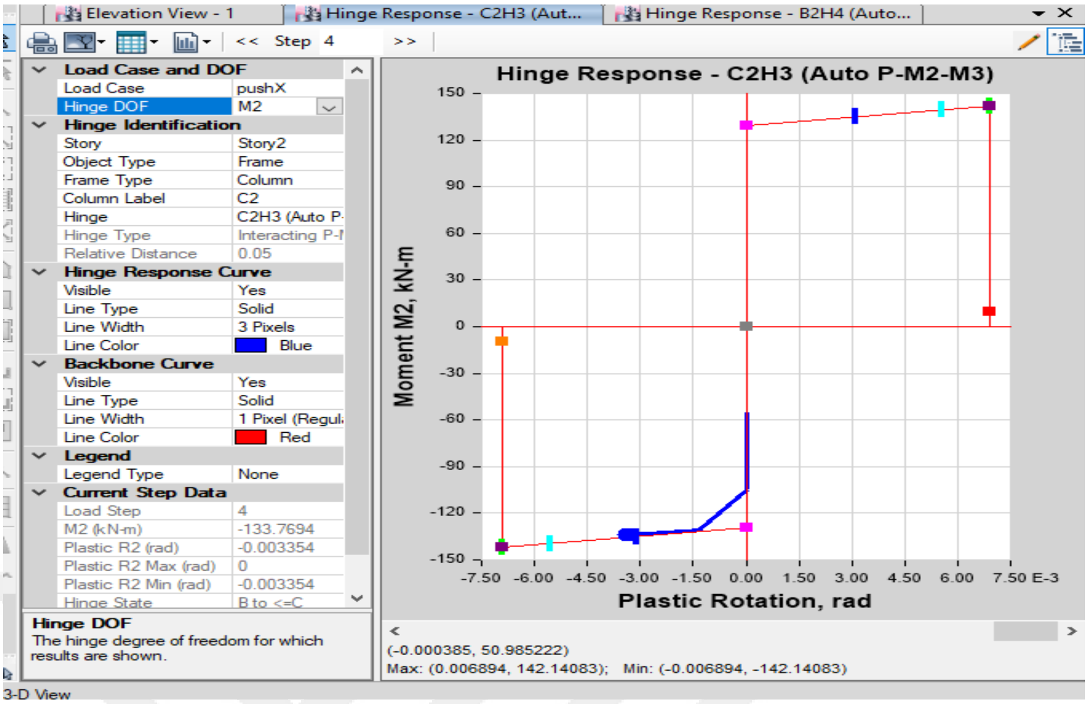

Figure 5.31: Moment vs Plastic rotation for column (c2) second floor

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Response Values

Hinge Response Values (Part 1 of 2)

Step	P kN	U1 mm	U1 Max mm	U1 Min mm	M2 kN	R2 rad	R2 Max rad	R2 Min rad	M3 kN	R3 rad	R3 Max rad
0	-861.5871	0	0	0	-55.2887	0	0	0	0	0	0
1	-870.1826	0	0	0	-104.633	0	0	0	0	0	0
2	-877.9557	0	0	0	-131.0568	-0.001337	0	-0.001337	-0.0014	1.728E-09	1.728E-09
3	-882.417	0	0	0	-133.7626	-0.003346	0	-0.003346	-0.0034	4.323E-09	4.323E-09
4	-882.3459	0	0	0	-133.7694	-0.003354	0	-0.003354	-0.0034	4.334E-09	4.334E-09

Hinge Response Values (Part 2 of 2)

R3 Min rad	State	Status
0	A to <=B	A to <=IO
0	A to <=B	A to <=IO
0	B to <=C	A to <=IO
0	B to <=C	IO to <=LS
0	B to <=C	IO to <=LS

Figure 5.32: Moment vs Plastic rotation details for column (C2) second floor

The above figures show that, how pushover curve is plotted in ETABS2016 which describes the relationship between base shear and lateral displacement. For this analysis the maximum base shear is 186.42 KN and maximum lateral displacement is 81,26mm. The moment vs plastic rotation relationship graphs and values for beam (B2) and column (C2) of second story is shown in the above figures.

Buckling analysis result

Buckling analysis has been performed in this analysis. The below figure shows the buckling factor for six modes.

Buckling Factors

1 of 6 Reload Apply

Case	Mode	Scale Factor
Buckling	1	51.358
Buckling	2	73.722
Buckling	3	111.422
Buckling	4	144.15
Buckling	5	200.664
Buckling	6	220.729

Figure 5.33: Buckling factor of structure

In the present work the buckling analysis of frame 1 (only for first mode) after formation of plastic hinges at the end of structural members (columns and beams) at each step of pushover analysis has been performed by adding manual hinges at place of plastic hinges generated. Here the value of moment-rotation from each formed plastic hinge is obtained and added to the manual hinge. The figures below show the result of buckling analysis of frame 1 at each steps of nonlinear pushover analysis.

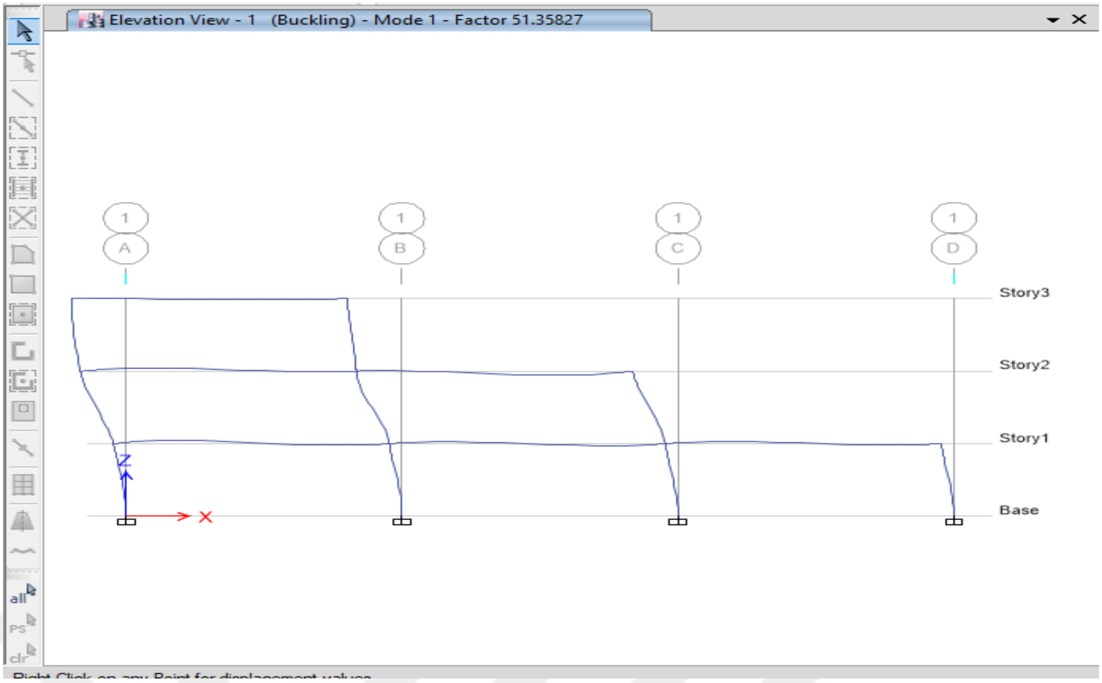

Figure 5.34: Buckling factor for the first mode of original structure

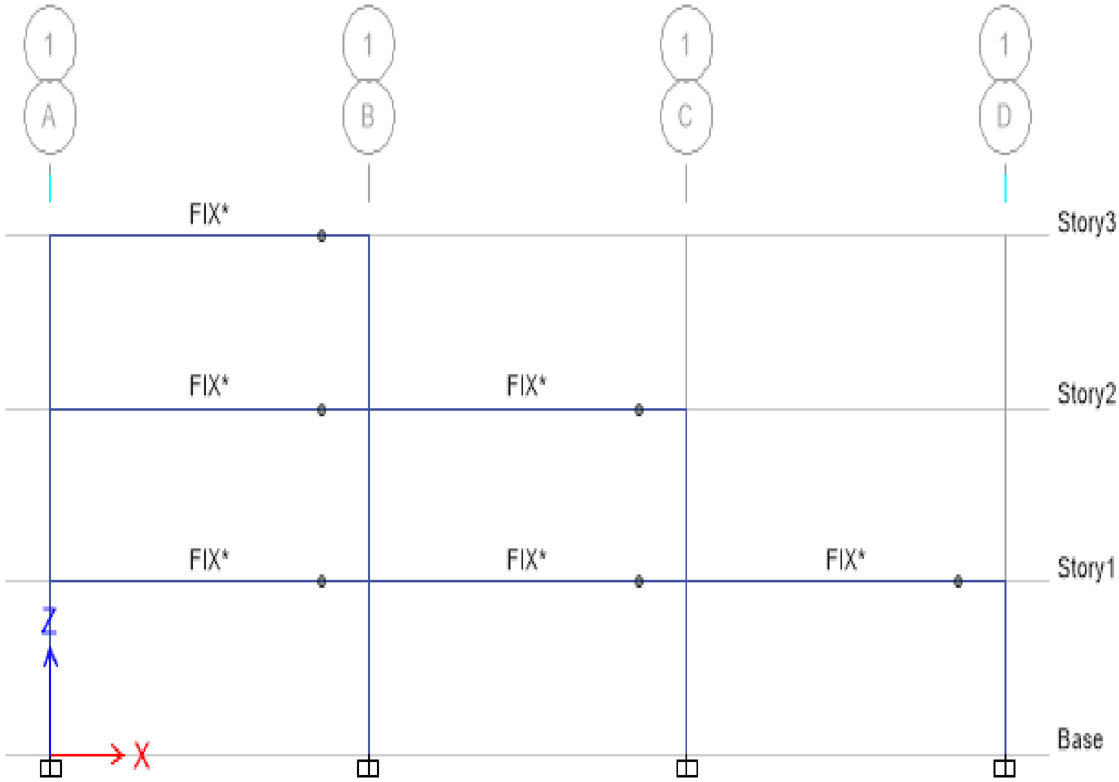

Figure 5.35: Adding hinges where plastic hinges observed at zero step of pushover analysis

Figure 5.36: Buckling factor for the first mode after adding hinges where plastic hinges observed at zero step of pushover analysis

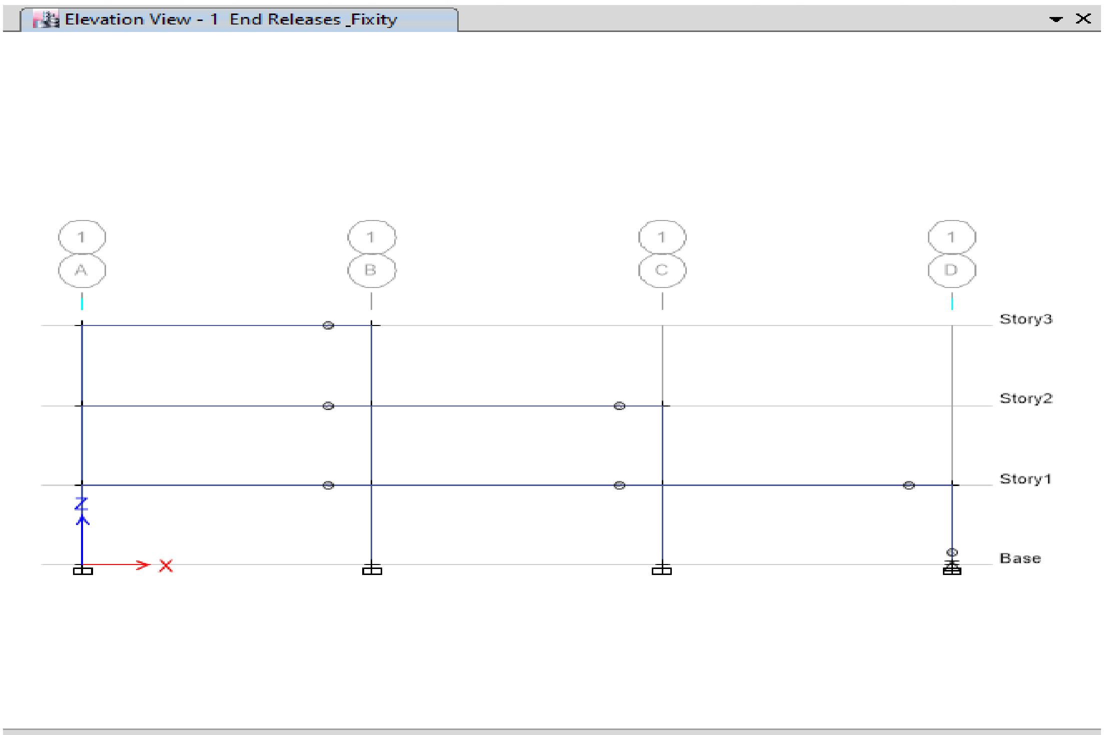

Figure 5.37: Adding hinges where plastic hinges observed at first step of pushover analysis

Figure 5.38: Buckling factor for the first mode after adding hinges where plastic hinges observed at first step of pushover analysis

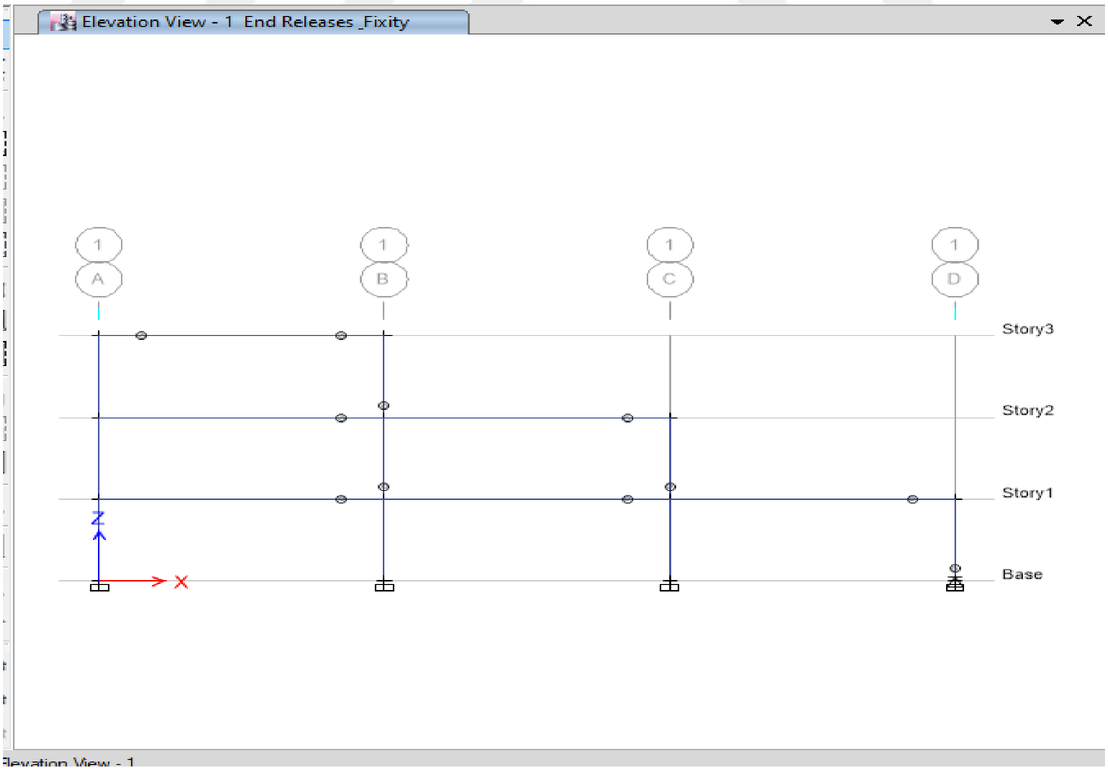

Figure 5.39: Adding hinges where plastic hinges observed at second step of pushover analysis

Figure 5.40: Buckling factor for the first mode after adding hinges where plastic hinges observed at second step of pushover analysis

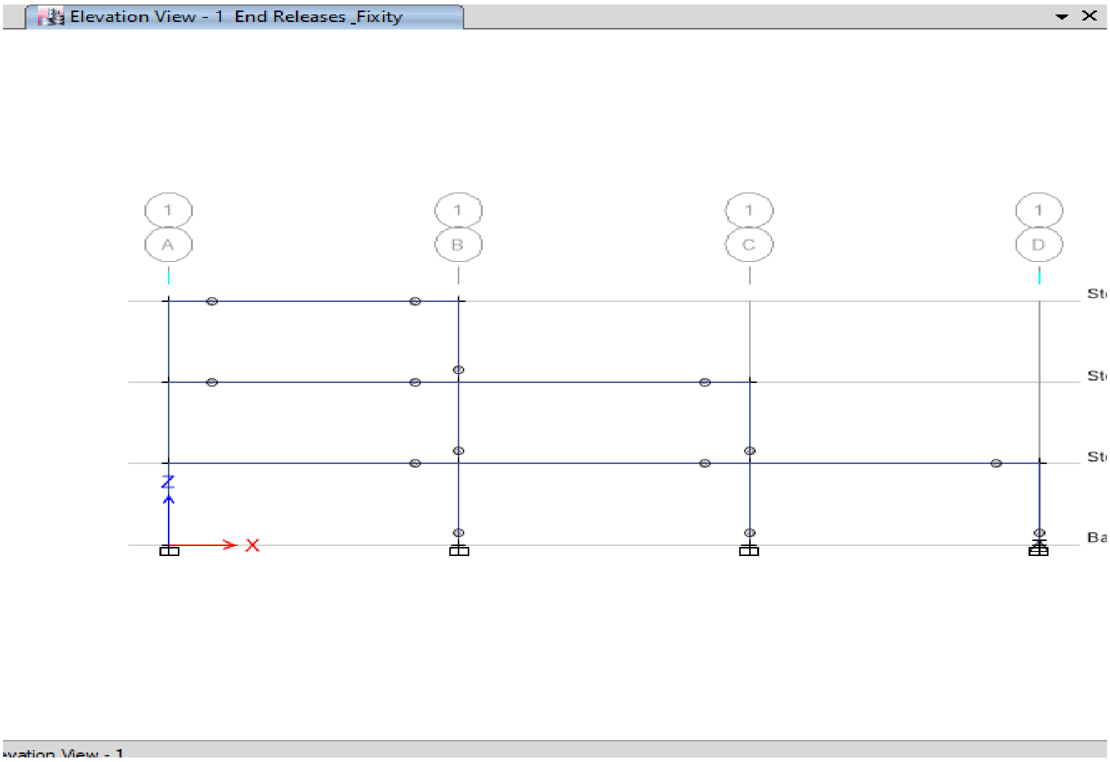

Figure 5.41: Adding hinges where plastic hinges observed at third and last step of pushover analysis

Figure 5.42: Buckling factor for the first mode after adding hinges where plastic hinges observed at third and last step of pushover analysis

from the result, buckling factor of original frame 1 is (51.35), after adding the manual hinges where plastic hinges observed for the step zero of pushover analysis, the buckling factor decrease to (49.12). the buckling factor for the first, second and third steps of pushover analysis are (43.18, 38.27 and 34.34) respectively.

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CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Results

In this research paper, pushover analysis of three, nine and fifteen thirty story rcc buildings by using ETABS2016 have been performed. Before running the models for pushover analysis, the buildings are linearly analyzed and designed properly according to IS 456-2000. The pushover loads are applied as per IS 1893-2002 part 1.
When pushover analysis performed, the first observed things are the deformed shapes of buildings, generation of plastic hinges and formation of pushover curve.
After running the pushover analysis, Now the pushover curve is obtained and plastic hinges are generated at the end of beams and columns. A table also generated which gives the coordinates of each step of the pushover curve and shows in detail the number of hinges in each step of pushover analysis at different state (for example, between IO, LS, CP, or between B, C, D and E).
P-delta analysis and buckling analysis for all three types of buildings have been performed. P-delta effect also known as geometric nonlinearity which is important for laterally displacing multi-story building with effect of gravity load. From result of buckling analysis, the buckling factor for each mode of each building is obtained.

6.1.1 Result of P-delta analysis

The comparison between result of linear static analysis while considering P-delta effect and linear static analysis without considering p-delta effects of all three buildings in term of overturning moment, base shear, lateral displacement and modal period are shown in the below tables.

6.1.1.2 Result of P-delta analysis for three story RCC building

A. Overturning moment at the base

	Load case	Overturning moment without p-delta effect(KN)	Overturning moment with p-delta effect(KN)
1	Seismic X	1410.1839	1424.4696
2	Seismic Y	1439.5813	1456.6211

Table 6.1: Overturning moment for three story building

B. Lateral displacement

Displacement of the joint at top story in mm with and without P-delta effect

Sr.No	Load case	Lateral displacement without p-delta effect(mm)	Lateral displacement with p-delta effect(mm)
1	Seismic X	14.514	14.686
2	Seismic Y	17.266	17.503

Table 6.2: Lateral displacement for three story building

C. Model period

Model period for different mode shape

Mode	Modal period without p-delta effect(sec)	Modal period with p-delta effect(mm)
1	0.805	0.816
2	0.789	0.8
3	0.507	0.51
4	0.312	0.314

Table 6.3: Model period for three story building

6.1.1.3 Result of P-delta analysis for nine story rcc building

A. Overturning moment at the base

	Load case	Overturning moment without p-delta effect(KN)	Overturning moment with p-delta effect(KN)
1	Seismic X	5510.3685	5659.8390658462
2	Seismic Y	5976.8535	6137.11407895173

Table 6.4: Overturning moment for nine story building

B. Lateral displacement

Displacement of the joint at top story in mm with and without P-delta effect

Sr.No	Load case	Lateral displacement without p-delta effect(mm)	Lateral displacement with p-delta effect(mm)
1	Seismic X	41.918	42.885
2	Seismic Y	51.452	53.071

Table 6.5: Lateral displacement for nine story building

C. Model period

Model period for different mode shape

Mode	Modal period without p-delta effect(sec)	Modal period with p-delta effect(mm)
1	2.112	2.189
2	1.947	2.011
3	1.331	1.357
4	0.808	0.826

Table 6.6: Model period for nine story building

6.1.1.4 Result of P-delta analysis for fifteen story rcc building

A. Overturning moment at the base

	Load case	Overturning moment without p-delta effect(KN)	Overturning moment with p-delta effect(KN)
1	Seismic X	11422.7427	11890.8396
2	Seismic Y	15960.8346	16312.5459

Table 6.7: Overturning moment for fifteen story building

B. Lateral displacement

Displacement of the joint at top story in mm with and without P-delta effect

Sr.No	Load case	Lateral displacement without p-delta effect(mm)	Lateral displacement with p-delta effect(mm)
1	Seismic X	49.88	50.77
3	Seismic Y	76.26	79.414

Table 6.8: Lateral displacement for fifteen story building

C. Model period

Model period for different mode shape

Mode	Modal period without p-delta effect(sec)	Modal period with p-delta effect(mm)
1	3.148	3.311
2	2.253	2.313
3	1.917	1.965
4	1.104	1.138

Table 6.9: Model period for fifteen story building

6.1.2 Result of Buckling Analysis of RCC Buildings

Buckling analysis is performed for all three buildings in ETABS2016. P-delta effect has been considered in this analysis. The figures below show the first buckling mode and corresponding buckling factor for each building separately.

6.1.2.1 Result of buckling analysis of three story RCC building without P-delta effect

First buckling mode of structure

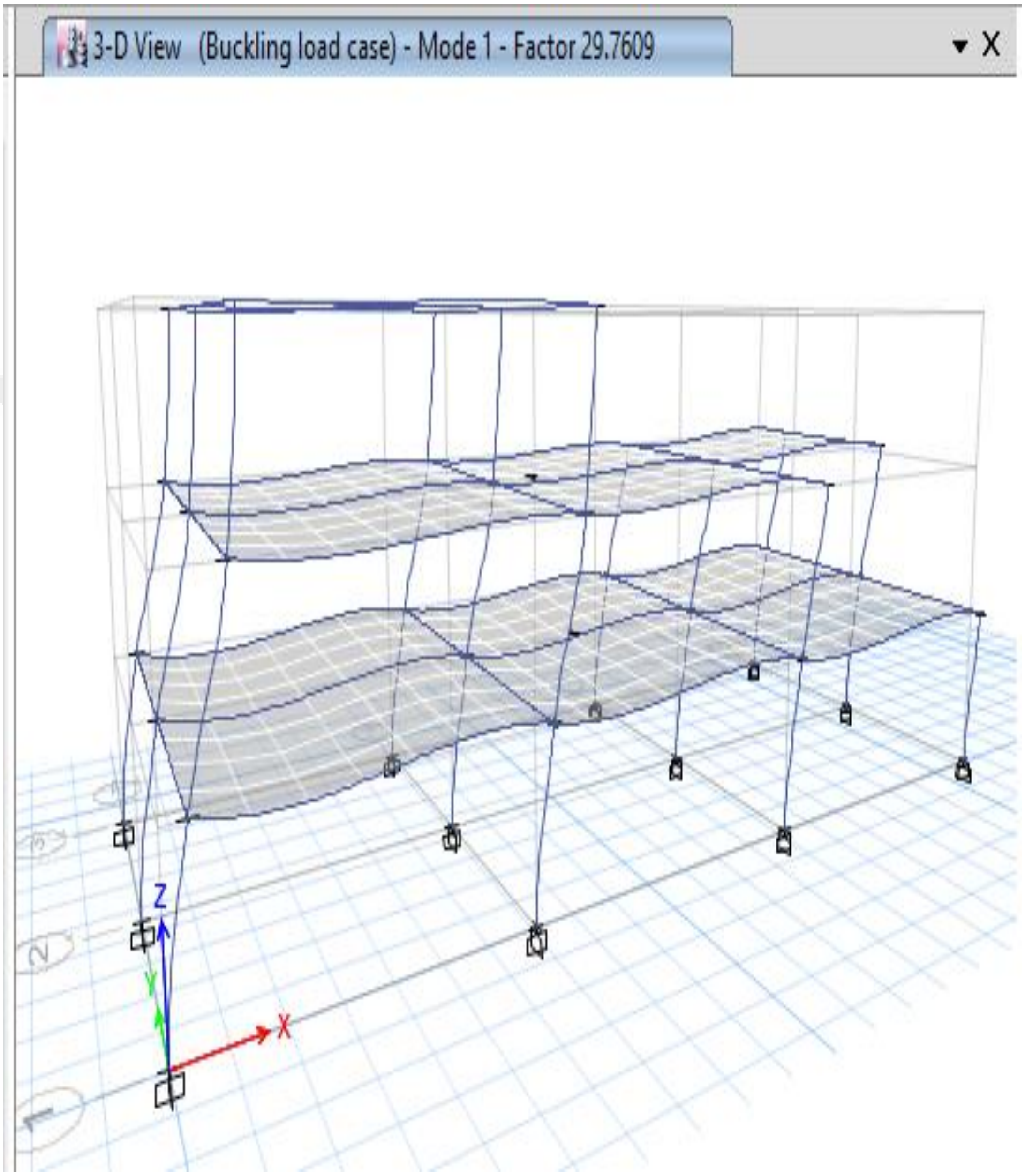

Figure 6.1: First buckling mode of three story structure without considering P-delta effect

6.1.2.2 Result of buckling analysis of three story RCC building with P-delta effect

First buckling mode of structure

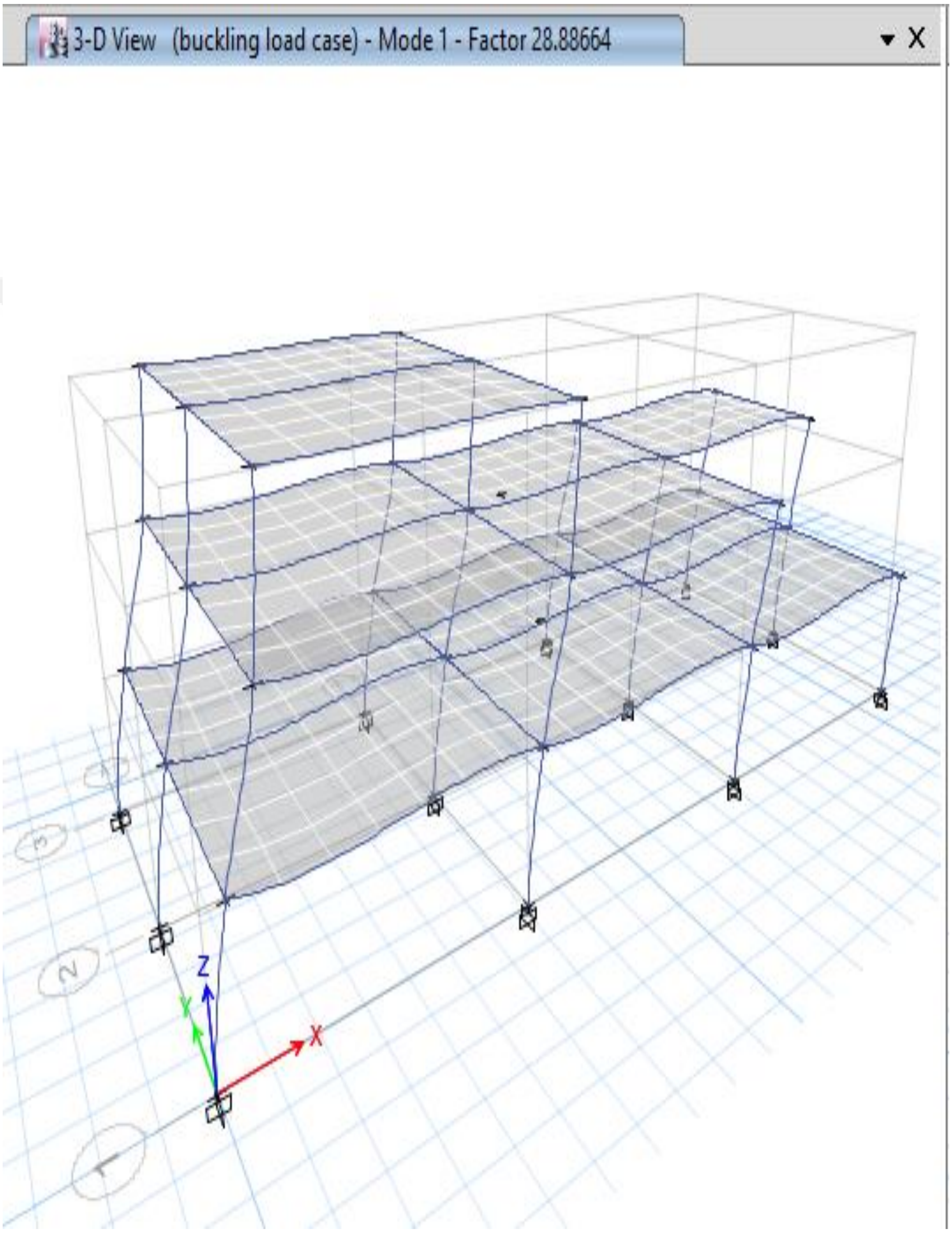

Figure 6.2: First buckling mode of three story structure while considering P-delta effect

6.1.2.3 Result of buckling analysis of nine story RCC building without P-delta effect

First buckling mode of structure

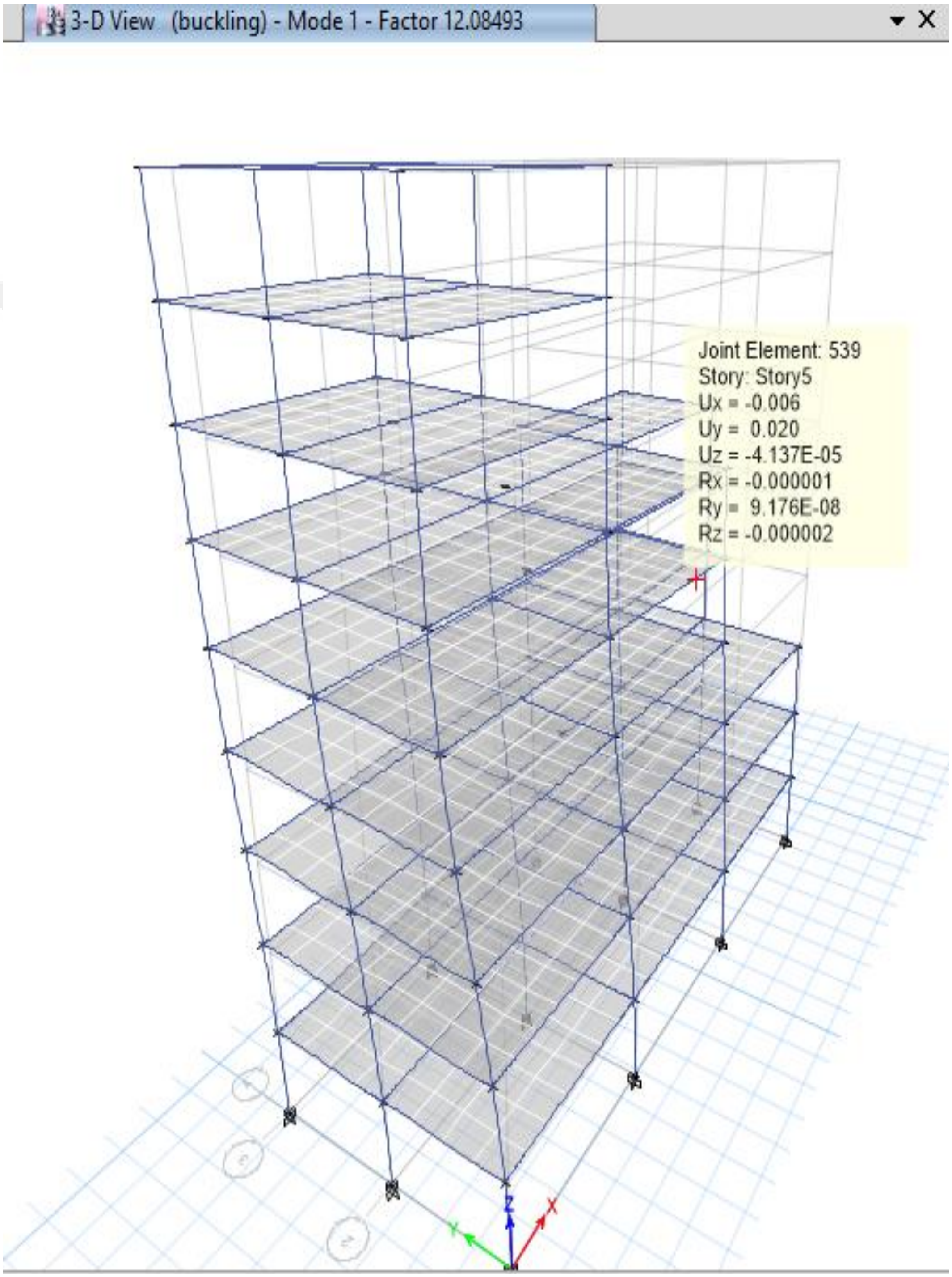

Figure 6.3: First buckling mode of nine story structure without considering P-delta

6.1.2.4 Result of buckling analysis of nine story RCC building with P-delta effect

First buckling mode of structure

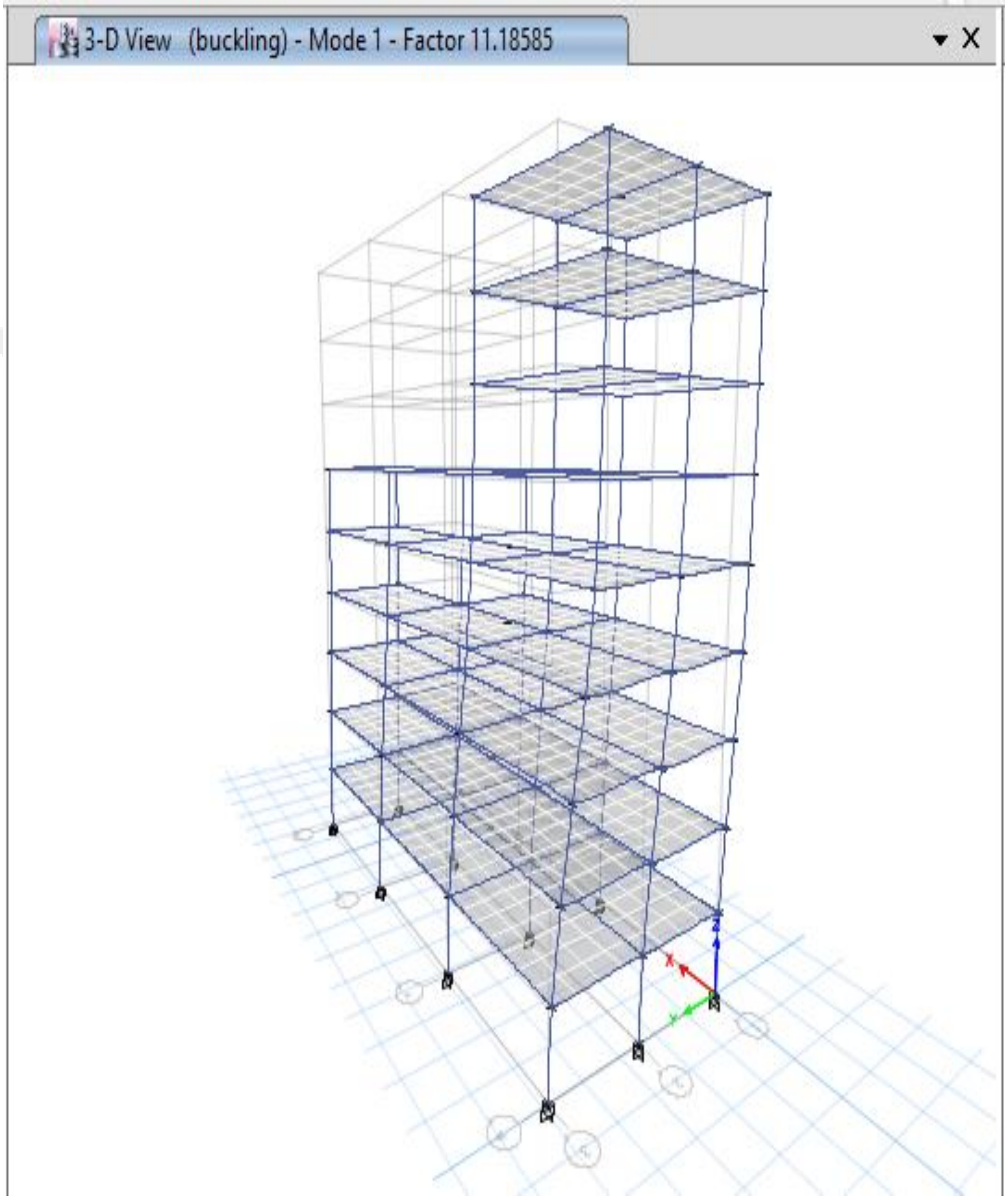

Figure 6.4: First buckling mode of nine story structure while considering P-delta effect

6.1.2.5 Result of buckling analysis of fifteen story RCC building without P-delta effect

First buckling mode of structure

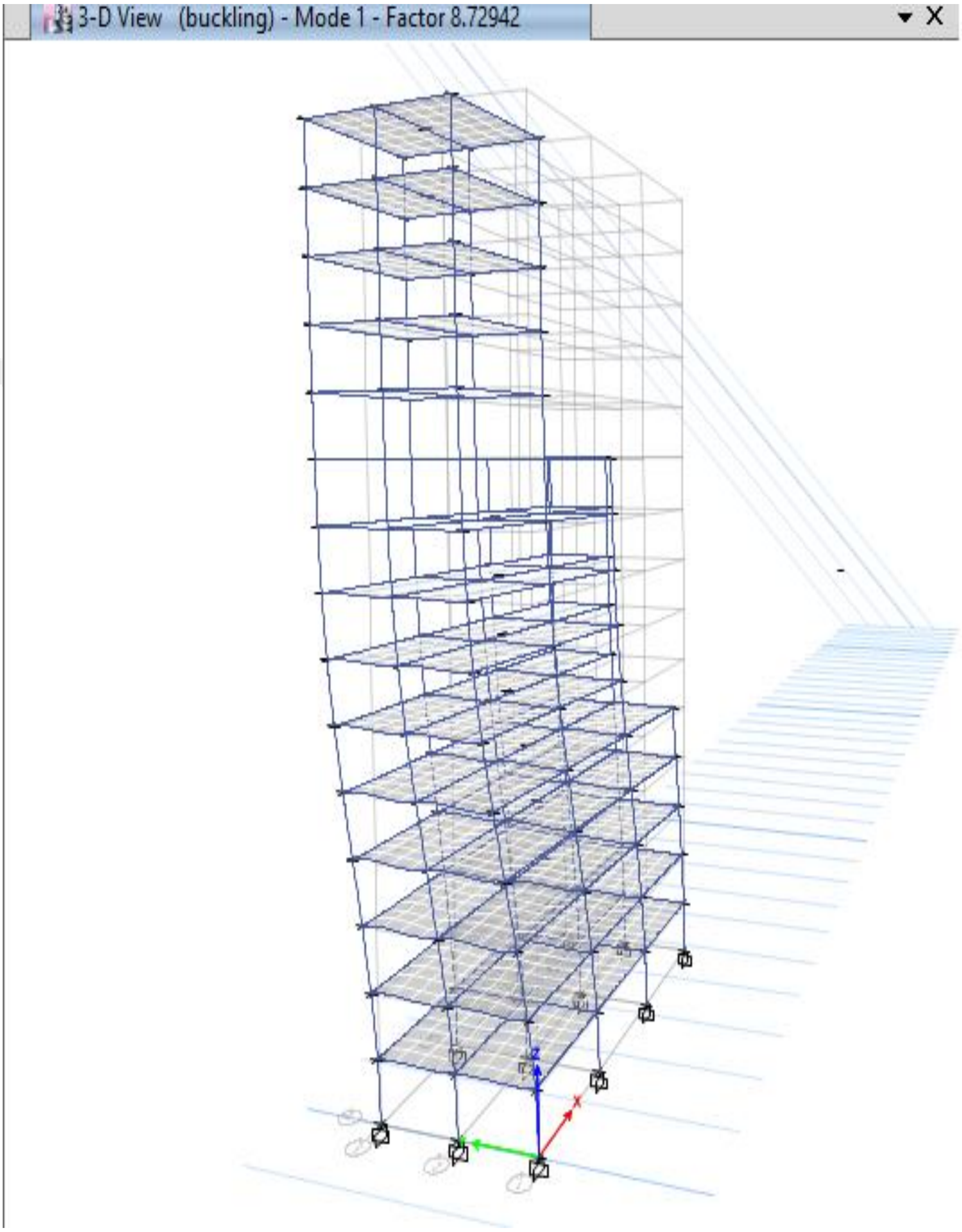

Figure 6.5: First buckling mode of fifteen story structure without considering P-delta effect

6.1.2.6 Result of buckling analysis of fifteen story RCC building with P-delta effect

First buckling mode of structure

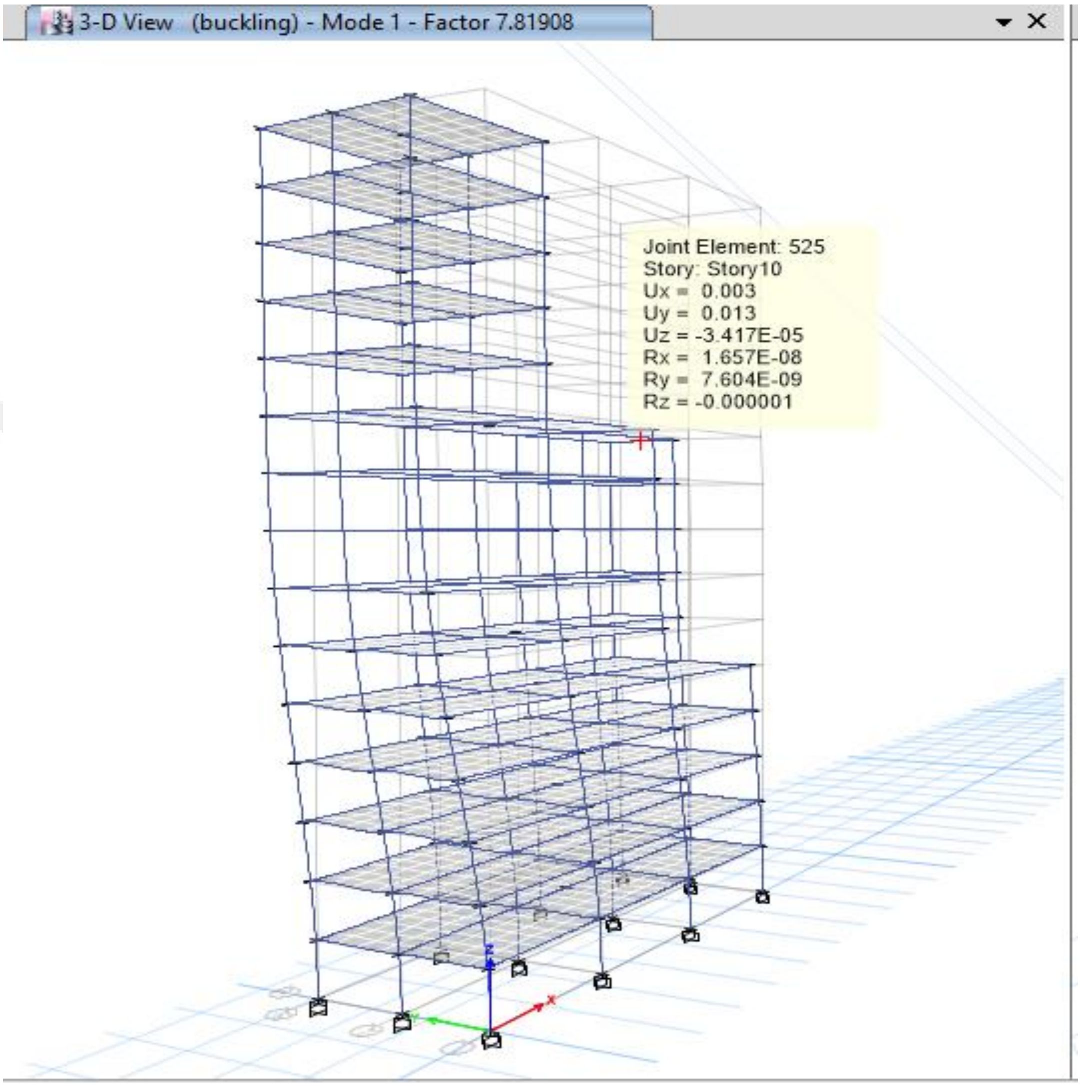

Figure 6.6: First buckling mode of fifteen story structure while considering P-delta effect

Story	Buckling factor without p-delta effect	Buckling factor with p-delta effect
3	29.76	28.88
9	12.08	11.18
15	8.72	7.81

Table 6.10: Buckling factor for first mode of structures

6.1.3 Result of Pushover Analysis for All Three Types of RCC Buildings

The figures below show the result of pushover analysis for each RCC building separately, which include pushover curve, tabular data for pushover analysis and formation of hinges at different steps of pushover analysis.

6.1.3.1 Result of pushover analysis for three story RCC building in x-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	Push X	Plot Type	V vs Displ

Plot

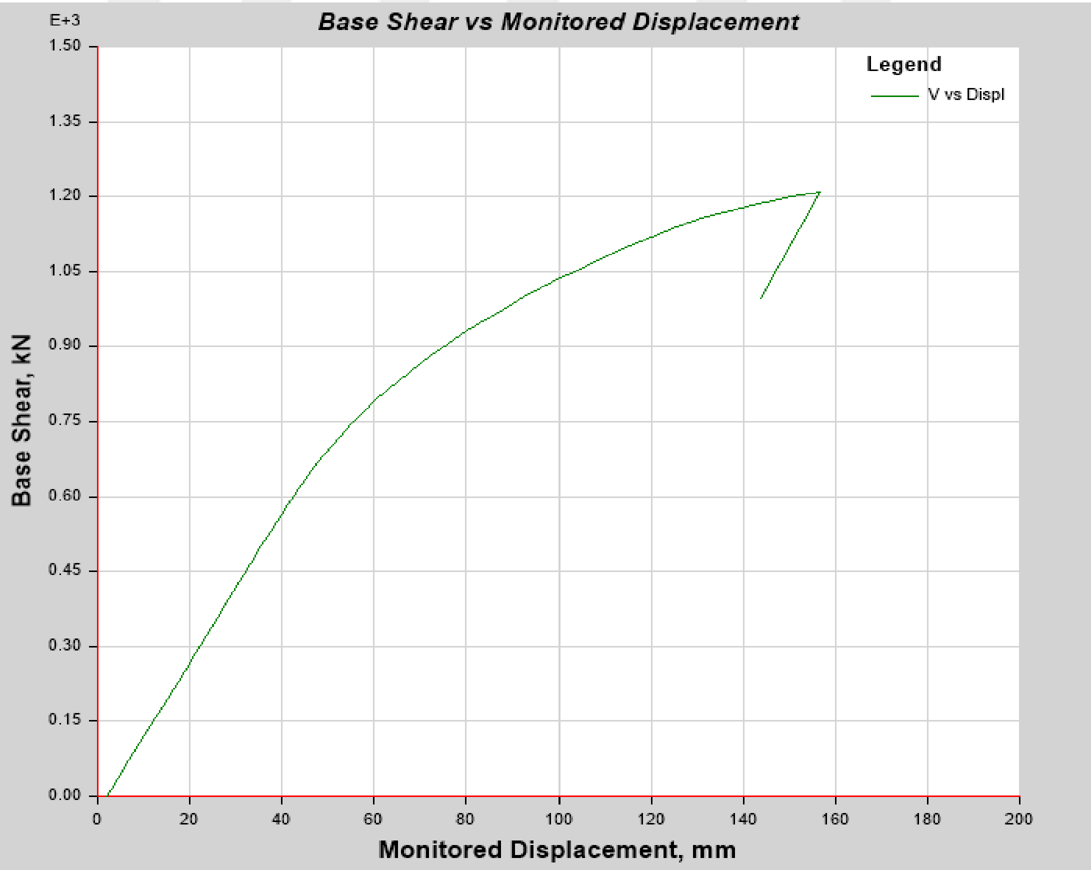

Figure 6.7: V vs L.D of three story building in x-direction

B) Formation of plastic hinges

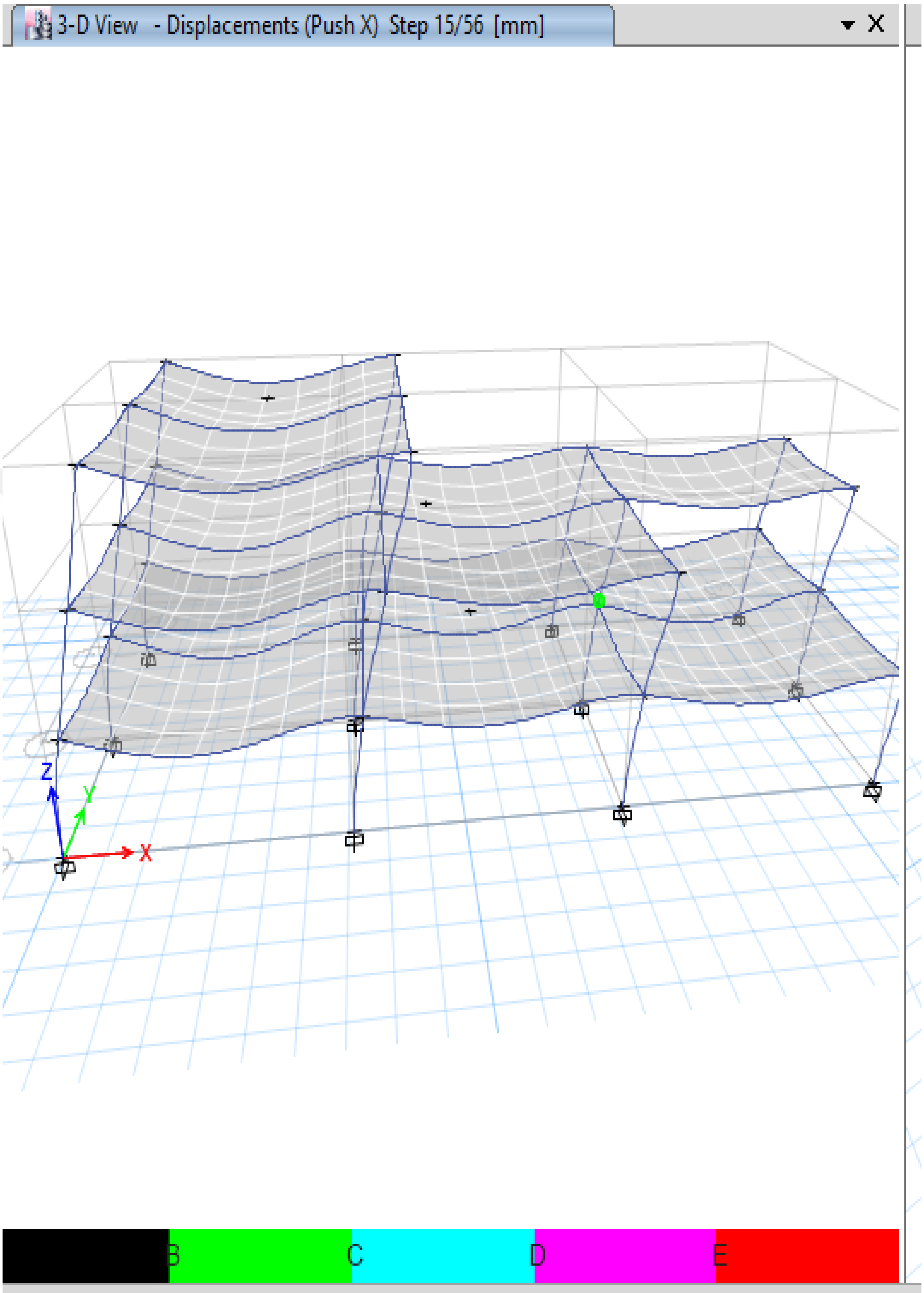

Figure 6.8: Formation of plastic hinges at step 15 in x direction

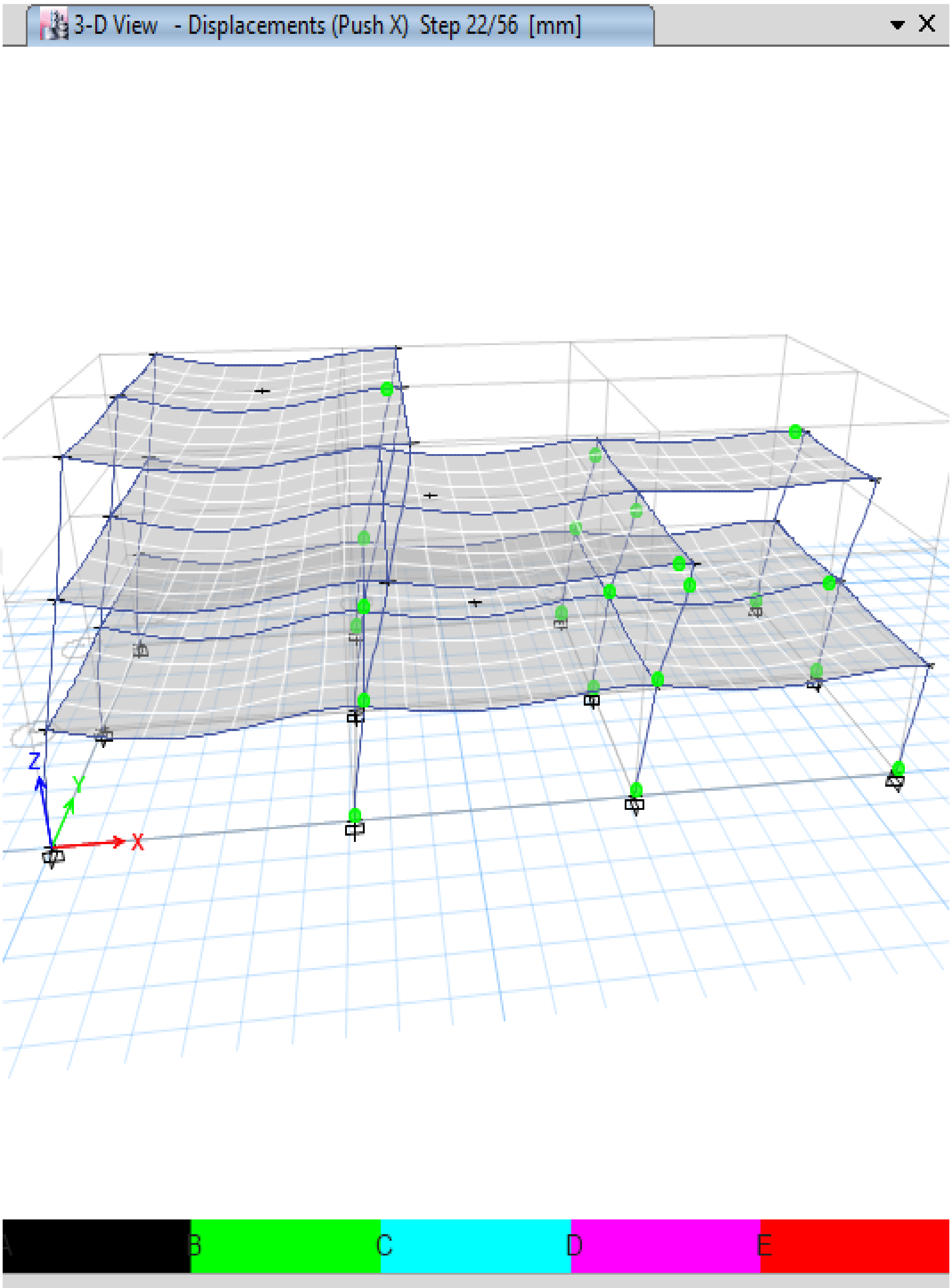

Figure 6.9: Formation of plastic hinges at step 22 in x direction

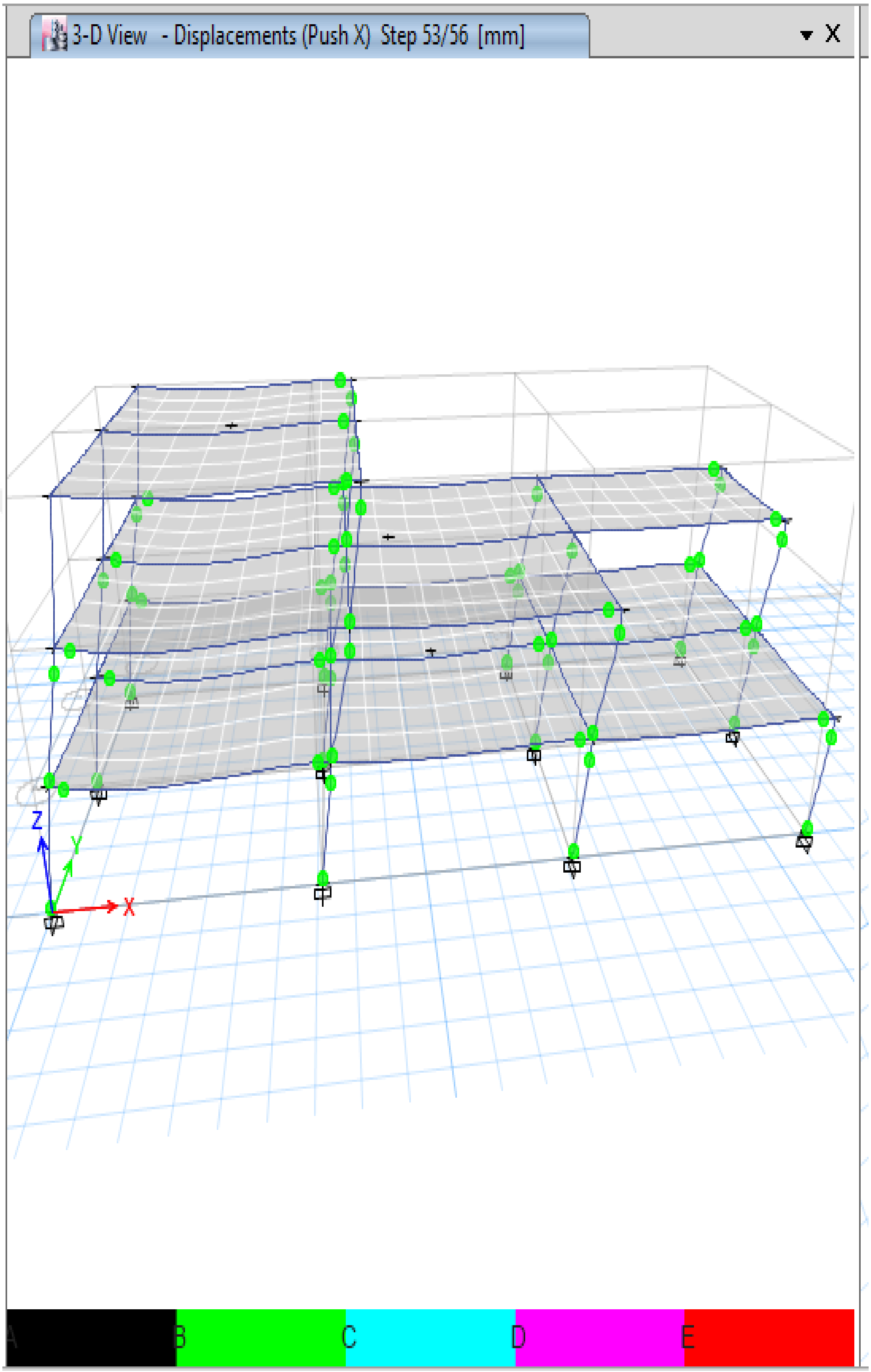

Figure 6.10: Formation of plastic hinges at step 53 in x direction

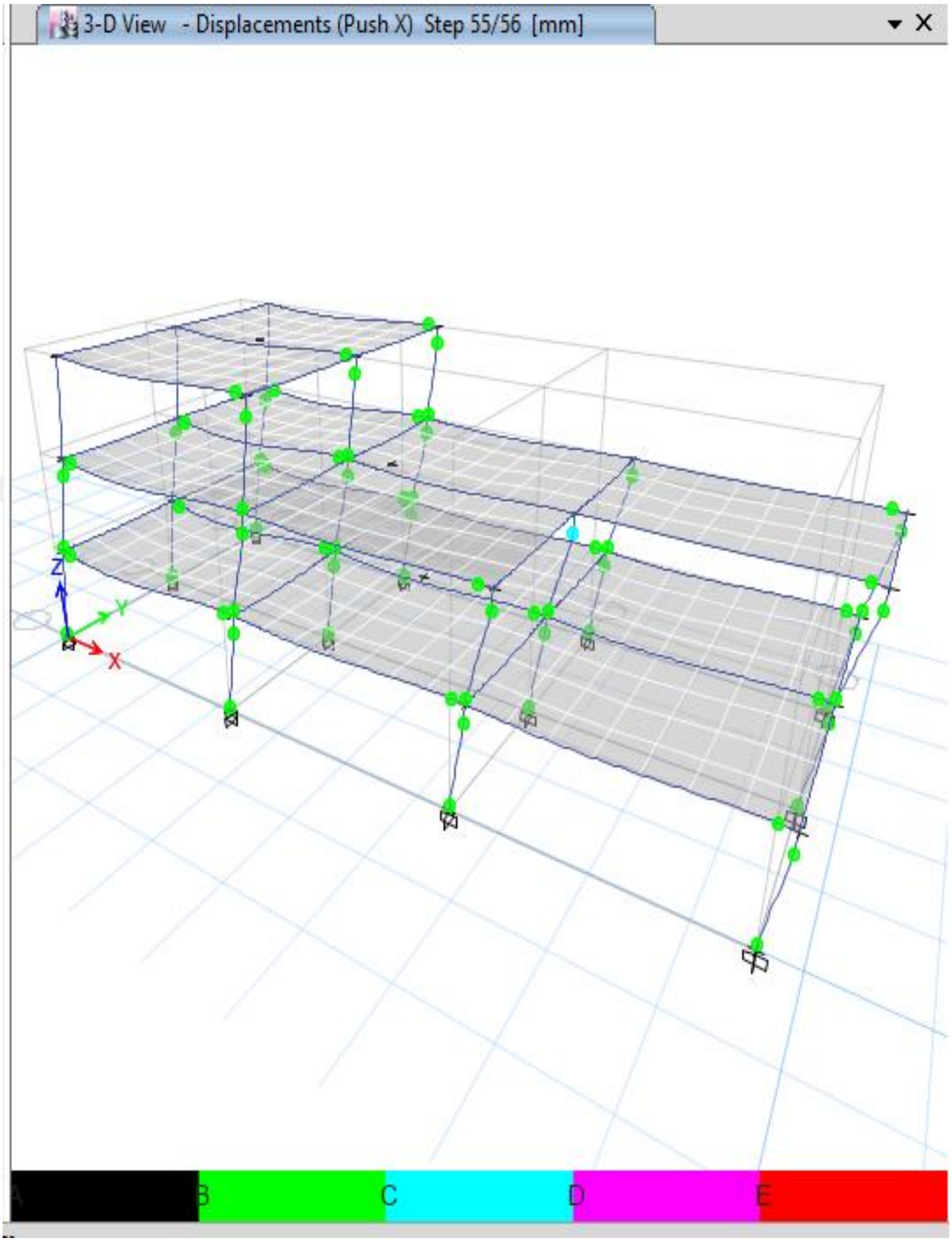

Figure 6.11: Formation of plastic hinges at step 55 in x direction

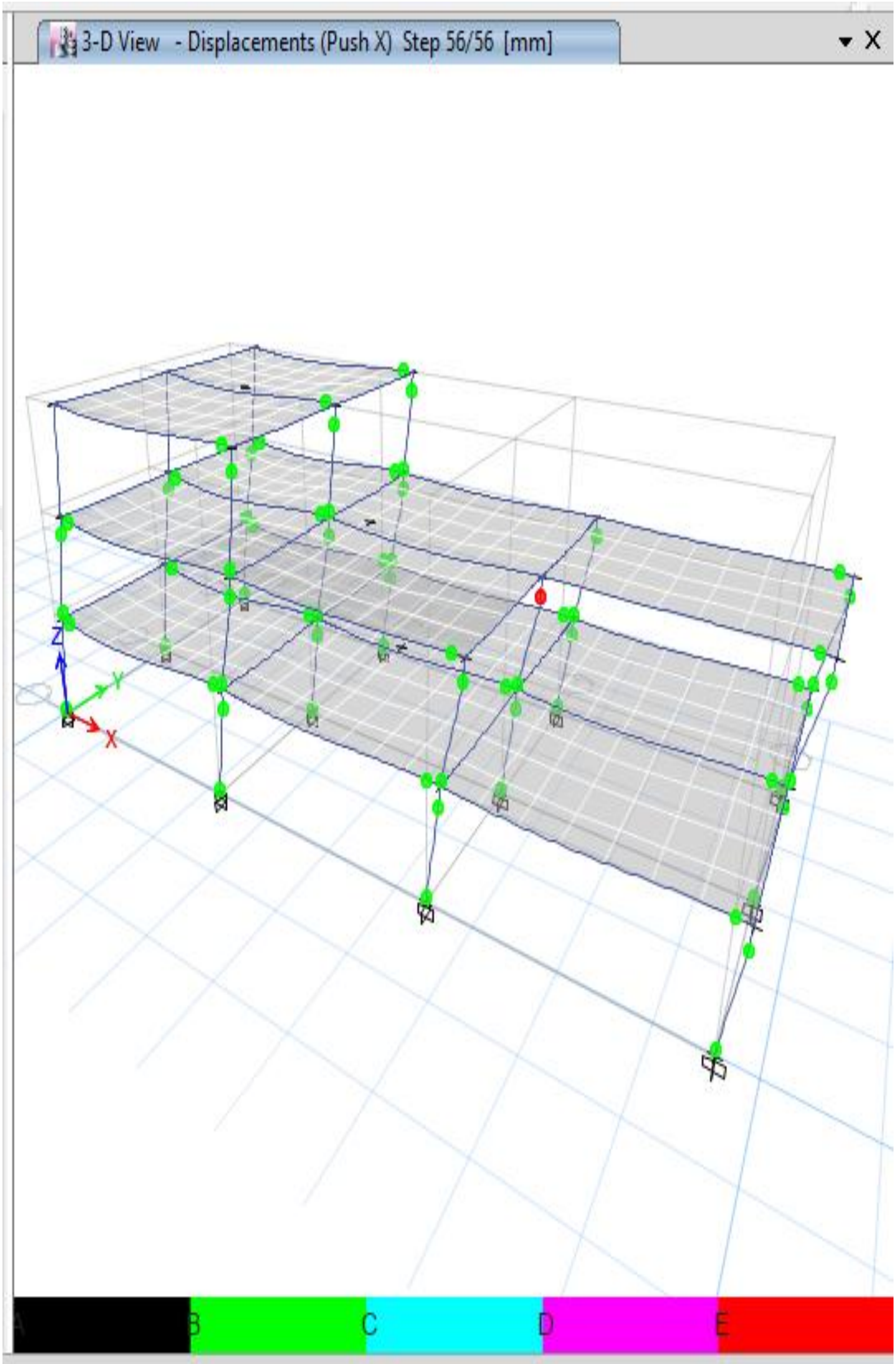

Figure 6.12: Formation of plastic hinges at last step in x direction

6.1.3.2 Result of pushover analysis for three story RCC building in y-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	Push Y	Plot Type	V vs Displ

Plot

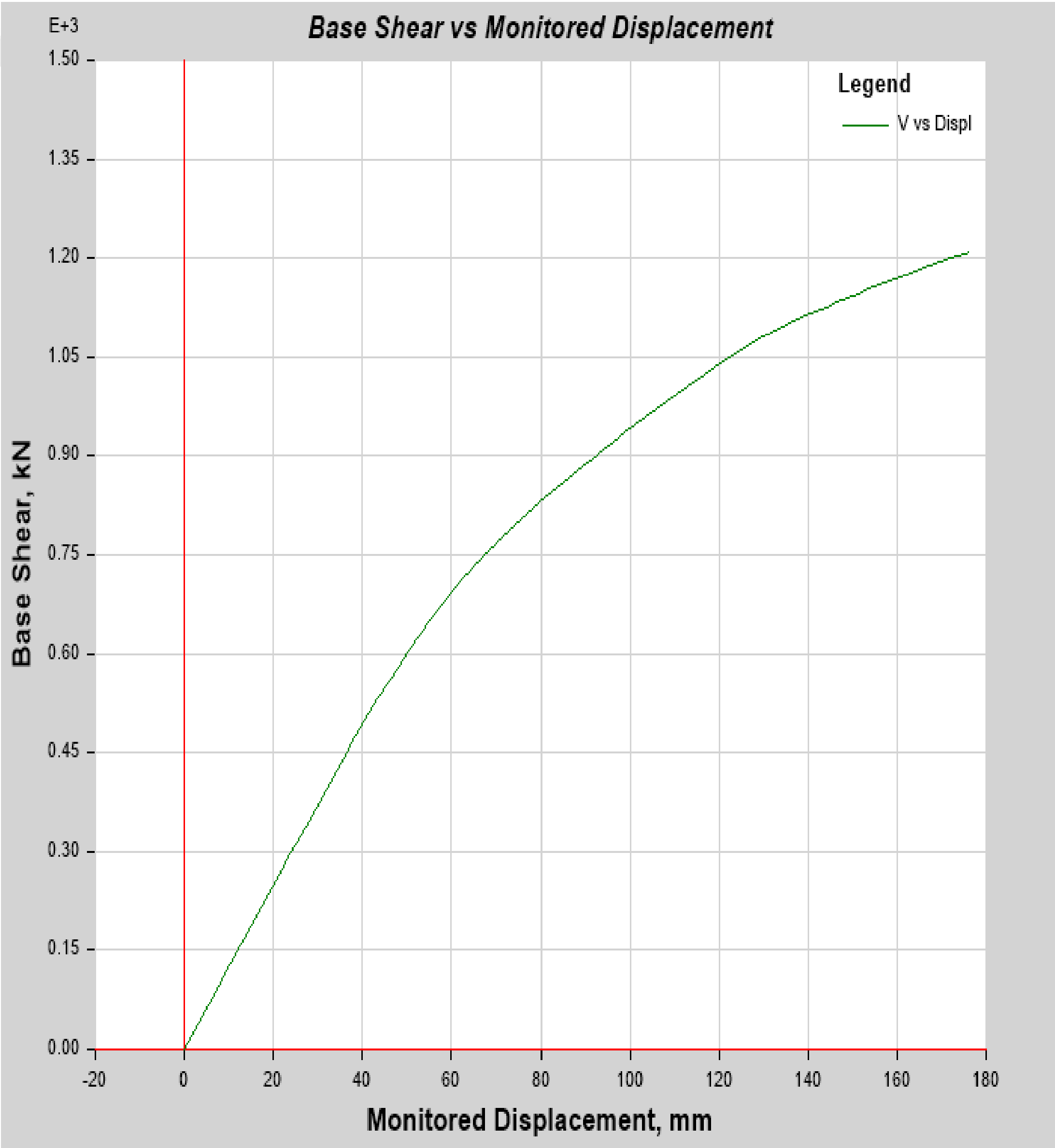

Figure 6.13: V vs L.D of three story building in y-direction

B) Formation of plastic hinges

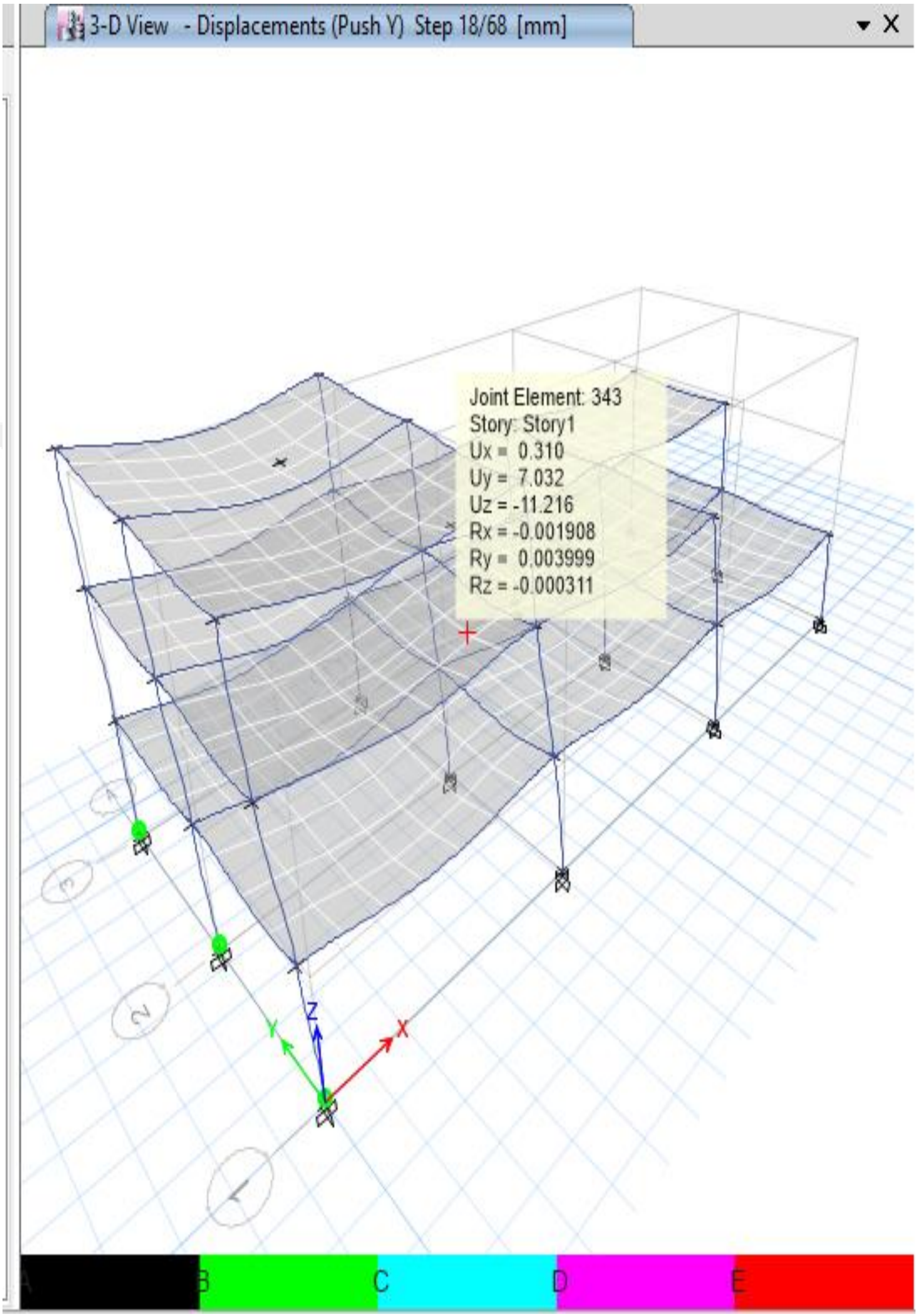

Figure 6.14: Formation of plastic hinges at step 18 in y-direction

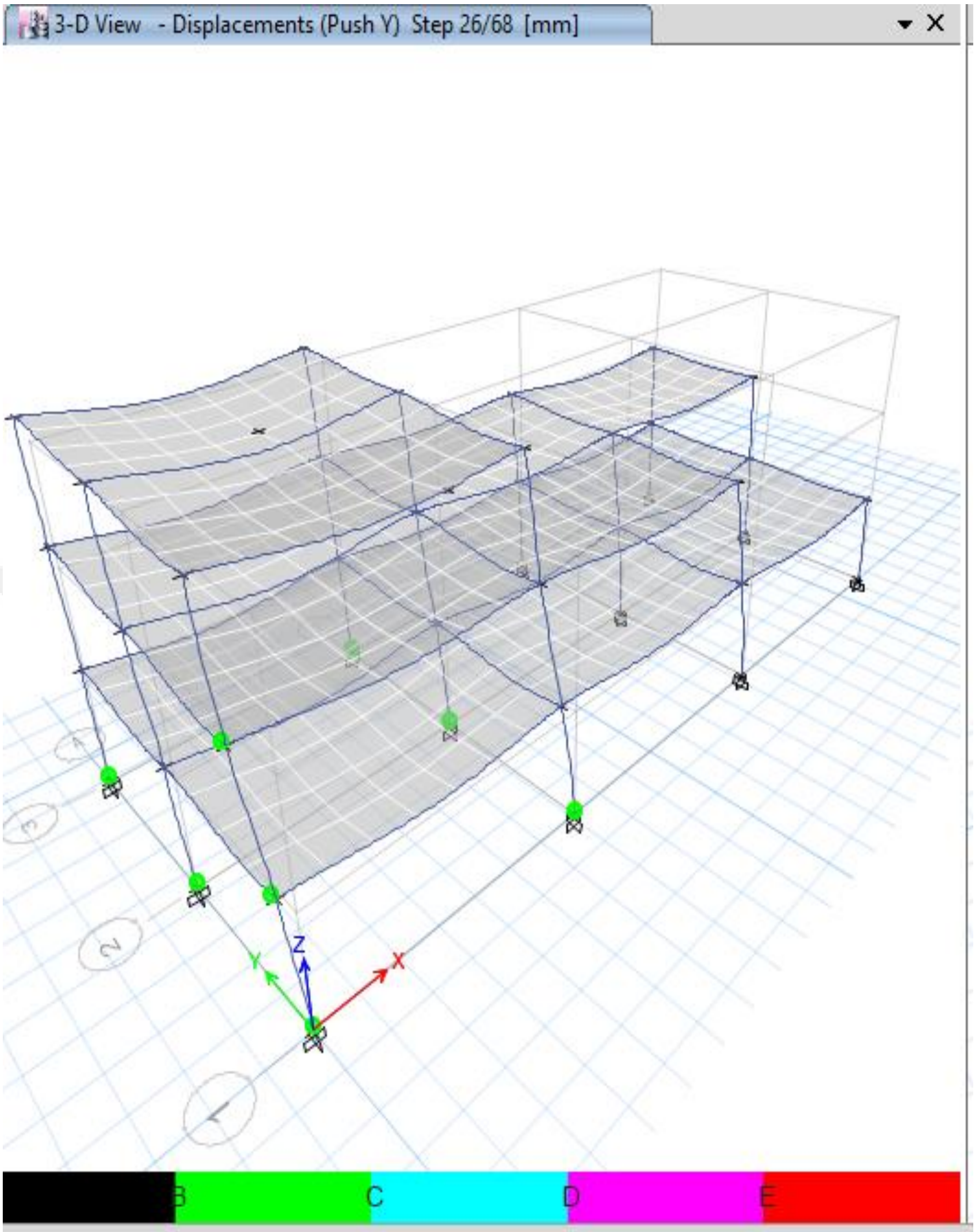

Figure 6.15: Formation of plastic hinges at step 26 in y-direction

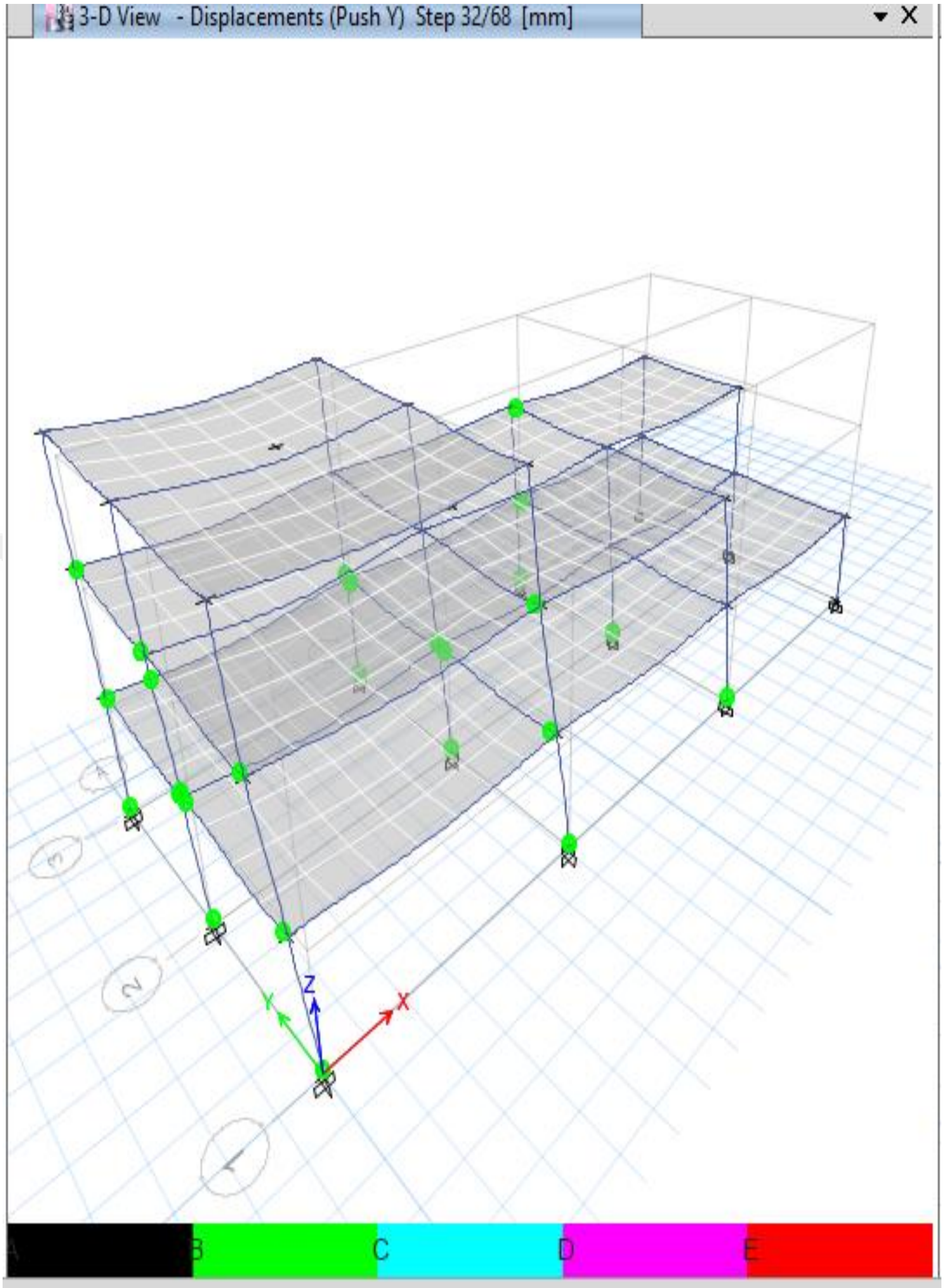

Figure 6.16: Formation of plastic hinges at step 32 in y-direction

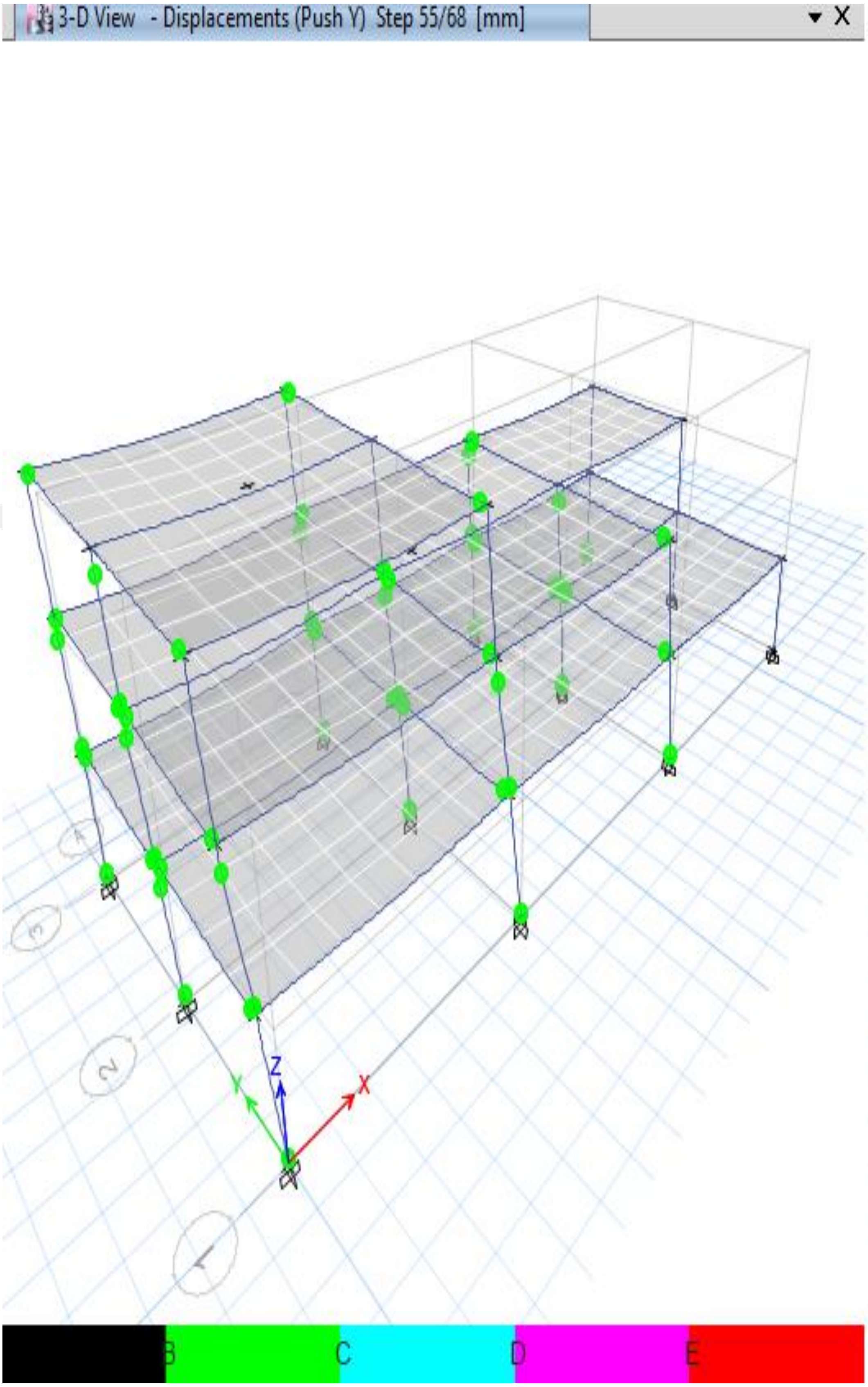

Figure 6.17: Formation of plastic hinges at step 55 in y-direction

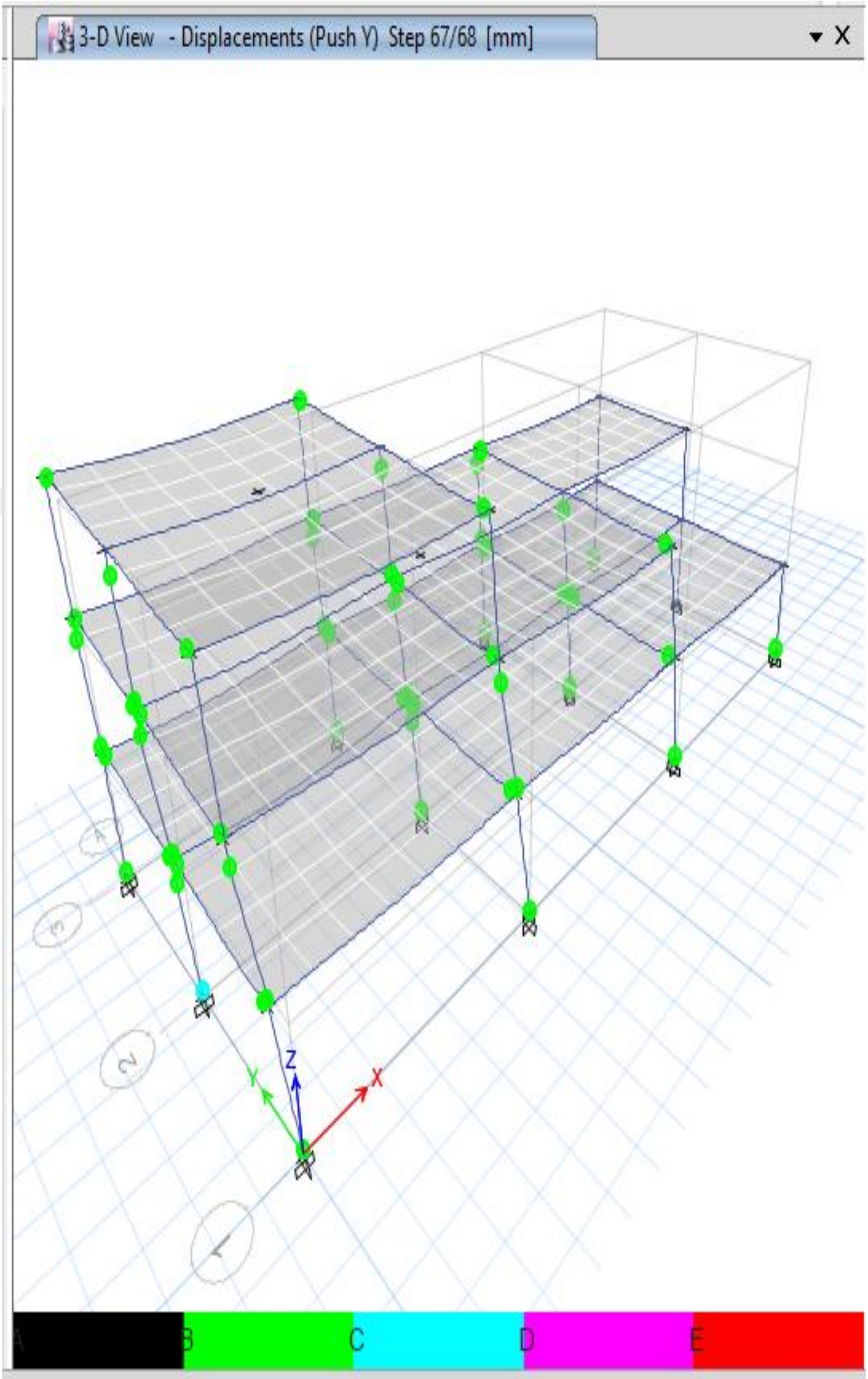

Figure 6.18: Formation of plastic hinges at step 67 in y-direction

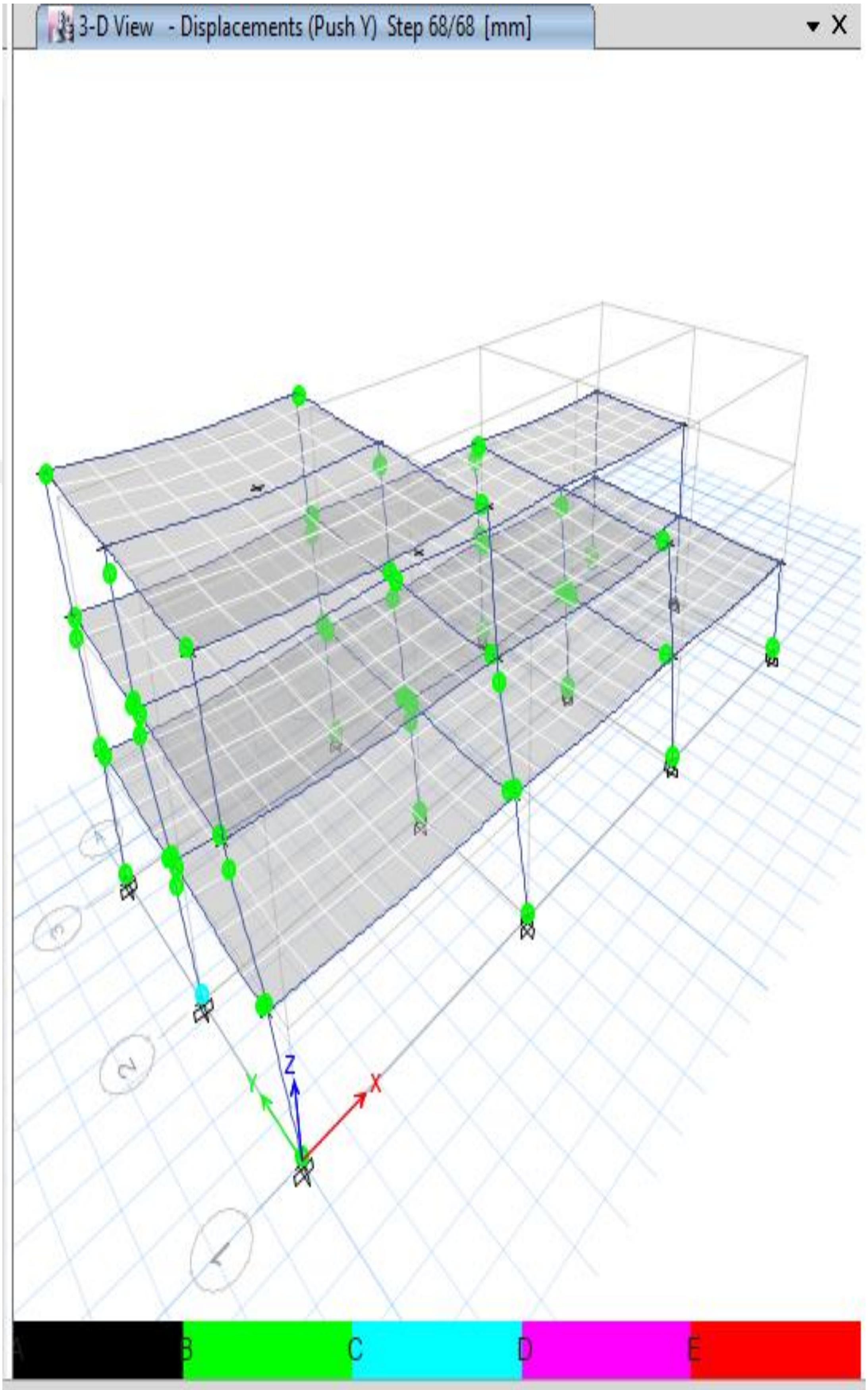

Figure 6.19: Formation of plastic hinges at last step in y-direction

6.1.3.3 Result of pushover analysis for nine story RCC building in x-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	Push X	Plot Type	V vs Displ

Plot

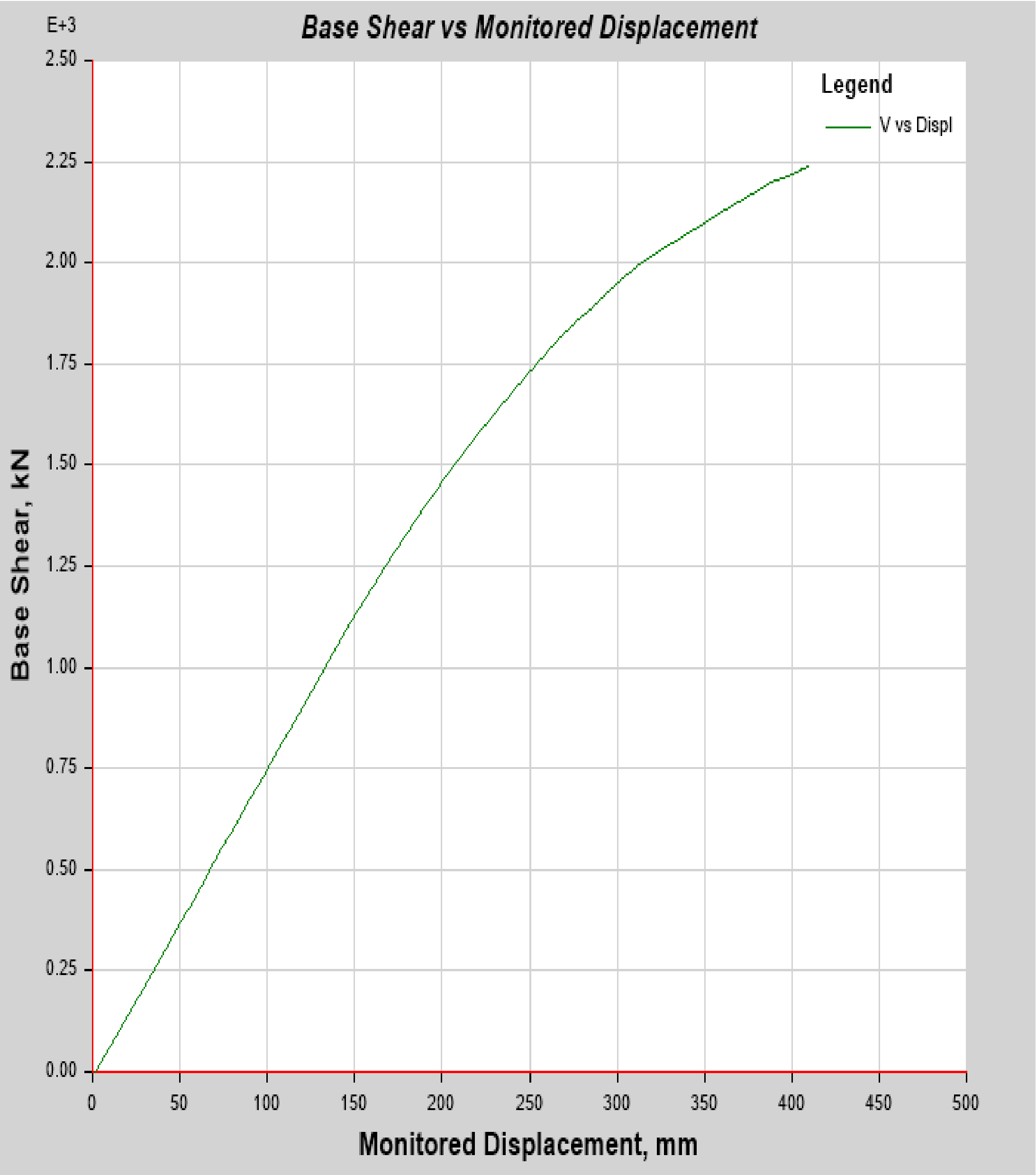

Figure 6.20: V vs L.D of nine story building in x-direction

B) Formation of plastic hinges

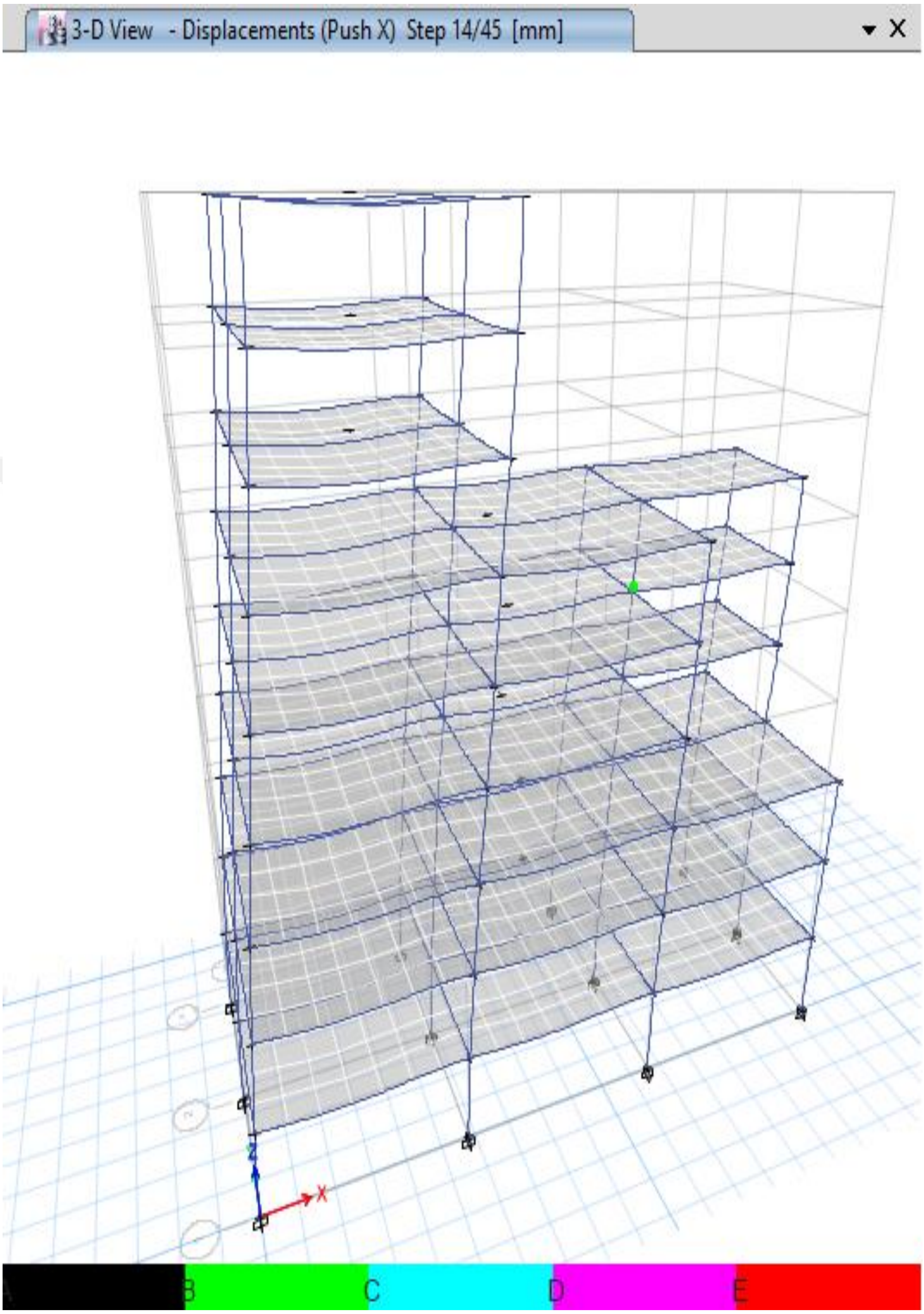

Figure 6.21: Formation of plastic hinges at step 14 in x-directiom

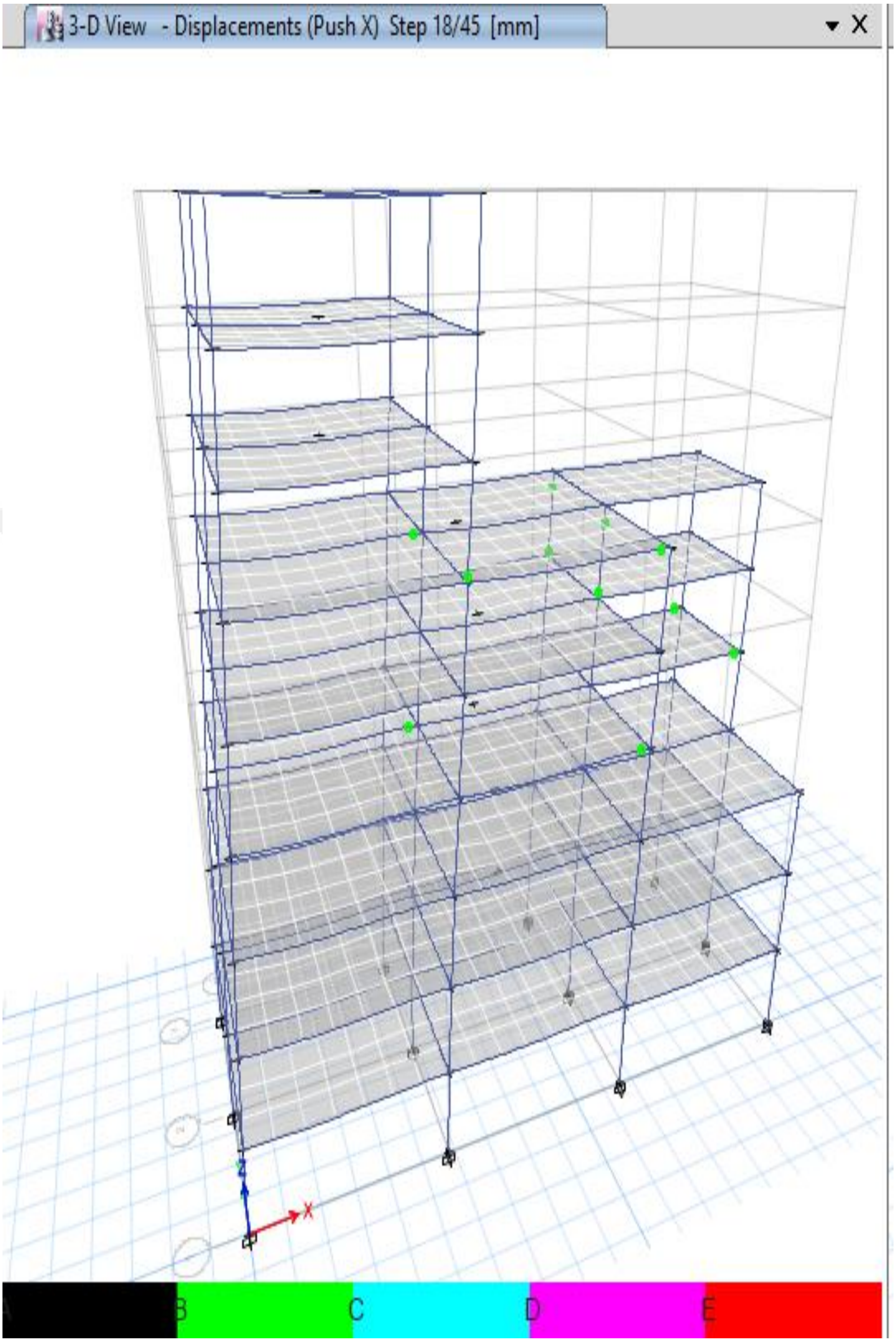

Figure 6.22: Formation of plastic hinges at step 18 in x-direction

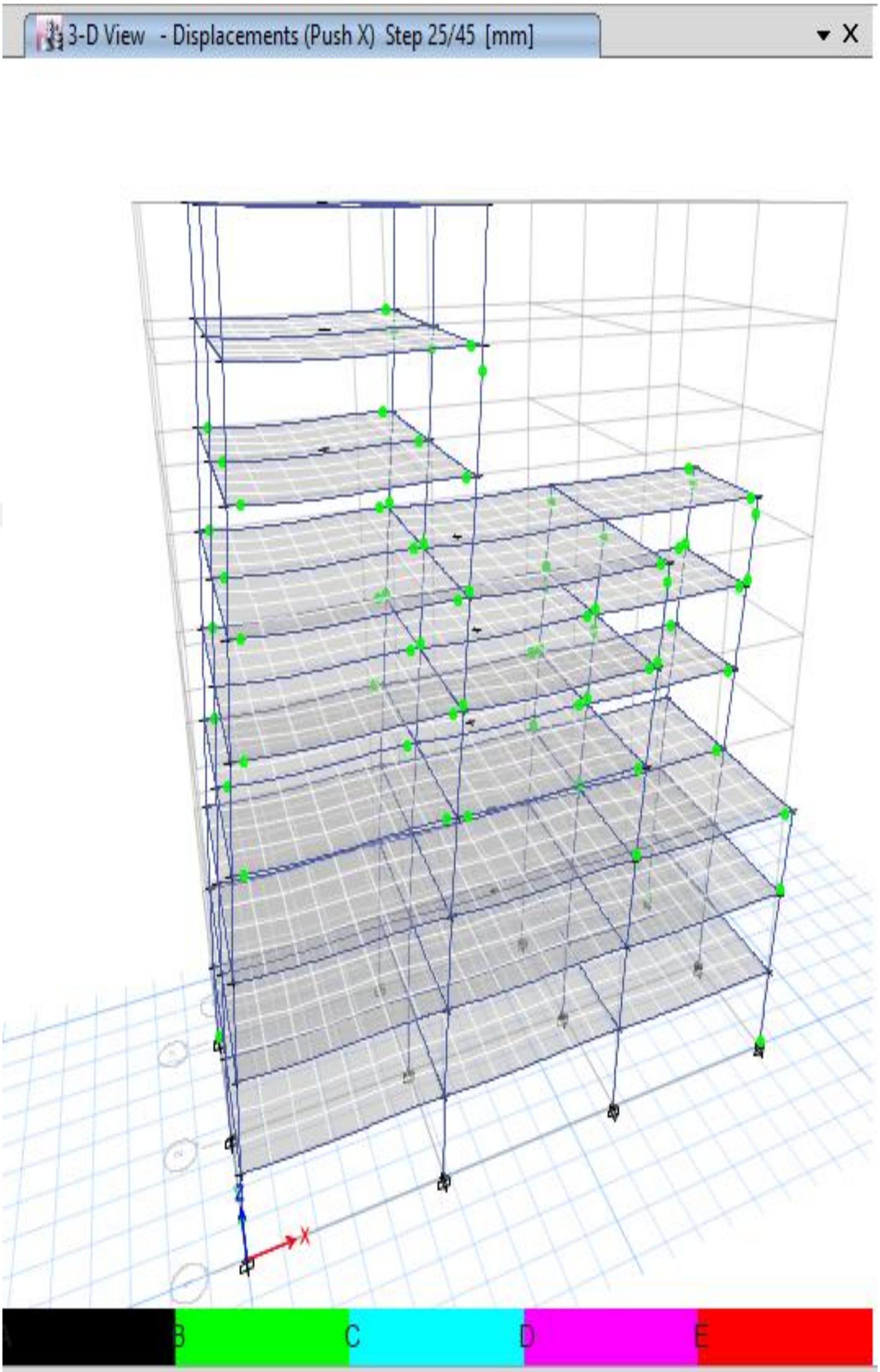

Figure 6.23: Formation of plastic hinges at step 25 in x-direction

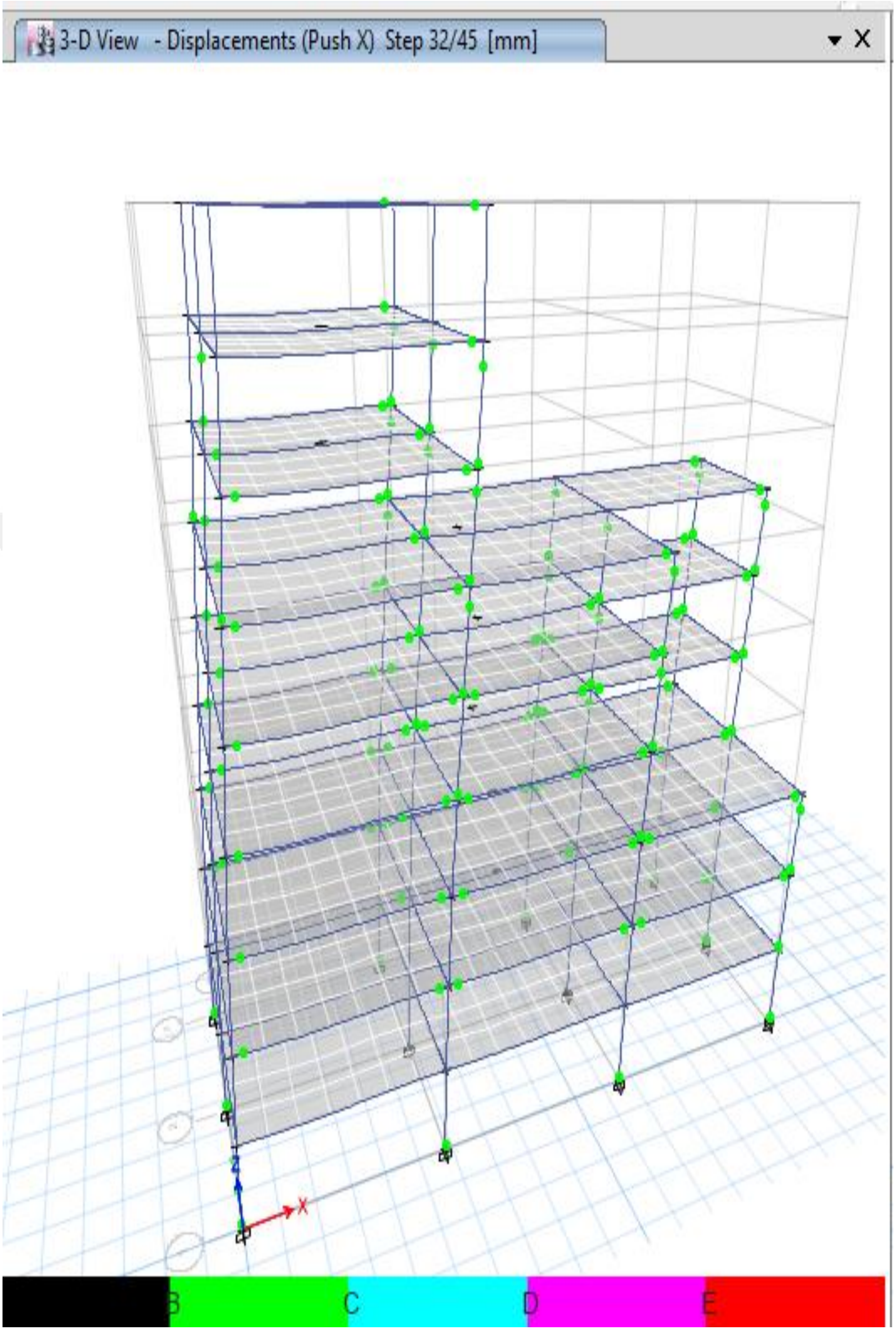

Figure 6.24: Formation of plastic hinges at step 32 in x-direction

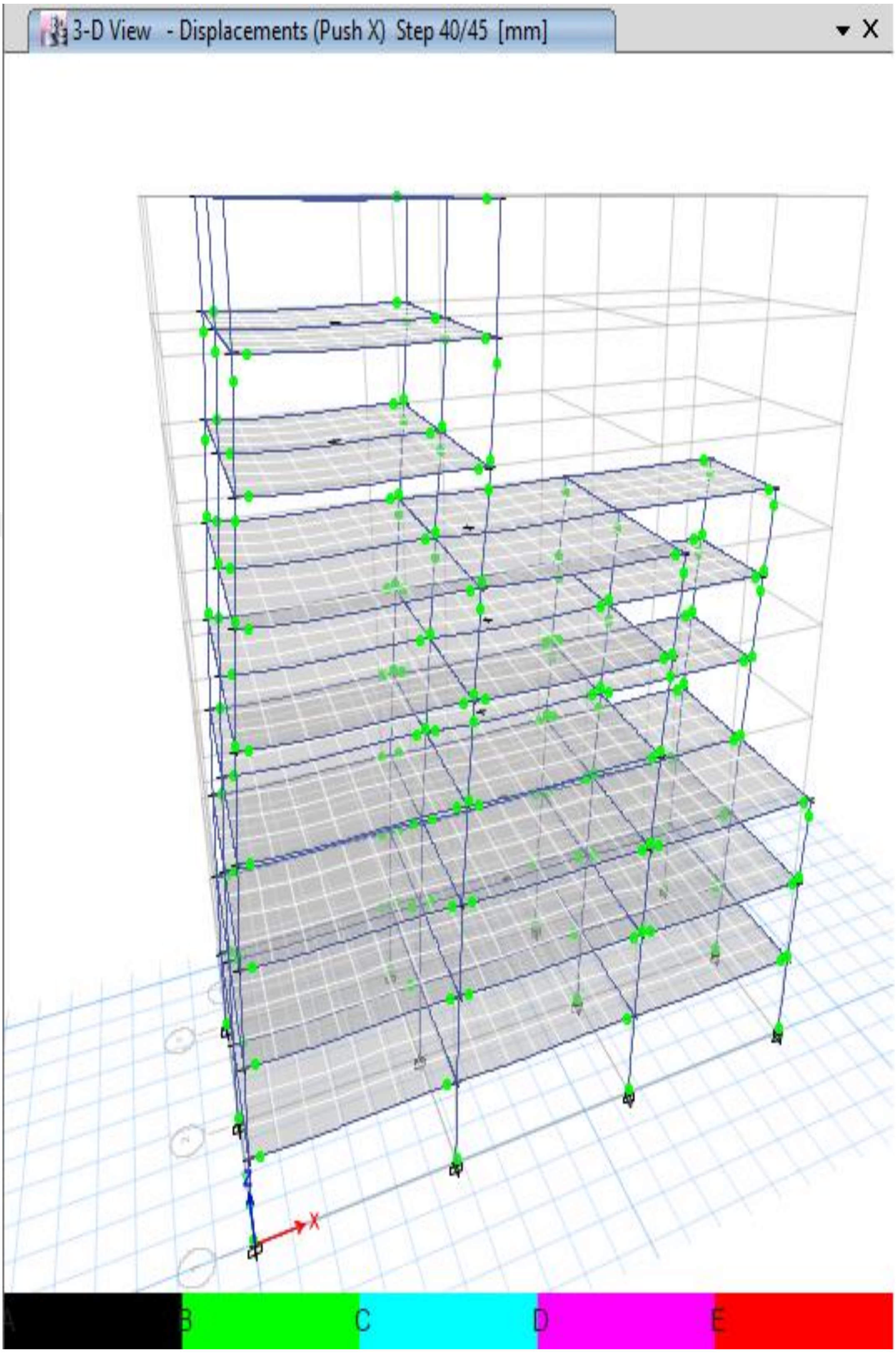

Figure 6.25: Formation of plastic hinges at step 40 in x-direction

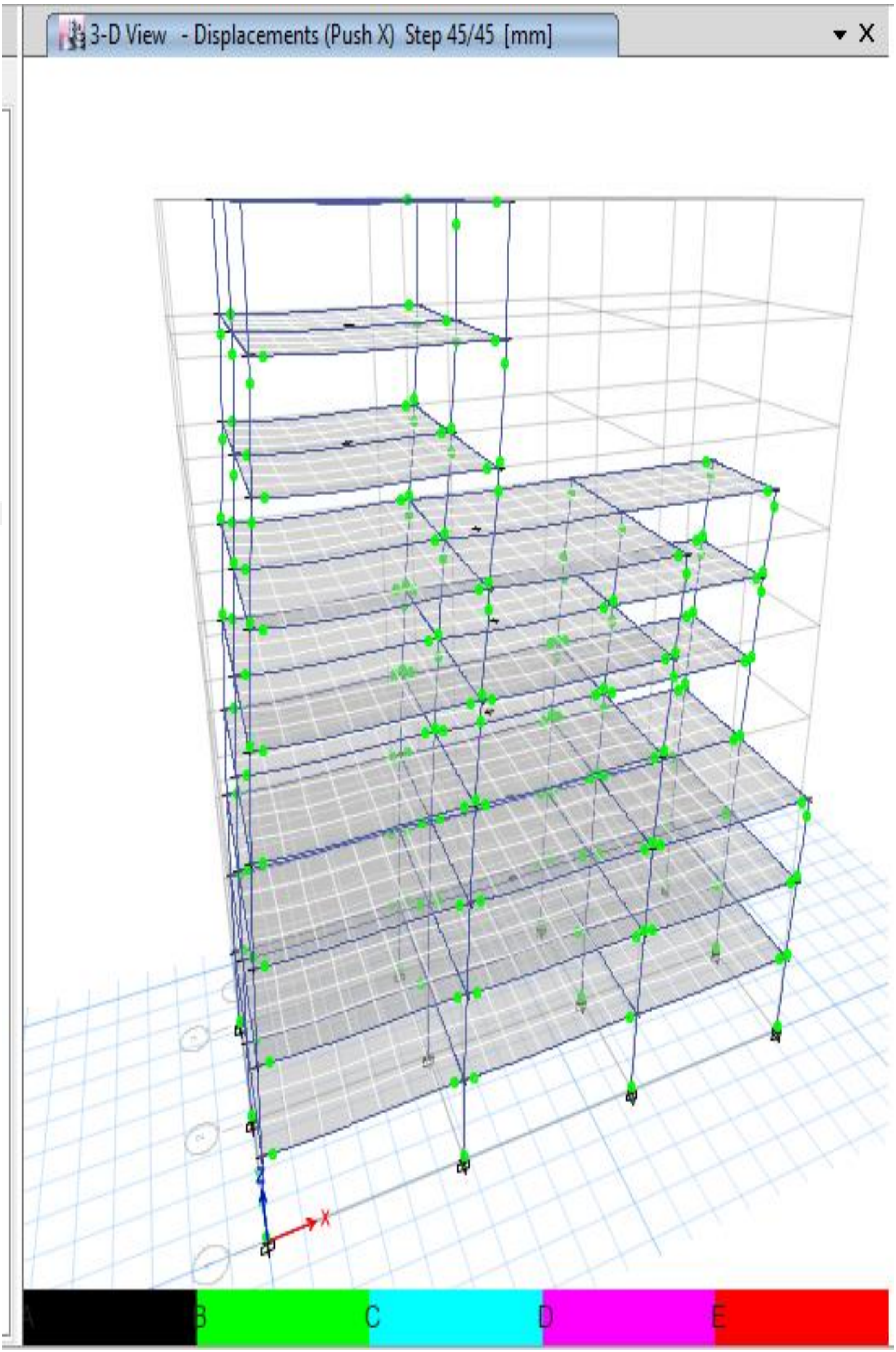

Figure 6.26: formation of plastic hinges at last step in x direction

6.1.3.4 Result of pushover analysis for nine story RCC building in y-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	Push Y	Plot Type	V vs Displ

Plot

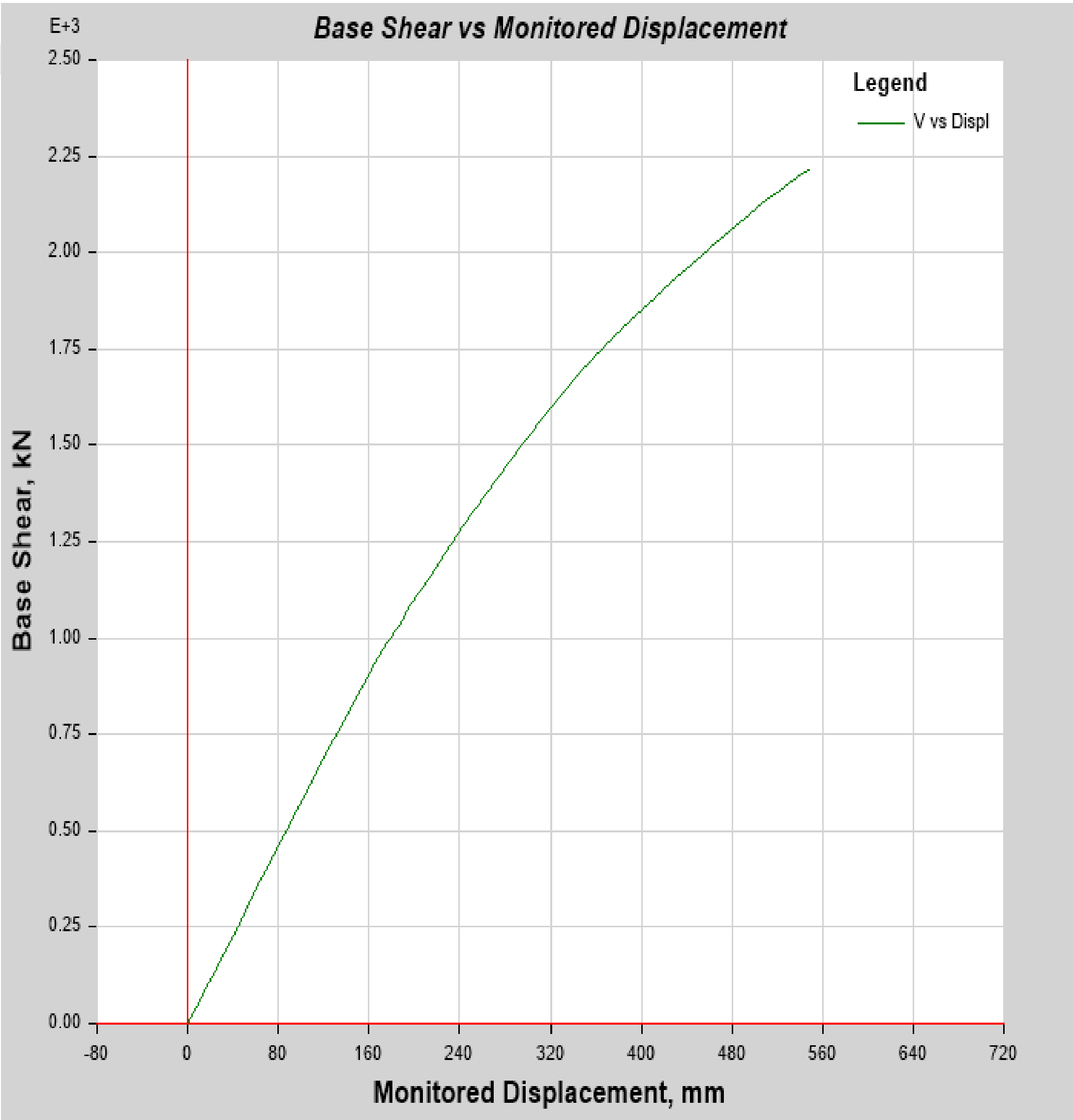

Figure 6.27: V vs L.D of nine story building in y-direction

B) Formation of plastic hinges

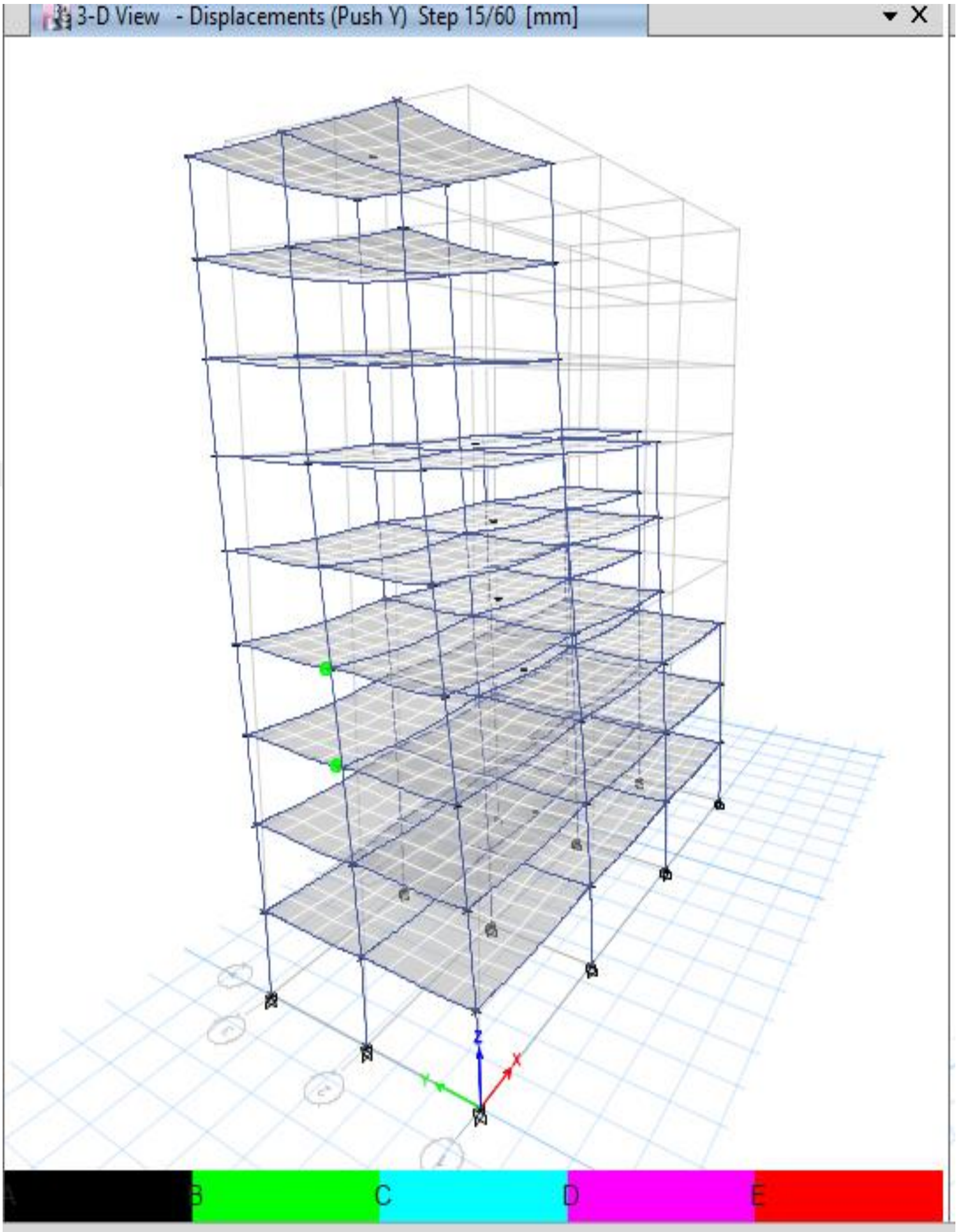

Figure 6.28: Formation of plastic hinges at step 15 in y-direction

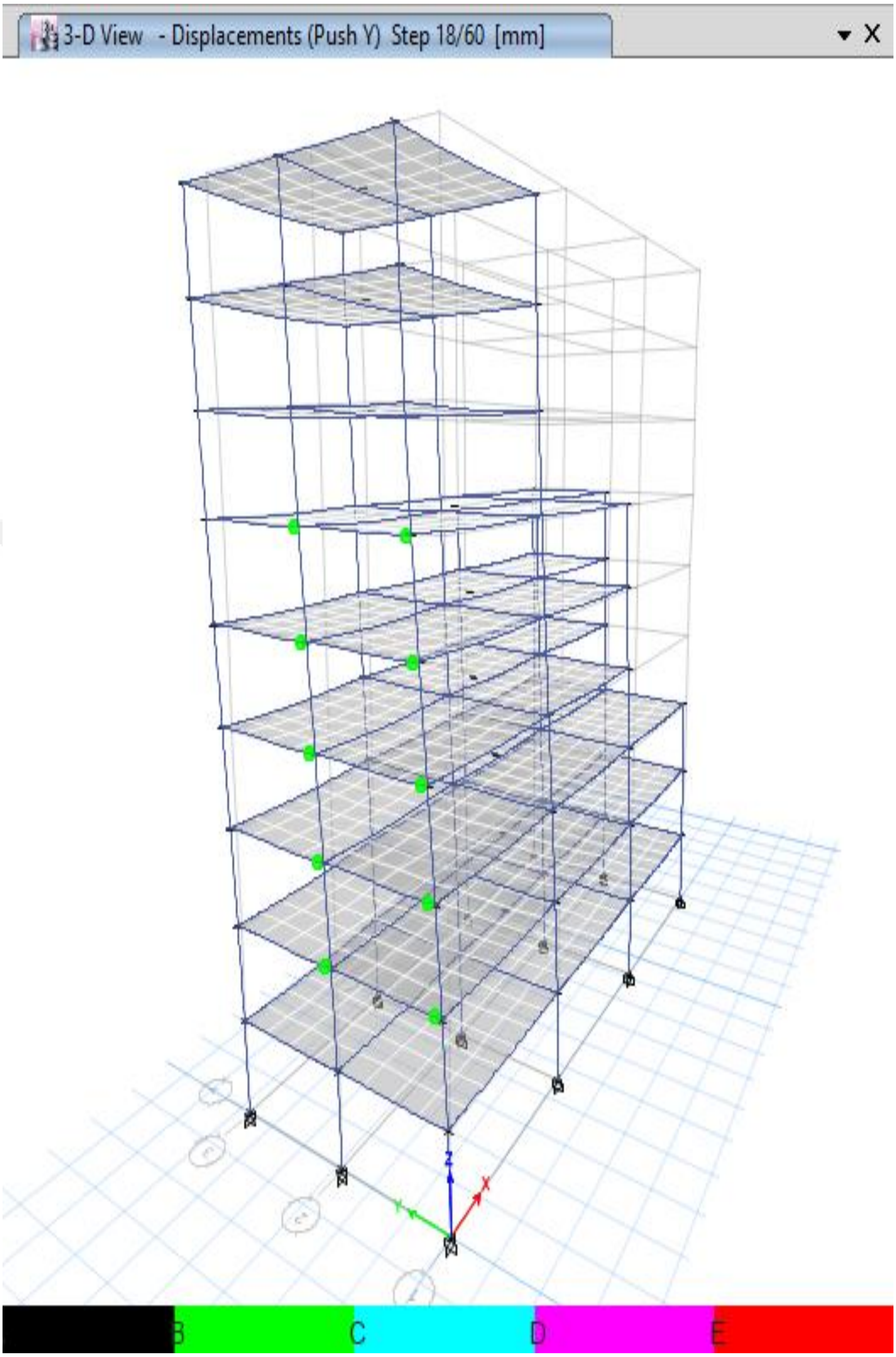

Figure 6.29: Formation of plastic hinges at step 18 in y-direction

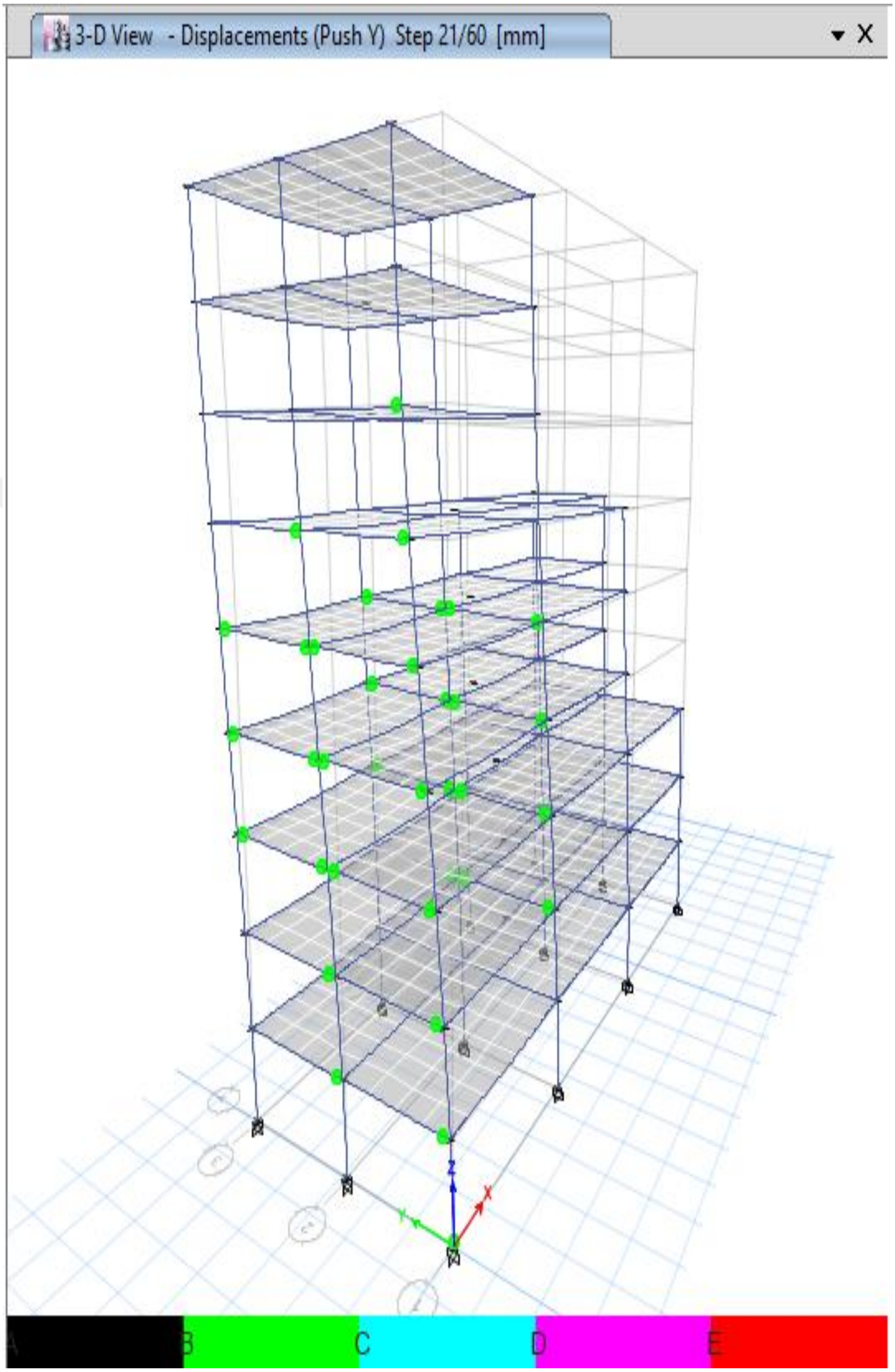

Figure 6.30: Formation of plastic hinges at step 21 in y-direction

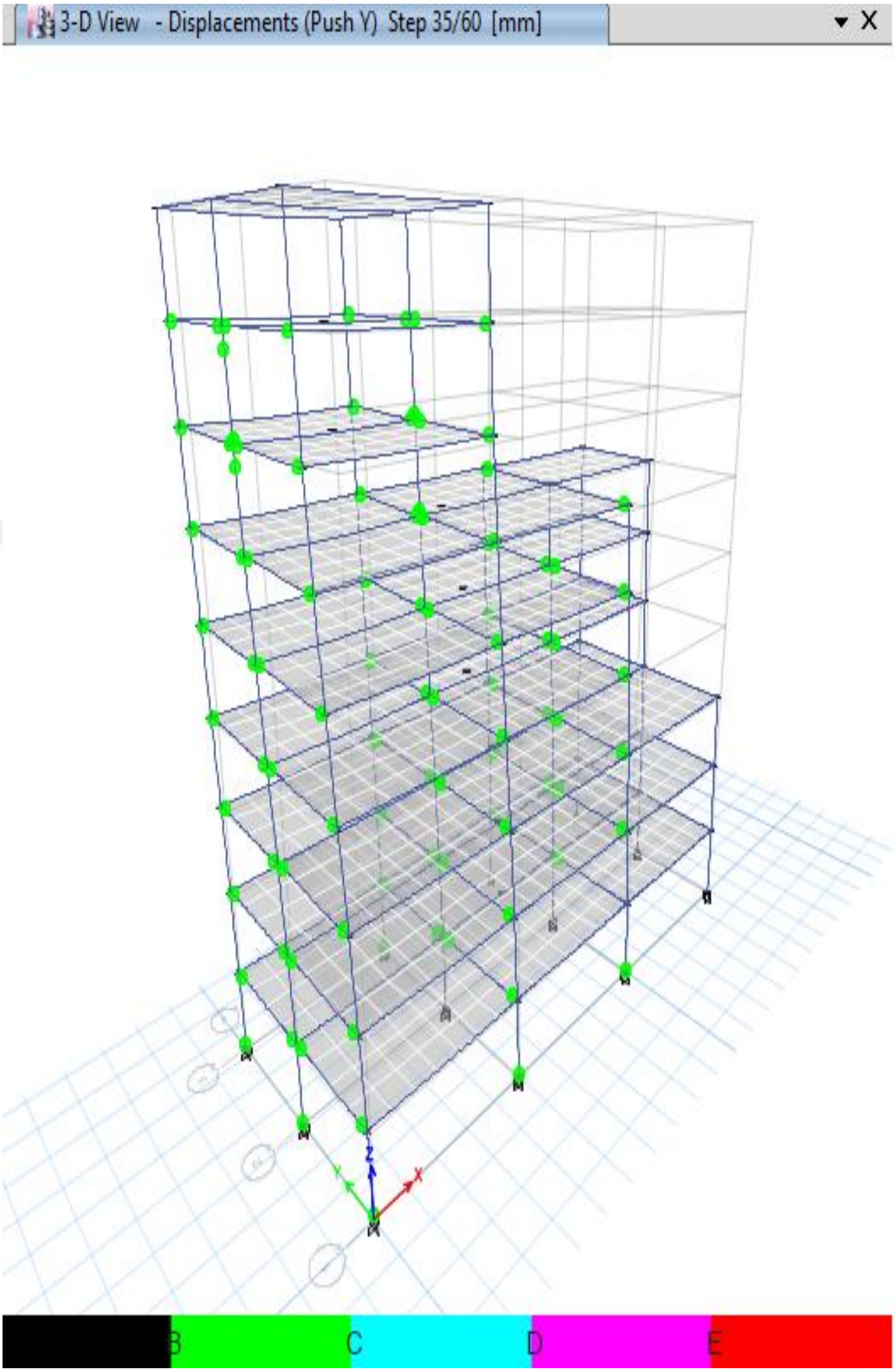

Figure 6.31: Formation of plastic hinges at step 35 in y-direction

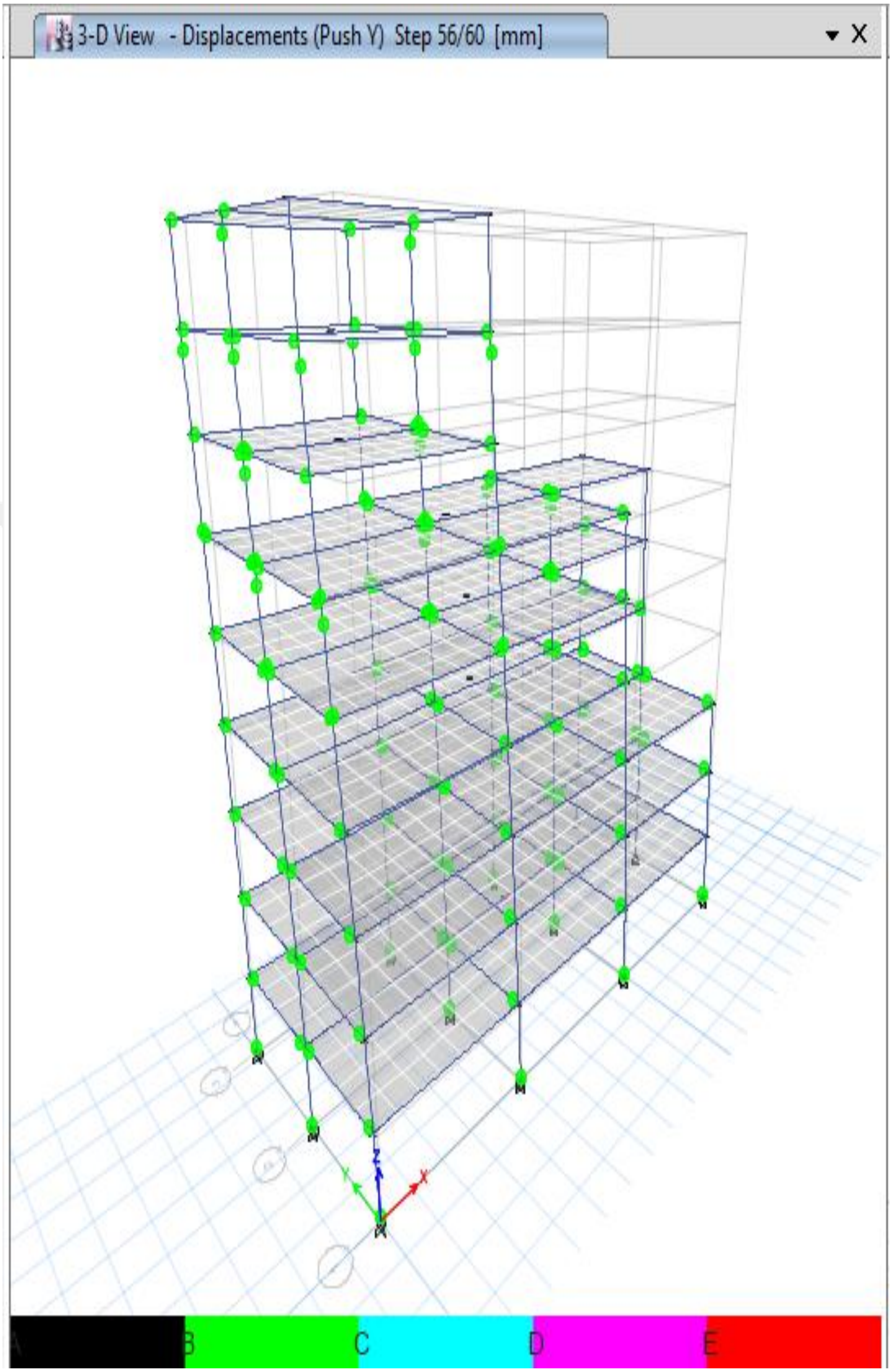

Figure 6.32: Formation of plastic hinges at step 56 in y-direction

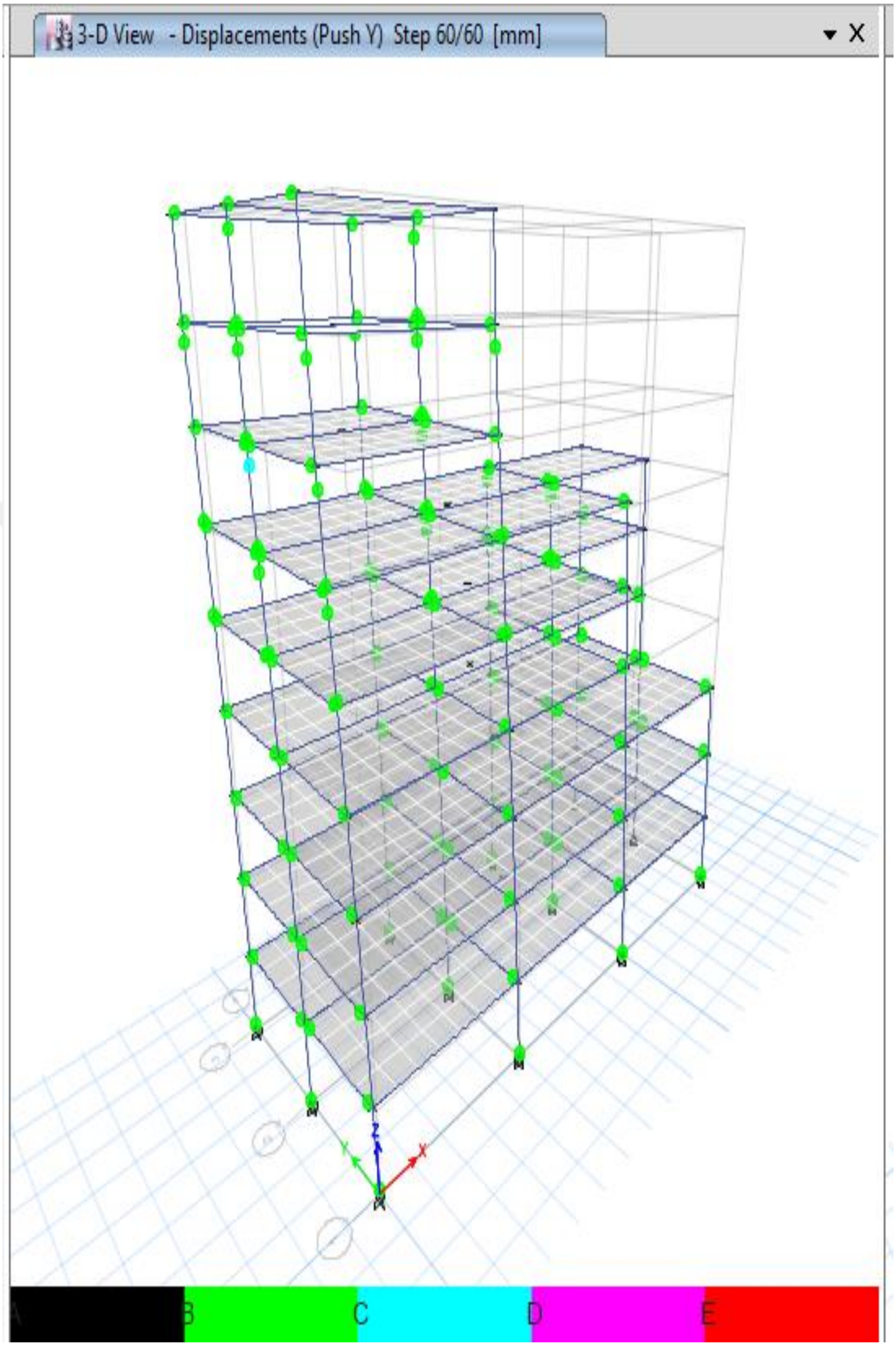

Figure 6.33: Formation of plastic hinges at last step in y-direction

6.1.3.5 Result of pushover analysis for fifteen story RCC building in x-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	PushX	Plot Type	V vs Displ

Plot

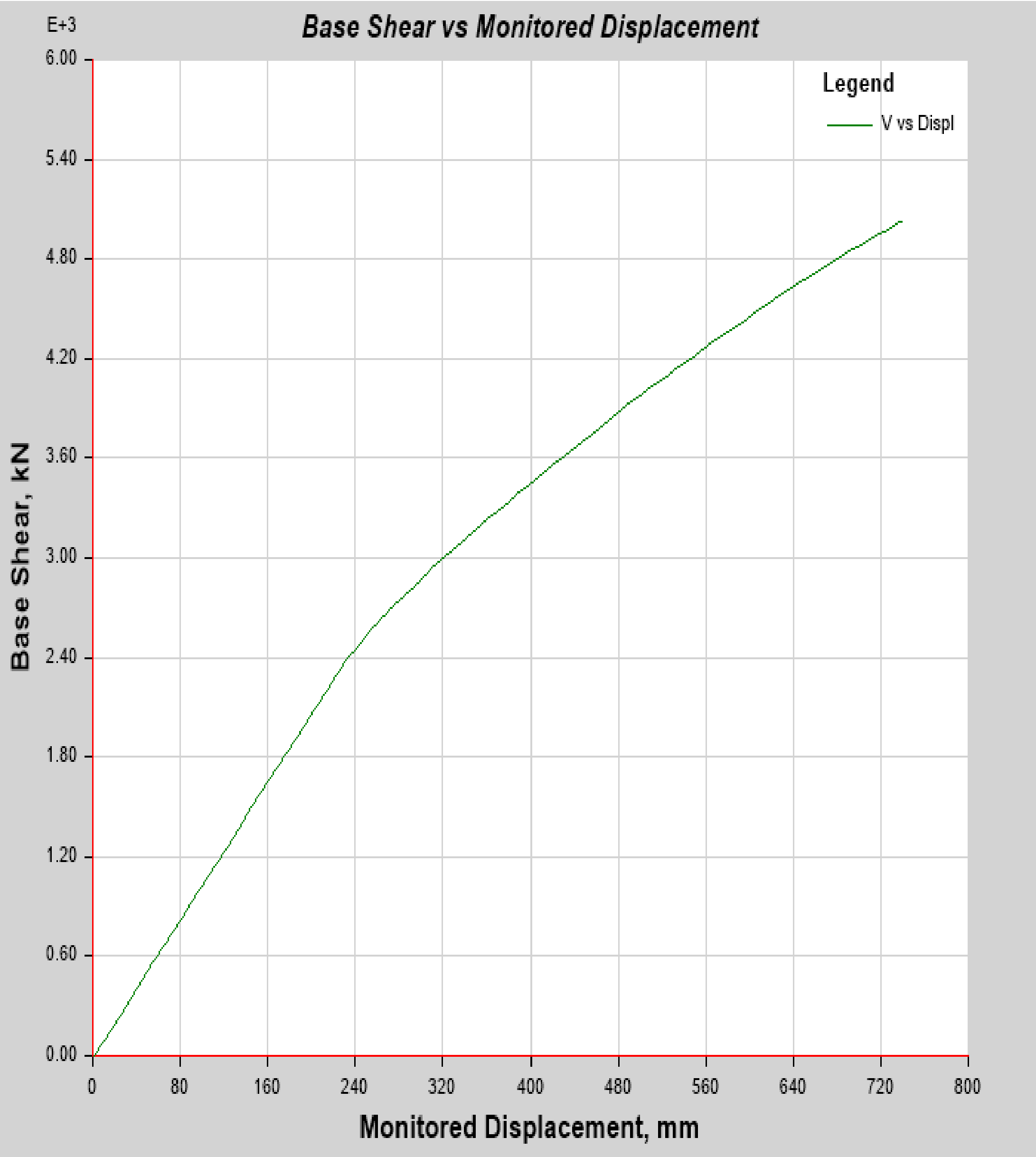

Figure 6.34: V vs L.D of fifteen story building in x-directio

B) Formation of plastic hinges

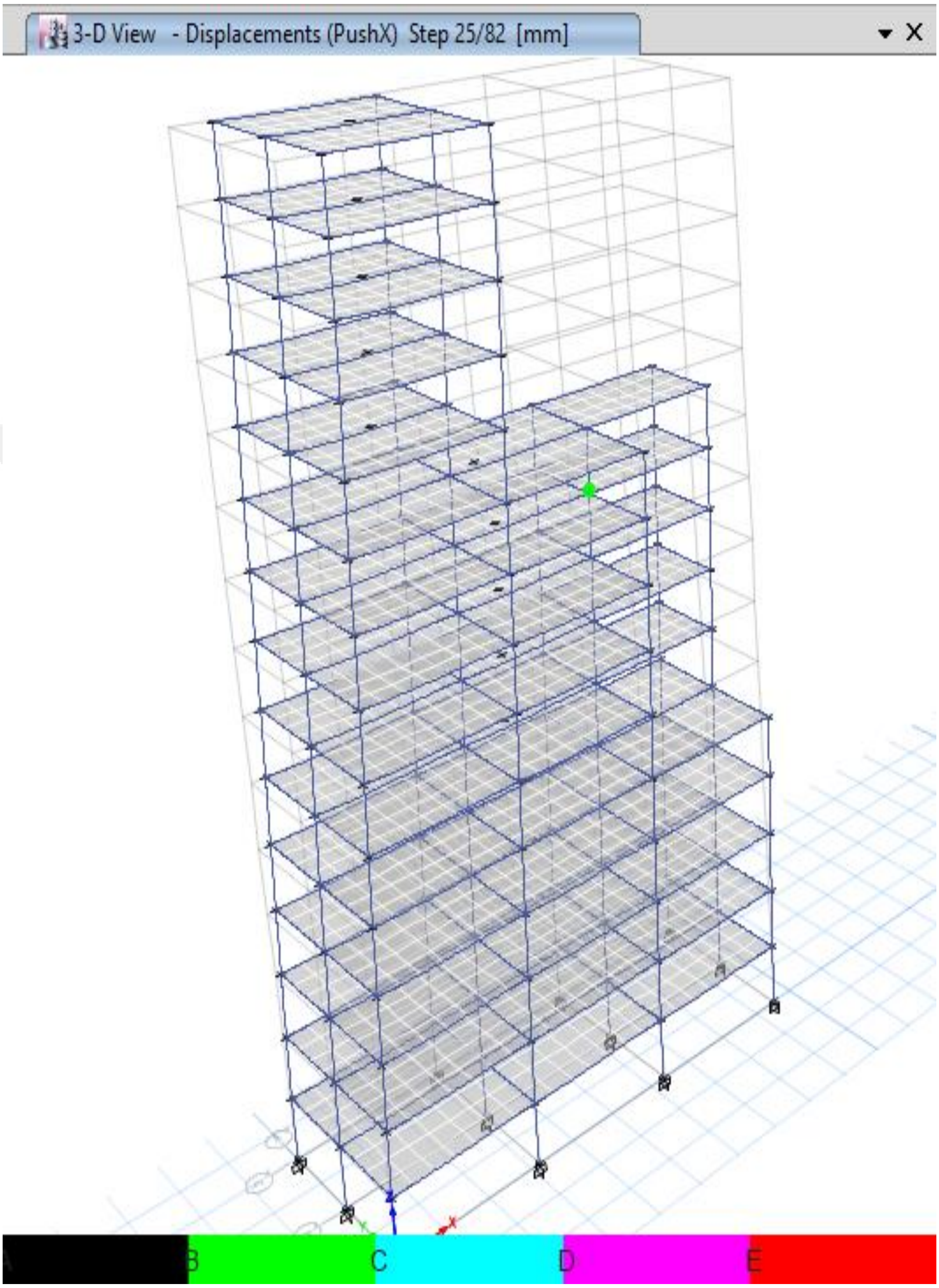

Figure 6.35: Formation of plastic hinges at step 25 in x-direction

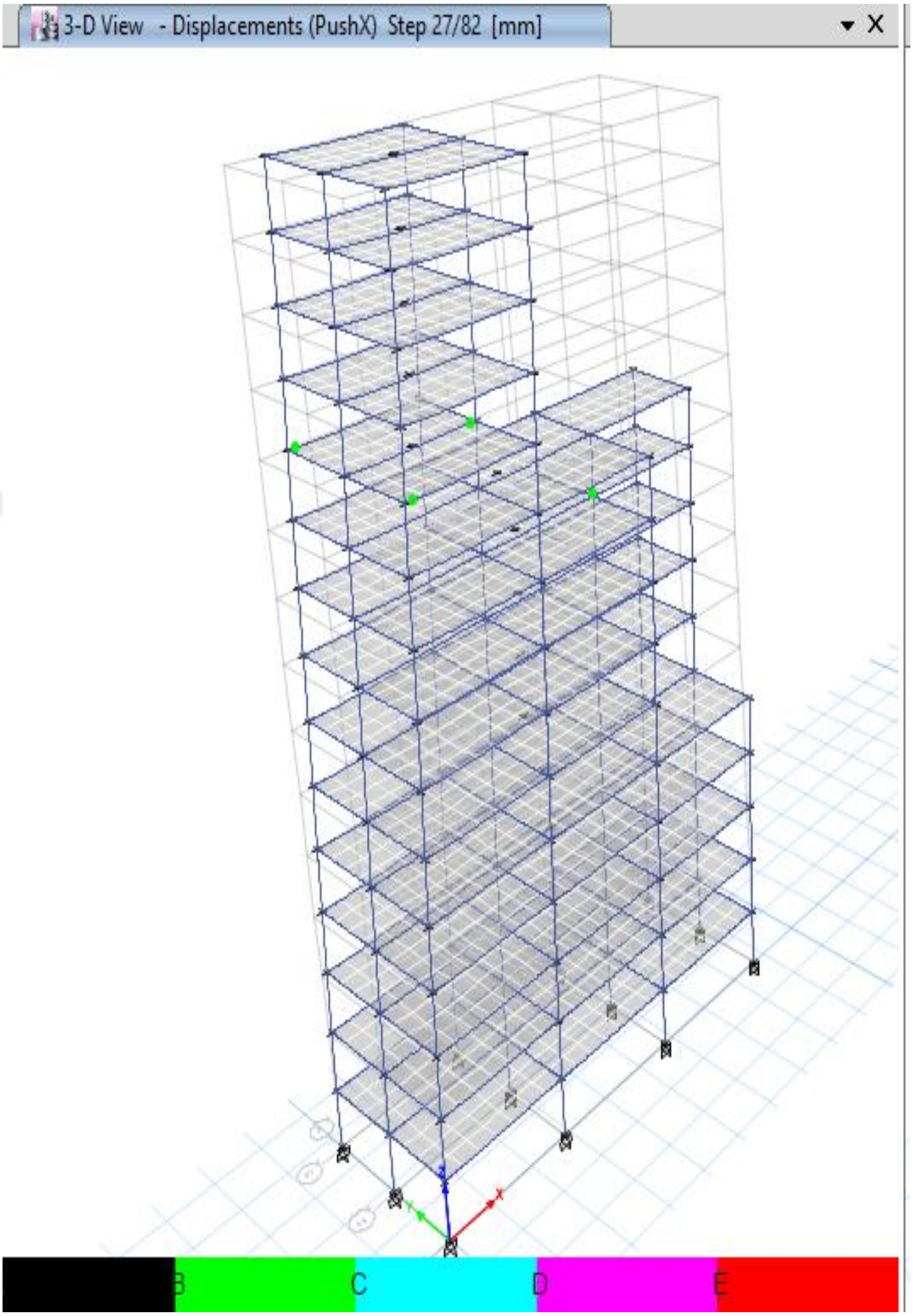

Figure 6.36: Formation of plastic hinges at step 27 in x-direction

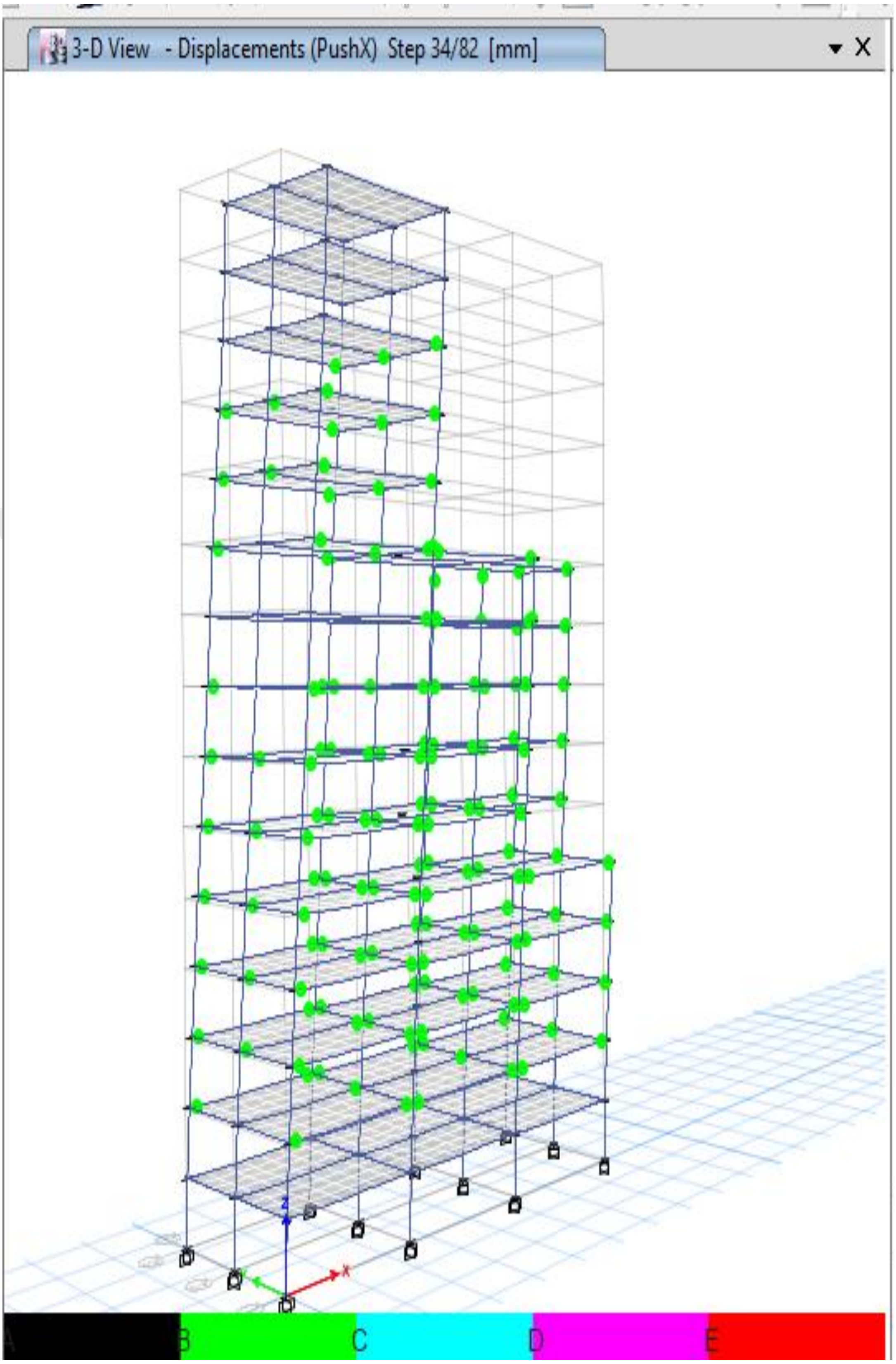

Figure 6.37: Formation of plastic hinges at step 34 in x-direction

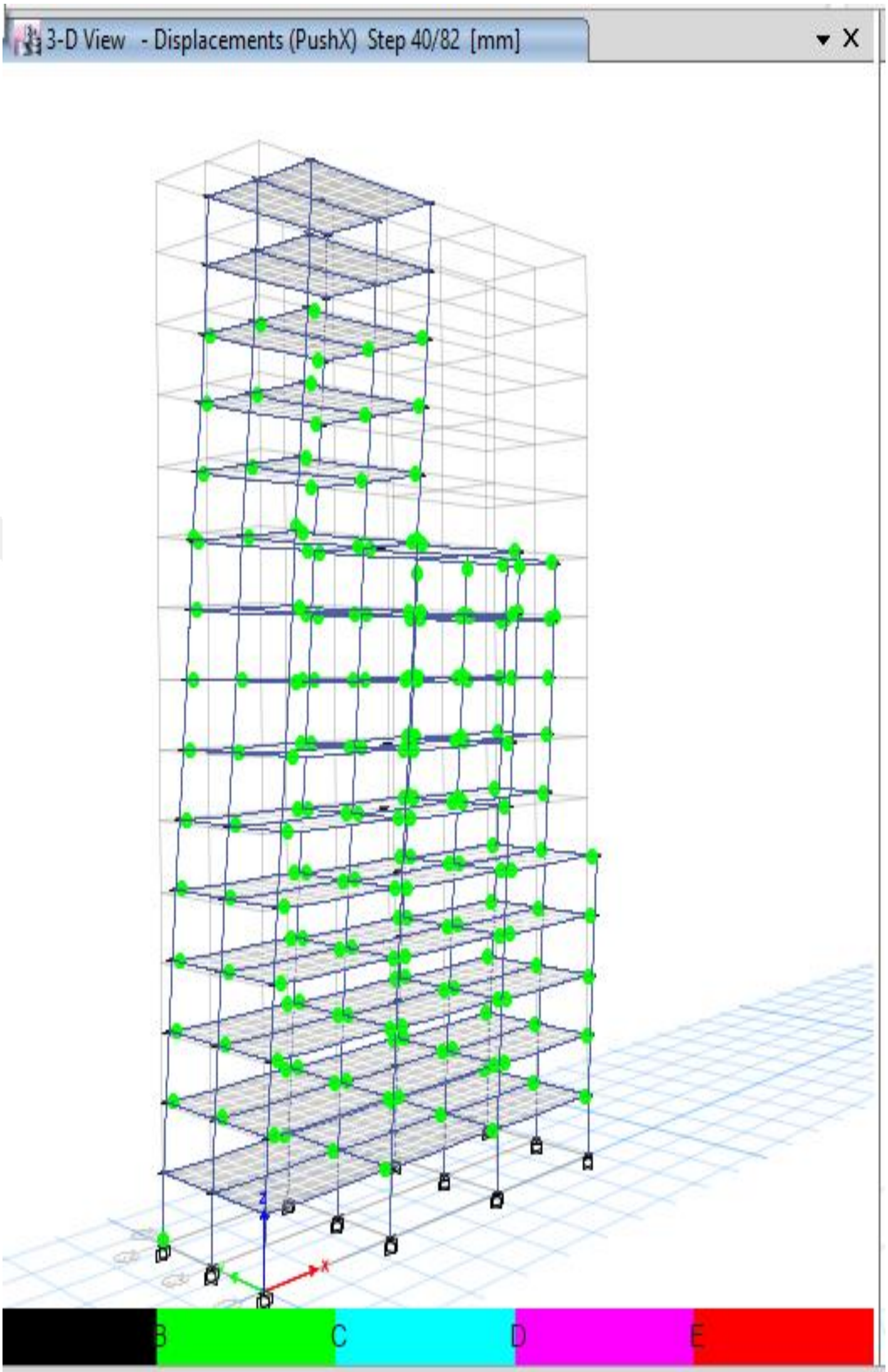

Figure 6.38: Formation of plastic hinges at step 40 in x-direction

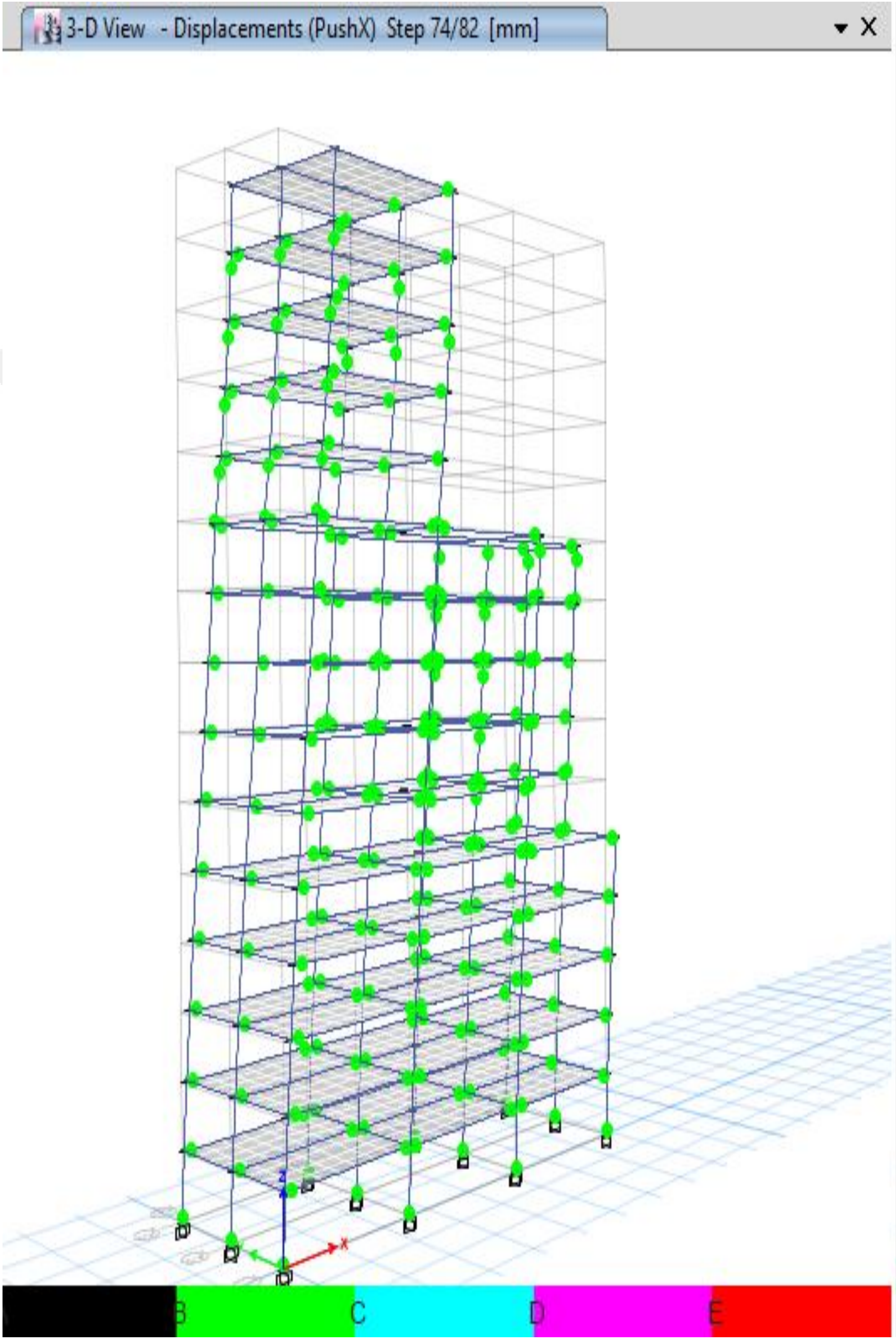

Figure 6.39: Formation of plastic hinges at step 74 in x-direction

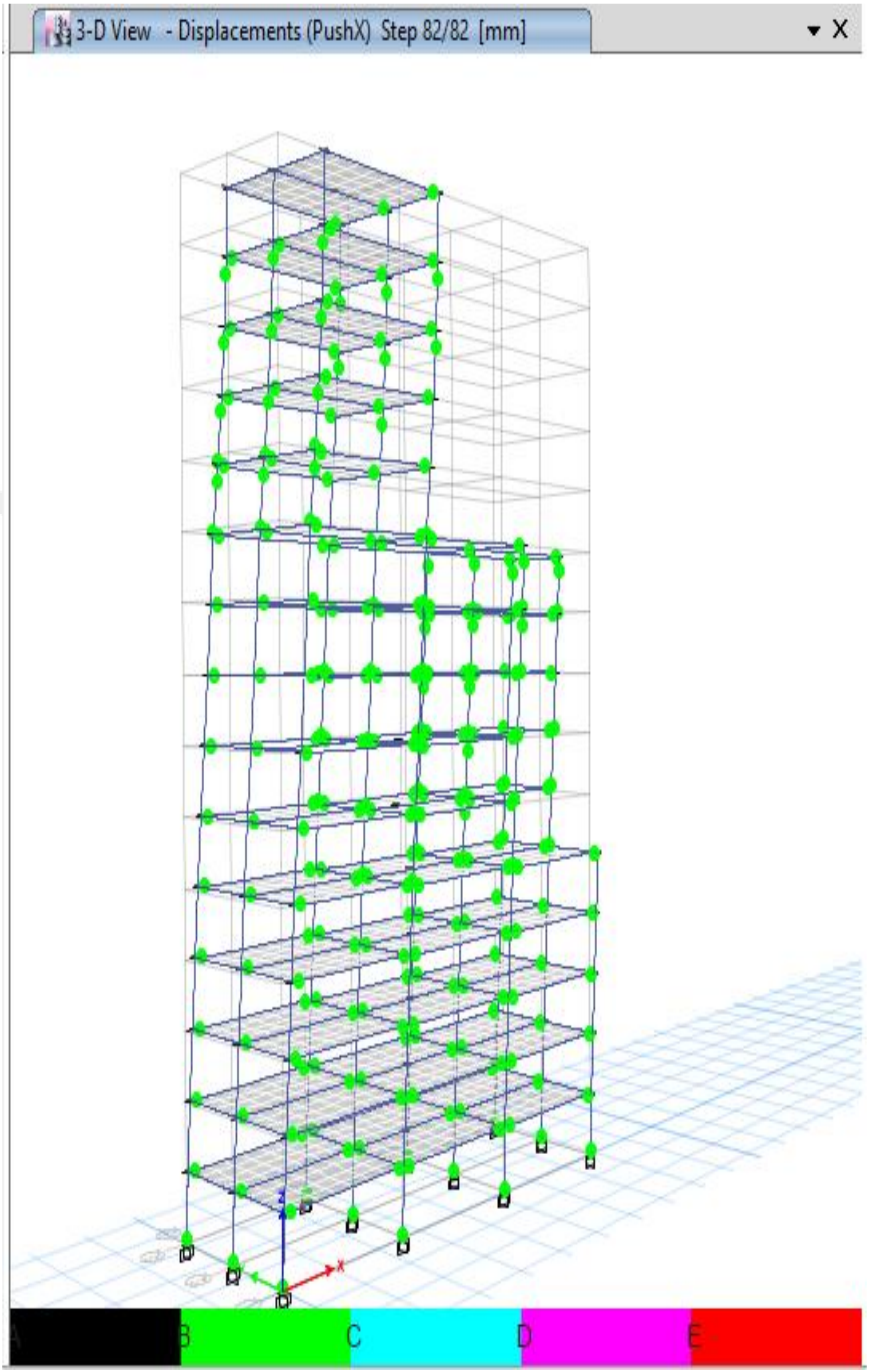

Figure 6.40: Formation of plastic hinges at last step in x-direction

6.1.3.6 Result of pushover analysis for fifteen story RCC building in y-direction

A) Pushover Curve - Base Shear vs Monitored Displacement

Summary Description

This is the base shear vs monitored displacement data for a pushover analysis.

Input Data

Name	Pushover		
Load Case	Push Y	Plot Type	V vs Displ

Plot

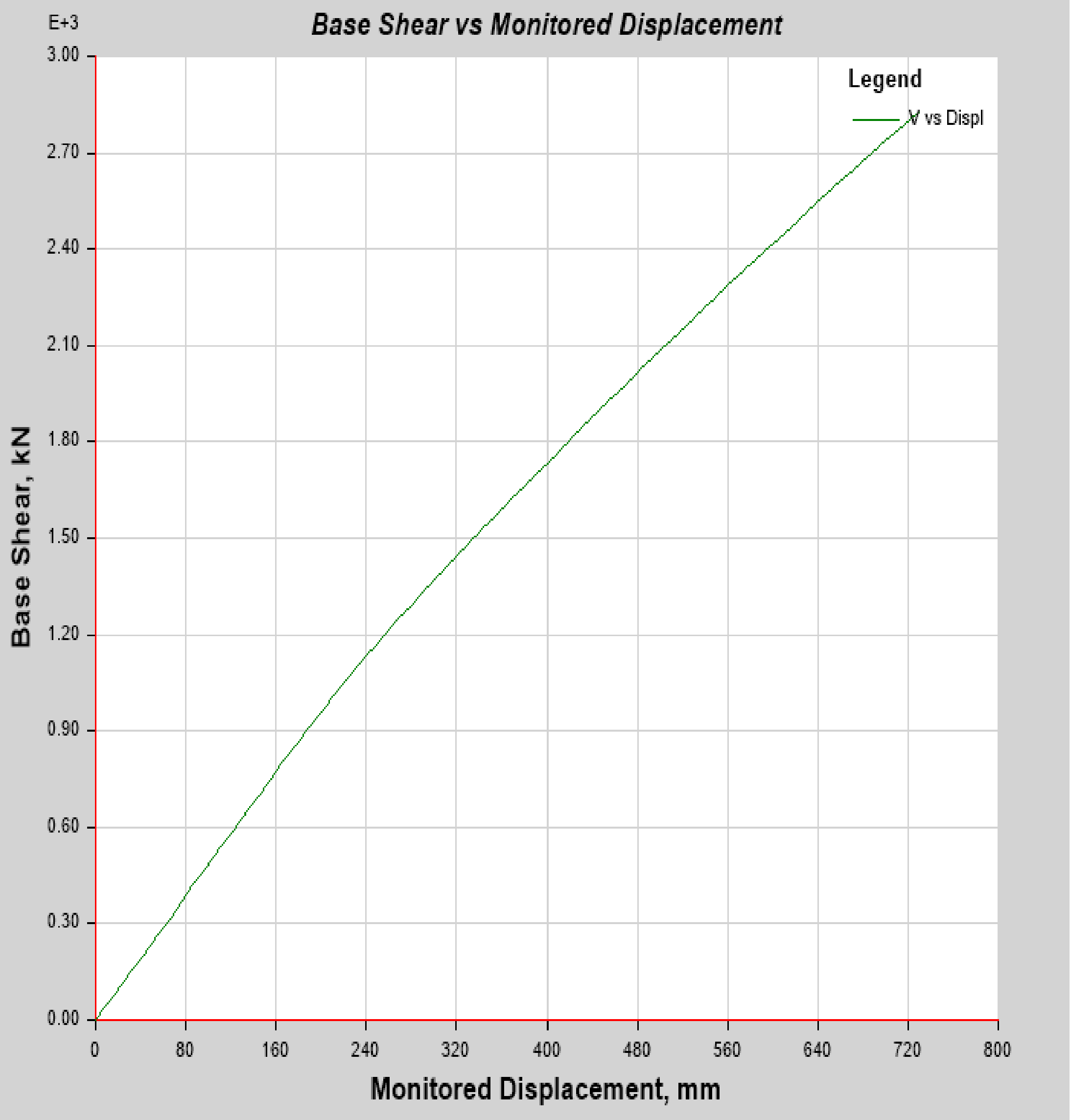

Figure 6.41: V vs L.D of fifteen story building in y-direction

B) Formation of plastic hinges

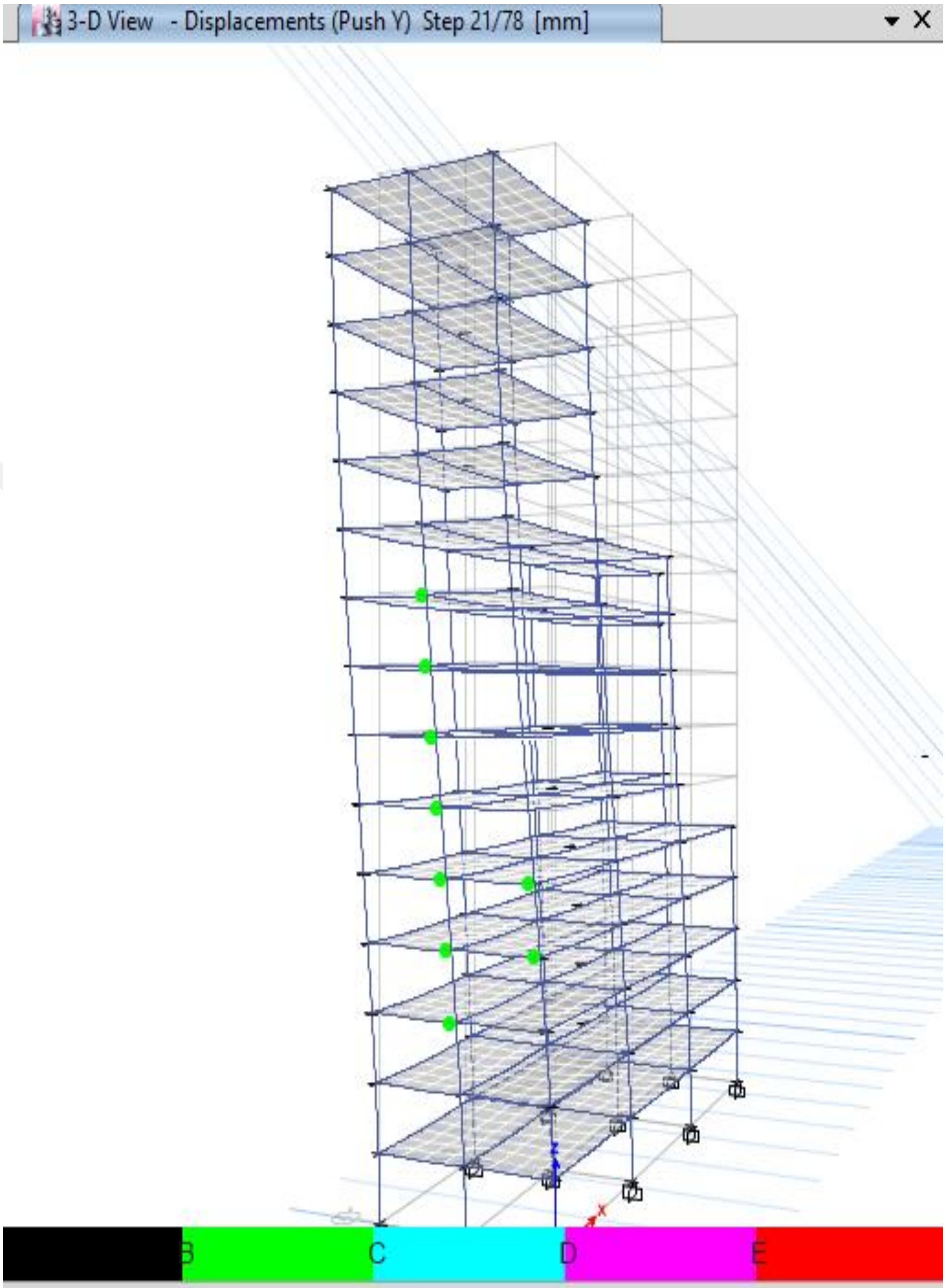

Figure 6.42: Formation of plastic hinges at step 21 in y-direction

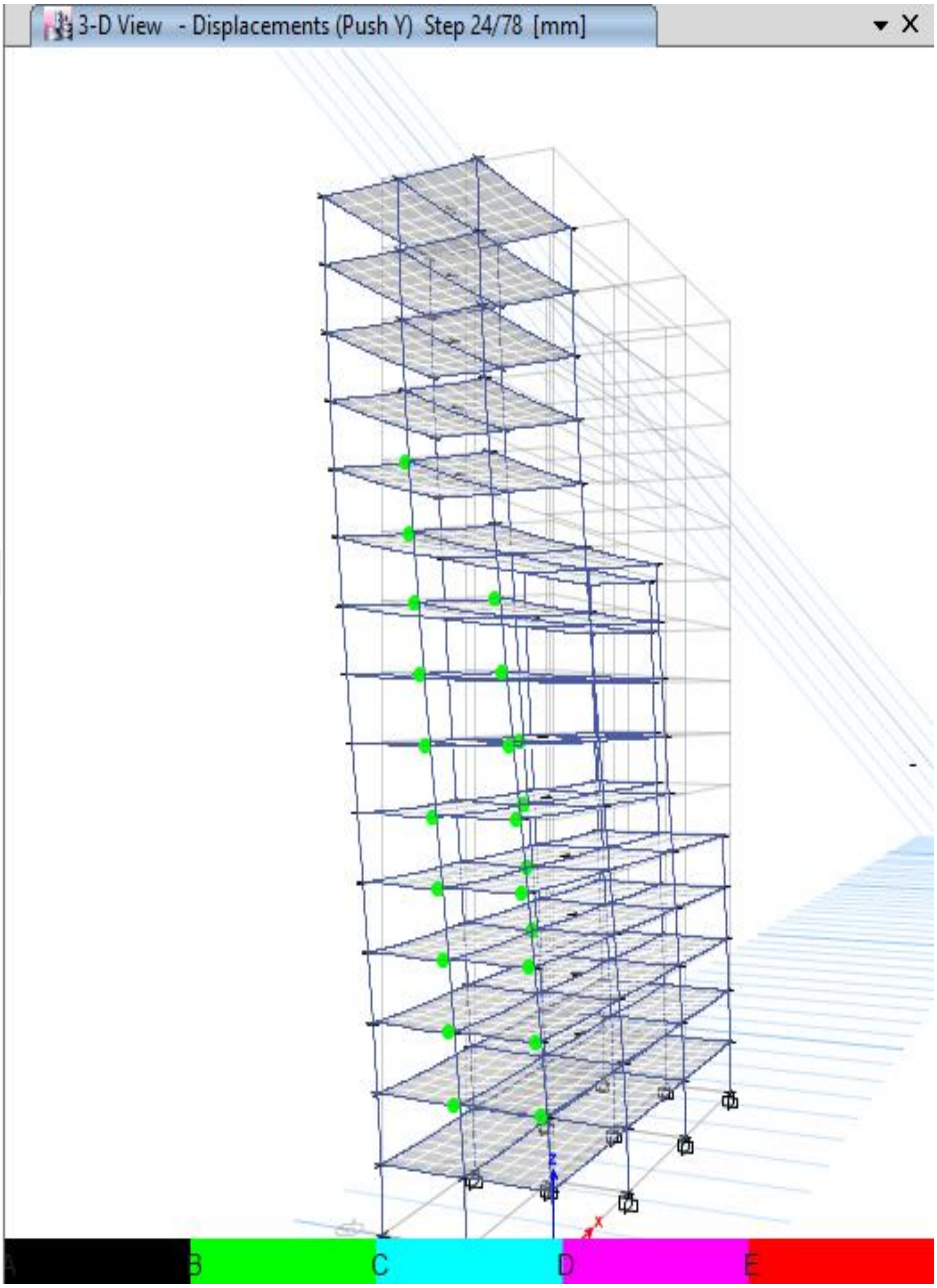

Figure 6.43: Formation of plastic hinges at step 24 in y-direction

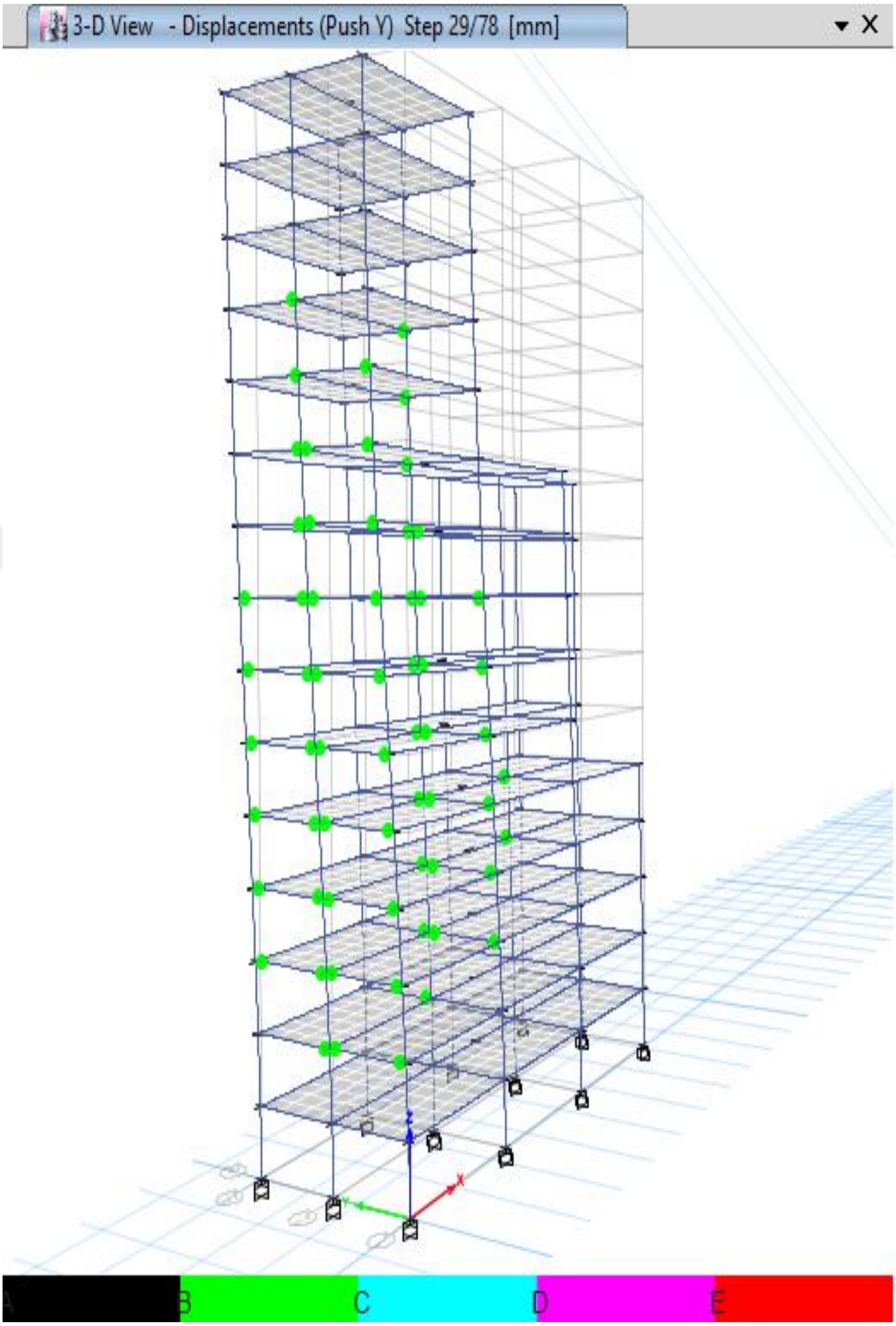

Figure 6.44: Formation of plastic hinges at step 29 in y-direction

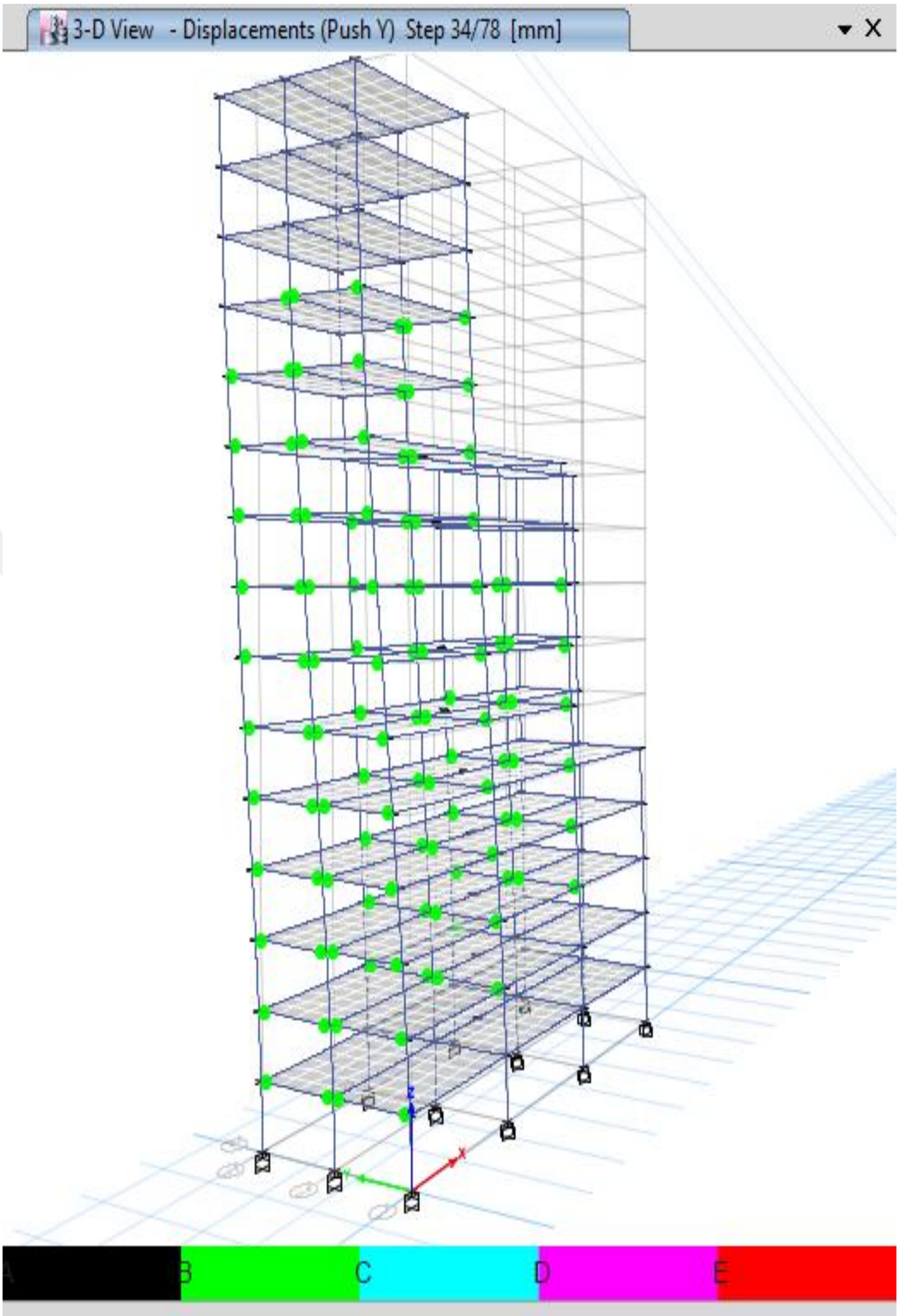

Figure 6.45: Formation of plastic hinges at step 34 in y-direction

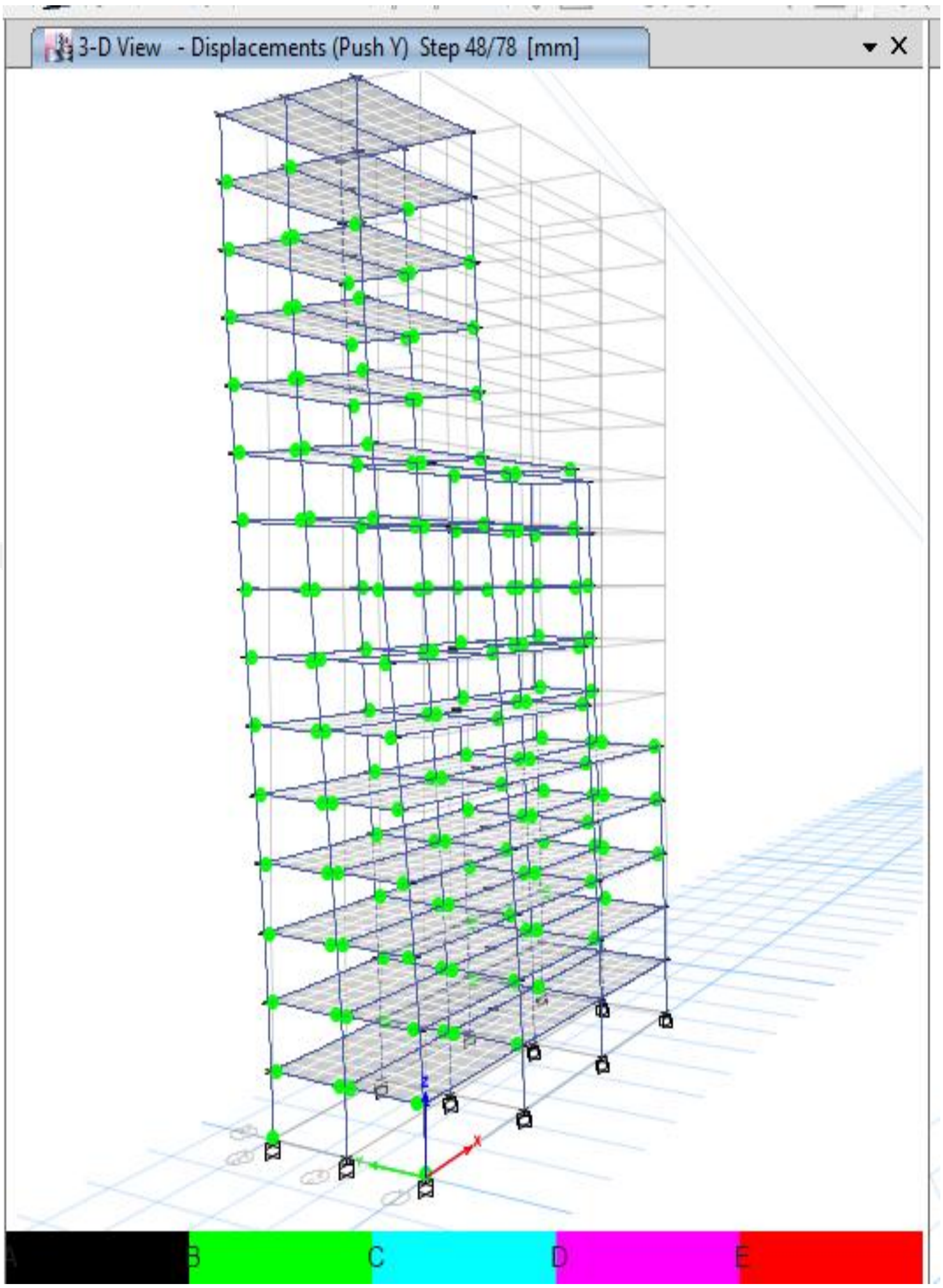

Figure 6.46: Formation of plastic hinges at step 48 in y-direction

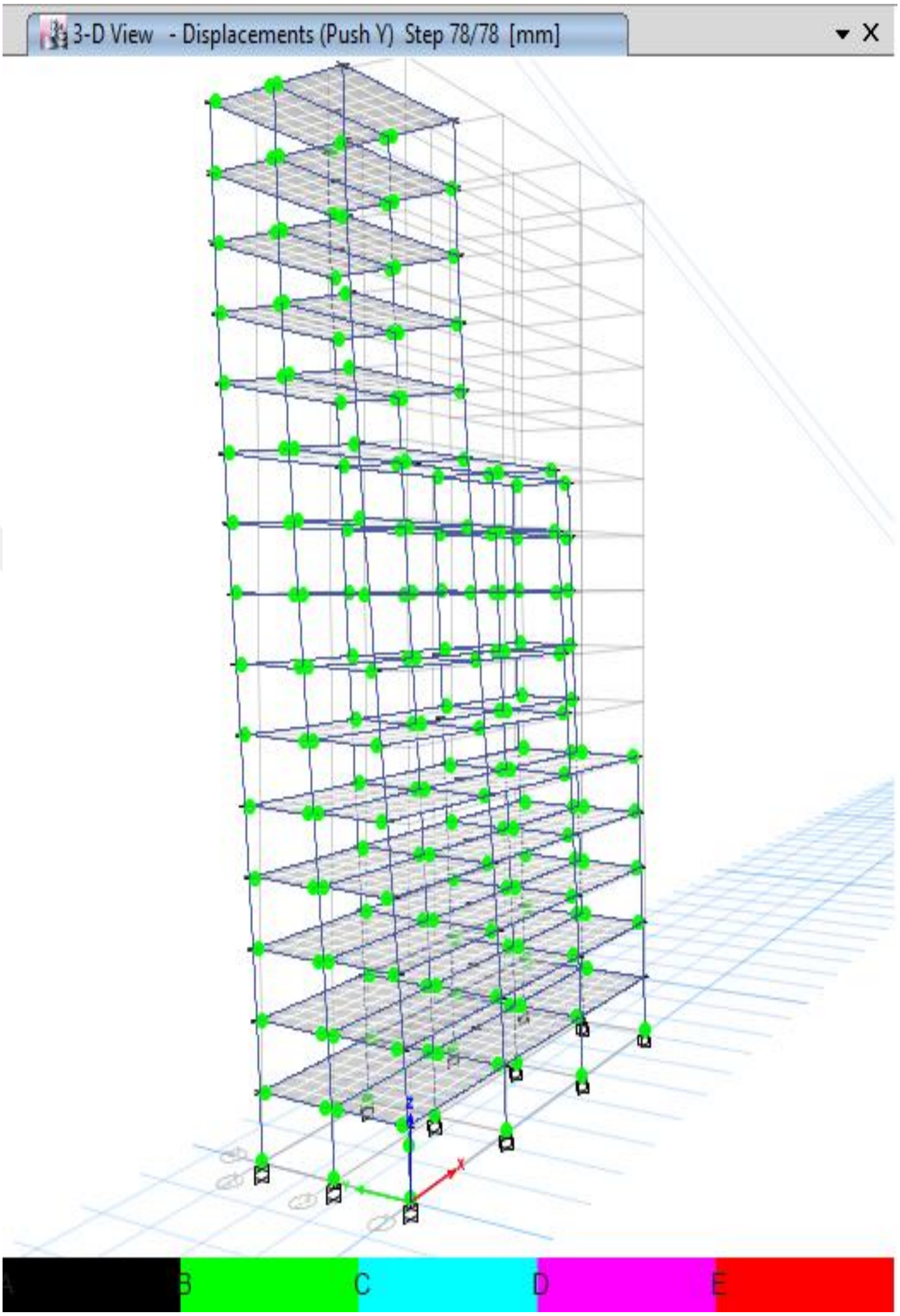

Figure 6.47: Formation of plastic hinges at last step in y-direction

6.2 Discussion

1. After modelling, linearly analyzed and designed, the pushover analysis, p-delta analysis and buckling analysis run for all three types of structures in ETABS2016.
2. IS 456:2000 used for designing of structural members and IS 1893 part 1 is used for Response spectrum analysis and calculation of earthquake loading.
3. M20(20N/mm^2) and M25(25N/mm^2) grade of concrete and Fe415(415N/mm^2) grade of steel are used to design the structural members.
4. Material nonlinearity is considered and assigned as hinges; M3 is assigned for beams and P-M-M is assigned for columns
5. Pushover analysis can be performed by applying lateral load pattern to the structures which is equivalent to earthquake load. Therefore, there are many guidelines to recommend load pattern for pushover analysis. For example, FEMA-356 documents recommend three lateral load pattern for pushover analysis such as uniform distribution pattern, Equivalent lateral force distribution pattern and SRSS distribution pattern. In the present study the lateral load is applied according to IS 1893 part 1.
6. After performing pushover analysis pushover curve is obtained and hinges are formed at different elements. From pushover curve base shear vs lateral displacement is obtained for each building separately.
7. From pushover curve of three story building it is observed that the maximum displacement and base reaction in X-direction up to elastic range is 35.65mm and 501.98KN and 38.213, 472.414KN in Y direction. The overall lateral displacement and base shear for this structure in X direction is 143.6mm, 997.92KN and in Y direction it is 176.27mm and 1209.27KN.
8. For three story structure, the capacity curve and demand curve intersected at lateral displacement and base shear of 80.35mm, 993.14KN in X-direction and 85,15mm, 860,57KN in Y-direction.
9. As a result of pushover analysis for nine story RCC frame structure, the yielding point in X-direction started from lateral displacement and base reaction of 105.959mm and 794.64KN and continued up to 409.83mm and 2239.094Kn in the inelastic range. The yielding point in Y-direction started from lateral displacement and base shear of 111.97mm, 642.78KN and ended at 547.53mm, 2216.19KN.

10. For nine story building the performance point obtained at displacement and base reaction of 253.93mm, 1749.39KN in x-direction and 284.91mm, 1462.03KN in Y-direction.
11. For fifteen story frame structure, the inelastic range in X-direction is started from lateral displacement and base shear of 193.36mmmm and 1992.98KN and ended at 738.82mm and 5028.5536KN. But in case of Y-direction the nonlinearity started at the point of lateral displacement and base force of 160.441mm, 777.44KN and ended at 729.59mm, 2827.81KN.
12. In case of fifteen story structure, the intersection of capacity curve and demand curve is obtained at lateral displacement and base force of 335,29mm, 3085,40KN in X-direction and 320.57mm, 1445.44KN in Y-direction.
13. From result of buckling analysis, it can be seen that the Buckling factor for the first mode of three, nine and fifteen story RCC frame structures without considering p-delta effect are 29.76, 12.08 and 8.72 and while considering p-delta effect the buckling factor obtained as 28.88, 11.18 and 7.81 respectively.
14. From result of buckling analysis and pushover analysis of 2D frame it is clear that, the formation of plastic hinges change the buckling safety of structures. For each step of formation of plastic hinges (appearing cracks at structural members) as a result of pushover analysis the buckling safety of structure reduce.
15. The variation of model period, lateral displacement and overturning moment while considering geometric nonlinearity is more for fifteen story structures as compare to nine story and three story buildings.

6.3 CONCLUSION

In this study, a nonlinear static analysis (pushover analysis) buckling analysis and p-delta analysis of three, nine and fifteen story RCC buildings have been performed in ETABS2016. Pushover analysis is very efficient approach to examine the behavior of new and existing structures under earthquake loading. Pushover curve and plastic hinges at the end of beams and columns are generated as a result of pushover analysis for each building separately. From the pushover curve the performance point is obtained which represent the global behavior of structure. Based on this work the following conclusions are made.

1. From the result of pushover analysis, it can be seen that the intersection of capacity curve and demand curve for all three types of buildings are near to elastic region.
2. The status of plastic hinges which are generated as a result of pushover analysis for all three structures up to performance points are located between point B and C (mostly near to immediate occupancy level). Therefore, no local collapse occurred at this point and all three structures perform very well during design earthquake.
3. Most of the hinges appeared below the immediate occupancy level and few of hinge passed collapse prevention level at last steps of analysis for all buildings. Therefore, it can be concluded that all three types of buildings are designed safely and can resist the earthquake loading without appearing major crack at structural members.
4. The lateral displacement, modal period and overturning moment are more for structures considered geometric nonlinearity as compare to structures not included geometric nonlinearity.
5. From result of p-delta analysis it can be observed that the variation of modal period, lateral displacement and overturning moments are more for fifteen story building as compare to other two buildings while considering geometric nonlinearity, Therefore, it can be concluded that the effect of geometric nonlinearity is more for high rise buildings as compare to low rise buildings and p-delta effect must be considered for high rise buildings.
6. Results of buckling analysis for all buildings clearly indicate that the Buckling safety decrease for all three structures while Considering p-delta effect in the analysis. and also due to appearing plastic hinges at different elements as a result of pushover analysis, the buckling factor decrease as the hinge formation increase.

Lots of analytical and experimental studies regarding nonlinear pushover analysis of structures have been done and still continuing which result in the continued growth of the concept of pushover analysis. From evaluating the nonlinear behavior of rcc buildings, it is concluded that the result of nonlinear static analysis can successfully evaluate the failure mechanism of buildings by showing hinge results and helps predict the overall performance of a structure. ETABS allow a user to model, analyze, design, and display the structure geometry, properties and analysis result, they are used for performing the nonlinear static analysis of the structures.

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Appendix

Table A.1: Status of plastic hinges from result of pushover analysis in x-direction of three story irregular rcc building

Step	Monitored Displ	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
	mm	kN										
0	2.05	0	272	0	0	0	0	272	0	0	0	272
1	4.45	35.8559	272	0	0	0	0	272	0	0	0	272
2	6.85	71.7119	272	0	0	0	0	272	0	0	0	272
3	9.25	107.5678	272	0	0	0	0	272	0	0	0	272
4	11.65	143.4237	272	0	0	0	0	272	0	0	0	272
5	14.05	179.2797	272	0	0	0	0	272	0	0	0	272
6	16.45	215.1356	272	0	0	0	0	272	0	0	0	272
7	18.85	250.9916	272	0	0	0	0	272	0	0	0	272
8	21.25	286.8475	272	0	0	0	0	272	0	0	0	272
9	23.65	322.7034	272	0	0	0	0	272	0	0	0	272
10	26.05	358.5594	272	0	0	0	0	272	0	0	0	272
11	28.45	394.4153	272	0	0	0	0	272	0	0	0	272
12	30.85	430.2712	272	0	0	0	0	272	0	0	0	272
13	33.25	466.1272	272	0	0	0	0	272	0	0	0	272
14	35.65	501.9831	272	0	0	0	0	272	0	0	0	272
15	37.552	530.4037	270	2	0	0	0	272	0	0	0	272
16	41.246	583.2957	264	8	0	0	0	272	0	0	0	272
17	44.981	634.1103	258	14	0	0	0	272	0	0	0	272
18	47.743	667.6751	250	22	0	0	0	270	0	0	2	272
19	52.429	718.7197	242	30	0	0	0	268	0	0	4	272
20	55.107	745.6964	236	36	0	0	0	268	0	0	4	272
21	57.507	768.1459	234	38	0	0	0	268	0	0	4	272
22	59.907	789.4602	230	42	0	0	0	268	0	0	4	272
23	62.885	814.1012	218	54	0	0	0	268	0	0	4	272
24	65.285	831.8467	218	54	0	0	0	268	0	0	4	272
25	67.685	849.3883	218	54	0	0	0	268	0	0	4	272
26	72.429	883.1339	214	58	0	0	0	268	0	0	4	272
27	75.728	904.8111	206	66	0	0	0	268	0	0	4	272
28	80.359	933.1488	200	72	0	0	0	268	0	0	4	272
29	82.759	946.9477	196	76	0	0	0	268	0	0	4	272
30	85.159	960.5126	194	78	0	0	0	266	2	0	4	272
31	89.862	986.011	190	82	0	0	0	264	4	0	4	272
32	92.262	998.6848	188	84	0	0	0	264	4	0	4	272
33	96.19	1018.0045	182	90	0	0	0	264	4	0	4	272
34	98.59	1029.0083	180	92	0	0	0	264	4	0	4	272
35	100.99	1039.9127	176	96	0	0	0	264	4	0	4	272
36	103.39	1050.6282	172	100	0	0	0	264	4	0	4	272
37	105.79	1061.1958	172	100	0	0	0	262	6	0	4	272
38	108.19	1071.6365	170	102	0	0	0	260	8	0	4	272
39	110.59	1082.1942	170	102	0	0	0	252	16	0	4	272
40	112.99	1092.5862	166	106	0	0	0	252	16	0	4	272
41	117.629	1111.1923	154	118	0	0	0	248	20	0	4	272
42	120.029	1120.1597	154	118	0	0	0	246	22	0	4	272
43	123.3	1131.9668	152	120	0	0	0	240	28	0	4	272
44	125.7	1140.3792	150	122	0	0	0	238	30	0	4	272
45	128.161	1148.2552	148	124	0	0	0	236	32	0	4	272
46	131.054	1156.6677	144	128	0	0	0	230	38	0	4	272
47	133.454	1162.9766	144	128	0	0	0	230	38	0	4	272
48	135.854	1169.499	138	134	0	0	0	230	36	2	4	272
49	138.254	1175.1858	136	136	0	0	0	226	40	2	4	272

50	140.654	1180.9023	134	138	0	0	0	226	40	2	4	272
51	143.167	1185.8314	134	138	0	0	0	224	42	2	4	272
52	146.617	1192.7698	134	138	0	0	0	222	42	4	4	272
53	150.392	1199.6391	132	140	0	0	0	220	44	4	4	272
54	154.592	1206.781	130	142	0	0	0	216	46	6	4	272
55	156.787	1210.732	130	140	2	0	0	216	44	6	6	272
56	143.658	997.9078	130	140	0	0	2	216	44	6	6	272

Table A.2: Status of plastic hinges from result of pushover analysis in y-direction of three story irregular rcc building

Step	**Monitored Displ**	**Base Force**	**A-B**	**B-C**	**C-D**	**D-E**	**>E**	**A-IO**	**IO-LS**	**LS-CP**	**>CP**	**Total Hinges**
	mm	**kN**										
0	-0.187	0	272	0	0	0	0	272	0	0	0	272
1	2.213	29.5259	272	0	0	0	0	272	0	0	0	272
2	4.613	59.0517	272	0	0	0	0	272	0	0	0	272
3	7.013	88.5776	272	0	0	0	0	272	0	0	0	272
4	9.413	118.1035	272	0	0	0	0	272	0	0	0	272
5	11.813	147.6294	272	0	0	0	0	272	0	0	0	272
6	14.213	177.1552	272	0	0	0	0	272	0	0	0	272
7	16.613	206.6811	272	0	0	0	0	272	0	0	0	272
8	19.013	236.207	272	0	0	0	0	272	0	0	0	272
9	21.413	265.7329	272	0	0	0	0	272	0	0	0	272
10	23.813	295.2587	272	0	0	0	0	272	0	0	0	272
11	26.213	324.7846	272	0	0	0	0	272	0	0	0	272
12	28.613	354.3105	272	0	0	0	0	272	0	0	0	272
13	31.013	383.8363	272	0	0	0	0	272	0	0	0	272
14	33.413	413.3622	272	0	0	0	0	272	0	0	0	272
15	35.813	442.8881	272	0	0	0	0	272	0	0	0	272
16	38.213	472.414	272	0	0	0	0	272	0	0	0	272
17	40.507	500.6348	270	2	0	0	0	272	0	0	0	272
18	43.137	530.5863	266	6	0	0	0	272	0	0	0	272
19	45.537	554.8599	266	6	0	0	0	272	0	0	0	272
20	47.937	579.1351	266	6	0	0	0	272	0	0	0	272
21	50.337	603.4103	266	6	0	0	0	272	0	0	0	272
22	52.737	627.6855	264	8	0	0	0	272	0	0	0	272
23	55.137	650.2097	264	8	0	0	0	272	0	0	0	272
24	59.427	688.8031	260	12	0	0	0	272	0	0	0	272
25	62.314	711.4278	256	16	0	0	0	272	0	0	0	272
26	64.714	729.5855	256	16	0	0	0	272	0	0	0	272
27	67.114	747.8897	256	16	0	0	0	272	0	0	0	272
28	71.58	779.1885	248	24	0	0	0	272	0	0	0	272
29	75.728	805.8551	238	34	0	0	0	272	0	0	0	272
30	78.592	823.1413	230	42	0	0	0	272	0	0	0	272
31	80.992	836.9382	226	46	0	0	0	272	0	0	0	272
32	85.16	860.5745	220	52	0	0	0	272	0	0	0	272
33	89.149	882.6168	212	60	0	0	0	272	0	0	0	272
34	91.549	895.85	212	60	0	0	0	272	0	0	0	272
35	93.949	908.7663	212	60	0	0	0	272	0	0	0	272
36	96.349	922.0324	210	62	0	0	0	272	0	0	0	272
37	98.749	934.8895	204	68	0	0	0	270	2	0	0	272
38	101.149	947.6003	202	70	0	0	0	270	2	0	0	272
39	103.549	959.9971	196	76	0	0	0	268	2	0	2	272
40	108.248	983.0622	190	82	0	0	0	264	6	0	2	272
41	110.648	994.9372	190	82	0	0	0	264	6	0	2	272
42	113.048	1006.2199	190	82	0	0	0	264	6	0	2	272
43	116.641	1023.3883	186	86	0	0	0	264	6	0	2	272

44	119.041	1034.762	186	86	0	0	0	264	6	0	2	272
45	121.441	1045.9543	184	88	0	0	0	262	8	0	2	272
46	125.28	1061.9367	176	96	0	0	0	262	8	0	2	272
47	127.68	1071.6569	174	98	0	0	0	260	10	0	2	272
48	130.08	1080.4487	172	100	0	0	0	260	10	0	2	272
49	132.48	1089.5495	170	102	0	0	0	260	10	0	2	272
50	136.845	1104.9378	166	106	0	0	0	258	12	0	2	272
51	139.245	1112.5362	164	108	0	0	0	256	14	0	2	272
52	141.645	1119.4551	162	110	0	0	0	256	14	0	2	272
53	144.045	1126.1752	162	110	0	0	0	256	14	0	2	272
54	146.445	1133.0055	162	110	0	0	0	256	14	0	2	272
55	148.845	1139.5307	162	110	0	0	0	256	12	2	2	272
56	151.245	1146.2065	162	110	0	0	0	255	13	2	2	272
57	153.645	1152.7744	162	110	0	0	0	254	14	2	2	272
58	156.045	1159.3322	162	110	0	0	0	254	14	2	2	272
59	158.445	1165.6244	162	110	0	0	0	254	14	2	2	272
60	160.845	1171.9921	162	110	0	0	0	254	14	2	2	272
61	163.245	1178.3263	162	110	0	0	0	252	16	2	2	272
62	166.059	1185.2135	160	112	0	0	0	250	18	2	2	272
63	168.459	1191.0569	158	114	0	0	0	250	16	4	2	272
64	170.859	1196.7172	156	116	0	0	0	248	18	4	2	272
65	173.259	1202.4509	156	116	0	0	0	246	20	2	4	272
66	175.659	1207.7291	156	116	0	0	0	246	20	2	4	272
67	176.034	1208.6113	156	114	2	0	0	246	20	2	4	272
68	176.083	1208.8047	156	114	2	0	0	246	20	2	4	272

Table A.3: Status of plastic hinges from result of pushover analysis in x-direction of nine story irregular rcc building

Step	**Monitored Displ**	**Base Force**	**A-B**	**B-C**	**C-D**	**D-E**	**>E**	**A-IO**	**IO-LS**	**LS-CP**	**>CP**	**Total Hinges**
	mm	**kN**										
0	1.959	0	816	0	0	0	0	816	0	0	0	816
1	9.959	61.1264	816	0	0	0	0	816	0	0	0	816
2	17.959	122.2529	816	0	0	0	0	816	0	0	0	816
3	25.959	183.3793	816	0	0	0	0	816	0	0	0	816
4	33.959	244.5057	816	0	0	0	0	816	0	0	0	816
5	41.959	305.6321	816	0	0	0	0	816	0	0	0	816
6	49.959	366.7586	816	0	0	0	0	816	0	0	0	816
7	57.959	427.885	816	0	0	0	0	816	0	0	0	816
8	65.959	489.0114	816	0	0	0	0	816	0	0	0	816
9	73.959	550.1378	816	0	0	0	0	816	0	0	0	816
10	81.959	611.2643	816	0	0	0	0	816	0	0	0	816
11	89.959	672.3907	816	0	0	0	0	816	0	0	0	816
12	97.959	733.5171	816	0	0	0	0	816	0	0	0	816
13	105.959	794.6435	816	0	0	0	0	816	0	0	0	816
14	112.185	842.2131	814	2	0	0	0	816	0	0	0	816
15	120.185	902.9068	814	2	0	0	0	816	0	0	0	816
16	132.597	996.7073	810	6	0	0	0	816	0	0	0	816
17	147.606	1107.6566	806	10	0	0	0	816	0	0	0	816
18	156.528	1172.435	794	22	0	0	0	816	0	0	0	816
19	167.852	1251.8569	770	46	0	0	0	816	0	0	0	816
20	178.552	1323.7521	764	52	0	0	0	816	0	0	0	816
21	191.116	1405.3082	744	72	0	0	0	816	0	0	0	816
22	205.522	1492.6652	732	84	0	0	0	816	0	0	0	816
23	218.819	1568.3209	710	106	0	0	0	816	0	0	0	816
24	229.912	1628.7735	698	118	0	0	0	816	0	0	0	816
25	241.442	1688.4167	676	140	0	0	0	816	0	0	0	816

26	253.934	1749.3936	656	160	0	0	0	816	0	0	0	816
27	265.932	1806.2225	640	176	0	0	0	810	6	0	0	816
28	276.775	1854.121	628	188	0	0	0	804	8	0	4	816
29	285.625	1891.4726	608	208	0	0	0	804	8	0	4	816
30	293.791	1924.3827	594	222	0	0	0	804	8	0	4	816
31	301.998	1956.5109	574	242	0	0	0	800	10	0	6	816
32	311.474	1991.7034	544	272	0	0	0	800	10	0	6	816
33	320.775	2019.5774	528	288	0	0	0	798	12	0	6	816
34	331.284	2049.6762	518	298	0	0	0	794	16	0	6	816
35	340.354	2074.0959	510	306	0	0	0	784	24	0	8	816
36	348.354	2095.4041	506	310	0	0	0	780	28	0	8	816
37	356.354	2118.0627	496	320	0	0	0	774	32	0	10	816
38	369.591	2151.7901	484	332	0	0	0	766	36	4	10	816
39	377.591	2170.9751	482	334	0	0	0	764	34	8	10	816
40	388.407	2198.2193	472	344	0	0	0	764	34	8	10	816
41	397.226	2215.7803	464	352	0	0	0	764	34	8	10	816
42	405.279	2230.7363	462	354	0	0	0	762	32	12	10	816
43	405.662	2231.5498	462	354	0	0	0	762	32	12	10	816
44	406.429	2232.4551	462	354	0	0	0	762	32	12	10	816
45	409.833	2239.094	456	360	0	0	0	761	31	14	10	816

Table A.4: Status of plastic hinges from result of pushover analysis in y-direction of nine story irregular rcc building

Step	**Monitored Displ**	**Base Force**	**A-B**	**B-C**	**C-D**	**D-E**	**>E**	**A-IO**	**IO-LS**	**LS-CP**	**>CP**	**Total Hinges**
	mm	**kN**										
0	-0.03	0	816	0	0	0	0	816	0	0	0	816
1	7.97	45.9129	816	0	0	0	0	816	0	0	0	816
2	15.97	91.8259	816	0	0	0	0	816	0	0	0	816
3	23.97	137.7388	816	0	0	0	0	816	0	0	0	816
4	31.97	183.6518	816	0	0	0	0	816	0	0	0	816
5	39.97	229.5647	816	0	0	0	0	816	0	0	0	816
6	47.97	275.4776	816	0	0	0	0	816	0	0	0	816
7	55.97	321.3906	816	0	0	0	0	816	0	0	0	816
8	63.97	367.3035	816	0	0	0	0	816	0	0	0	816
9	71.97	413.2165	816	0	0	0	0	816	0	0	0	816
10	79.97	459.1294	816	0	0	0	0	816	0	0	0	816
11	87.97	505.0423	816	0	0	0	0	816	0	0	0	816
12	95.97	550.9553	816	0	0	0	0	816	0	0	0	816
13	103.97	596.8682	816	0	0	0	0	816	0	0	0	816
14	111.97	642.7812	816	0	0	0	0	816	0	0	0	816
15	116.194	667.0261	812	4	0	0	0	816	0	0	0	816
16	126.167	722.6651	804	12	0	0	0	816	0	0	0	816
17	134.845	770.1291	798	18	0	0	0	816	0	0	0	816
18	150.113	852.29	796	20	0	0	0	816	0	0	0	816
19	158.269	895.8858	782	34	0	0	0	816	0	0	0	816
20	168.307	947.7819	762	54	0	0	0	816	0	0	0	816
21	176.313	987.4892	746	70	0	0	0	816	0	0	0	816
22	186.103	1034.1623	728	88	0	0	0	816	0	0	0	816
23	196.678	1083.3467	712	104	0	0	0	816	0	0	0	816
24	204.678	1120.2512	708	108	0	0	0	816	0	0	0	816
25	213.421	1160.3019	696	120	0	0	0	816	0	0	0	816
26	221.421	1196.6843	694	122	0	0	0	816	0	0	0	816
27	232.999	1247.2902	680	136	0	0	0	816	0	0	0	816
28	243.745	1293.1546	670	146	0	0	0	816	0	0	0	816
29	251.745	1326.9759	670	146	0	0	0	816	0	0	0	816
30	263.756	1376.98	658	158	0	0	0	816	0	0	0	816

31	271.756	1409.8142	656	160	0	0	0	816	0	0	0	816
32	284.916	1462.0319	646	170	0	0	0	816	0	0	0	816
33	294.043	1497.5099	636	180	0	0	0	816	0	0	0	816
34	303.354	1532.9914	628	188	0	0	0	816	0	0	0	816
35	311.354	1562.7758	626	190	0	0	0	816	0	0	0	816
36	323.167	1606.2387	618	198	0	0	0	816	0	0	0	816
37	335.634	1651.1364	608	208	0	0	0	816	0	0	0	816
38	346.935	1689.547	606	210	0	0	0	816	0	0	0	816
39	357.26	1724.4548	600	216	0	0	0	816	0	0	0	816
40	367.659	1757.3148	590	226	0	0	0	816	0	0	0	816
41	375.659	1781.2411	586	230	0	0	0	816	0	0	0	816
42	389.068	1820.3686	580	236	0	0	0	816	0	0	0	816
43	397.068	1842.9717	578	238	0	0	0	816	0	0	0	816
44	412.641	1886.0001	566	250	0	0	0	812	4	0	0	816
45	420.641	1908.0205	566	250	0	0	0	812	4	0	0	816
46	435.818	1948.7327	554	262	0	0	0	808	8	0	0	816
47	443.818	1969.3402	554	262	0	0	0	807	9	0	0	816
48	444.657	1971.5518	554	262	0	0	0	805	11	0	0	816
49	444.664	1971.5399	554	262	0	0	0	805	11	0	0	816
50	453.089	1993.0746	544	272	0	0	0	800	16	0	0	816
51	461.089	2013.4062	544	272	0	0	0	800	16	0	0	816
52	469.089	2033.5733	544	272	0	0	0	796	20	0	0	816
53	483.087	2068.643	540	276	0	0	0	792	24	0	0	816
54	491.087	2088.4667	540	276	0	0	0	792	24	0	0	816
55	502.391	2115.6083	534	282	0	0	0	792	24	0	0	816
56	510.391	2134.2522	530	286	0	0	0	792	22	2	0	816
57	521.862	2160.2639	524	292	0	0	0	788	20	8	0	816
58	529.862	2178.2501	522	294	0	0	0	788	20	8	0	816
59	541.362	2202.8421	520	296	0	0	0	788	20	8	0	816
60	547.534	2216.1999	520	294	2	0	0	783	19	10	4	816

Table A.5: Status of plastic hinges from result of pushover analysis in x-direction of fifteen story irregular rcc building

Step	Monitored Displ	Base Force	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total Hinges
	mm	kN										
0	1.367	0	1360	0	0	0	0	1360	0	0	0	1360
1	9.367	83.0408	1360	0	0	0	0	1360	0	0	0	1360
2	17.367	166.0817	1360	0	0	0	0	1360	0	0	0	1360
3	25.367	249.1225	1360	0	0	0	0	1360	0	0	0	1360
4	33.367	332.1633	1360	0	0	0	0	1360	0	0	0	1360
5	41.367	415.2042	1360	0	0	0	0	1360	0	0	0	1360
6	49.367	498.245	1360	0	0	0	0	1360	0	0	0	1360
7	57.367	581.2858	1360	0	0	0	0	1360	0	0	0	1360
8	65.367	664.3267	1360	0	0	0	0	1360	0	0	0	1360

9	73.367	747.3675	1360	0	0	0	0	1360	0	0	0	1360
10	81.367	830.4083	1360	0	0	0	0	1360	0	0	0	1360
11	89.367	913.4492	1360	0	0	0	0	1360	0	0	0	1360
12	97.367	996.49	1360	0	0	0	0	1360	0	0	0	1360
13	105.367	1079.5309	1360	0	0	0	0	1360	0	0	0	1360
14	113.367	1162.5717	1360	0	0	0	0	1360	0	0	0	1360
15	121.367	1245.6125	1360	0	0	0	0	1360	0	0	0	1360
16	129.367	1328.6534	1360	0	0	0	0	1360	0	0	0	1360
17	137.367	1411.6942	1360	0	0	0	0	1360	0	0	0	1360
18	145.367	1494.735	1360	0	0	0	0	1360	0	0	0	1360
19	153.367	1577.7759	1360	0	0	0	0	1360	0	0	0	1360
20	161.367	1660.8167	1360	0	0	0	0	1360	0	0	0	1360
21	169.367	1743.8575	1360	0	0	0	0	1360	0	0	0	1360
22	177.367	1826.8984	1360	0	0	0	0	1360	0	0	0	1360
23	185.367	1909.9392	1360	0	0	0	0	1360	0	0	0	1360
24	193.367	1992.98	1360	0	0	0	0	1360	0	0	0	1360
25	201.367	2076.0209	1358	2	0	0	0	1360	0	0	0	1360
26	205.544	2119.2031	1354	6	0	0	0	1360	0	0	0	1360
27	213.544	2200.7122	1352	8	0	0	0	1360	0	0	0	1360
28	223.647	2302.4362	1332	28	0	0	0	1360	0	0	0	1360
29	233.345	2393.9889	1300	60	0	0	0	1360	0	0	0	1360
30	243.188	2480.2201	1212	148	0	0	0	1360	0	0	0	1360
31	254.066	2566.2389	1154	206	0	0	0	1360	0	0	0	1360
32	262.499	2628.1557	1112	248	0	0	0	1360	0	0	0	1360
33	270.829	2685.1836	1082	278	0	0	0	1360	0	0	0	1360
34	279.626	2743.6414	1060	300	0	0	0	1360	0	0	0	1360
35	289.229	2805.0213	1046	314	0	0	0	1360	0	0	0	1360

36	298.699	2864.63	1032	328	0	0	0	1360	0	0	0	1360
37	310.438	2937.084	1020	340	0	0	0	1358	0	0	2	1360
38	322.651	3011.1452	1000	360	0	0	0	1358	0	0	2	1360
39	332.884	3071.7482	980	380	0	0	0	1358	0	0	2	1360
40	345.986	3147.1304	972	388	0	0	0	1358	0	0	2	1360
41	360.179	3228.443	966	394	0	0	0	1358	0	0	2	1360
42	376.067	3317.166	958	402	0	0	0	1358	0	0	2	1360
43	391.658	3402.9985	950	410	0	0	0	1358	0	0	2	1360
44	399.658	3446.9522	946	414	0	0	0	1358	0	0	2	1360
45	407.658	3490.3373	940	420	0	0	0	1358	0	0	2	1360
46	415.658	3533.6678	936	424	0	0	0	1358	0	0	2	1360
47	423.658	3576.4079	936	424	0	0	0	1358	0	0	2	1360
48	431.658	3619.2251	934	426	0	0	0	1358	0	0	2	1360
49	447.202	3701.3833	928	432	0	0	0	1358	0	0	2	1360
50	462.714	3782.6378	924	436	0	0	0	1358	0	0	2	1360
51	475.515	3849.3301	922	438	0	0	0	1356	0	0	4	1360
52	487.879	3913.7483	916	444	0	0	0	1356	0	0	4	1360
53	502.732	3989.1197	912	448	0	0	0	1354	2	0	4	1360
54	510.732	4029.4353	906	454	0	0	0	1354	2	0	4	1360
55	518.732	4069.5105	906	454	0	0	0	1352	4	0	4	1360
56	526.732	4109.4831	904	456	0	0	0	1352	4	0	4	1360
57	534.732	4149.6057	900	460	0	0	0	1350	4	0	6	1360
58	542.732	4188.7574	896	464	0	0	0	1350	4	0	6	1360
59	550.732	4226.7424	896	464	0	0	0	1350	4	0	6	1360
60	566.023	4299.139	886	474	0	0	0	1348	6	0	6	1360
61	574.023	4336.7268	884	476	0	0	0	1344	8	0	8	1360
62	582.023	4373.6704	880	480	0	0	0	1342	10	0	8	1360

63	590.023	4410.874	872	488	0	0	0	1342	10	0	8	1360
64	598.023	4447.0401	870	490	0	0	0	1340	10	0	10	1360
65	606.023	4483.8282	868	492	0	0	0	1339	11	0	10	1360
66	614.023	4519.6965	864	496	0	0	0	1337	13	0	10	1360
67	622.023	4556.0232	860	500	0	0	0	1336	14	0	10	1360
68	630.023	4591.8823	852	508	0	0	0	1336	14	0	10	1360
69	638.023	4627.5887	848	512	0	0	0	1336	14	0	10	1360
70	650.327	4680.1082	840	520	0	0	0	1336	14	0	10	1360
71	658.327	4714.2658	826	534	0	0	0	1334	14	0	12	1360
72	666.327	4746.6319	826	534	0	0	0	1330	18	0	12	1360
73	674.327	4779.9365	826	534	0	0	0	1326	20	0	14	1360
74	682.327	4812.1208	824	536	0	0	0	1324	22	0	14	1360
75	690.327	4844.9585	816	544	0	0	0	1319	27	0	14	1360
76	698.327	4875.9947	806	554	0	0	0	1316	30	0	14	1360
77	706.327	4906.8151	802	558	0	0	0	1314	30	0	16	1360
78	714.327	4936.5307	802	558	0	0	0	1312	32	0	16	1360
79	722.327	4966.9418	798	562	0	0	0	1309	35	0	16	1360
80	730.327	4996.4311	796	564	0	0	0	1306	38	0	16	1360
81	738.327	5026.7129	794	566	0	0	0	1306	38	0	16	1360
82	738.829	5028.5536	794	566	0	0	0	1306	38	0	16	1360

Table A.6: Status of plastic hinges from result of pushover analysis in y-direction of fifteen story irregular rcc building

Step	**Monitored Displ**	**Base Force**	**A-B**	**B-C**	**C-D**	**D-E**	**>E**	**A-IO**	**IO-LS**	**LS-CP**	**>CP**	**Total Hinges**
	mm	**kN**										
0	0.441	0	1360	0	0	0	0	1360	0	0	0	1360
1	8.441	38.8721	1360	0	0	0	0	1360	0	0	0	1360
2	16.441	77.7442	1360	0	0	0	0	1360	0	0	0	1360
3	24.441	116.6163	1360	0	0	0	0	1360	0	0	0	1360

4	32.441	155.4884	1360	0	0	0	0	1360	0	0	0	1360
5	40.441	194.3606	1360	0	0	0	0	1360	0	0	0	1360
6	48.441	233.2327	1360	0	0	0	0	1360	0	0	0	1360
7	56.441	272.1048	1360	0	0	0	0	1360	0	0	0	1360
8	64.441	310.9769	1360	0	0	0	0	1360	0	0	0	1360
9	72.441	349.849	1360	0	0	0	0	1360	0	0	0	1360
10	80.441	388.7211	1360	0	0	0	0	1360	0	0	0	1360
11	88.441	427.5932	1360	0	0	0	0	1360	0	0	0	1360
12	96.441	466.4653	1360	0	0	0	0	1360	0	0	0	1360
13	104.441	505.3374	1360	0	0	0	0	1360	0	0	0	1360
14	112.441	544.2096	1360	0	0	0	0	1360	0	0	0	1360
15	120.441	583.0817	1360	0	0	0	0	1360	0	0	0	1360
16	128.441	621.9538	1360	0	0	0	0	1360	0	0	0	1360
17	136.441	660.8259	1360	0	0	0	0	1360	0	0	0	1360
18	144.441	699.698	1360	0	0	0	0	1360	0	0	0	1360
19	152.441	738.5701	1360	0	0	0	0	1360	0	0	0	1360
20	160.441	777.4422	1360	0	0	0	0	1360	0	0	0	1360
21	163.012	789.9362	1342	18	0	0	0	1360	0	0	0	1360
22	177.251	856.2372	1334	26	0	0	0	1360	0	0	0	1360
23	189.244	911.1987	1324	36	0	0	0	1360	0	0	0	1360
24	202.655	971.7847	1316	44	0	0	0	1360	0	0	0	1360
25	211.464	1011.1539	1302	58	0	0	0	1360	0	0	0	1360
26	219.464	1046.5077	1298	62	0	0	0	1360	0	0	0	1360
27	230.535	1094.4343	1282	78	0	0	0	1360	0	0	0	1360
28	238.825	1129.6248	1258	102	0	0	0	1360	0	0	0	1360
29	250.117	1175.7843	1236	124	0	0	0	1360	0	0	0	1360
30	258.652	1209.9736	1212	148	0	0	0	1360	0	0	0	1360

31	269.786	1253.8157	1186	174	0	0	0	1360	0	0	0	1360
32	279.766	1292.2783	1174	186	0	0	0	1360	0	0	0	1360
33	289.475	1329.2776	1154	206	0	0	0	1360	0	0	0	1360
34	299.766	1368.1014	1138	222	0	0	0	1360	0	0	0	1360
35	311.47	1411.8239	1120	240	0	0	0	1360	0	0	0	1360
36	320.574	1445.4483	1112	248	0	0	0	1360	0	0	0	1360
37	330.095	1480.3039	1102	258	0	0	0	1360	0	0	0	1360
38	342.873	1526.9538	1094	266	0	0	0	1360	0	0	0	1360
39	354.076	1567.4801	1090	270	0	0	0	1360	0	0	0	1360
40	368.41	1619.1868	1080	280	0	0	0	1360	0	0	0	1360
41	380.14	1661.3647	1066	294	0	0	0	1360	0	0	0	1360
42	390.235	1697.4577	1050	310	0	0	0	1360	0	0	0	1360
43	402.321	1740.5456	1040	320	0	0	0	1360	0	0	0	1360
44	410.321	1769.019	1040	320	0	0	0	1360	0	0	0	1360
45	424.187	1818.37	1034	326	0	0	0	1360	0	0	0	1360
46	432.187	1846.8436	1034	326	0	0	0	1360	0	0	0	1360
47	445.199	1893.1429	1028	332	0	0	0	1360	0	0	0	1360
48	455.013	1927.681	1024	336	0	0	0	1360	0	0	0	1360
49	467.948	1973.0129	1018	342	0	0	0	1360	0	0	0	1360
50	482.466	2023.7929	1016	344	0	0	0	1360	0	0	0	1360
51	493.746	2062.9896	1014	346	0	0	0	1360	0	0	0	1360
52	501.746	2090.4945	1012	348	0	0	0	1360	0	0	0	1360
53	509.746	2117.8762	1012	348	0	0	0	1360	0	0	0	1360
54	523.687	2165.5918	1000	360	0	0	0	1360	0	0	0	1360
55	531.687	2192.4328	998	362	0	0	0	1360	0	0	0	1360
56	539.687	2219.2547	998	362	0	0	0	1360	0	0	0	1360
57	547.687	2246.0618	998	362	0	0	0	1360	0	0	0	1360

58	560.667	2288.9135	992	368	0	0	0	1360	0	0	0	1360
59	568.667	2314.9744	992	368	0	0	0	1360	0	0	0	1360
60	576.667	2341.0345	992	368	0	0	0	1360	0	0	0	1360
61	584.667	2367.0936	990	370	0	0	0	1360	0	0	0	1360
62	592.667	2393.1222	988	372	0	0	0	1360	0	0	0	1360
63	600.667	2419.1507	988	372	0	0	0	1360	0	0	0	1360
64	615.425	2467.141	986	374	0	0	0	1360	0	0	0	1360
65	623.425	2493.1115	980	380	0	0	0	1360	0	0	0	1360
66	631.425	2519.0413	980	380	0	0	0	1360	0	0	0	1360
67	639.425	2544.9435	978	382	0	0	0	1360	0	0	0	1360
68	647.425	2570.6622	978	382	0	0	0	1360	0	0	0	1360
69	655.425	2596.2897	978	382	0	0	0	1360	0	0	0	1360
70	663.425	2621.9791	974	386	0	0	0	1360	0	0	0	1360
71	671.425	2647.553	974	386	0	0	0	1360	0	0	0	1360
72	679.425	2673.0808	972	388	0	0	0	1360	0	0	0	1360
73	687.425	2698.5877	972	388	0	0	0	1360	0	0	0	1360
74	695.425	2723.972	972	388	0	0	0	1360	0	0	0	1360
75	703.908	2750.5363	968	392	0	0	0	1360	0	0	0	1360
76	715.409	2785.3687	966	394	0	0	0	1360	0	0	0	1360
77	723.409	2809.4443	964	396	0	0	0	1360	0	0	0	1360
78	729.596	2827.8172	964	396	0	0	0	1358	2	0	0	1360

Hinge Response - C5H1 (Auto P-M2-M3)

Summary Description

This is hinge response output for a specific hinge and a selected load case.

General Input Data

Load Case	Push X	Hinge	C5H1 (Auto P-M2-M3)
Story	Story1	Hinge DOF	M2
Column	C5	Hinge Rel. Dist.	0.05

Hinge Response Plot

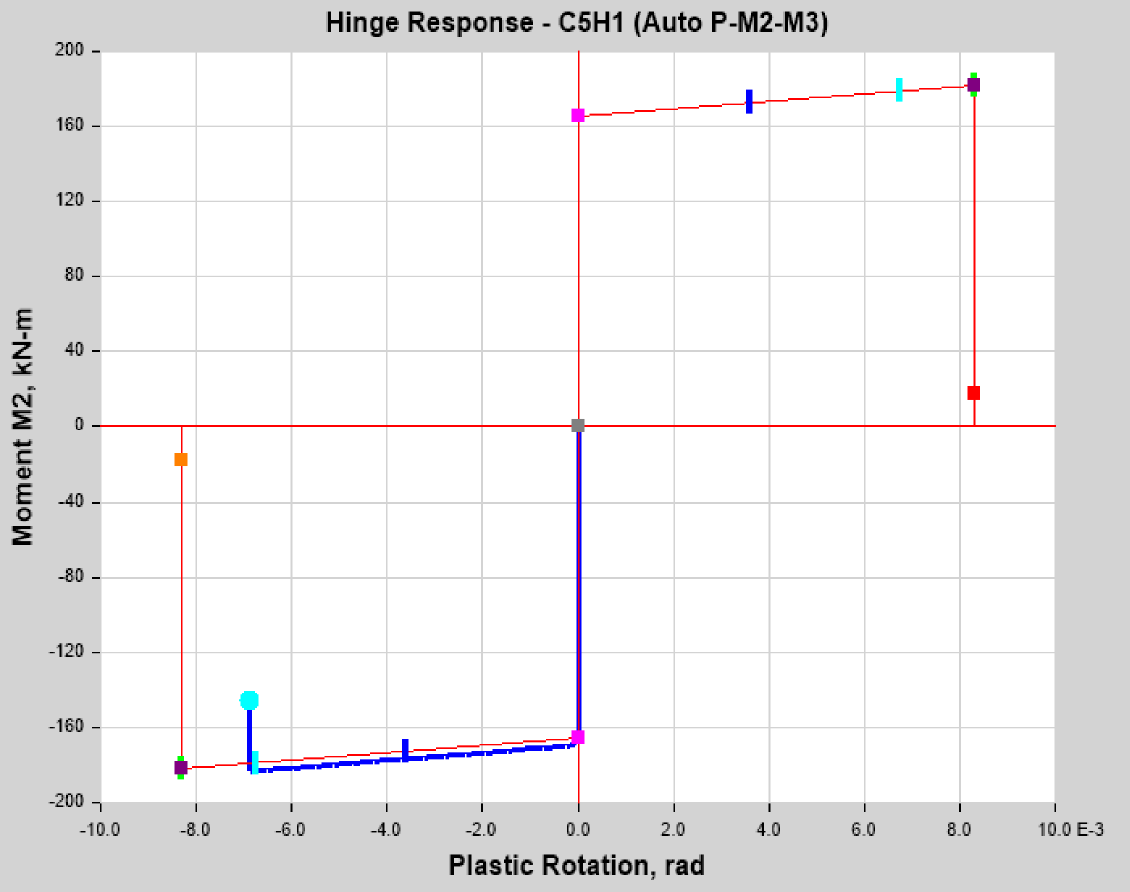

Figure A.1: Moment-Rotation curve for column C5 story1 of three story building

Current Step Data

Step	57	Plastic Rotation Max	0 rad
Moment M2	-145.8465 kN-m	Plastic Rotation Min	-0.006871 rad
Plastic Rotation	-0.006871 rad	Hinge State	B to <=C
		Hinge Status	LS to <=CP

Hinge Response - B11H3 (Auto M3)

Summary Description

This is hinge response output for a specific hinge and a selected load case.

General Input Data

Load Case	Push X	Hinge	B11H3 (Auto M3)
Story	Story1	Hinge DOF	M3
Beam	B11	Hinge Rel. Dist.	0.95

Hinge Response Plot

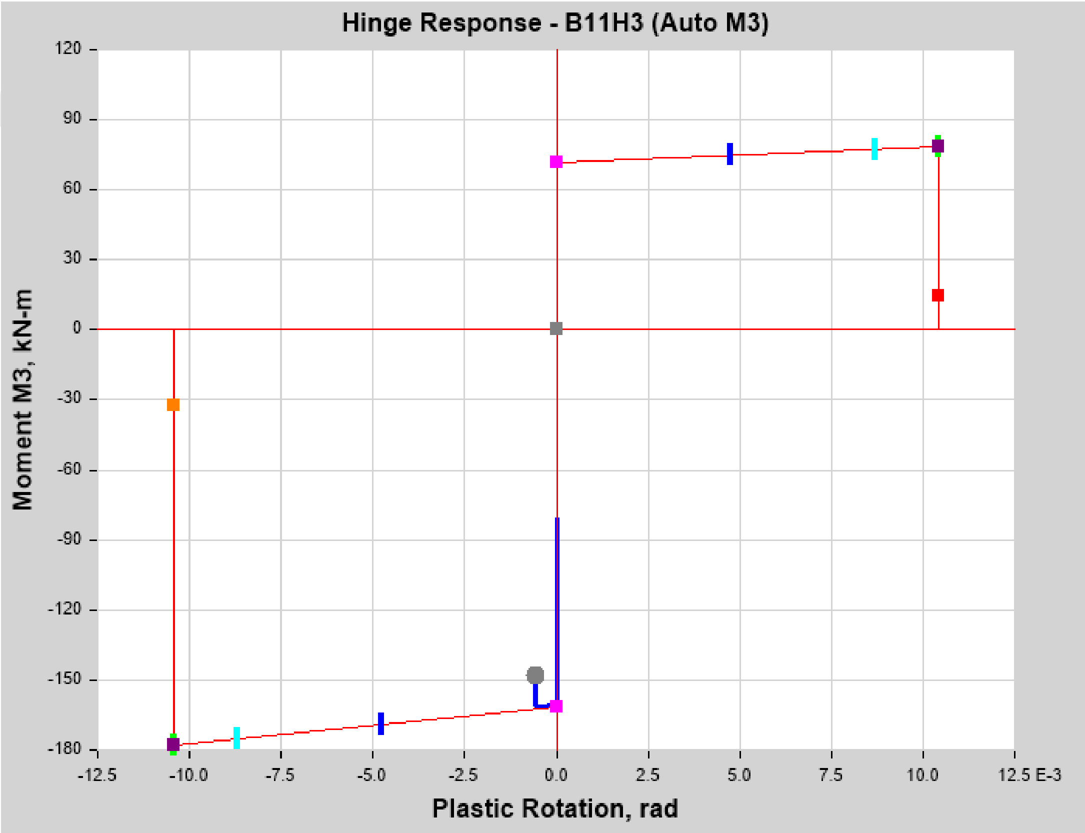

Figure A.2: Moment-Rotation curve for beam B11 story1 of three story building

Current Step Data

Step	57	Plastic Rotation Max	0 rad
Moment M3	-148.107 kN-m	Plastic Rotation Min	-0.000555 rad
Plastic Rotation	-0.000555 rad	Hinge State	B to <=C
		Hinge Status	A to <=IO