ANALYSIS ON THE EFFECT OF DIFFERENT BRACING TYPES AND LAYOUTS ON LATERAL DRIFT OF 30-STOREY STEEL FRAMED BUILDING SUBJECTED TO LATERAL FORCES USING ANSYS

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Thesis submitted in fulfillment of the requirements for the award of the
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Dedicated to my parents Bala Krisnain and Nirmala Devi for their everlasting and unconditional love.

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ABSTRACT

High-rise steel construction is increasing at an expanding scale and in modern construction stiffness of the structure has become paramount criteria as the building increases in height. However, the aerial threat of wind forces had become a crucial factor to affect the building stiffness. Designers see great danger of this situation and it has led to introduction of bracing system that was often used to provide sufficient lateral stiffness to the structure. The main objective of this study is to determine the effect of different types and orientations of bracing on the frame structure in terms of lateral drift. Finite Element Analysis (FEA) of ANSYS 12.0 software has been used to model 30-storey of 90 m height steel frame building subjected to substantial basic wind speed, or 3-second gust, of 24 meter per second, and wind load of 0.969 kPa. Four types of bracing: X-bracing, Inverted V-bracing, K-bracing and single-diagonal bracing were explored and 84 models of different configurations were run. Prior to limiting the lateral drift, the 84 models were again used to study the effect of changing from using pin connections to a combined pin-moment connections. All the beam and column used is made up of I-beam of structural steel grade S275 and of 3D Spar Link 8 element type. The X-bracing and Inverted V-bracing were relatively known as good in limiting lateral drift with regard to both types and configurations of bracing compared to K-bracing and single diagonal bracing. Meanwhile, changing from using pin connection to a combined pin-moment connections had reduced the lateral drift to about 26% to 48% depending on the type of bracing used.

ABSTRAK

Bangunan tinggi struktur keluli meningkat secara mendadak dan pesat pada masa kini dan semestinya kekukuhan struktur adalah mustahak sama sekali dalam sebarang pembinaan moden terutamanya apabila bangunan itu melangkah tinggi. Walau bagaimanapun, kekuatan sesuatu bangunan akan menjadi lumpuh di bawah pengaruh daya angin. Isu yang kritikal ini dilihat sendiri oleh pereka bangunan dan oleh yang demikian sistem struktur perambatan telah diperkenalkan untuk mengukuhkan sesuatu bangunan. Pada dasarnya, objektif utama kajian ini adalah untuk mengetahui kesan pengunaaan perambat dan orientasinya yang berbeza terhadap struktur kerangka sesuatu bangunan dalam perspektif kepesongan sisi struktur tersebut. Finite Element Analysis (FEA) daripada perisian ANSYS 12.0 telah digunakan untuk menghasilkan model struktur kerangka keluli 30 tingkat, bersamaan dengan tinggi 90m, di mana ia dikenakan kelajuan angin asas dengan kadar tiupan 3 minit atau 24 meter sesaat dan beban angin sebanyak 0.969 kPa. Empat jenis perambat iaitu: Perambat X, Perambat V-Terbalik, Perambat K, dan perambat pepenjuru tungal telah dikenalpasti untuk dikaji dan 84 model yang berbeza susun aturnya dalam struktur kerangka keluli telah dikaji dalam perisian tersebut. Selanjutnya, 84 model ini digunakan untuk tujuan mengkaji kesan perubahan daripada pengunaan sambungan pin dalam struktur kerangka berkenaan kepada sambungan pin moment bagi tujuan mengurangkan kadar kepesongan sisi bangunan. Kesemua rasuk dan tiang yang digunakan dalam kajian ini adalah rasuk-I yang merupakan grad keluli S275 dan daripada elemen jenis 3D Spar Link 8. Kesimpulannya, Perambat X dan Perambat V-Terbalik dapat menstabilkan struktur kerangka pada kadar yang lebih baik berbanding dengan Perambat K dan perambat pepenjuru tungal dalam kedua-dua aspek jenis dan orientasi perambat. Malahan, perubahan daripada pengunaan sambungan pin kepada sambungan pin moment telahpun mengurangkan kepesongan sisi sebanyak 26% hingga 48% bergantung kepada jenis perambat yang digunapakai.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

High-rise buildings have always been a key construction development over the years in keeping pace with the increasing demand of human population. This in turn had shifted the attention of engineers and designers in looking into various possible way of building or constructing the safe sound structure. Typical high-rise building can be categorized as reinforced concrete frame or steel frame.

Rapid advancement in the field of construction had given a platform for steel construction to develop at enlarging scale. Steel frame, for instance is a structure in which the weight is carried by steel skeleton or framework, as it is opposite to wall support system. It was true enough that steel frame has many advantages compared to ordinary reinforced concrete frame in terms of faster time of erection, better quality control, design flexibility, sustainability, and lesser weight than RC structures which in turn requires lighter foundation, and occupies less space which can be designed for larger span/column free spaces. Basically, the mechanism of loads distribution for both steel frame and reinforced concrete frame are similar, in which load from the beam was transferred to column, and finally to the foundation. Steel frame particularly function well under high lateral (wind) loading, because of its ductility, and that's make it preferable in high-rise structure. More than that, steel frame has capability to bend without breaking and absorb the energy acting on it. Steel frames were able to carry the weight of more floors, so walls became simply cladding for the purpose of insulating and adorning the building.

On the other hand, the construction of braced steel frame structure has become equally important in construction industry as it will resist the lateral forces that might act on the structure. Braced steel frame is well known in Malaysia in the context of high-rise structure. Generally, this frame exists under the provision of bracing elements that was aimed to provide stability and resist wind loads. Bracing is an element used to support and strengthen various part of a building and it will usually provide lateral stability for columns and beams. Steel braced frame with lateral bracing is very common in high-rise construction and has advantages in terms of simplicity and economical construction.

Typically, there are four types of bracing that are used in practice, which includes X-bracing, Inverted V-bracing, K-bracing and diagonal bracing. Each of these bracing provides has different strength on the structural integrity of steel frame. Similarly, each of these bracing types can be used either on one bay or multiple bays. Therefore, there are plenty of ways in which to brace a building. For this study, multitude of these combinations were modeled and analyzed to determine the appropriate bracing type and layout for 30-stories steel frame building subjected to wind load.

1.2 PROBLEM STATEMENT

A very significant parameter that influences the limits of today's high rise construction is the wind loading, and yet one of the biggest concerns is to deal with the lateral drift. Over the years, numerous studies have been conducted on the issue of lateral drift on the structure that was deemed the biggest threat to high-rise construction due to wind loading and any serviceability issues that may arise from this lateral movement. Engineers and designers faced a hardest task when designing high-rise structure subjected to substantial wind forces which has lead them to address the issue in the early stage of design development. Building is about to face severe damages if too much of drift takes place on the building under lateral loading. According to Ho and Schierle (1990), excessive lateral drift on building can cause significant damage on secondary systems, such as partitions, curtain walls and structure's interior walls, which in turn will generate secondary column stress due to P-delta moments that can also induce problem on column stability. Basically, there are three paramount perspectives in regards to drift and lateral stability, which are structural stability, architectural integrity and potential damage to various non-structural components and lastly human comfort during and after the building experiences the motions. Thus, in buildings over approximately 30-stories, the bracing technique becomes a vital part of the design. Providing bracing to the steel frame could reduce the lateral drift of the structure and thus lead to safer building to the users. However, choosing the correct bracing type and its' appropriate orientations in frame structure is of utmost importance in order to generate fruitful results of resisting the lateral forces.

1.3 OBJECTIVES OF STUDY

The objectives of this study are:

i. To study the effect of different bracing type on the lateral drift of 30-stories steel frame building.
ii. To analyze the effect of varying the position of bracing prior to minimization of lateral drift of 30-stories steel frame building.
iii. To compare the effect of pin connection only to a combination of pin-moment connection in reducing the lateral drift of 30-stories steel frame building.

1.4 SCOPE OF STUDY

The scope of this study was related to the design of steel frame structures with different bracing technique and its' orientations on frame structure using Eurocode 3 of ANSYS. The general information regarding the steel frame was shown in Table 1. The structural integrity of 30-stories steel frame building to take on drift control with different bracing types and layouts was discussed in detail. Illustrated in Figure 1.1, four types of bracing were used throughout this course of study, which includes X-bracing, Inverted-V-bracing, K-bracing and single diagonal bracing. Moreover, each of the bracing system was tested using 21 different models, at which each model will have different bracing location prior to lateral drift minimization, as shown in Figure 1.2 (for

X-bracing), Figure 1.3 (for Inverted-V-bracing), Figure 1.4 (K-bracing) and Figure 1.5 (for single diagonal bracing). Each of these different types of bracing has capability to show different resistance to drift control. In that sense, this study offers a platform to determine the effective bracing type and layout that could best fit the 30-stories steel frame. In all cases the bracing that was used is of size L 90 x 90 x 7.

Generally, X-bracing (also known as cross bracing) was arguably the most common bracing method and yet utilizes its two full length members to connect to four beam-column joints in a bay. The members were considered to be only stressed in tension and only one member was stressed at a time, resulting in the possibility to use smallest member sizes. Meanwhile, Inverted V-bracing is another form of bracing used commonly to effectively brace a structure against lateral drift. Usually, two members at the bottom were connected to the beam-column joints and the top member was connected to center of beam. The advantage of this bracing was more towards architectural insight than the structural perspective. The bracing allows for the placement of doorways and corridors. From structural angle, tying the Inverted V-bracing into the middle of the span of the floor above allows for the beam to be analyzed as a two span continuous beam, which in turn allowing for that particular member to be reduced in size. Unlike X-bracing, both members of this bracing are considered to be working at all times in both compression and tension.

As for K-bracing, two members were connected to two beam-column joints in one direction, while the opposite direction was connected into the mid-section of each column at each story. Normally, K-bracing was used when full height openings are required. However it was believed that K-bracing is not as efficient as X-bracing due to the fact of potential of collapse of column as the compression brace buckles in K-bracing. Apart from that, diagonal bracing was a form of bracing used to achieve lateral stability for the structural frame. This technique is not nearly as common in high-rise buildings. Since the members have to bear tension and compression load, the member sizes to accommodate the load would have to be quite large.

Table 1.1: General Properties of Steel Frame

Item	Properties
Total frame height	90m (3m/story)
Total bay distance	9m (3m/bay)
Steel Grade	S275
Beam Size	UB 457 x 191 x 89
Column Size	UC 356 x 406 x 634 (1st - 5th Floor) UC 356 x 406 x 467 (6th - 10th Floor) UC 356 x 406 x 393 (11th - 15th Floor) UC 356 x 406 x 287 (16th - 20th Floor) UC 356 x 406 x 235 (21st - 25th Floor) UC 305 x 305 x 198 (26th - 30th Floor)
Bracing Size	L 90 x 90 x 7
Bracing Lengths	
- X-bracing	6.8 m
- Inverted-V-bracing	4.3 m
- K-bracing	6.3 m
- Diagonal bracing	6.8 m

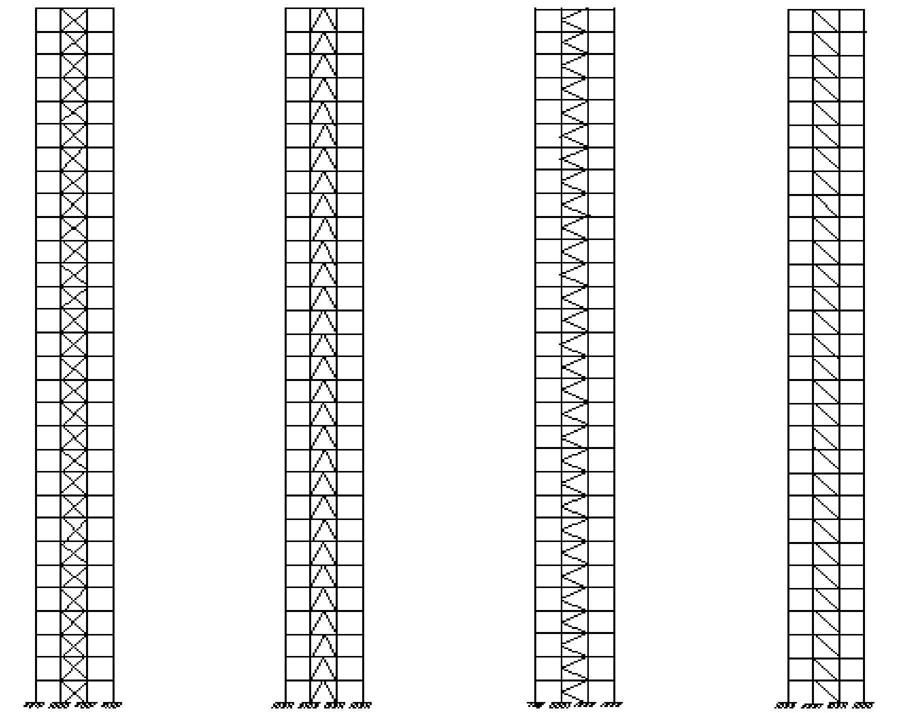


Figure 1.1: Four different types of bracing

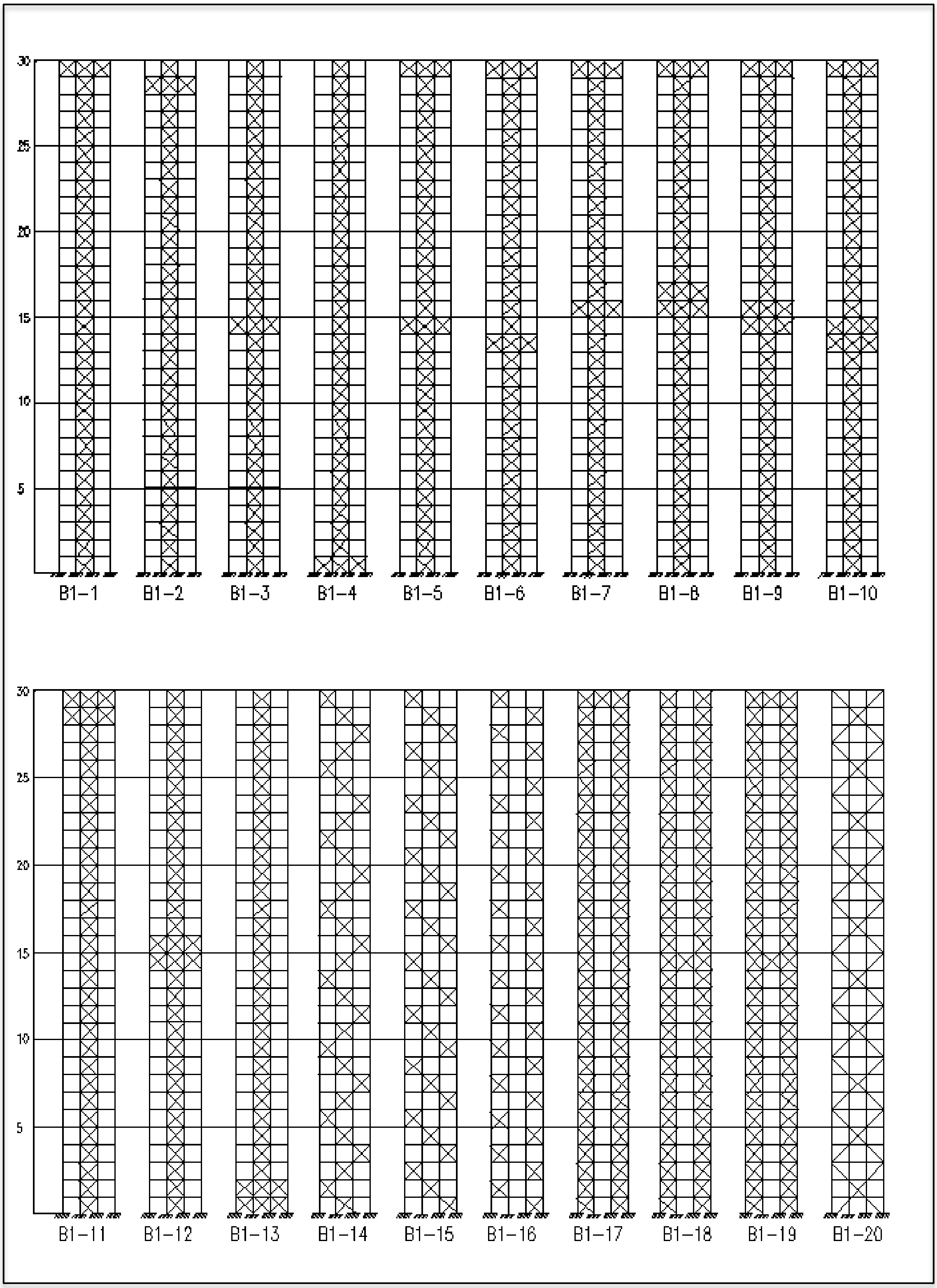


Figure 1.2: Models of X-bracing

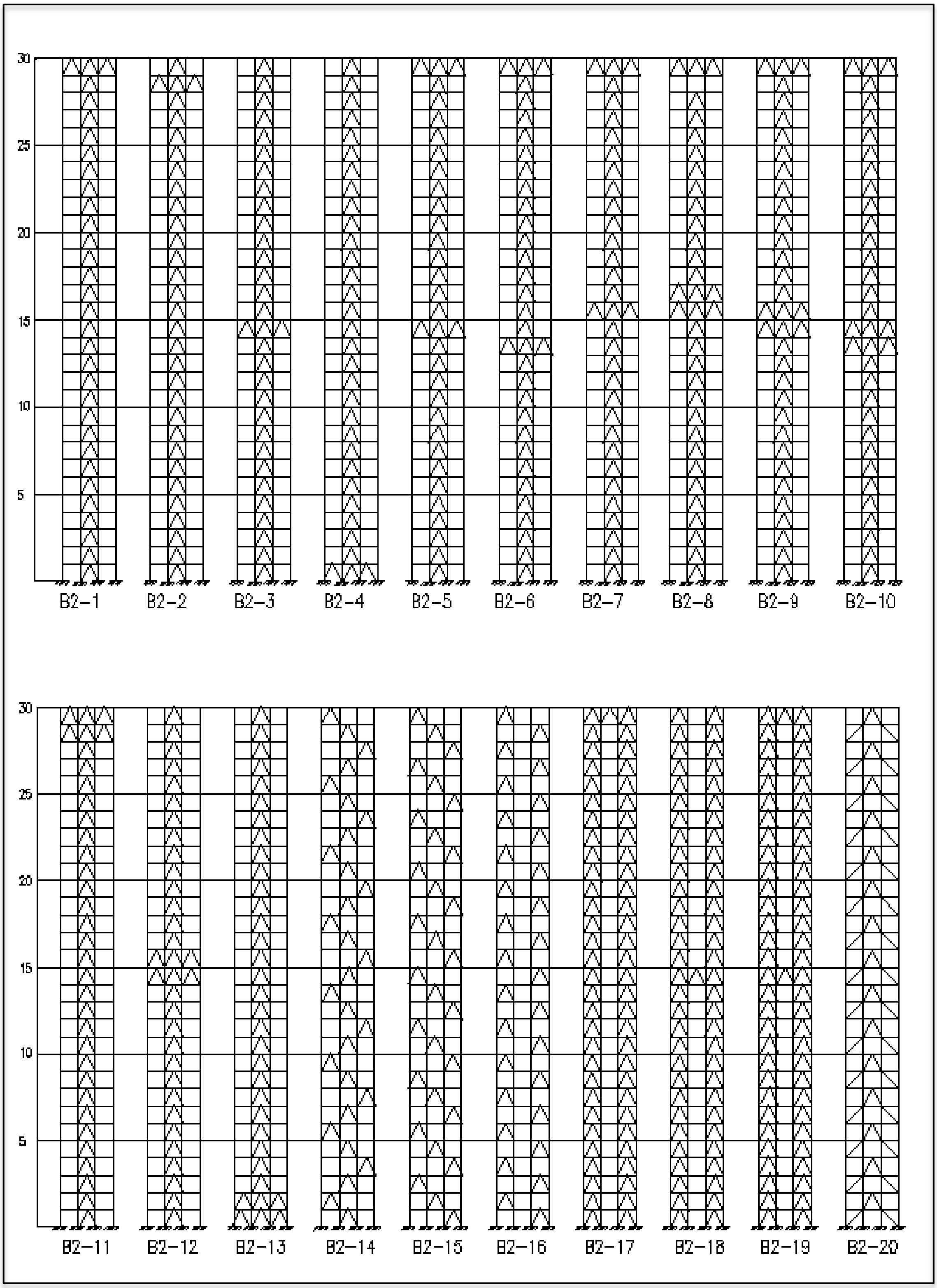


Figure 1.3: Models of Inverted V-bracing

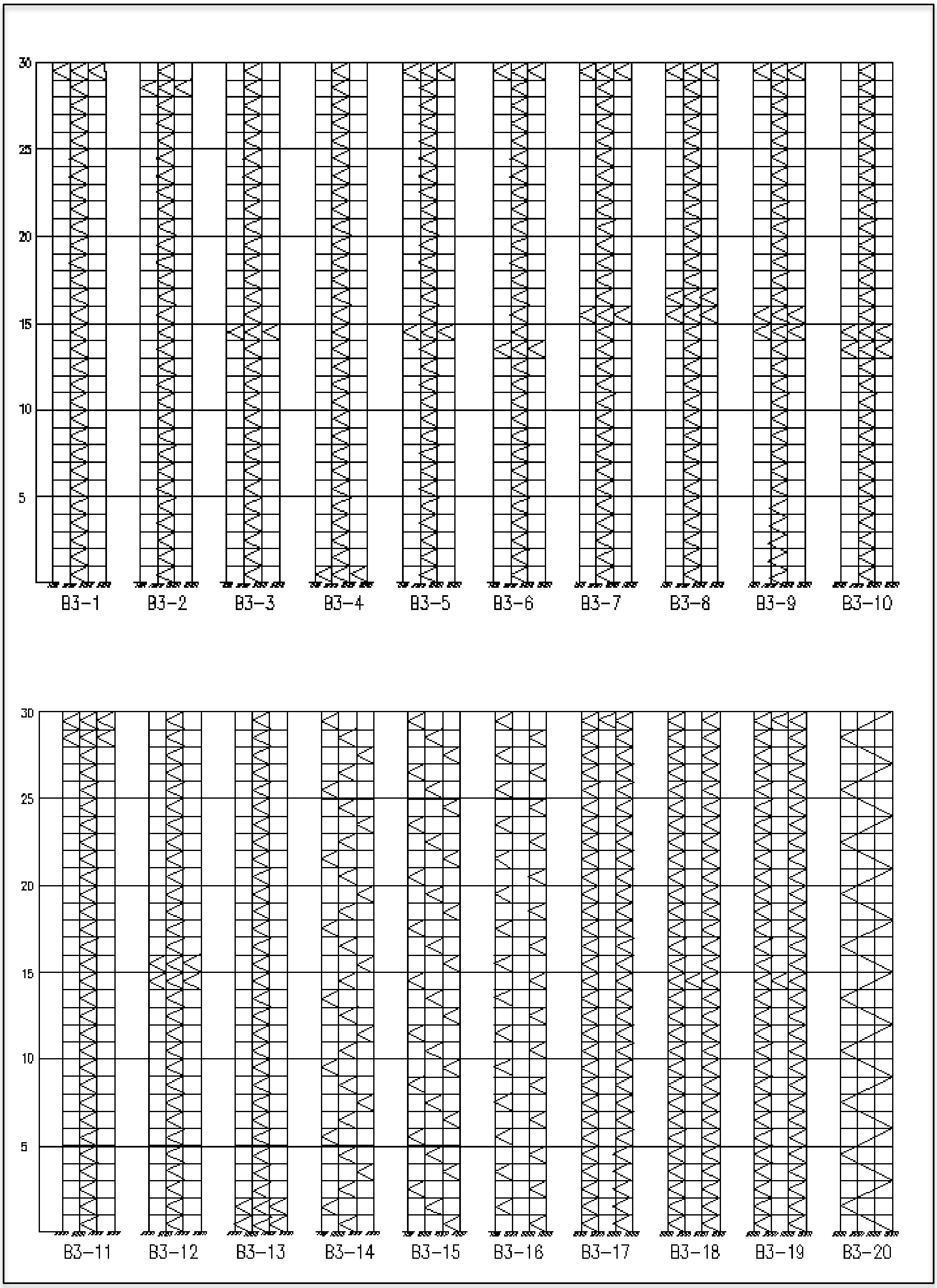


Figure 1.4: Models of K-bracing

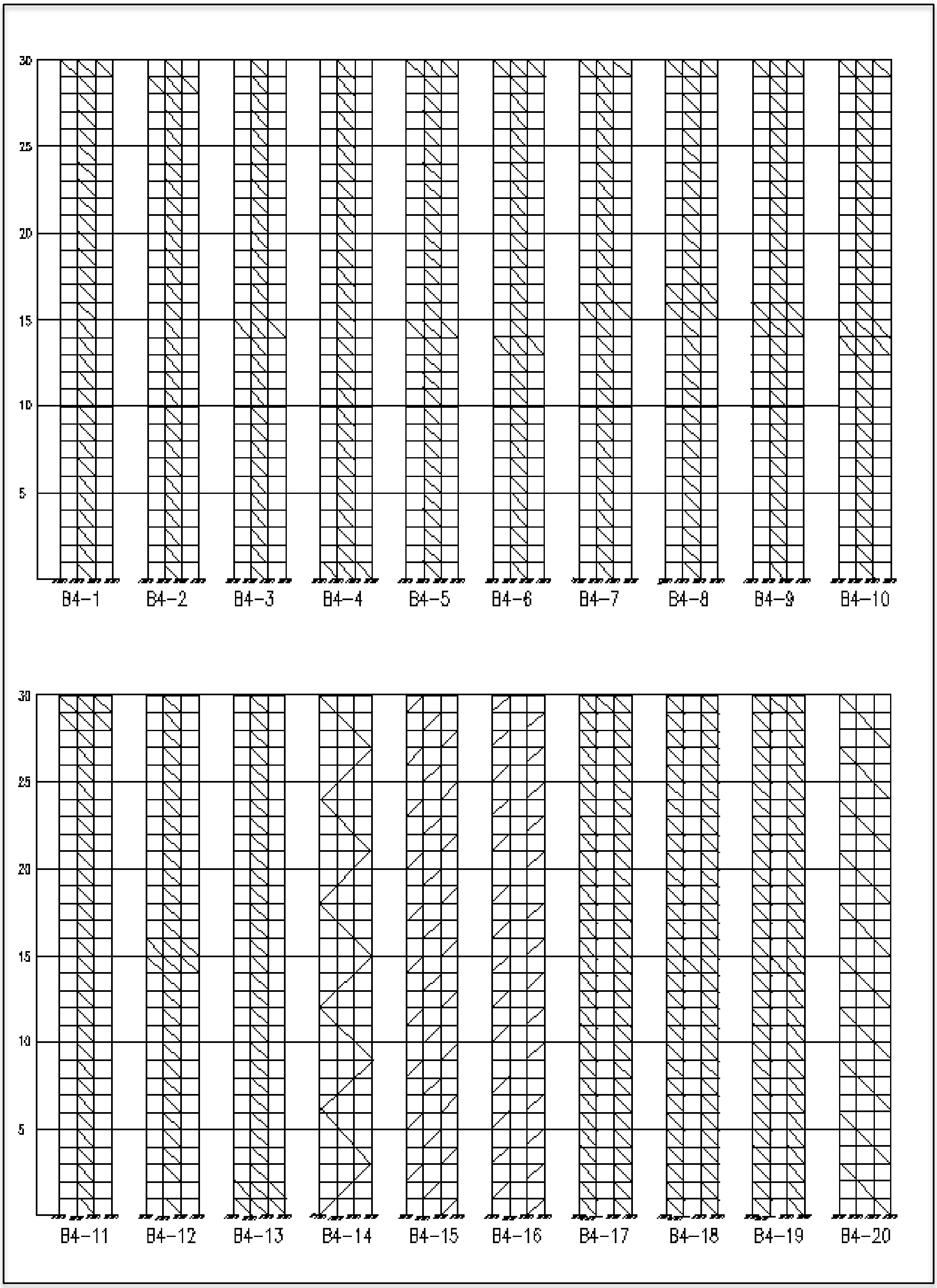


Figure 1.5: Models of single diagonal-bracing

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Over the years, numerous research literatures and studies have been conducted regarding the design of multi-story steel frame. One of the largest, yet hardest tasks of the designer in high-rise building was to limiting the lateral drift that was associated with wind forces. Generally, the design of steel frame must not fail under ultimate limit states (strength, yielding, buckling) or serviceability limit states (deflection) either. In this study, a method known as Direct Design Method which has the capability to analyze drift criteria of steel frame was used to model the structures. The method does not stand alone as computer simulation program called ANSYS 12.0 software was used throughout this study to test the steel frame with lateral bracing against the frame's lateral drift under substantial lateral forces.

2.2 HIGH RISE BUILDING

Nowadays, the construction of high rise buildings has become vital especially for developing country like Malaysia. There is no absolute definition of what constitutes a high-rise building. The definition for high-rise building is still not clear and not precise, since various bodies quoted different meanings for that. To illustrate, Emporis Standard (2010), define high-rise buildings as multi-story structures with height ranges from 35-100 meters tall, or the building which has 12-39 floors for unknown height.

But, most building engineers and architects insists high rise as building with minimum height of 23 meter or approximately 6 stories high (IBC, 2009). Nevertheless, high-rise building is known as any structure at which the height can have a serious impact on evacuation, according to The International Conference on Fire Safety in High-Rise Buildings, 1971.

Apart from that, 'The Council of Tall Buildings and Urban Habitat' (2014) defines tall buildings as the one that exhibits some elements of tallness in or more of the following categories. First, this is about height relative to context. High rise building is not just about height, but it is also about the context in which it exists. For instance, in high-rise city such as Hong Kong and Chicago, 14-story building may not be considered a tall building compared to provincial European city or a suburb which may consider it tall. Next, it is about proportion, which define that a tall building is not just about height but also about proportion. There are numerous buildings which are slender enough to give the appearance of a tall building, but then there are not particularly high. In contrast to that, there are numerous big or large footprint buildings which are apparently tall but their size or floor area rules them out as being classified as a tall building.

Then, the last one is about tall building technologies. Building can be classed as a high-rise structure provided the building contains technologies which may be attributed them as being a product of 'tall' (structural wind bracing as a product of height). Thus, in general 'The Council of Tall Buildings and Urban Habitat' (2014) define high-rise building as a building of perhaps 14 or more stories or over 50 meters (165 feet) in height.

2.3 STEEL FRAME

There have been significant developments in the structural design of steel-framed buildings in developing countries, like Malaysia. Steel structure becomes an ideal solution for multi-story residential buildings requiring open plan space. Basically, most of the multi-story frames are three dimensional structures with orthogonal horizontal grids, that is the primary and secondary beams are in two directions at 90° (ESE Strategies, 2010). High-rise steel buildings have become prominent since the introduction of Bessemer's process in 1856. Even the PETRONAS Twin Towers of the World Trade Centre has clearly established the suitability and compatibility of steel frame construction for high-rise buildings.

Frames can be classified as braced or unbraced, depending on the provision of bracing component. Braced frame usually consist of bracing system provided to resist lateral drift on the structure. Braced frame, unlike to rigid or semi-rigid frames was found to improve the shear racking component of deflection produced by the bending of columns and girders which causes the building drift to be too large and thus it providing a balance between shear racking and bending (Connor, J.J, 2003). Conversely, unbraced frame does not any bracing system and under lateral loading it will have greater susceptibility to instability problems due to deflection (George Driscoll, 1963). Unbraced frames apparently rely on the stiffness and strength of connections between beams and columns, and it will resist the lateral loads through the bending actions of these elements. Steel braced frames are most economically designed using simple connections, in which beam to column connections are normally pinned and it only transmit shear from the beam ends to the columns (ESE Strategies, 2010).

2.4 BRACING

The major concern in the design of multi-storied steel building is to have good lateral load resisting system. Bracing is an element used to support and strengthen various part of a building. It will usually associate on the job to provide lateral stability for columns and beams. In high rise building, it is highly recommended to brace the structure to minimize the lateral drift resulting from the wind load. Too much of lateral drift on the building will certainly induces some significant damages on the building structure. Thus it is crucial to have a bracing system in high rise buildings. Nevertheless, provision of bracing system in the structure has provide more stability to the building as it can resist the lateral loadings from winds and this lateral loadings are not taken by the column and beam (Schodek, 2004).

According to Palmer (2012), when the X-braces intersect and connect at mid-section, then buckling capacity of X-bracing can be best estimated by using one half the brace length. However, this will reduce the inelastic deformation capacity of X-bracing as the inelastic deformation is only concentrated in one-half the brace length. X-bracing only utilizing half of its member: tension member makes it very efficient use of the structural steel shape and will result in using the smallest members' size (Designing with Structural Steel, A Guide for Architect, 2nd Edition, 2002). Besides that, according to Okazaki (2012), the beam deformation due to unbalanced forces in Inverted –V bracing increases the axial compressive deformation of the brace and which reduces the inelastic deformation capacity prior to brace fracture.

Meanwhile, the K-bracing will experiencing the same unbalanced force issue and the bending moments and inelastic deformation will take place in the column and may lead to its failure. This indicates the K-bracing is not very effective to withstand the lateral drift due to the fact of potential of collapse of column as the compression brace buckles in K-bracing (Jagadish and Doshi, 2012). Apart from that, diagonal bracing is another form of bracing used to achieve lateral stability for the structural frame which deals with the fact that its member must take on the full tension and compression load when lateral force acts on it. This technique is not commonly permitted in high-rise buildings as the members having to bear tension and compression load, the member sizes to accommodate the load would have to be quite large (Nicholas Mcewen, 2011).

2.5 LATERAL DRIFT

Lateral drift can be defined as the predicted movement or sway of a structure under lateral loads. According to ASCE 7-05 (2006), the serviceability of structures should not be impaired by lateral drift of structures or deformation of horizontal diaphragms and bracing systems due to wind forces. Basically, the drift can have three primary effects on a structure; the lateral movement can affect the structural elements, such as beam and column; the lateral sway can affect non-structural elements, like windows and cladding; and the movements can affect adjacent structures (Gary Searer and Sigmund Freeman, 2004). For instance, high rise frames under excessive lateral drift are susceptible to cause damage on partitions and curtains walls, which also geared the development of secondary column stress on the structure (Ho and Schierle, 1990). In such a way, with regards to serviceability, designing for drift must be done to avoid or limit unacceptable damage to nonstructural building components, which includes interior cladding and partitions, besides to ensure the functionality of mechanical systems such as elevators (Daniel Christopher Berding, 2006).

2.6 DRIFT LIMITS AND DAMAGEABIITY

Adequate building stiffness can be achieved by designing the building within reasonable drift limits. Drift limits are imposed for two reasons first is to limit a second order effect which is necessary from a strength perspective and second is to control damage to nonstructural components which is a necessary from a serviceability consideration. As far as concerning about specific limits on allowable drift limit; study on the matter will conclude that no definite value is explicitly stated in the design codes for current practice. Some codes, for instance American Society Civil Engineers ASCE 7-05 (2006), has stated the drift index (drift divided by corresponding height) should be limited to between 1/600 and 1/400 of the story height or to 0.375 inches (0.009525m). According to McCormac (2006) the drift index should be limited to 0.002 radians so that there is a very slim chance of any building damage. Meanwhile, Steel and Building Design of Eurocode3 and British Standard (BS 5950) has provided the deflection limit in terms of beams and columns. For beams, the deflection limit can be calculated as span/ 360 for beams carrying plaster or other brittle finish. For column, the deflection limit is limited to this expression: height/ 300. Any values that deviates from the specified drift limits can cause stability issue to frame structure and at a greater extend the structure could be deemed to failed.

Drift can be defined in two terms: total drift index (the total lateral displacement at the top of the building) as shown in Equation 2.1 and interstory drift index (the relative lateral displacement occurring between two consecutive building levels) as shown in Equation 2.2. Meanwhile, Figure 2.1 represents the drift indices measurement.

$$\textit{Total Drift Index: Total drift/Building height} = \Delta/H \qquad (2.1)$$

$$\textit{Interstory Drift Index} = \textit{Interstory drift/Story height} = \delta/h \qquad (2.2)$$

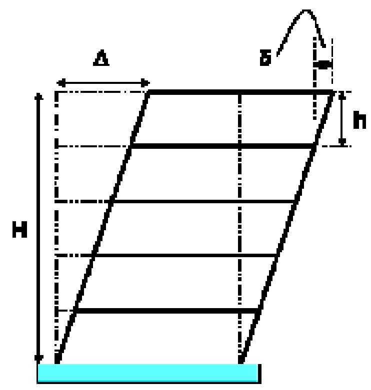


Figure 2.1: Drift measurements

However, it is worth noting that using drift indices is a straightforward but it oversimplifies the structural performance as the entire building is judged by a single value of lateral drift. Besides that, using drift indices any torsional component of deflection and material damage is ignored and it only accounts for the horizontal racking and vertical racking is ignored. The true measure of damage in a material is the shear strain that consist of a combination of horizontal and vertical racking (Daniel Christopher Berding, 2006). Nevertheless, Charney (1990c) and Griffis (1993) have come out with the idea of quantifying damage in terms of a drift damage index (DDI). DDI that takes into account horizontal and vertical racking and any rigid body rotation is ignored. The DDI which is simply the average shear strain in a rectangular element can be calculated by talking into account planar, drift damageable zone (DDZ), with height H and width L is defined with local X,Y displaced coordinates at each corner. Basically, DDZ is bounded by columns on both sides and floor diaphragms at the top and bottom, as represented in Equation 2.3 and shown in Figure 2.2. Equation 2.3 provides the average shear strain in the panel that is the average of the horizontal and vertical components of racking drift. Moreover, if the DDI is multiplied by the panel height, the result is the tangential interstory drift (Bertero et al. 1991) that provides better estimates of damage than the conventional or interstory drift index.

$$DDI = 0.5 * [\frac{X_A - X_C}{H} + \frac{X_B - X_D}{H} + \frac{Y_D - Y_C}{L} + \frac{Y_B - Y_A}{L}] \qquad (2.3)$$

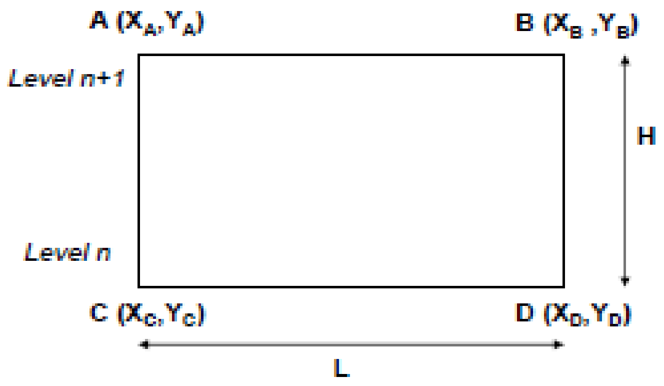


Figure 2.2: Drift damagaeable zone (DDF)

2.7 ANSYS MODELING

Due to difficulties in assembling the actual size frame for the experimental purpose, the Finite Element Analysis (FEA) method using computer simulation, known as ANSYS (Analysis System) package was introduced to model the braced steel frame using Eurocode 3. Basically, finite element method is known as a numerical procedure that can be used to obtain solutions to solve a large class of engineering problems (Saeed Moaveni, 1999). Finite element analysis basically consists of computer program that uses the finite element method to design a material that is stressed and analyzed to obtain specific results. In the other word, finite element analysis is known as numerical method used to find out an approximate solution for variables in a problem that is difficult to obtain analytically. Similarly, FEA can be used to determine any points of weakness associated in the design before the construction begins. The concept of FEA is to solve a continuum by a discrete model, which is done by dividing the problem into small several elements. The associated element is always in simple geometry and this is easier to be analyzed than the real structure. The FEA method is generally effective and in handling the complexities of material non-linearity and the structural behavior in three-dimensional (A.O. Abdelatif et al, 2014). The ANSYS software is a comprehensive FEA tool that has high advantage in producing excellent graphic displays in both preprocessing and postprocessing modes (Carl T.F Ross et al, 2006).

The element of steel frame was modeled using discrete axial members, known as 3D Spar Link 8. This three-dimensional spar element is a uniaxial tension-compression element, which has three degrees of freedom at each node, which is a translation in the nodal x (UX) y (UY) and z (UZ) directions. Besides that, the material used for this case was steel grade S275, which is the lowest strength of steel, but it is most commonly used in steel construction. The steel frame was modeled using a combination of different universal columns (UC) and one universal beam (UB) throughout the structure. The size of universal column getting smaller as the numbers of height increases, while the controlled variable used for steel bracing was L 90 x 90 x 7. For the purpose of the analysis the bottom connections were fixed, at which it was constrained in three directions (x, y, z). Since the analysis is based on braced frames, no consideration was given to the P-delta effects as its amplification factor is taken as zero.

2.8 WIND LOAD, W_K

Malaysia, basically experiences low wind speed and usually the assumption of wind loading in accordance to several code requirements was normally be considered safe for any simple building. But, when it comes to densely populated building areas, like Kuala Lumpur, Penang and Johor the designers have to undertake critical measures at the design stage to examine the consequential effects of winds to ensure safe and economical design is achieved. The wind loading for structural design in Malaysia was estimated and calculated based on Eurocode 1: Actions on structures- Part 1-4:General actions- Wind actions and MS1553: Code of Practice on Wind Loading for Building Structures, 2002. These codes specifies all general procedures in determining wind speed and resulting wind actions to be used in the design for structures subjected to wind forces. The detail wind load calculations were shown in Appendix A.

The fundamental value of the basic wind velocity, $V_{b,0}$ can be defined as the characteristic 10 minutes mean wind velocity, without considering the wind direction and time (year), at 10 m above ground level in open country terrain. As defined in Malaysian Standard, MS 1553: 2002, the basic wind speed for Zone I (Kuala Lumpur, Pahang, etc.) was 33.5 m/s for 3 second gust wind speed when translated into 10 minutes, the mean wind speed, $V_{b,0}$ was 24 m/s. Since most of the high-rise structure in

Malaysia was located in Kuala Lumpur, then the wind load was calculated with based to that place. For the terrain categories and terrain parameters selections the area of study should be at least 15 % of the surface which is covered with buildings, which its average height should exceeds 15m. Then, the terrain was categorized under terrain class IV (building height < 200m). Terrain category IV, Z_0= 1 m, Zmin= 10 m, Zmax= 200 m, in which z is height (m). By taking C_{dir} and C_{season} as 1.0, the basic wind velocity was V_b= 24 m/s. Finally, the calculated wind load was 0.969kN/m^2, which was then translated into point load of 17442N by means of multiplying the wind pressure with the tributary width of 3m and tributary height of 6m.

2.9 EFFECT OF DIFFERENT BRACING TYPE ON THE LATERAL DRIFT OF HIGH-RISE STEEL FRAME

The significance of each bracing member in every high-rise steel frame structure can be known through the resistance it provides against the lateral drift. Essentially, the type of bracing that could reduce the lateral drift to a greater extend was to be given the preference over the others. Over the years, numerous studies that were conducted revealed that bracing member could reduce the lateral drift in steel structures but what matters the most to designers was the choosing of appropriate bracing type for the steel structures. In this study, the building 84 models were analyzed in two-dimensional at the location of the braced frame in order to simplify the analysis and allow for a large number of cases to be run. Some sources claimed that bracing the center bay was only effective for lesser number of stories (example 10 stories) and become least effective for higher number of stories (example 30 stories) due to increase in height/width ratio. According to Ho and Schierle (1990), the effectiveness of bracing decreases with increasing aspect ratio (the ratio of longest dimension to the narrowest dimension of building). On the other hand, according to Nicholas Mcewen (2011), the Inverted V-bracing was opted as optimal bracing technique as it likely requires less material weight than X-bracing, and it allows much greater space or openings in each bay, while only contribute to small amount of resistance to drift compared to X-bracing. Similarly, the inverted V-bracing was chosen to be the optimal method of bracing by means of a resistance to lateral drift and from economical insight for forty story high-rise office building (Alshamrani, 2009).

2.10 EFFECT OF VARYING THE POSITION OF BRACING PRIOR TO MINIMIZATION OF LATERAL DRIFT OF 30-STORIES STEEL FRAME

Generally, bracing the center bay only cannot be taken granted as best means of limiting lateral drift in structure. Rather, this study was brought to a extend to explore the effect on the lateral drift through providing bracing at different locations along the steel frame structure. 84 models were manipulated in terms of its orientations and subsequent lateral drift of it were recorded. Basically, the steel structure can be braced in the exterior bays. This method could increase the stiffness of a structure, but of course it is much more expensive than bracing the center bay only due to the increased weight of steel and due to increased number of joints and members [Nicholas Mcewen (2011)]. Moreover, as could be expected, fully bracing the exterior two bays provides significantly more resistance to drift, but the issue becomes one of cost versus benefit. As per explained by Nicholas Mcewen (2011), optimal bracing layouts depend on several governing factor on drift control. These includes drift index, total extra weight of bracing material, total number of joints required, and the number of openings affected by the bracing. The layouts which met most of the parameters was given the preference over the others.

2.11 EFFECT OF CHANGING THE ALL PIN TO COMBINATION OF PIN-MOMENT CONNECTIONS ON THE LATERAL DRIFT OF 30-STORIES STEEL FRAME

Besides varying the bracing types and its layouts, another parameter that was analyzed and discussed in this study was the use of a pin and pin-moment connection. A pin connection was defined as the one which fully transmits the forces but no moments between the connected elements. In practice pin connections provide some rigidity, but it was to be ignored in design. Meanwhile, a pin-moment (or rigid) connection is one which fully transmits both forces and moments between the elements connecting each other. As with most design considerations, pin and moment connection have their very own advantages and disadvantages. To illustrate, using pin connection, the construction process becomes simplified and thus requiring less skilled labor with less time on site and at the same time it cut down the cost. Certainly, the structural design complexity was significantly reduced. Unlike pin connection, the moment connection deals with fact that there was a certain reduction in drift. The connection presents the redundancy in the structure and it producing a safer building.

Basically, the general modeling method associated with the combined pin and moment connection deals with releasing the moment between the beam and the column at every location where a bracing member ties into a beam joint. It was believed that significant reduction in drift can be achieved when using combination of pin and moment connection than the pin connection itself (Nicholas Mcewen, 2011). Additionally, reduction of drift in the range of 8% to 13% can be realized depending on the type of bracing used in 17 stories steel frame building when changing from using pin connections to a combined pin and moment connections (Nicholas Mcewen, 2011). In this study, 84 models were compared using both pin connection and combined pin-moment connection to find out whether significant drift reduction can be obtained in pin-moment connection as per stated in the previous studies.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

In this chapter, there are several significance steps and methods governing the entire ANSYS simulation program. Apparently, the methodology of this study consists of three main phases, namely preprocessing, solution, and postprocessing. Before delving into the details or the procedures of the ANSYS program, the definition of these terms has to be highlighted first.

At first, preprocessing step, or the model generation step was known as the method of simplifications, idealizations and definition of geometric and material properties as well as generation of solid and finite element models. Basically, there are two methods for creating a finite element models, known as solid modeling and direct generation method. The solid modeling method deals with pre-defined geometric shapes, known to be 'Primitives' plus operations alike to computer-aided design (CAD) tools. It generates the nodes and the elements internally as specified by users. Generally, solid modeling approach was the most commonly used approach due to its versatility and powerfulness. This method requires the user to pose adequate understanding pertaining to the concept of meshing in order to successfully utilize the solid modeling. On the contrary, direct generation approach was completely dependent on user input for size, shape, plus connectivity of each element member and coordinates of each node that creates the nodes and elements one at a time. Moreover, it requires the user to have a full control over the model's node and element numbering, which may become tedious or even impractical for complex situation requiring thousands of nodes.

The second step was about solution phase that closely related to defining boundary conditions and obtaining solutions for the models. Indeed, there are three main analysis types under this phase that includes static, transient (time-dependent), or sub-modeling and sub-structuring. Considering Structural Analysis discipline, it contained several analysis types, for instance harmonic, modal, spectrum and eigenvalue buckling. On top of that, there are two prime deciding factors in selecting the analysis type: loading conditions and results of interest. In loading condition, the analysis type was known to be Transient if the boundary conditions changed as a regard to time or if there are initial conditions. Taking into account structural discipline, the analysis type was of harmonic when the loading is a sinusoidal function of time. Likewise, the analysis type was of seismic spectrum when the loading deals with seismic spectrum. Meanwhile, in result of interest technique, and in structural discipline the analysis type was of Modal if the results of interest are from the natural structural frequencies. Similarly, the analysis type was of eigenvalue buckling if the interest is about determining the load at which the structure loses stability or it buckles.

The last step of ANSYS program is postprocessing. Postprocessing is a way to review the results of an analysis. Probably it was considered the most important step in the analysis, from which it will indicate how the applied loads affect the design, how good the finite element mesh is, and etc. Under this phase, the results at a specific time (transient analysis type) over the portion or entire models were reviewed. Likewise, contours plotting, vector displays, deformed shapes, and listings of the results in tabular format can be obtained in this processor. Basically, there are two postprocessors available to review the results. First was the general postprocessor, which reviewed the results over the entire model at specific load steps and sub-steps. Second was the time-history postprocessor that reviewed the variation of a particular result item at specific points in the model with respect to time, frequency, or some other result item.

3.2 FLOWCART

The flowchart of this study is shown in Figure 3.1 that covers all the three phases of ANSYS simulation process: Preprocessing, Solution, and Postprocessing.

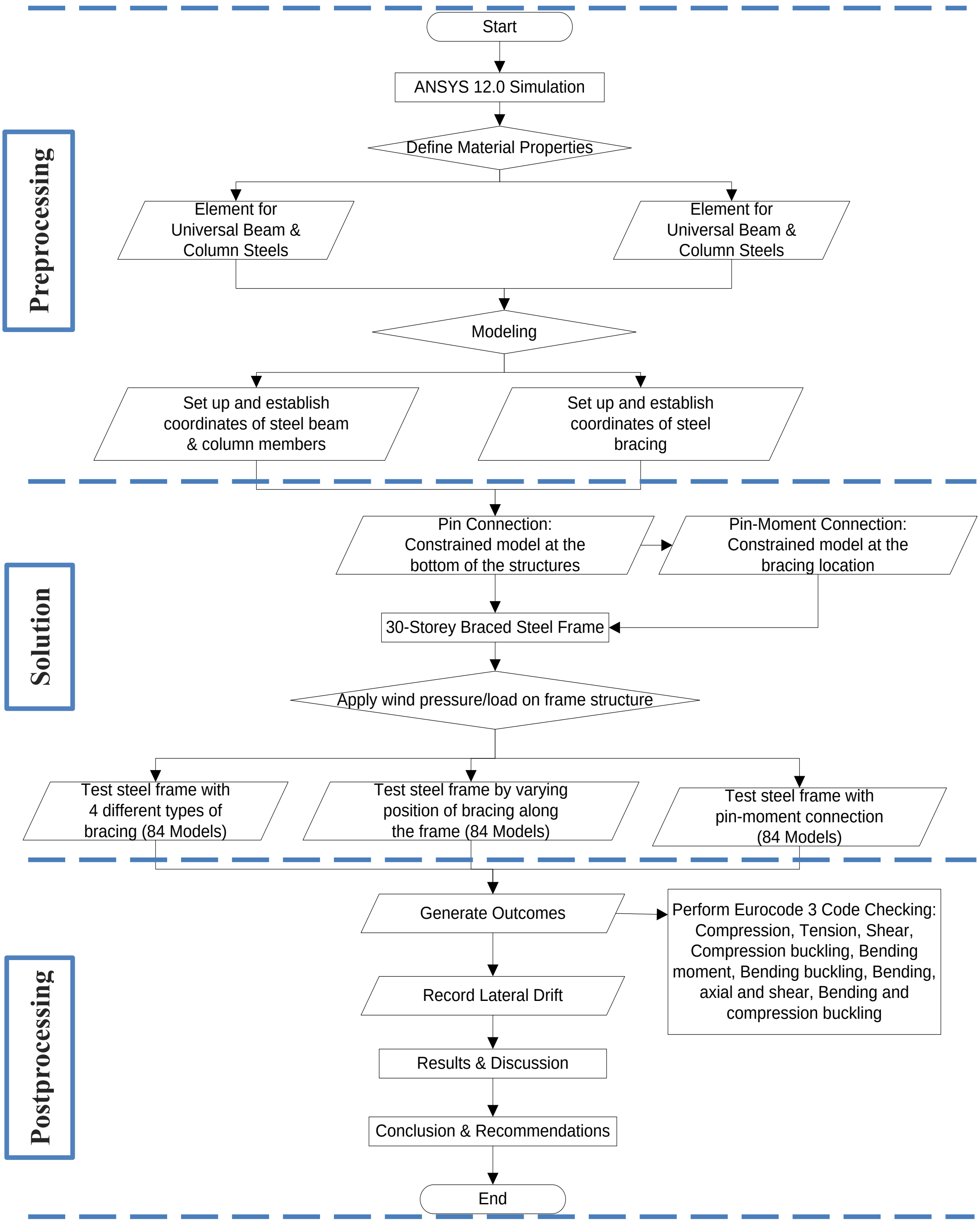


Figure 3.1: Methodology flowchart

3.3 PREPROCESSING

Preprocessing or defined as “Civil Preprocessor” in ANSYS always begins with providing data such as the units system, active code, materials, element types, and section and model geometry definition. The method chosen for this processor was direct generation approach, whereby the specifications and other details were directly put into the ANSYS program to create the nodes and models. As a side note, it is important to activate CivilFEM and specify title before analysis on each and every model can be performed.

3.3.1 ANSYS Codes and Units

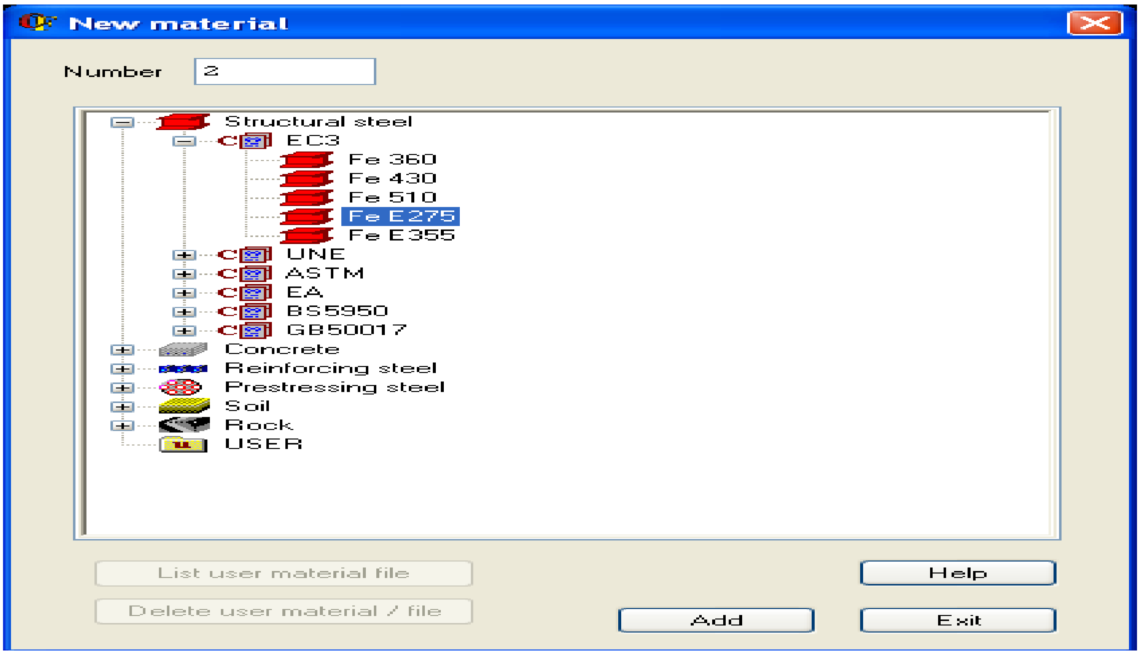
This step was a common procedure that requires the choosing of different codes for checking and designing. In CivilFEM, it was worth to notice that one can uphold or choose different active codes simultaneously, for instance one for concrete calculations another one for steel calculations and a third one for seismic design. In this study, the chosen active code is Eurocode 3, which was the default option for steel design.

An important criterion just after setting the code system was defining a unit system in CivilFEM. Such system was well known in CivilFEM as it can perform calculations according to Code selected and it has to be maintained during the entire design. In this study, the selected unit was SI units: meters, seconds, and newton.

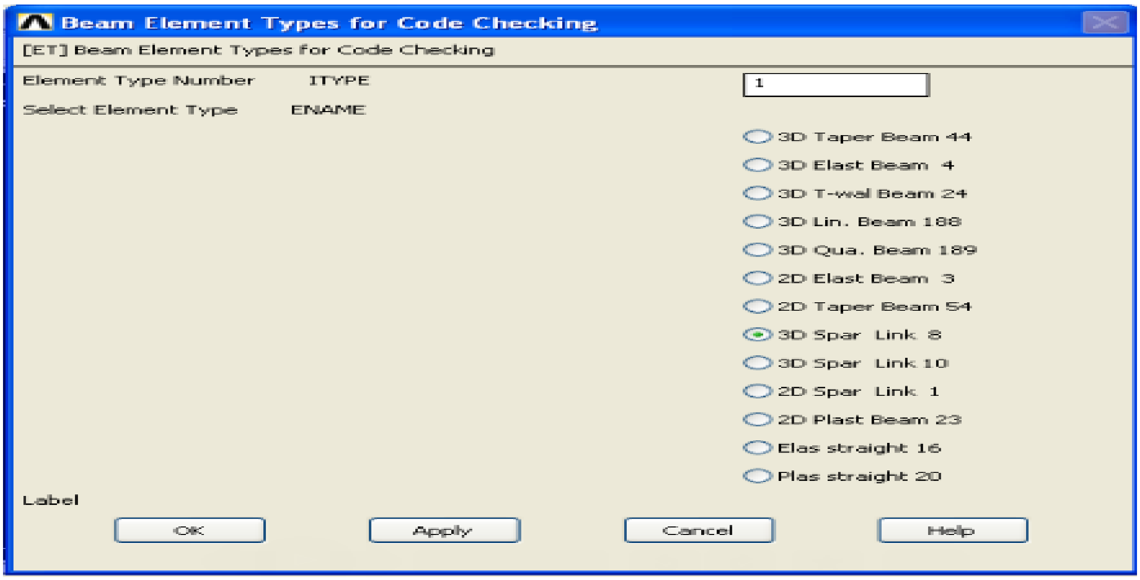
3.3.2 ANSYS Material Properties and Element Type

Material properties have to be defined in CivilFEM-CFMP command. One special thing about this command is it will automatically define the ANSYS material properties, such as density, Poisson’s ratio, Young’s modulus of elasticity, and etc. Nevertheless, this command contains CivilFEM material properties necessary for code checking. For this study, the material that was used is Fe E275, which is a structural steel of grade S275 under the provision of Eurocode 3. Figure 3.2 illustrate the step of defining the material to be used in the design.

It was worth noting that although ANSYS element can be used to define the models, but only CivilFEM supported element types are able to perform the checking and designing according to the codes. In this analysis '3D Spar Link 8' was used as beam element types for code checking under Eurocode No.3. The step to define the required element types can be found in Figure 3.3.



Figures 3.2: Define the materials



Figures 3.3: Defining the element types

3.3.3 Cross Section Properties of Steel Frame

The selection of column and beam cross sections has been opted under the hot rolled shapes library. As it were acknowledge before, there are total of six manipulated variables or column sizes and one controlled variable of beam size that was used throughout the design, as shown in Table 1.1.

Basically, the selection of each and every cross-section will automatically define the ANSYS cross-section properties, without the need for manually inserting the values. The properties of the cross-section will covering these items: depth of section (h), width of section (b), thickness of web (t_w) and flange (t_f), root radius (r1, r2), depth between fillets (d), area of section (A), second moment of area about x, y, z axis (Ixx, Iyy, Izz), elastic modulus about y, z axis (Wy, Wz), and plastic modulus about y, z axis (Wpy, Wpz). For instance, Figure 3.4 shows the cross-section properties of beam section and Figure 3.5 shows the example of column cross-section properties (spanning along the first until fifth floors). On top of that, bracing cross-section properties that was used to assemble the model can be found in Figure 3.6.

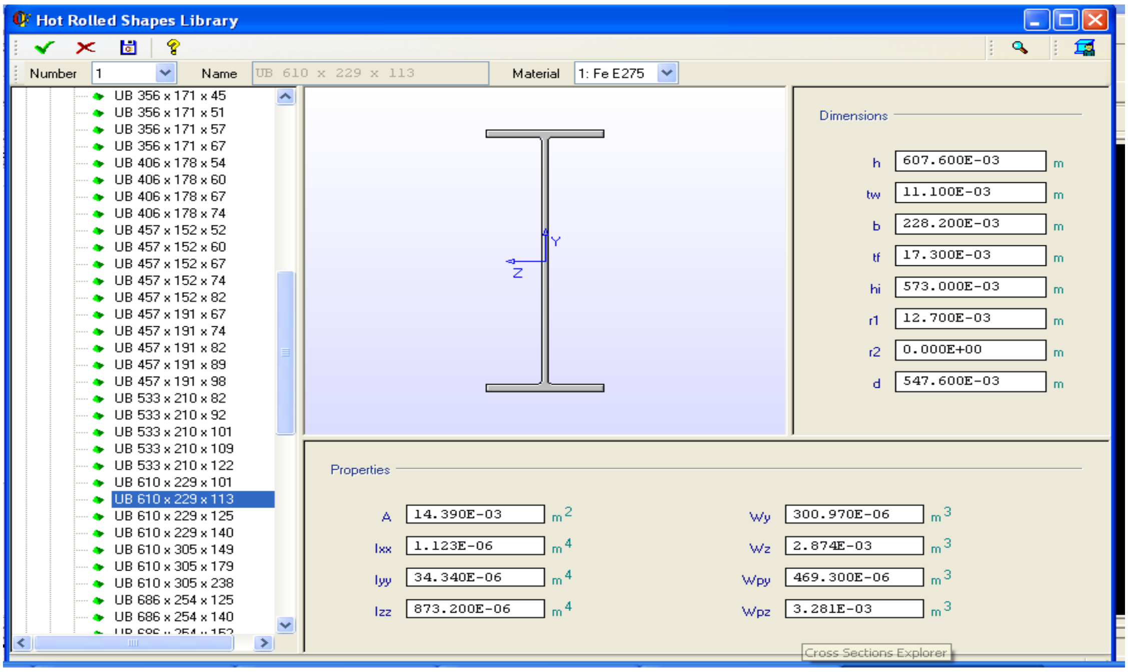


Figure 3.4: Beam cross-section properties

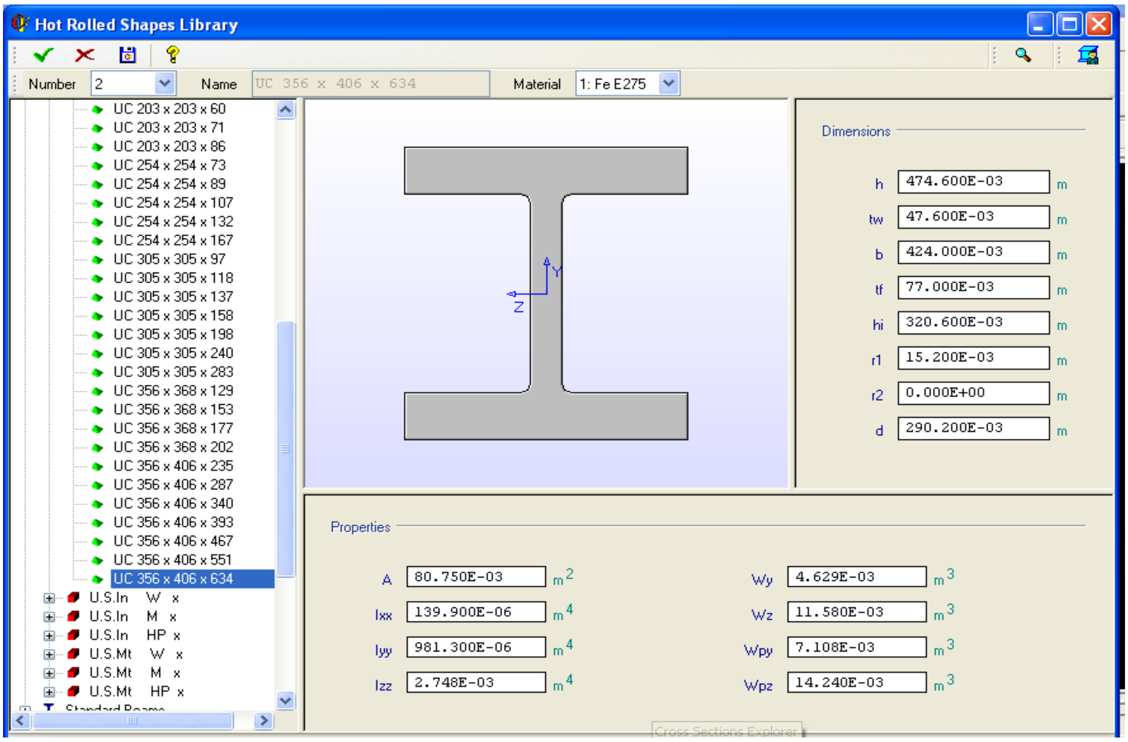


Figure 3.5: Example of column cross-section properties (for 1st-5th floor)

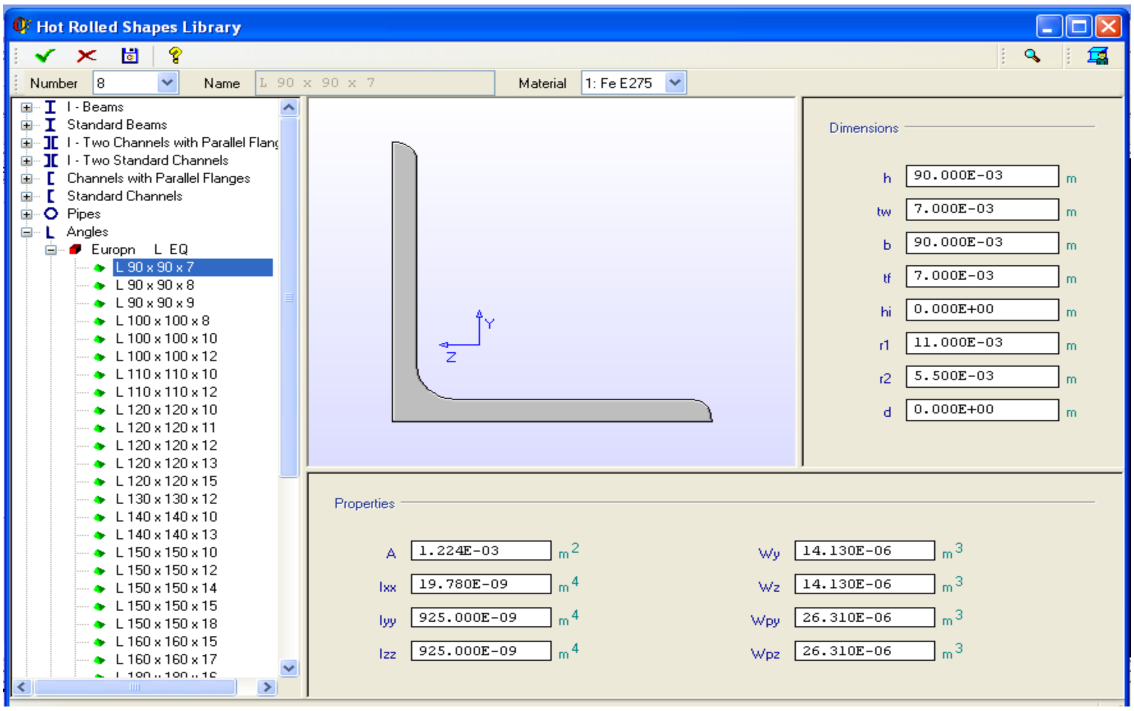


Figure 3.6: Bracing cross-section properties

3.3.4 Member Properties and Real Constants of Steel Frame

Member properties just have to be defined for the checking to be accomplished. In this study, the member properties definition was necessary to check for compression buckling. Figure 3.7 shows the member properties setting out.

CivilFEM through its' command ~BMSHPRO has provide a medium to define ANSYS real constants. All the previously defined properties such as material, element types, and cross section has to be put into this section. Figure 3.8 shows the beam/column/bracing properties being defined for design purpose.

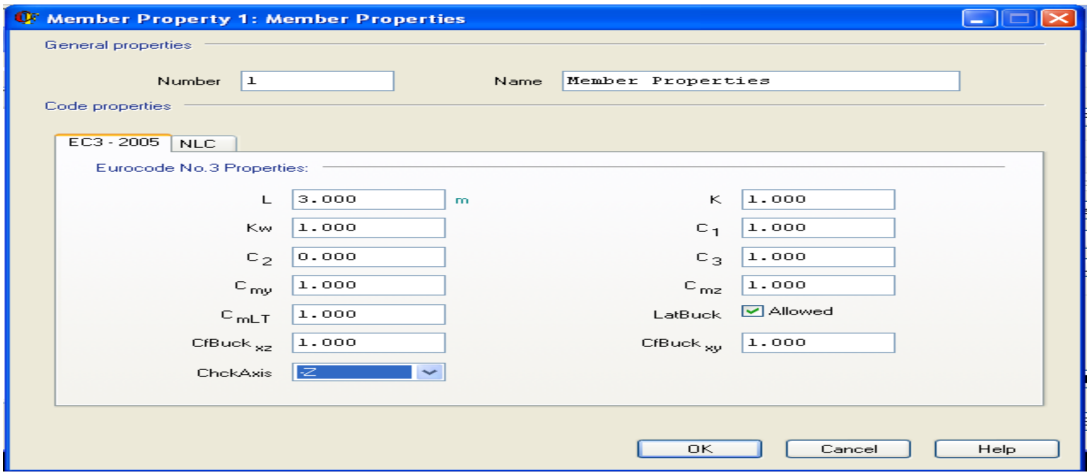


Figure 3.7: Defining the member properties

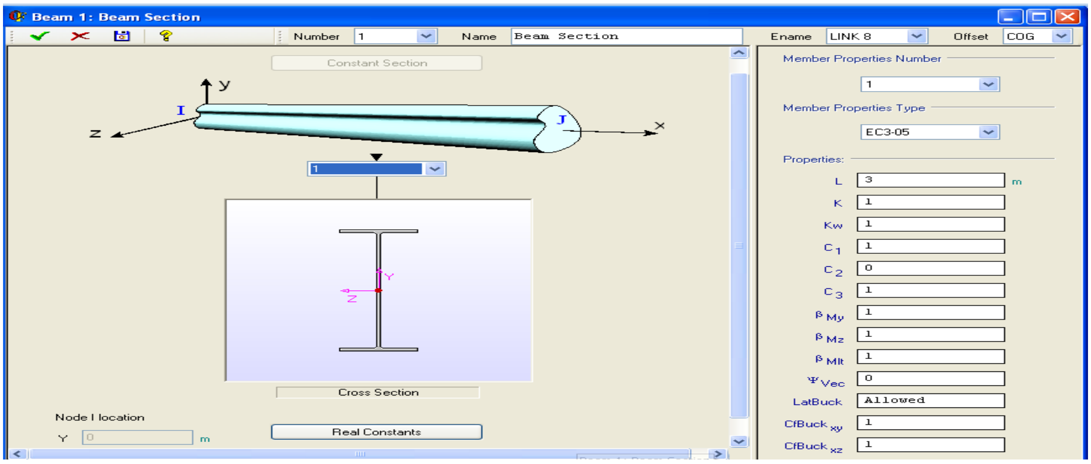


Figure 3.8: Defining the beam/column/bracing properties

3.3.5 ANSYS Model Generation via Nodes and Elements

The model generation was defined by direct nodes and elements generation. The nodes have to be defined first, followed by elements that were joined with all the created nodes. The nodes were generally created in active coordinate system. As in this study, the nodes have been defined by means of 6m bay per bay horizontally for beam and 3m floor to floor vertically for column. Figure 3.9 indicate the procedure of defining the nodes and elements by first setting the node at coordinate (0, 0). Then, the next node has to start at coordinate (6, 0) as shown in Figure 3.10.

Upon completing the establishment of all the required nodes as shown in Figure 3.11, then the elements were defined. It is worth noting that each element that was used to join the nodes have been attributed according to its designated real constants. For instance, the beam element was under real constant set 1, the element for columns were under real constant set 2-7, and the element for bracing was under real constant set 8 (as shown in Figure 3.12, Figure 3.14, and Figure 3.16 respectively) defined earlier in the beam and shell properties section. Nevertheless, Figure 3.13 shows the elements were connected horizontally to form beam member, and Figure 3.15 shows the elements were connected vertically to form columns member. Likewise, the bracing elements have been connected in a numerous way to represent different bracing techniques. One of the bracing techniques for X-bracing is shown in Figure 3.17.

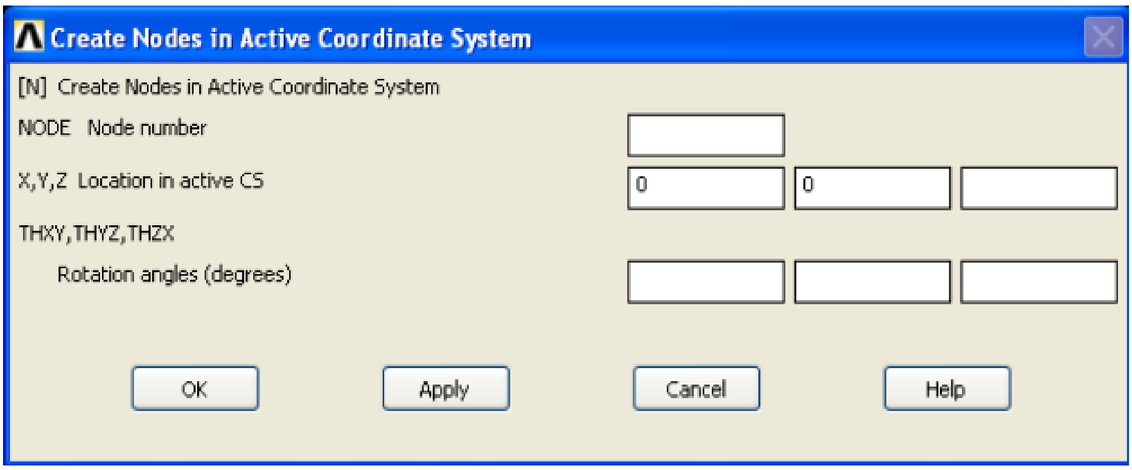


Figure 3.9: Set node at (0, 0) first

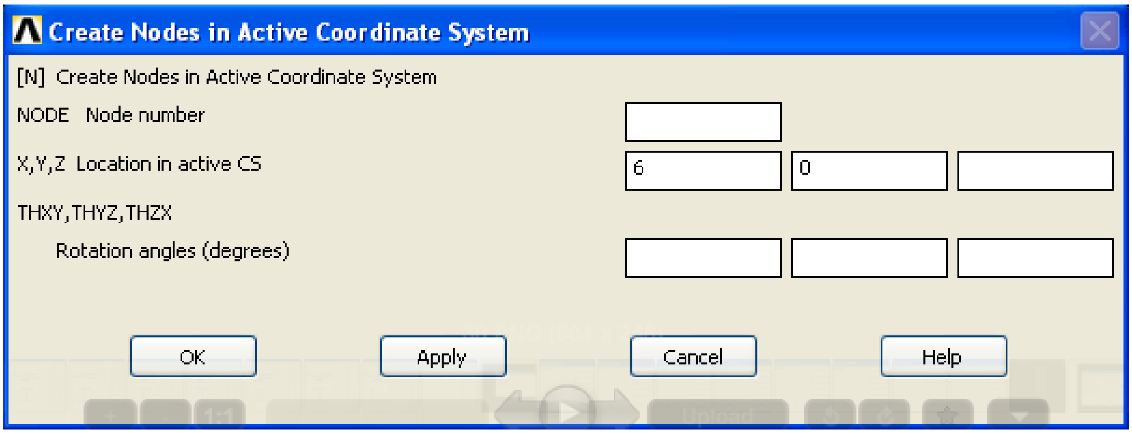


Figure 3.10: Second node start at (6, 0)

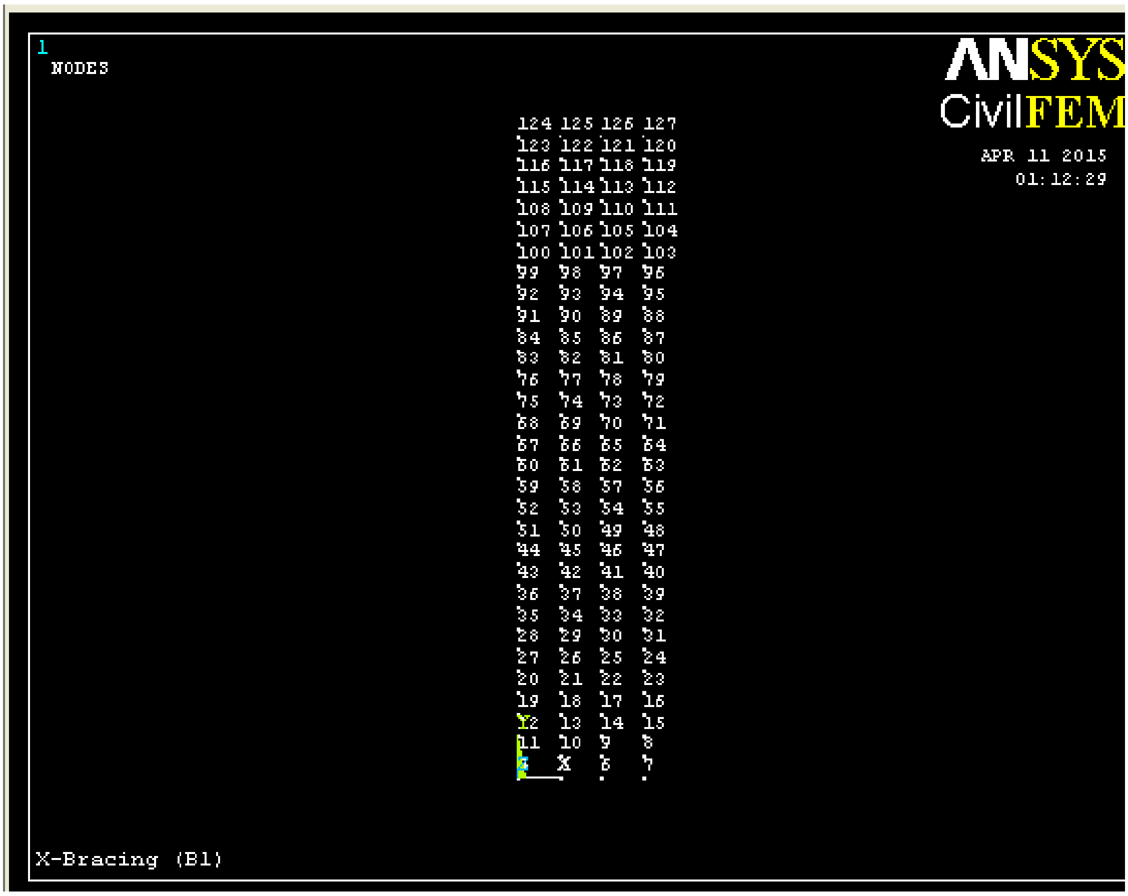


Figure 3.11: The complete establishment of nodes for steel frame

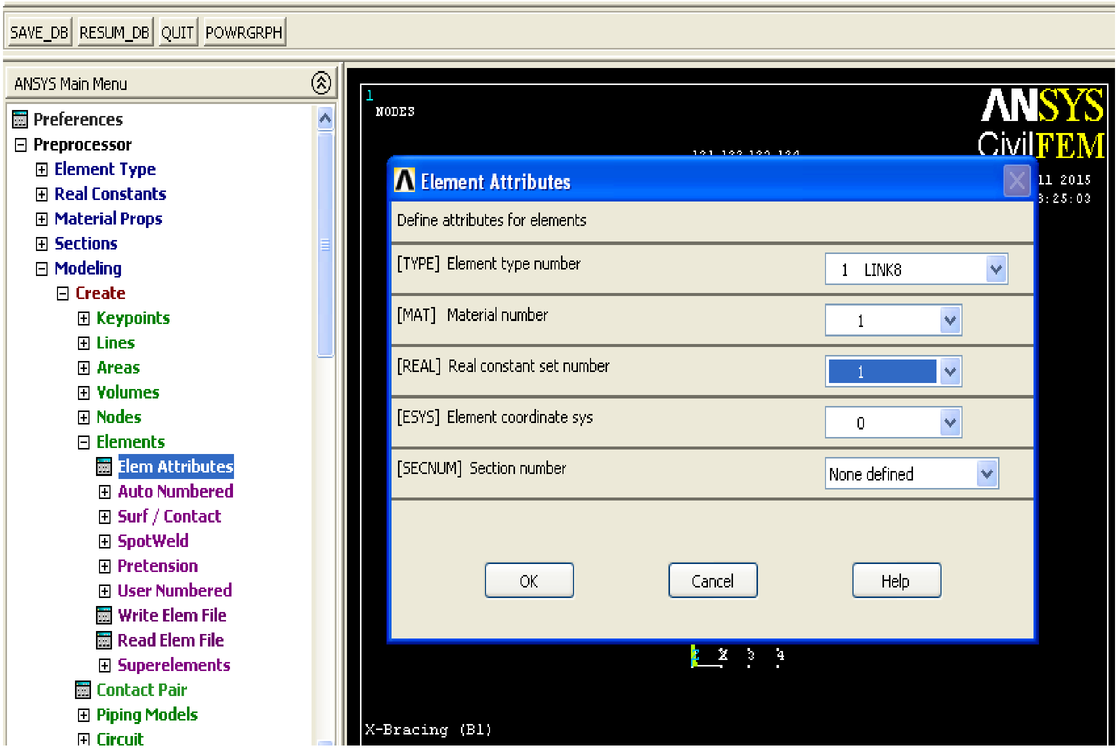


Figure 3.12: Element attributes for beam

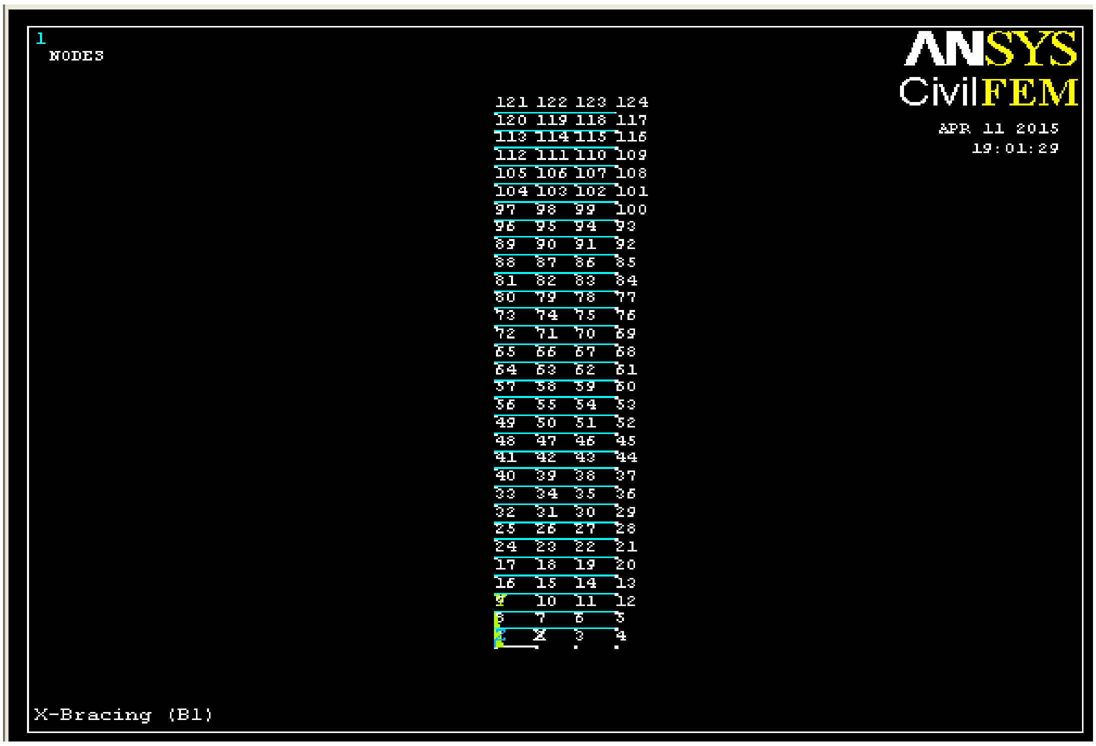


Figure 3.13: Defining the elements to connect the nodes horizontally to form beam members

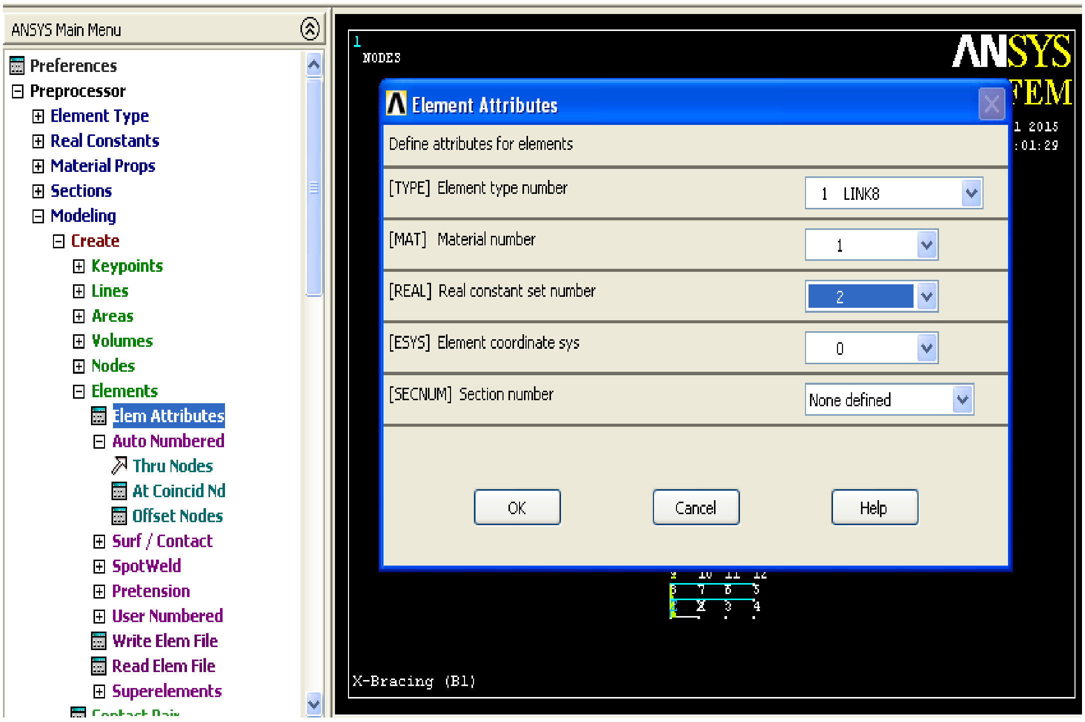


Figure 3.14: Element attributes for columns

Figure 3.15: Defining the elements to connect the nodes vertically to form column members

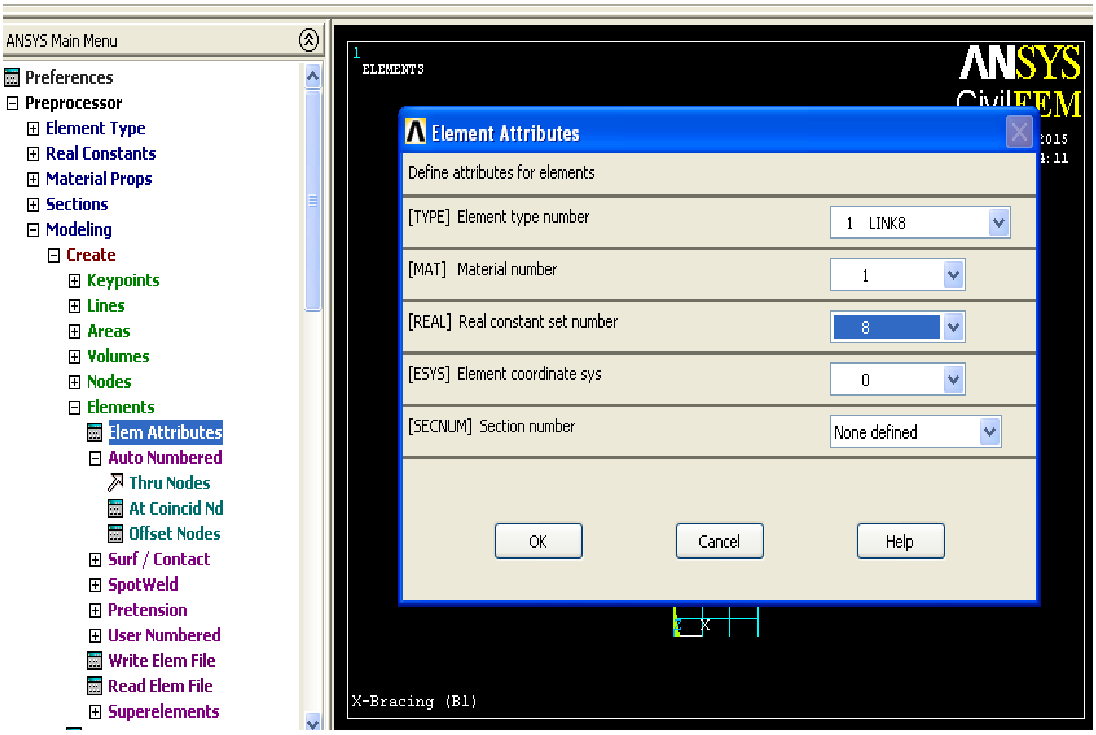


Figure 3.16: Element attributes for bracing member

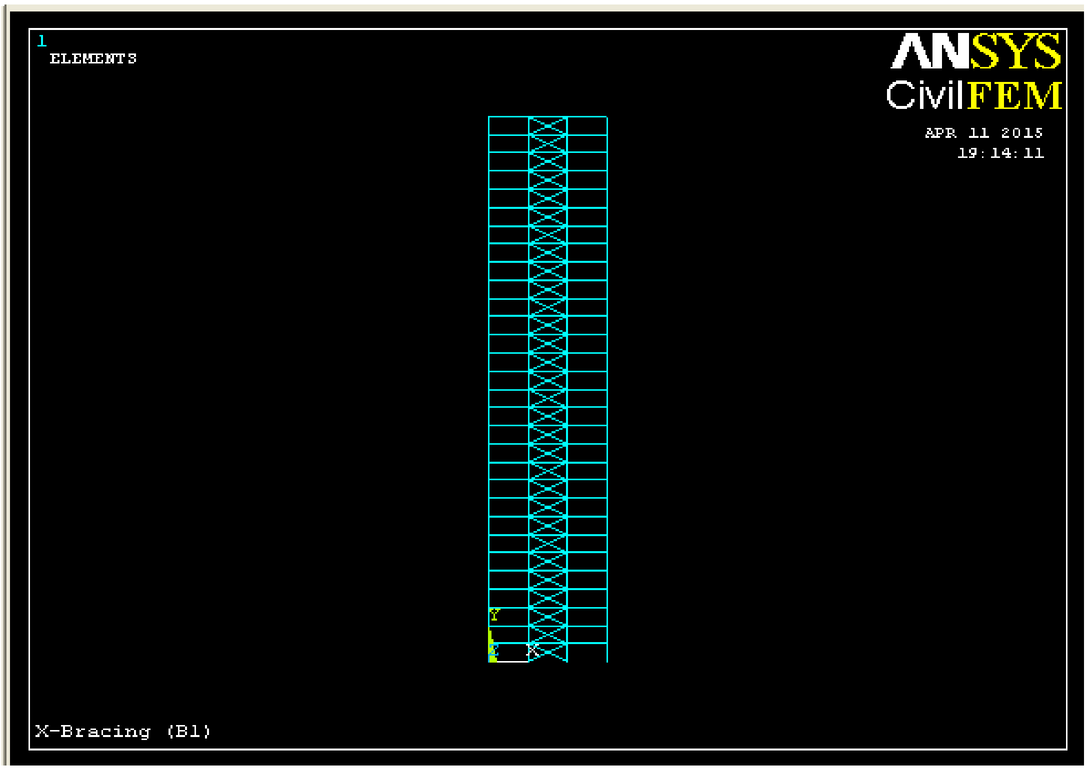


Figure 3.17: Defining bracing elements between the nodes to form bracing members

3.4 SOLUTION

This step was important as the analysis type and its options were defined, the loads were applied, finite element solution was initiated. For this study, a new, static analysis was the default option, thus there is no need to specify analysis type**.**

3.4.1 Displacement Constraints for Pin Connection Models

At the very bottom of the frame structure, the part connecting the column to the stump and foundation, it has to be constrained all degree of freedom (DOF) in the x, y, z directions. This was shown in Figure 3.18, which represents the model that has been constrained in all DOF.

3.4.2 Displacement Constraints for Combined Pin-Moment Connections Model

One of the objectives of this study is to determine the effect of pin-moment connection compared to ordinary pin connection. The pin-moment connection has been modeled by constraining y-axis and z-axis of every node at the location of the bracing member, which ties into a beam joint. The procedure of constraining the model was shown in Figure 3.19 and the constrained pin-moment connections model was shown in Figure 3.20.

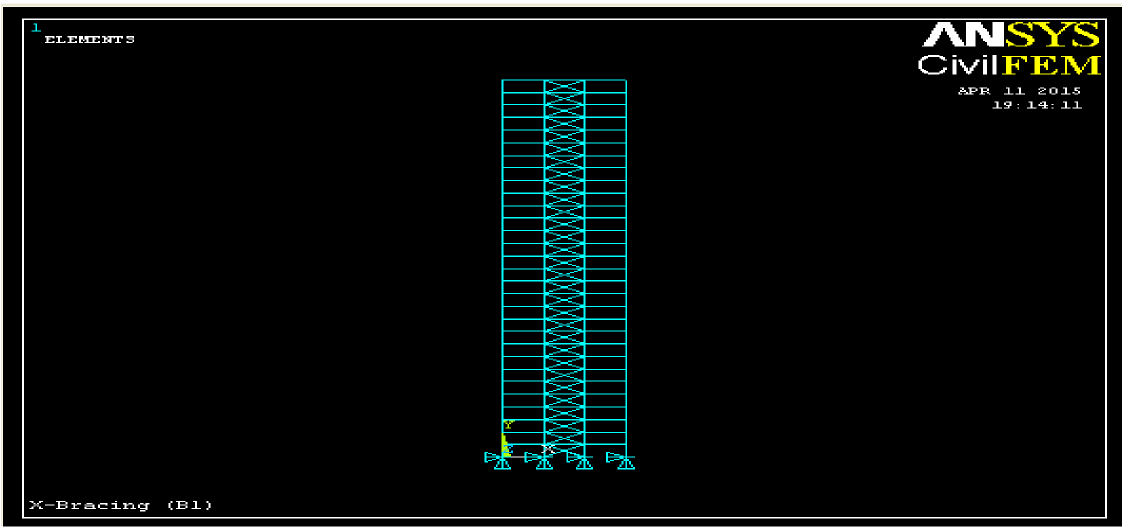


Figure 3.18: Model constrained in all DOF

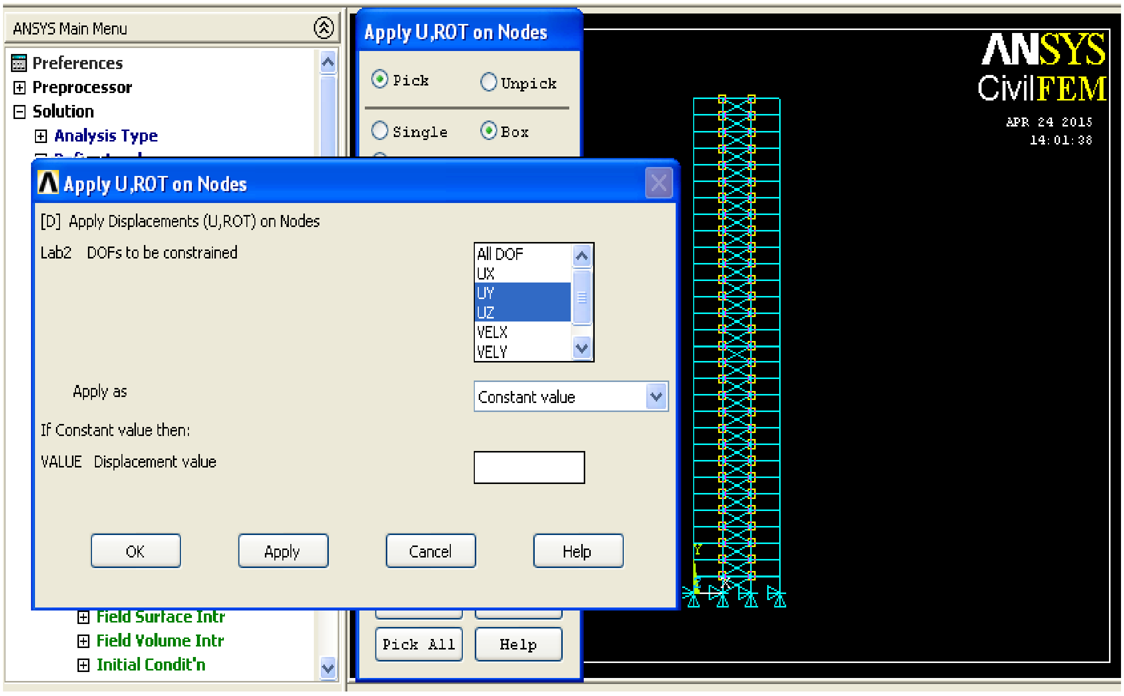


Figure 3.19: Constraining y-axis and z-axis at each bracing node to form pin-moment connection

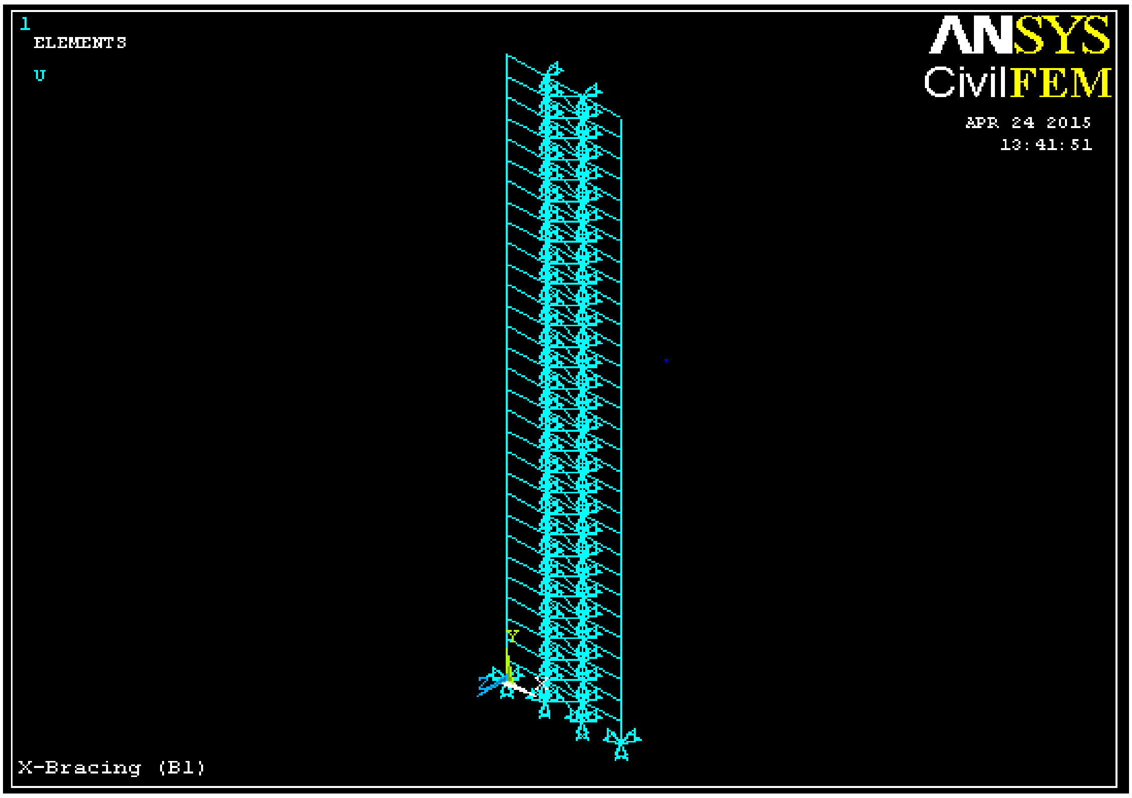


Figure 3.20: Constrained pin-moment connection model

3.4.3 Lateral Loads Application into Steel Frame

The type of force that was applied to the model or the structural frame is lateral forces along the column face both in the windward and leeward directions. As a side note, the force to be applied in windward direction is higher, that is about 13953.6 N compared to force in leeward direction which is just 3488.4 N. To illustrate, Figure 3.21 and Figure 3.22 shows the nodes picked up to apply lateral forces in the windward and leeward directions respectively. Basically, the load is applied on each floor level upon which the wind pressures were converted into newton by multiplying the pressures by the tributary widths between adjacent braced frames in the structure. In overall, the total lateral force directed towards the steel frame structure is 17442 N as shown in Figure 3.23. At the very final stage of solution phase, the models were solved and subsequent data of drift was obtained for analysis.

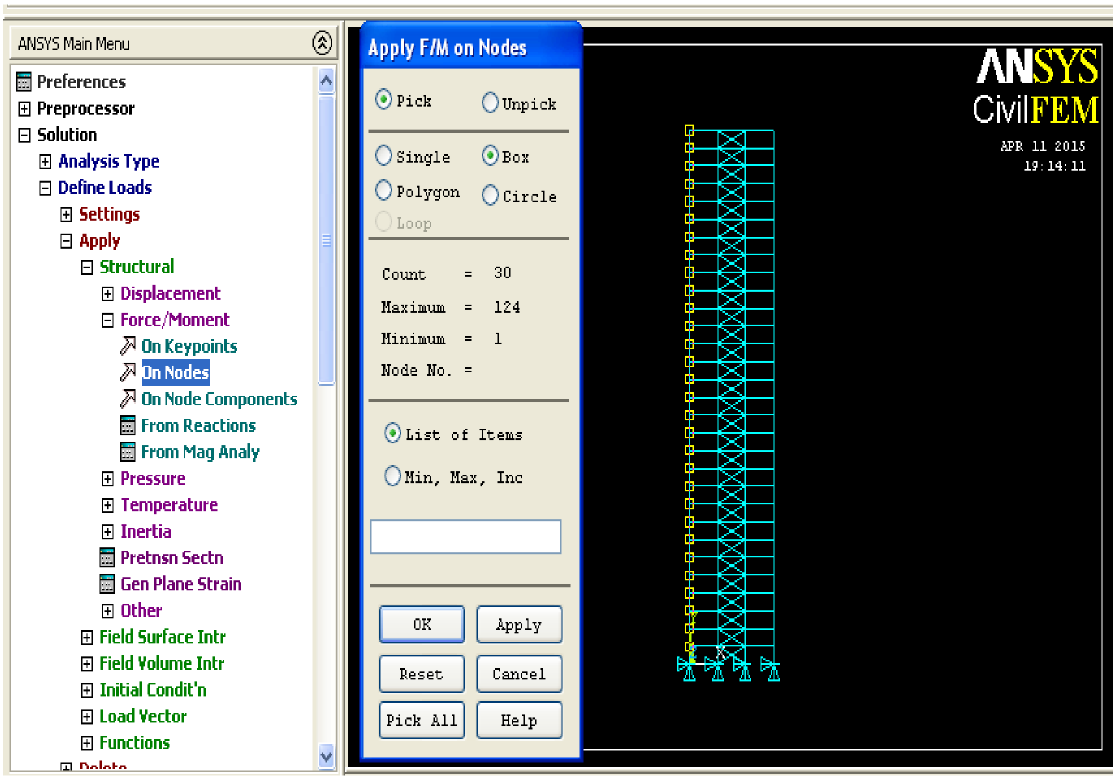


Figure 3.21: Picking the nodes to be applied with lateral loading

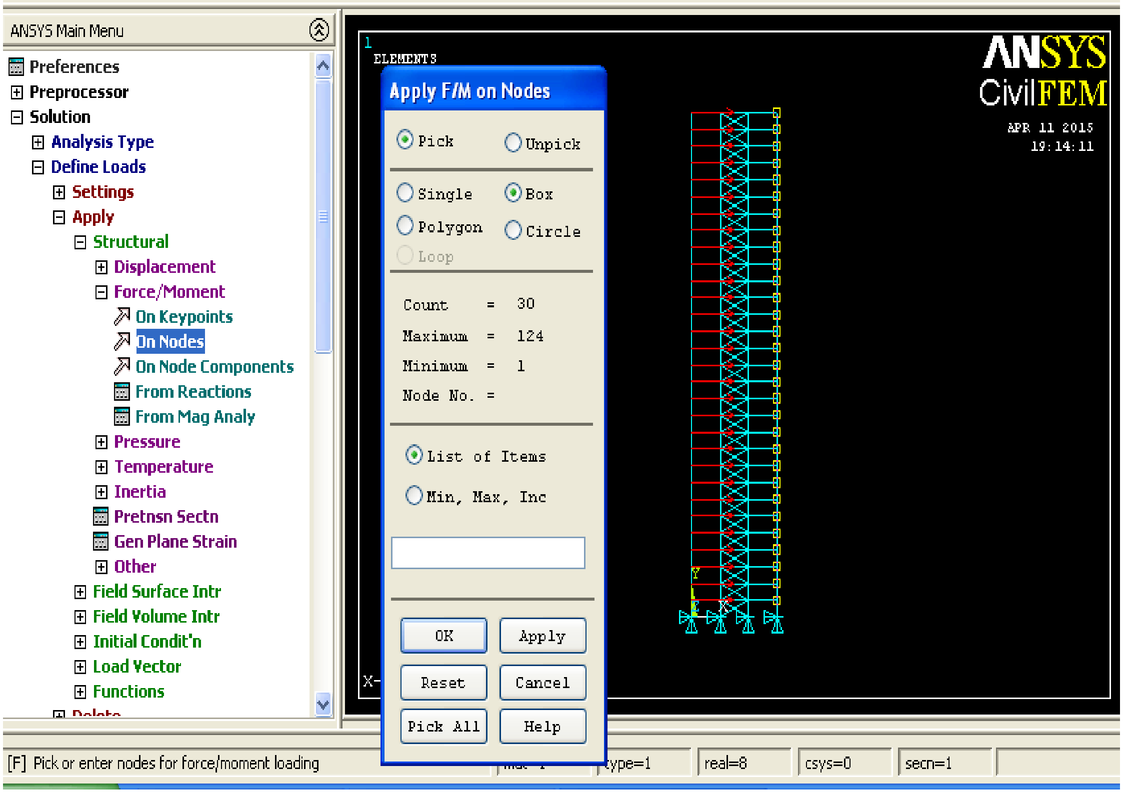


Figure 3.22: Picking the nodes to be applied with lateral loading

Figure 3.23: Total applied load of 17442 N loads to the frame

3.5 POSTPROCESSING

Postprocessing is the part to review the analysis results through graphic displays and tabular listings. The postprocessor used to review the results was general postprocessor. It involves two major steps that are plotting/reviewing the results and next, listing out the results. In this study, the lateral drift results of the models were obtained in contour plot of nodal solution section under the degree of freedom or displacement sub-section. Figure 3.24 shows how the results of lateral drift can be plotted for each model and Figure 3.25 represents the procedure to list out the results of drift in the x-direction. The importance of listing out the drift results in both x and y directions are to calculate the drift damageability index and other drift indices of the models. All other figures of ANSYS simulation process were shown in Appendix B.

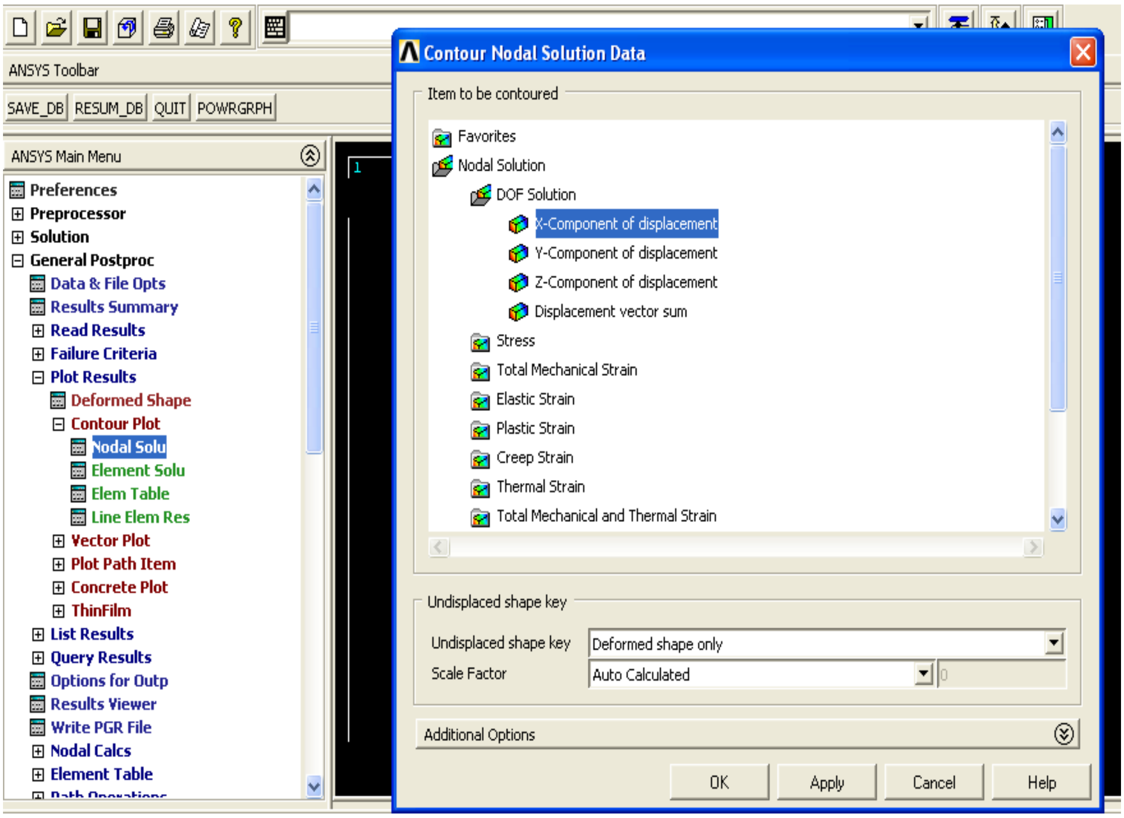


Figure 3.24: Plotting the drift result of the model in the x-direction

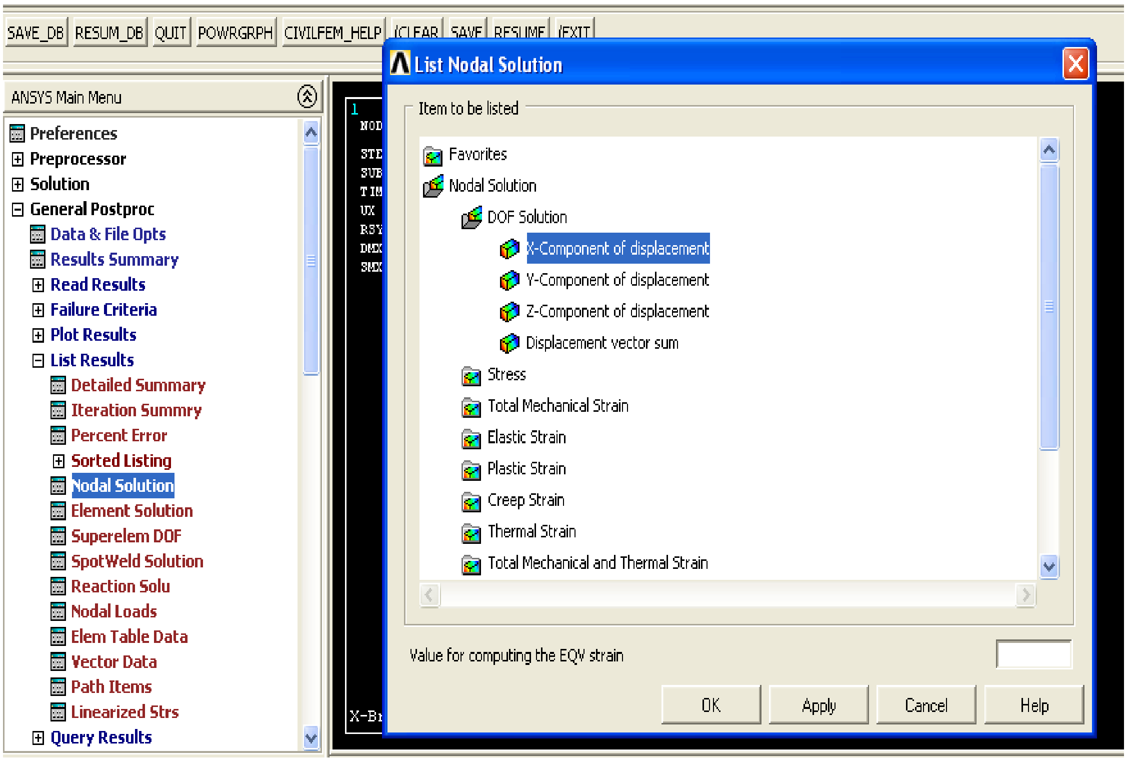


Figure 3.25: Listing out the x-direction drift result of the model

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

As was briefly discussed above, the analysis process cannot be made by simply establishing one bracing type or layout as the most effective method to brace every steel structure building or even more than one particular building as all circumstances are always appeared to be different. There are some differences in structures that could be notified to cause significant variance in the required bracing technique which includes basic wind speed, wind exposure category, the tributary height and width between floors, architectural requirements, etc. These were known as the so called fundamental factors that can either dramatically change the load applied at each floor or handicap the number of options due to accessibility. At some point, the necessity of bracing member has to be identified in order to get know whether the bracing system really works in limiting the drift on the structure. Upon analyzing the drift damage index (DDI) using equation 2.3, it was proved that provision of bracing in bays has reduced the drift damage index and shear distortion of the frame structure compared to the unbraced bay, which was also represented in Table 4.1. It literally shows the significance of bracing member in limiting lateral drift in structural steel was certainly undeniable and the equation 2.3 was proved working.

4.2 ANALYSIS ON THE EFFECT OF DIFFERENT BRACING TYPES ON THE LATERAL DRIFT OF STEEL FRAME

There are various criteria to be analyzed upon comparing the effect of different types of bracing on lateral drift. Traditionally, drift has been defined in these two terms: total drift index and inter-story drift index. So does in this case, these two terms were used, apart from maximum floor drift to analyze and compare the drift results. This analysis was made by comparing the four types of bracing: X-bracing, Inverted V-bracing, K-bracing, and single diagonal bracing for 21 different bracing orientations. As shown in Table 4.2 (for maximum lateral drift), Table 4.3 (for interstory drift index), and Table 4.4 (total drift index), for the case of bracing the center bay only, the maximum floor drift was in the range of 0.33074 to 0.62231, for the inter-story drift index the range was between 0.00298 to 0.00906, and total drift index was in the range of 0.00377 to 0.00691 which these three indicates that drifts were minimal in X-bracing and Inverted V-bracing compared to K-bracing and single diagonal bracing. Likewise, in model no.1 (B1-1, B2-1, B3-1, and B4-1), the maximum floor drift was in the range of 0.29432 to 0.59662, for the inter-story drift index the range was between 0.00298 to 0.00906, and total drift index was in the range of 0.00322 to 0.00663. Thereafter, in model no.2 (B1-2, B2-2, B3-2, and B4-2), it again shows that the maximum floor drift, inter-story drift index, and total drift index are all smaller in X-bracing and Inverted V-bracing, compared to K-bracing and single diagonal bracing. For instance, the maximum floor drift was in the range of 0.28875 to 0.59526, for the inter-story drift index the range was 0.00297 to 0.00905 and total drift index was in the range of 0.00321 to 0.00661. Besides that, in model no.3 (B1-3, B2-3, B3-3, and B4-3), the maximum floor drift was in the range of 0.29465 to 0.58907, for the inter-story drift index the range was between 0.00296 to 0.00905, and total drift index was in the range of 0.00327 to 0.00655. In model no.4 (B1-4, B2-4, B3-4, and B4-4), the maximum floor drift was in the range of 0.32486 to 0.59474, for the inter-story drift index the range was between 0.00003 to 0.00177, and total drift index was in the range of 0.00361 to 0.00661. It was quite clear that in these models the maximum floor drift, inter-story and total drift indices were the least for Inverted V-bracing out of all other bracing type. The second least was X-bracing, followed by single diagonal bracing. K-bracing, on the other hand always comes out to be the least stiff bracing type.

Next, the analysis was made by comparing the drift values for models braced at multiple floors. In model no.5 (B1-5, B2-5, B3-5 and B4-5), the maximum floor drift was in the range of 0.26229 to 0.56630, for the inter-story drift index the range was between 0.00296 to 0.00905, and total drift index was in the range of 0.00291 to 0.00629. Taking into account model no.6 (B1-6, B2-6, B3-6, and B4-6), the maximum floor drift was in the range of 0.26333 to 0.56653, for the inter-story drift index the range was 0.00296 to 0.00905, and total drift index was in the range of 0.00293 to 0.00629. Thereafter, in model no.7 (B1-7, B2-7, B3-7, and B4-7), the maximum floor drift was in the range of 0.26147 to 0.56604, meanwhile for the inter-story drift index the range was 0.00296 to 0.00905, and total drift index was in the range of 0.00291 to 0.00629. As per comparing model no.5 to no.7, it was noticed that the Inverted V-bracing and X-bracing induced great amount stiffness on the frame structure, unlike to K-bracing and single diagonal bracing.

Starting from model no.8 onwards up to model no.13 the bracing analysis was made concerning two rows of bracing placed at multitude ways along the frame structure. For example, in model no.8 which was braced at 16^{th}, 17^{th}, and the 30^{th} floors, the maximum floor drift was in the range of 0.23813 to 0.53760, for the inter-story drift index the range was 0.00295 to 0.00904, and total drift index was in the range of 0.00265 to 0.00597. Similarly, in model no.9, braced at 15^{th}, 16^{th}, and 30^{th} floors, the maximum floor drift was in the range of 0.23945 to 0.53786, for the inter-story drift index the range was 0.00295 to 0.00904, and total drift index was in the range of 0.00266 to 0.00598. In the 10^{th} model, which was braced at 14^{th}, 15^{th}, and 30^{th} floors, the maximum floor drift was in the range of 0.24073 to 0.53811, for the inter-story drift index the range was 0.00295 to 0.00904, and total drift index was in the range of 0.00267 to 0.00598. Moving to model no.11, which got braced at first two top floors, the maximum floor drift was in the range of 0.26734 to 0.57539, for the inter-story drift index the range was 0.00296 to 0.00905, and total drift index was in the range of 0.00297 to 0.00639. Thereafter, in model no.12, which was braced at two middle floors of the frame, the maximum floor drift was in the range of 0.26520 to 0.55781, for the inter-story drift index the range was 0.00295 to 0.00905, and total drift index was in the range of 0.00295 to 0.00620. Likewise, in model no.13 which had been braced at the first two bottom floors, the maximum floor drift was in the range of 0.31709 to 0.58348, for the inter-story drift index the range was 0.00097 to 0.00299, and total drift index was in the range of 0.00352 to 0.00648. To sum up, it was worth noting that irrespective of bracing location as per in model no.8 to no.13, the Inverted V-bracing and X-bracing always have very slight drift difference between them, but in terms of limiting the drift by means of providing good restrained to steel frame, it were the right option, unlike the K-bracing and single diagonal bracing which deflect more upon receiving wind loading.

The analysis was then made on model no.14, no.15, no.16, and no.20, which was braced over multiple bays and floors. To illustrate, in model no.14, which the bracing schemes was braced in a zigzag pattern along the bays, the maximum floor drift was in the range of 0.16521 to 0.45579, for the inter-story drift index the range was 0.00314 to 0.00931, and total drift index was in the range of 0.00184 to 0.00506. In model no.15, which the bracing schemes was braced in a perpendicular pattern along the bays, the maximum floor drift was in the range of 0.16784 to 0.45838, for the inter-story drift index the range was 0.00313 to 0.00931, and total drift index was in the range of 0.00186 to 0.00509. Additionally, in frame model no.16, the bracing was applied one after the other floor at the first and third bay. The results for this model were the maximum floor drift was in the range of 0.25783 to 0.54974, for the inter-story drift index the range was 0.00351 to 0.00968, and total drift index was in the range of 0.00286 to 0.00611. The model no.20 was a kind of model that dealing with bracing stretched along the bays. It can be seen that the maximum floor drift was in the range of 0.15528 to 0.43791, for the inter-story drift index the range was 0.00283 to 0.00893, and total drift index was in the range of 0.00173 to 0.00487. Throughout the analysis of these models, it was worth noting that X-bracing come out to be the effective type of bracing along with Inverted V-bracing as it can provide a very minimal drift result compared to K-bracing and single diagonal bracing.

Next, the analysis was dealing with bracing braced completely the exterior bays, which involves model no.17, no.18, and no.19. In model no.17, which was braced completely the exterior bays and the 30th floor, the maximum floor drift was in the range of 0.15068 to 0.30097, for the inter-story drift index the range was 0.00149 to 0.00453, and total drift index was in the range of 0.00167 to 0.00334. Then, in model no.18, which was braced completely the exterior bays and the 15th floor, the maximum floor drift was in the range of 0.15439 to 0.29997, for the inter-story drift index the range was 0.00148 to 0.00453, and total drift index was in the range of 0.00168 to 0.00333. Finally, the last model is the model no.19, that was braced completely the exterior bays, 30th and the 15th floor, the maximum floor drift was in the range of 0.13765 to 0.29694, for the interstory drift index the range was 0.00148 to 0.00453, and total drift index was in the range of 0.00153 to 0.00330. All these results were outstanding with very fine drift values, sufficient enough not to cause any harm to the frame structure. Again, the results were favorable to X-bracing and Inverted V-bracing, instead of K-bracing and single diagonal-bracing. All the details drift results for each floor level can be referred in Appendices C.

Table 4.1: Drift Indices and Drift Damage Indices

		Interstory Drift Index (m)	Drift Damage Index (m)	Shear Distortion (%)
X-Bracing (B1)	**Bay A**	0.0029749	0.00516	0.516
	Bay B	0.0029749	0.00010	0.010
	Bay C	0.0029749	0.00516	0.516
Inverted V-Bracing (B2)	**Bay A**	0.0029799	0.00487	0.487
	Bay B	0.0029799	0.00010	0.010
	Bay C	0.0029799	0.00487	0.487
K-Bracing (B3)	**Bay A**	0.0090587	0.00536	0.536
	Bay B	0.0090587	0.00030	0.030
	Bay C	0.0090587	0.00536	0.536
Single Diagonal-Bracing (B4)	**Bay A**	0.0058210	0.00536	0.536
	Bay B	0.0058210	0.00020	0.020
	Bay C	0.0058210	0.00515	0.515

Table 4.2: Comparison of 4 different types of bracing in terms of maximum lateral drift

Frame	X-Bracing	Inverted V-Bracing	K-Bracing	Single Diagonal-Bracing
	(B1)	**(B2)**	**(B3)**	**(B4)**
Max. Lateral Drift	0.33974	0.33074	0.62231	0.48738
Frame	**(B1-1)**	**(B2-1)**	**(B3-1)**	**(B4-1)**
Max. Lateral Drift	0.29432	0.28997	0.59662	0.45545
Frame	**(B1-2)**	**(B2-2)**	**(B3-2)**	**(B4-2)**
Max. Lateral Drift	0.29303	0.28875	0.59526	0.45402
Frame	**(B1-3)**	**(B2-3)**	**(B3-3)**	**(B4-3)**
Max. Lateral Drift	0.30001	0.29465	0.58907	0.45267
Frame	**(B1-4)**	**(B2-4)**	**(B3-4)**	**(B4-4)**
Max. Lateral Drift	0.33303	0.32486	0.59474	0.47442
Frame	**(B1-5)**	**(B2-5)**	**(B3-5)**	**(B4-5)**
Max. Lateral Drift	0.26448	0.26229	0.56630	0.42542
Frame	**(B1-6)**	**(B2-6)**	**(B3-6)**	**(B4-6)**
Max. Lateral Drift	0.26554	0.26333	0.56653	0.42598
Frame	**(B1-7)**	**(B2-7)**	**(B3-7)**	**(B4-7)**
Max. Lateral Drift	0.26337	0.26147	0.56604	0.42481
Frame	**(B1-8)**	**(B2-8)**	**(B3-8)**	**(B4-8)**
Max. Lateral Drift	0.23828	0.23813	0.53760	0.39845
Frame	**(B1-9)**	**(B2-9)**	**(B3-9)**	**(B4-9)**
Max. Lateral Drift	0.24001	0.23945	0.53786	0.39926
Frame	**(B1-10)**	**(B2-10)**	**(B3-10)**	**(B4-10)**
Max. Lateral Drift	0.24157	0.24073	0.53811	0.40008
Frame	**(B1-11)**	**(B2-11)**	**(B3-11)**	**(B4-11)**
Max. Lateral Drift	0.27003	0.26734	0.57539	0.43304
Frame	**(B1-12)**	**(B2-12)**	**(B3-12)**	**(B4-12)**
Max. Lateral Drift	0.26783	0.26520	0.55781	0.42241
Frame	**(B1-13)**	**(B2-13)**	**(B3-13)**	**(B4-13)**
Max. Lateral Drift	0.32437	0.31709	0.58348	0.45973
Frame	**(B1-14)**	**(B2-14)**	**(B3-14)**	**(B4-14)**
Max. Lateral Drift	0.16521	0.16945	0.45579	0.28783
Frame	**(B1-15)**	**(B2-15)**	**(B3-15)**	**(B4-15)**
Max. Lateral Drift	0.16784	0.17225	0.45838	0.31513
Frame	**(B1-16)**	**(B2-16)**	**(B3-16)**	**(B4-16)**
Max. Lateral Drift	0.25939	0.25783	0.54974	0.40082
Frame	**(B1-17)**	**(B2-17)**	**(B3-17)**	**(B4-17)**
Max. Lateral Drift	0.15068	0.16538	0.30097	0.23042
Frame	**(B1-18)**	**(B2-18)**	**(B3-18)**	**(B4-18)**
Max. Lateral Drift	0.15439	0.17927	0.29997	0.23107
Frame	**(B1-19)**	**(B2-19)**	**(B3-19)**	**(B4-19)**
Max. Lateral Drift	0.13917	0.13765	0.29694	0.21982
Frame	**(B1-20)**	**(B2-20)**	**(B3-20)**	**(B4-20)**
Max. Lateral Drift	0.15528	0.16186	0.43791	0.30168

Table 4.3: Comparison of 4 different types of bracing in terms of interstory drift index

Frame	X-Bracing	Inverted V-Bracing	K-Bracing	Single Diagonal-Bracing
	(B1)	**(B2)**	**(B3)**	**(B4)**
Interstory Drift Index	0.00297	0.00298	0.00906	0.00582
Frame	**(B1-1)**	**(B2-1)**	**(B3-1)**	**(B4-1)**
Interstory Drift Index	0.00297	0.00298	0.00906	0.00582
Frame	**(B1-2)**	**(B2-2)**	**(B3-2)**	**(B4-2)**
Interstory Drift Index	0.00297	0.00298	0.00905	0.00582
Frame	**(B1-3)**	**(B2-3)**	**(B3-3)**	**(B4-3)**
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581
Frame	**(B1-4)**	**(B2-4)**	**(B3-4)**	**(B4-4)**
Interstory Drift Index	0.00092	0.00096	0.00003	0.00177
Frame	**(B1-5)**	**(B2-5)**	**(B3-5)**	**(B4-5)**
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581
Frame	**(B1-6)**	**(B2-6)**	**(B3-6)**	**(B4-6)**
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581
Frame	**(B1-7)**	**(B2-7)**	**(B3-7)**	**(B4-7)**
Interstory Drift Index	0.00905	0.00298	0.00296	0.00581
Frame	**(B1-8)**	**(B2-8)**	**(B3-8)**	**(B4-8)**
Interstory Drift Index	0.00295	0.00298	0.00904	0.00580
Frame	**(B1-9)**	**(B2-9)**	**(B3-9)**	**(B4-9)**
Interstory Drift Index	0.00295	0.00298	0.00904	0.00580
Frame	**(B1-10)**	**(B2-10)**	**(B3-10)**	**(B4-10)**
Interstory Drift Index	0.00295	0.00298	0.00904	0.00580
Frame	**(B1-11)**	**(B2-11)**	**(B3-11)**	**(B4-11)**
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581
Frame	**(B1-12)**	**(B2-12)**	**(B3-12)**	**(B4-12)**
Interstory Drift Index	0.00295	0.00298	0.00905	0.00581
Frame	**(B1-13)**	**(B2-13)**	**(B3-13)**	**(B4-13)**
Interstory Drift Index	0.00097	0.00100	0.00299	0.00180
Frame	**(B1-14)**	**(B2-14)**	**(B3-14)**	**(B4-14)**
Interstory Drift Index	0.00314	0.00323	0.00931	0.00570
Frame	**(B1-15)**	**(B2-15)**	**(B3-15)**	**(B4-15)**
Interstory Drift Index	0.00313	0.00324	0.00931	0.00644
Frame	**(B1-16)**	**(B2-16)**	**(B3-16)**	**(B4-16)**
Interstory Drift Index	0.00351	0.00358	0.00968	0.00679
Frame	**(B1-17)**	**(B2-17)**	**(B3-17)**	**(B4-17)**
Interstory Drift Index	0.00149	0.00149	0.00453	0.00283
Frame	**(B1-18)**	**(B2-18)**	**(B3-18)**	**(B4-18)**
Interstory Drift Index	0.00148	0.00149	0.00453	0.00283
Frame	**(B1-19)**	**(B2-19)**	**(B3-19)**	**(B4-19)**
Interstory Drift Index	0.00148	0.00149	0.00453	0.00283
Frame	**(B1-20)**	**(B2-20)**	**(B3-20)**	**(B4-20)**
Interstory Drift Index	0.00286	0.00283	0.00893	0.00572

Table 4.4: Comparison of 4 different types of bracing in terms of total drift index

Frame	X-Bracing	Inverted V-Bracing	K-Bracing	Single Diagonal-Bracing
	(B1)	**(B2)**	**(B3)**	**(B4)**
Total Drift Index	0.00377	0.00367	0.00691	0.00542
Frame	**(B1-1)**	**(B2-1)**	**(B3-1)**	**(B4-1)**
Total Drift Index	0.00327	0.00322	0.00663	0.00506
Frame	**(B1-2)**	**(B2-2)**	**(B3-2)**	**(B4-2)**
Total Drift Index	0.00326	0.00321	0.00661	0.00504
Frame	**(B1-3)**	**(B2-3)**	**(B3-3)**	**(B4-3)**
Total Drift Index	0.00333	0.00327	0.00655	0.00503
Frame	**(B1-4)**	**(B2-4)**	**(B3-4)**	**(B4-4)**
Total Drift Index	0.00370	0.00361	0.00661	0.00527
Frame	**(B1-5)**	**(B2-5)**	**(B3-5)**	**(B4-5)**
Total Drift Index	0.00294	0.00291	0.00629	0.00473
Frame	**(B1-6)**	**(B2-6)**	**(B3-6)**	**(B4-6)**
Total Drift Index	0.00295	0.00293	0.00629	0.00473
Frame	**(B1-7)**	**(B2-7)**	**(B3-7)**	**(B4-7)**
Total Drift Index	0.00293	0.00291	0.00629	0.00472
Frame	**(B1-8)**	**(B2-8)**	**(B3-8)**	**(B4-8)**
Total Drift Index	0.00265	0.00265	0.00597	0.00443
Frame	**(B1-9)**	**(B2-9)**	**(B3-9)**	**(B4-9)**
Total Drift Index	0.00267	0.00266	0.00598	0.00444
Frame	**(B1-10)**	**(B2-10)**	**(B3-10)**	**(B4-10)**
Total Drift Index	0.00268	0.00267	0.00598	0.00445
Frame	**(B1-11)**	**(B2-11)**	**(B3-11)**	**(B4-11)**
Total Drift Index	0.00300	0.00297	0.00639	0.00481
Frame	**(B1-12)**	**(B2-12)**	**(B3-12)**	**(B4-12)**
Total Drift Index	0.00298	0.00295	0.00620	0.00469
Frame	**(B1-13)**	**(B2-13)**	**(B3-13)**	**(B4-13)**
Total Drift Index	0.00360	0.00352	0.00648	0.00511
Frame	**(B1-14)**	**(B2-14)**	**(B3-14)**	**(B4-14)**
Total Drift Index	0.00184	0.00188	0.00506	0.00320
Frame	**(B1-15)**	**(B2-15)**	**(B3-15)**	**(B4-15)**
Total Drift Index	0.00186	0.00191	0.00509	0.00350
Frame	**(B1-16)**	**(B2-16)**	**(B3-16)**	**(B4-16)**
Total Drift Index	0.00288	0.00286	0.00611	0.00445
Frame	**(B1-17)**	**(B2-17)**	**(B3-17)**	**(B4-17)**
Total Drift Index	0.00167	0.00184	0.00334	0.00256
Frame	**(B1-18)**	**(B2-18)**	**(B3-18)**	**(B4-18)**
Total Drift Index	0.00172	0.00168	0.00333	0.00257
Frame	**(B1-19)**	**(B2-19)**	**(B3-19)**	**(B4-19)**
Total Drift Index	0.00155	0.00153	0.00330	0.00244
Frame	**(B1-20)**	**(B2-20)**	**(B3-20)**	**(B4-20)**
Total Drift Index	0.00173	0.00180	0.00487	0.00335

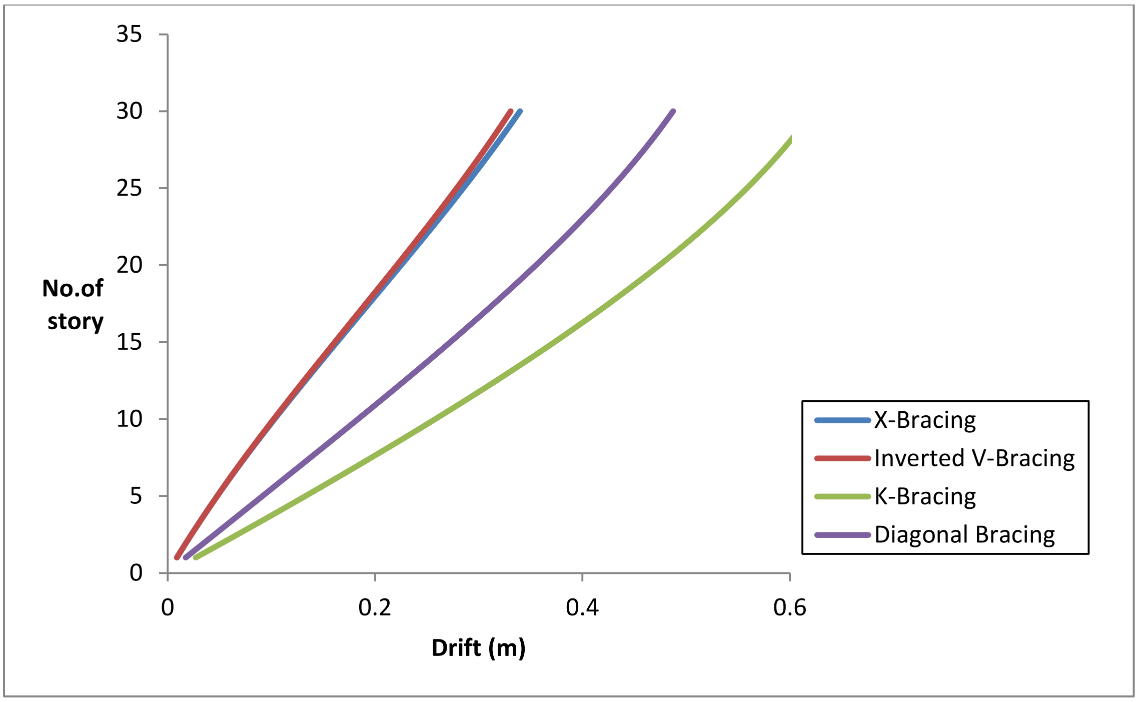


Figure 4.1: Comparison of 4 different types of bracing: Braced along the center bay only for model B1, B2, B3, and B4

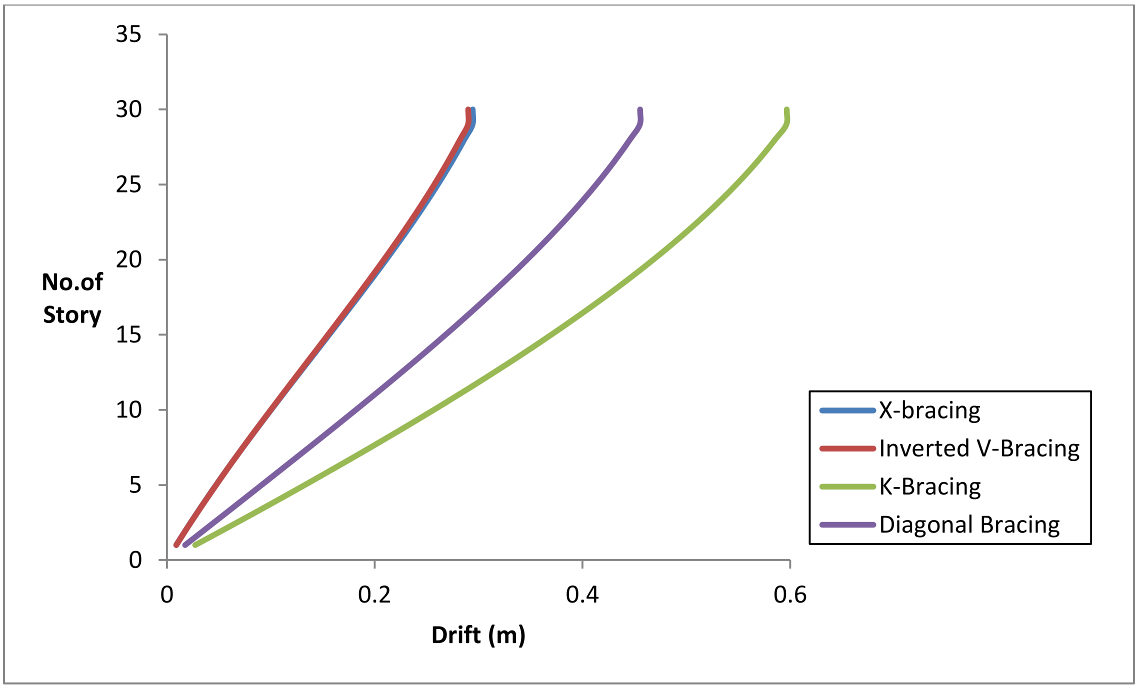


Figure 4.2: Comparison of 4 different types of bracing: Braced along the center bay and at the top floor for model B1-1, B2-1, B3-1, and B4-1

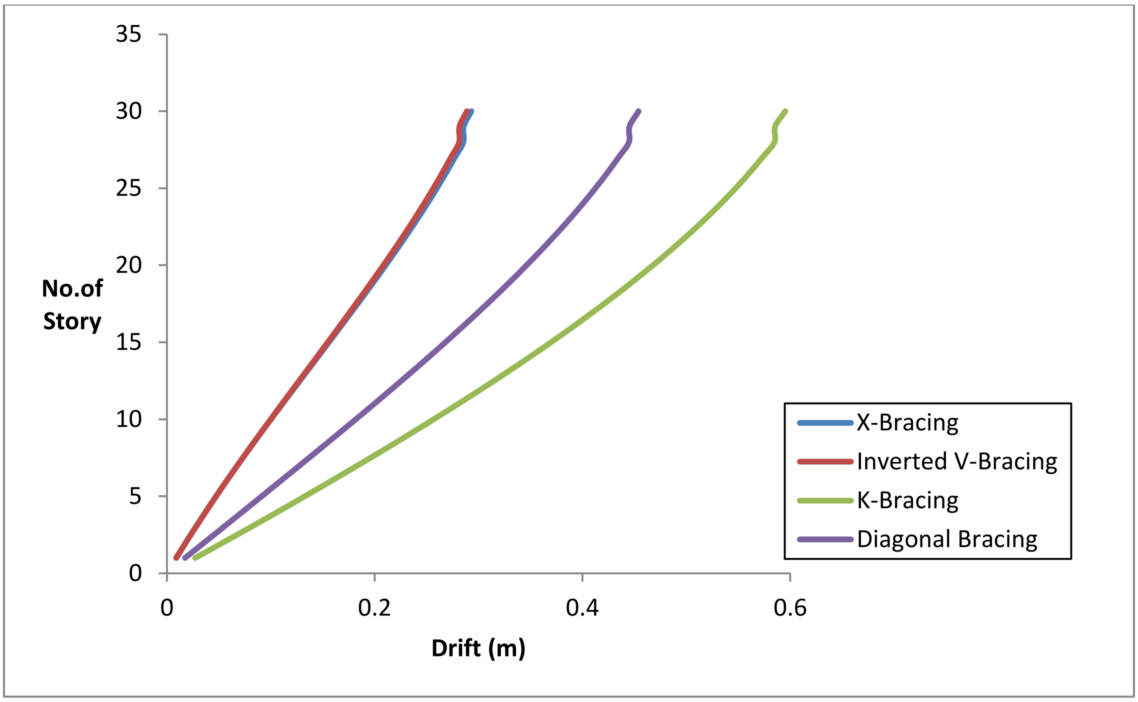


Figure 4.3: Comparison of 4 different types of bracing: Braced along the center bay and at the 2nd top floor for model B1-2, B2-2, B3-2, and B4-2

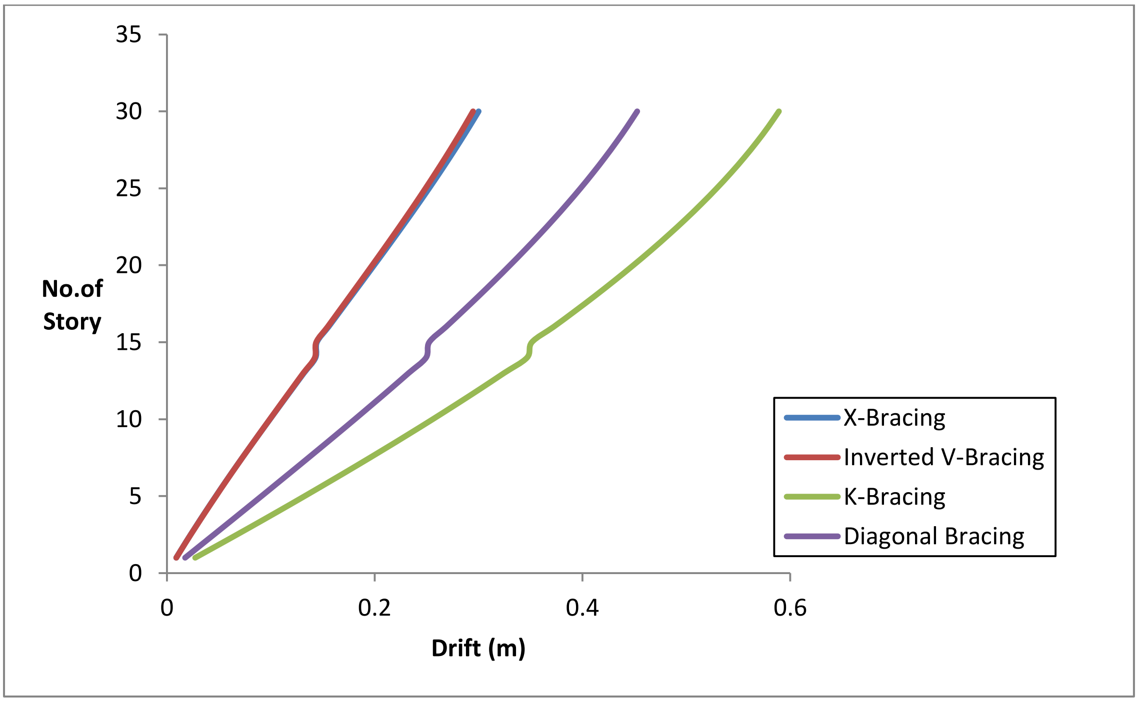


Figure 4.4: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th floor for model B1-3, B2-3, B3-3, and B4-3

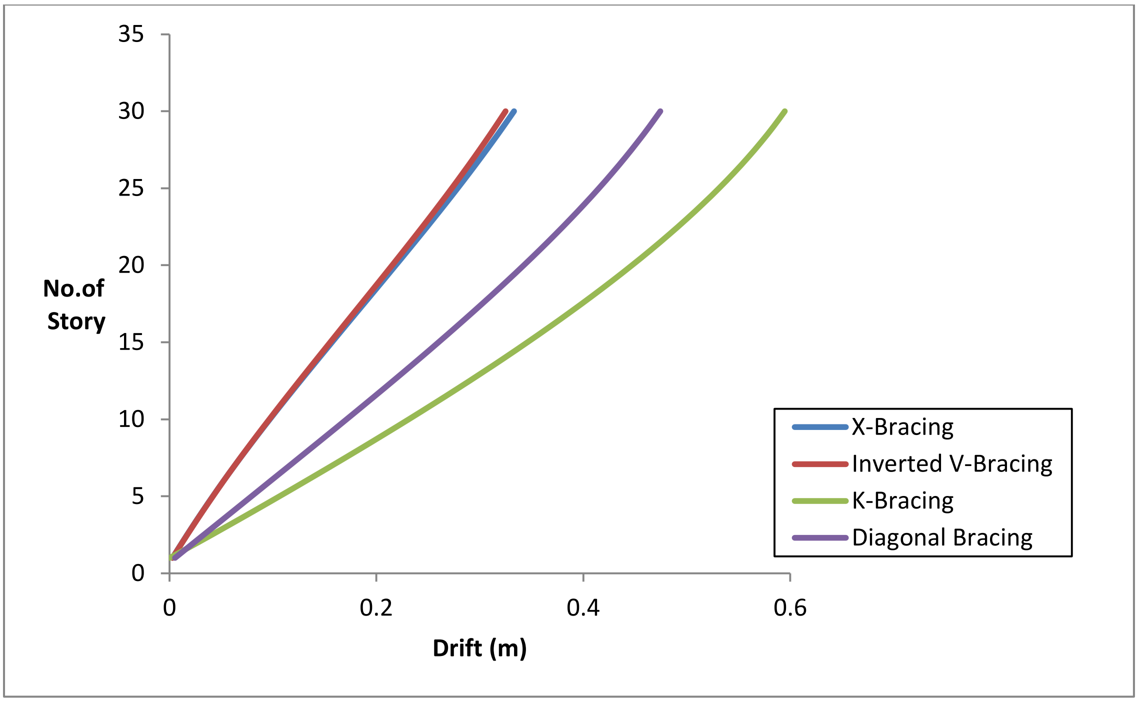


Figure 4.5: Comparison of 4 different types of bracing: Braced along the center bay and at the 1st floor for model B1-4, B2-4, B3-4, and B4-4

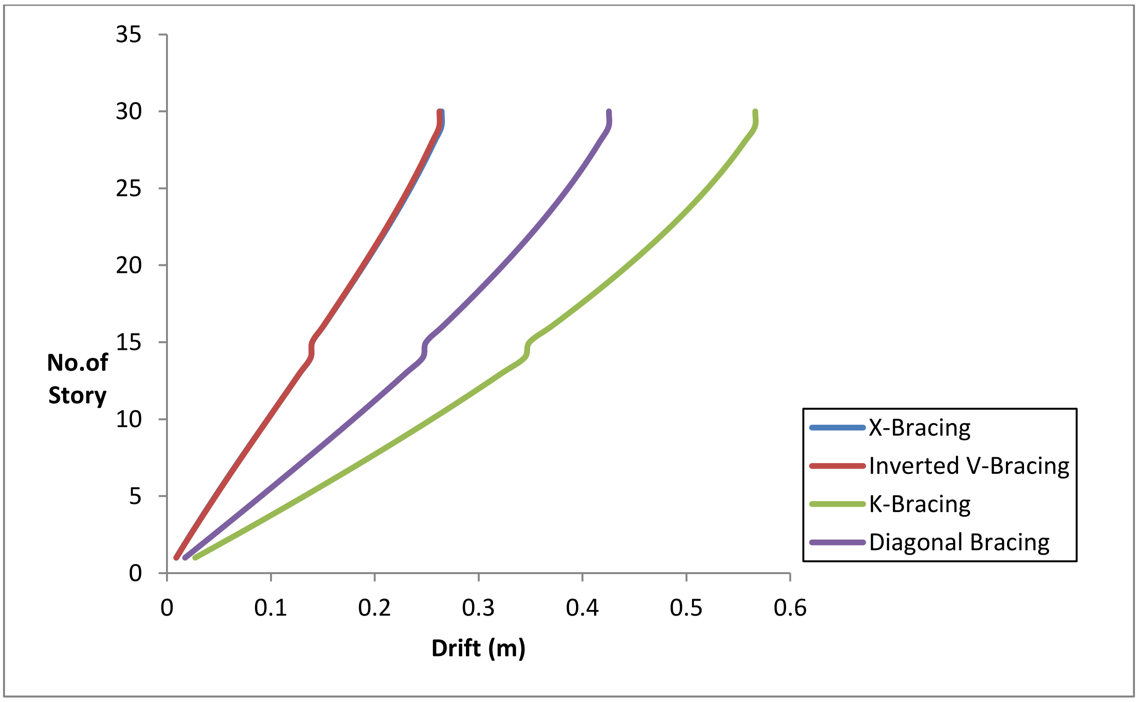


Figure 4.6: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 30th floors for model B1-5, B2-5, B3-5, and B4-5

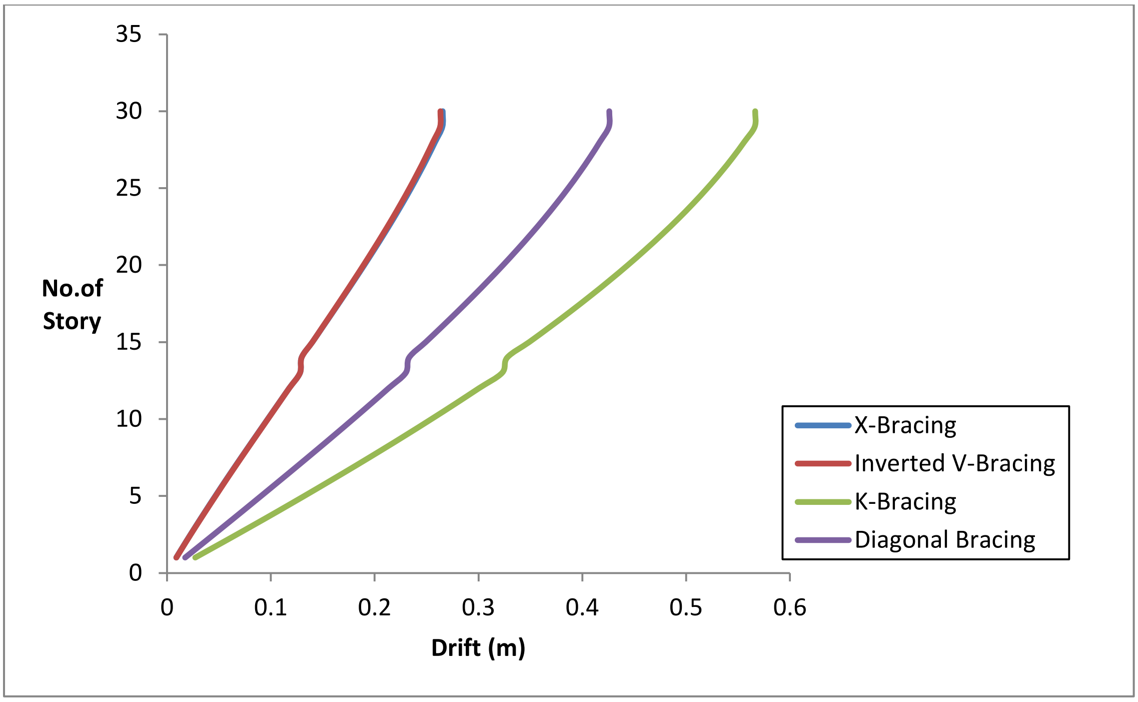


Figure 4.7: Comparison of 4 different types of bracing: Braced along the center bay and at the 14th and 30th floors for model B1-6, B2-6, B3-6, and B4-6

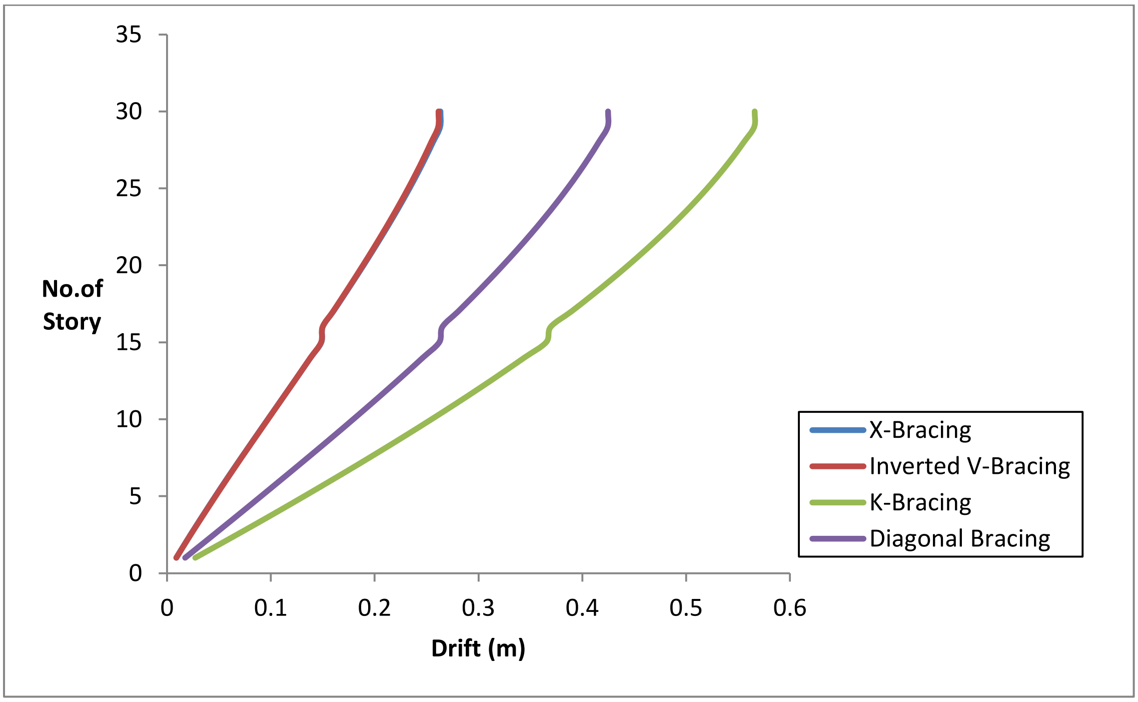


Figure 4.8: Comparison of 4 different types of bracing: Braced along the center bay and at the 16th and 30th floors for model B1-7, B2-7, B3-7, and B4-7

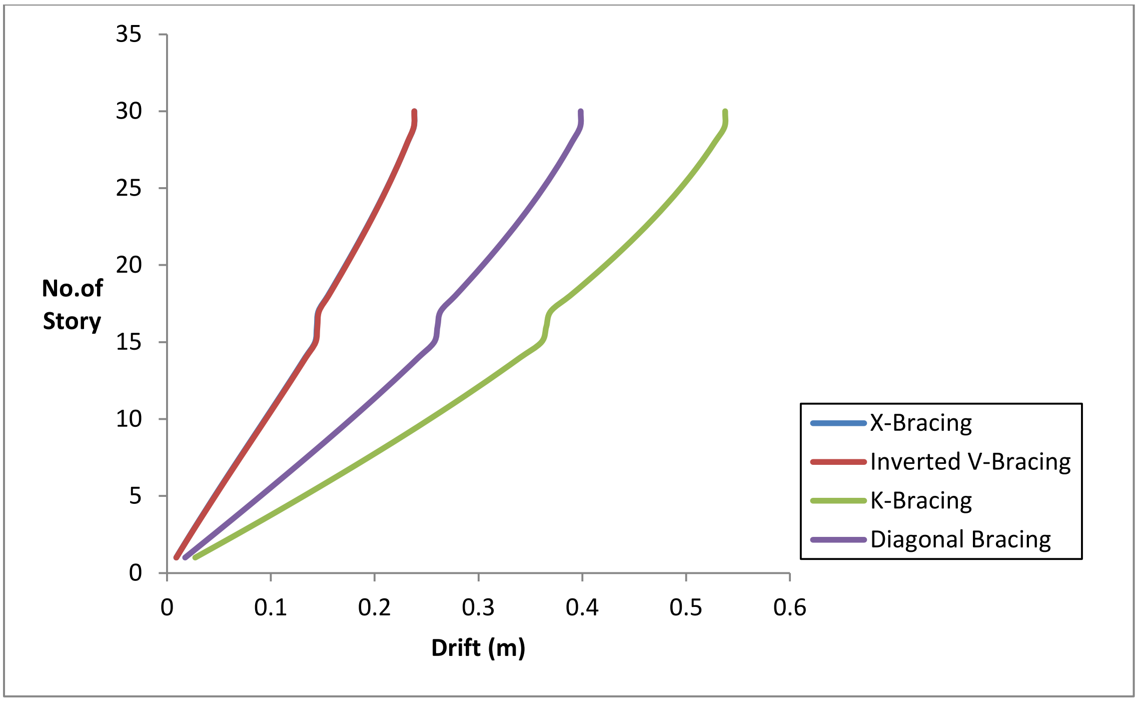


Figure 4.9: Comparison of 4 different types of bracing: Braced along the center bay and at the 16 &17th and 30th floors for model B1-8, B2-8, B3-8, and B4-8

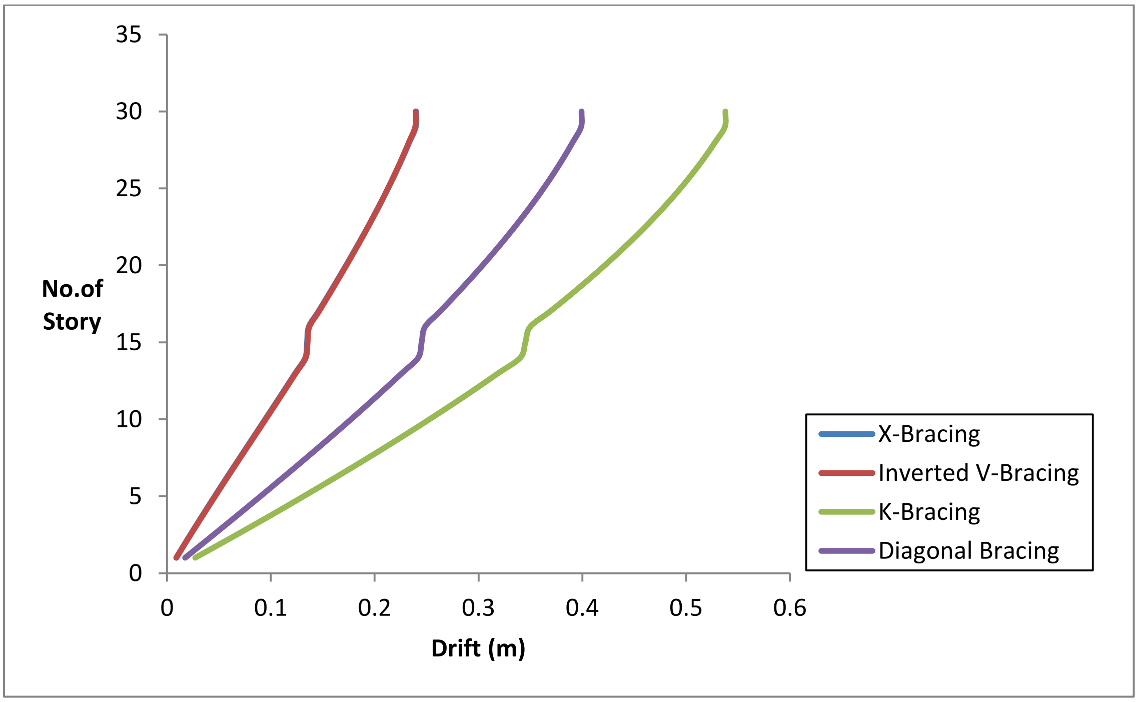


Figure 4.10: Comparison of 4 different types of bracing: Braced along the center bay and at the 15 &16th and 30th floors for model B1-9, B2-9, B3-9, and B4-9

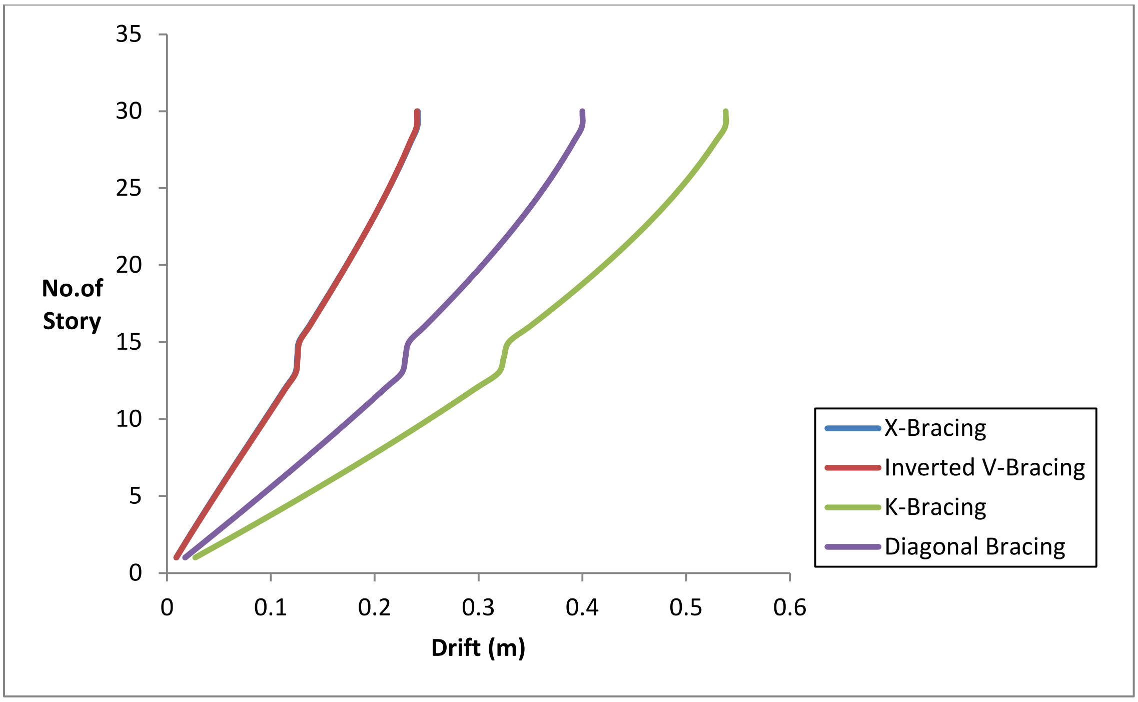


Figure 4.11: Comparison of 4 different types of bracing: Braced along the center bay and at the 14 &15th and 30th floors for model B1-10, B2-10, B3-10, and B4-10

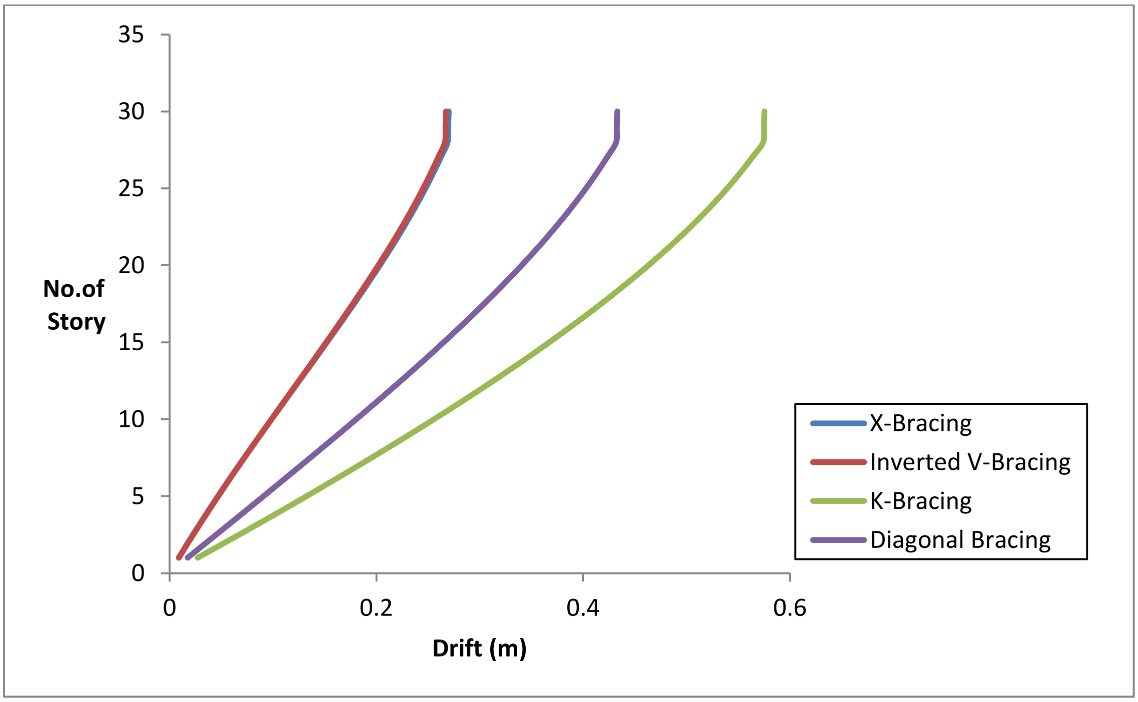


Figure 4.12: Comparison of 4 different types of bracing: Braced along the center bay and at the 29th and 30th floors for model B1-11, B2-11, B3-11, and B4-11

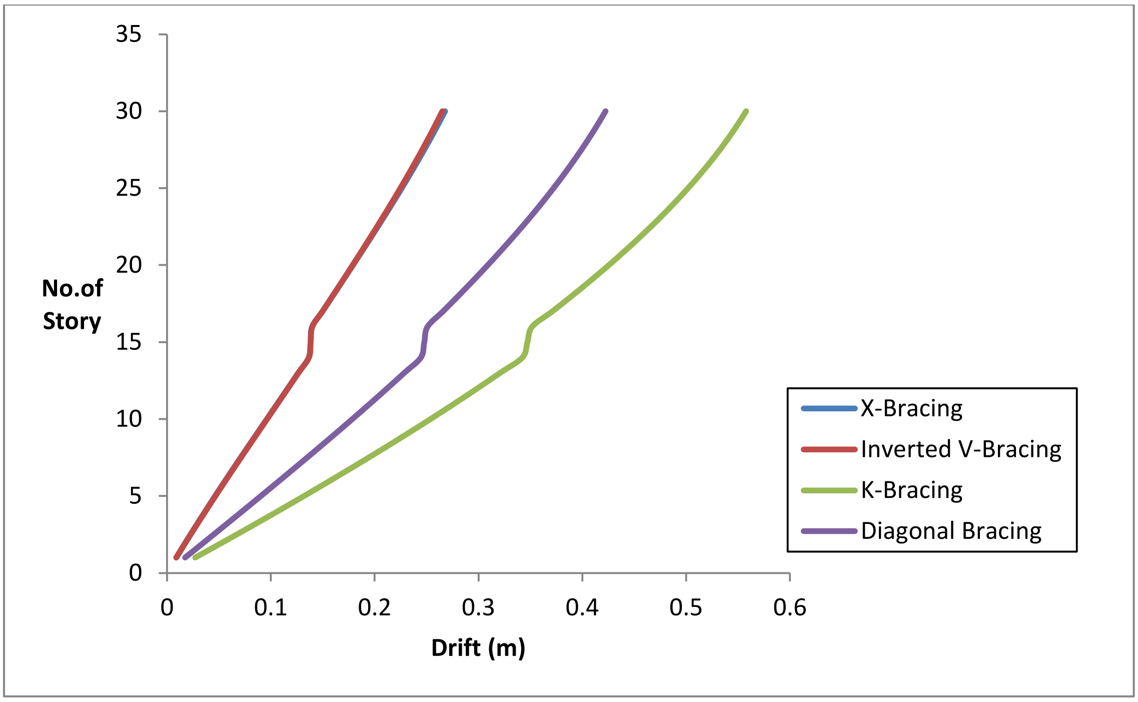


Figure 4.13: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 16th floors for model B1-12, B2-12, B3-12, and B4-12

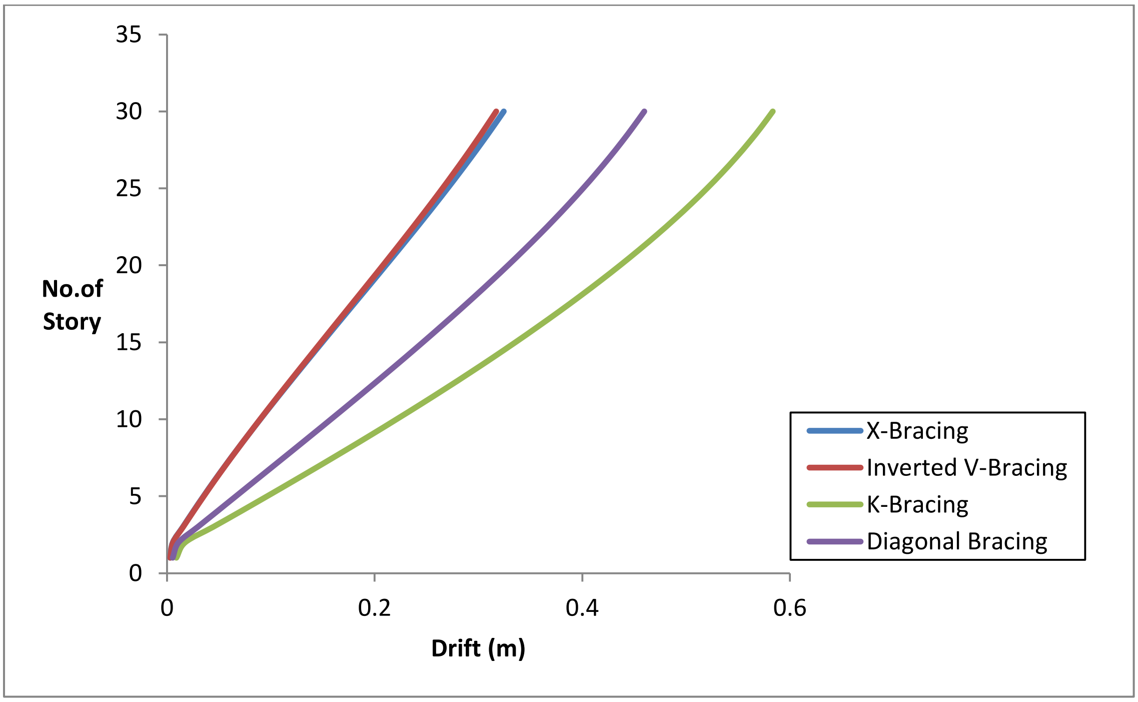


Figure 4.14: Comparison of 4 different types of bracing: Braced along the center bay and at the 1st and 2nd floors for model B1-13, B2-13, B3-13, and B4-13

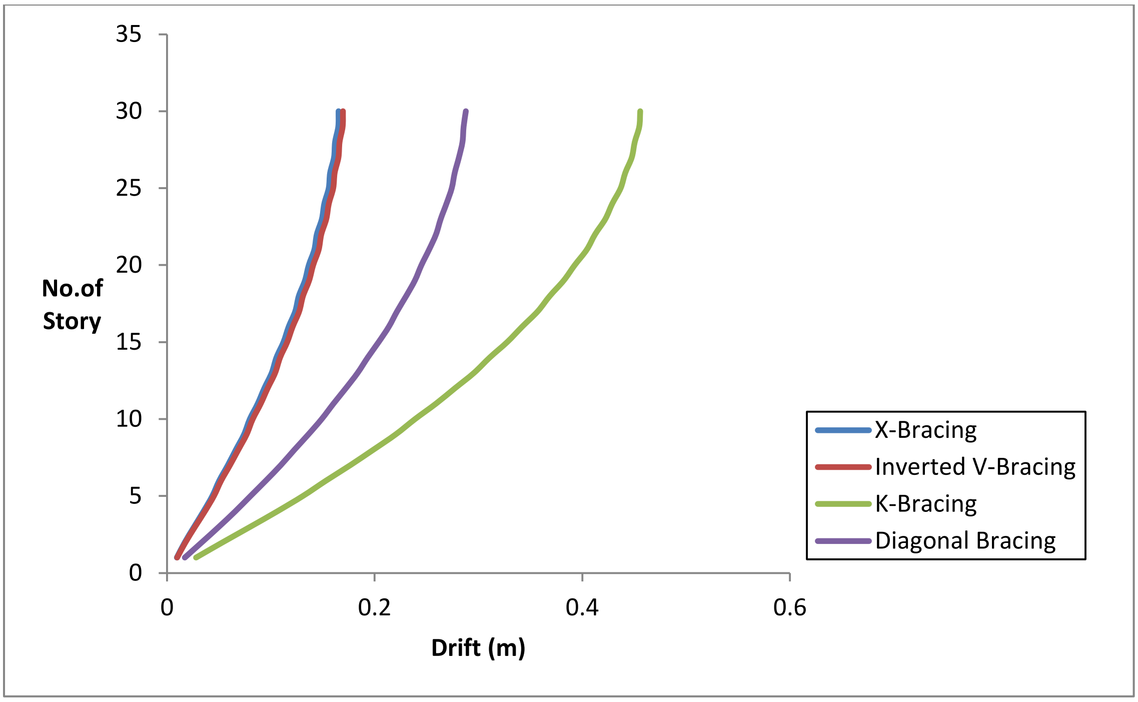


Figure 4.15: Comparison of 4 different types of bracing schemes spread over buildings width (zigzag) for model B1-14, B2-14, B3-14, and B4-14

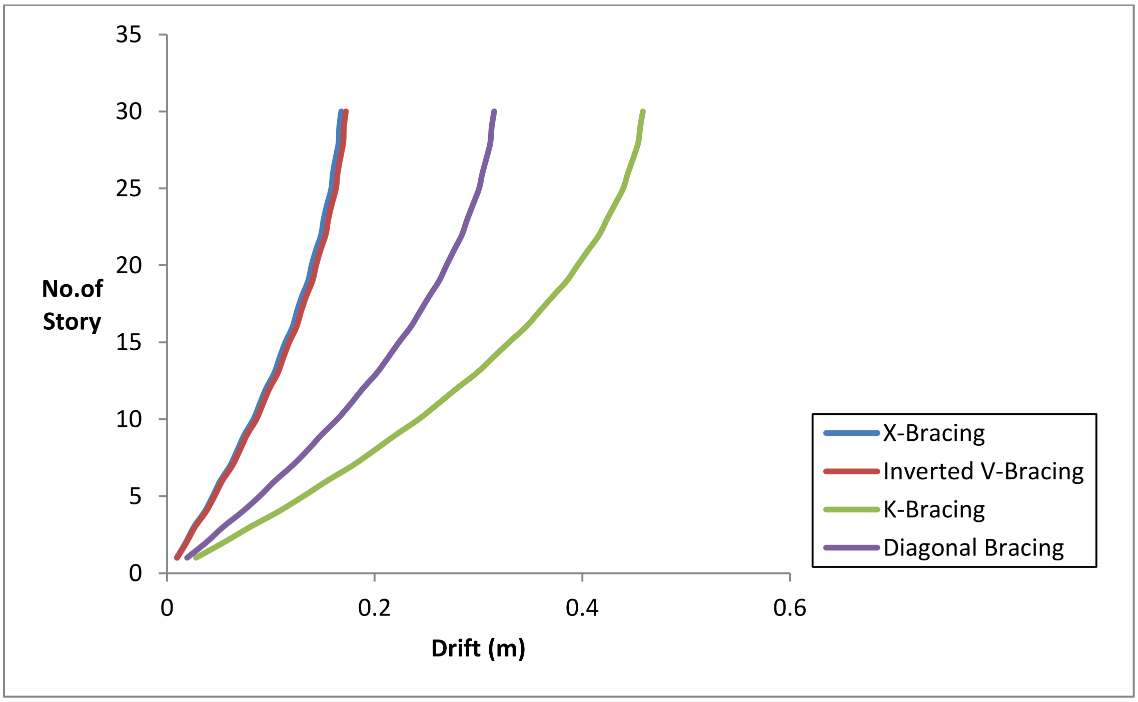


Figure 4.16: Comparison of 4 different types of bracing schemes spread over buildings width (diagonal) for model B1-15, B2-15, B3-15, and B4-15

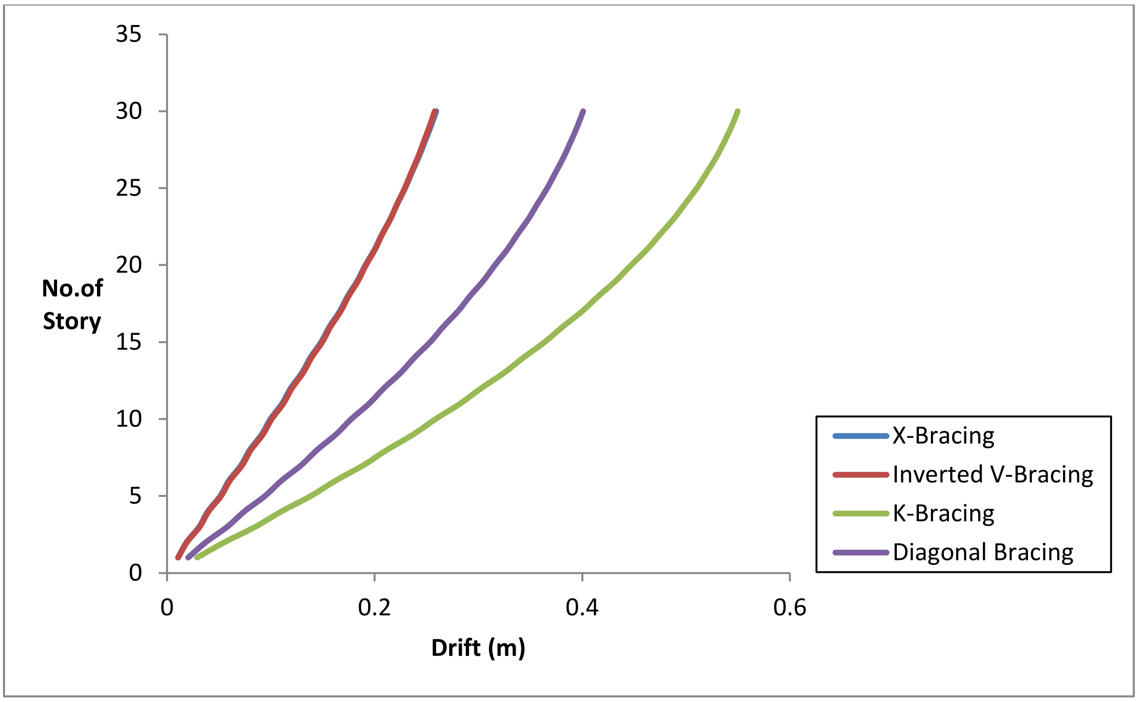


Figure 4.17: Comparison of 4 different types of bracing schemes spread over the first and third bay for model B1-16, B2-16, B3-16, and B4-16

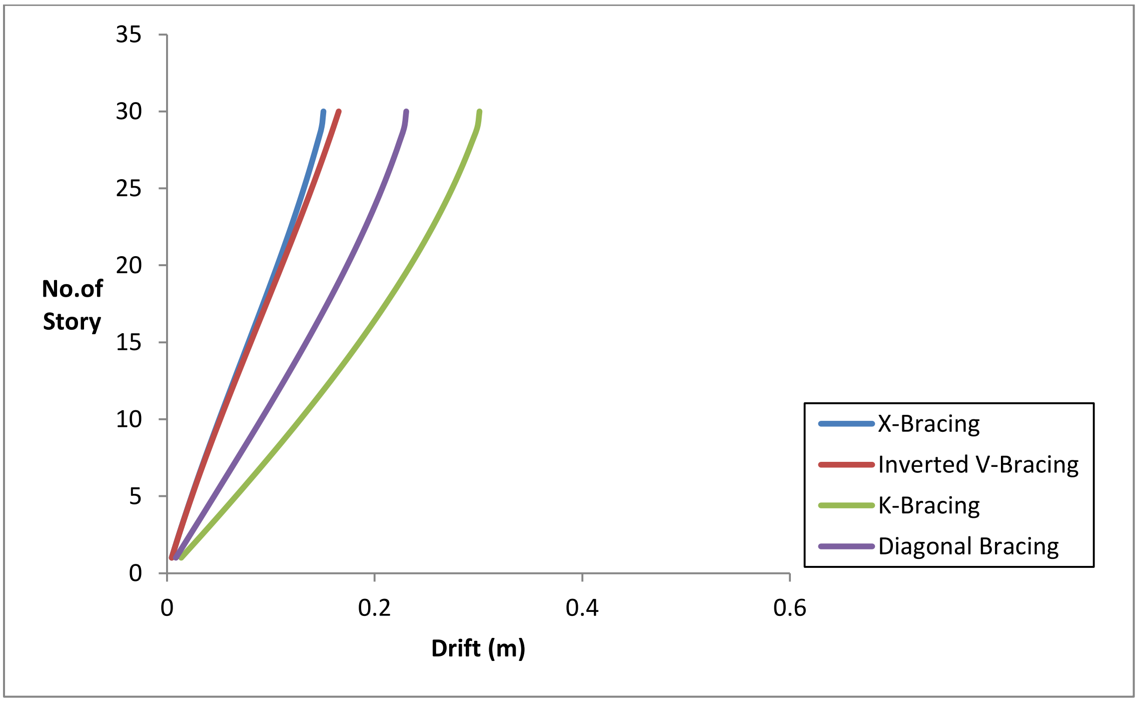


Figure 4.18: Comparison of 4 different types of bracing: Braced completely the outer bays and the 30th floor for model B1-17, B2-17, B3-17, and B4-17

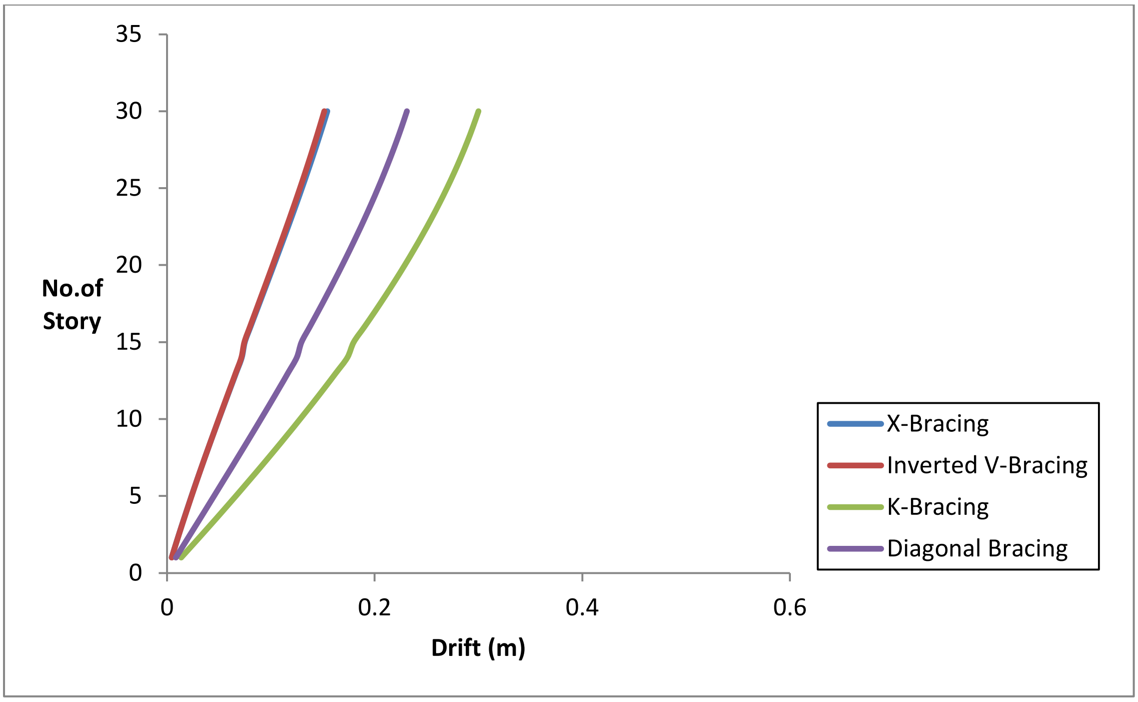


Figure 4.19: Comparison of 4 different types of bracing: Braced completely the outer bays and the 15th floor for model B1-18, B2-18, B3-18, and B4-18

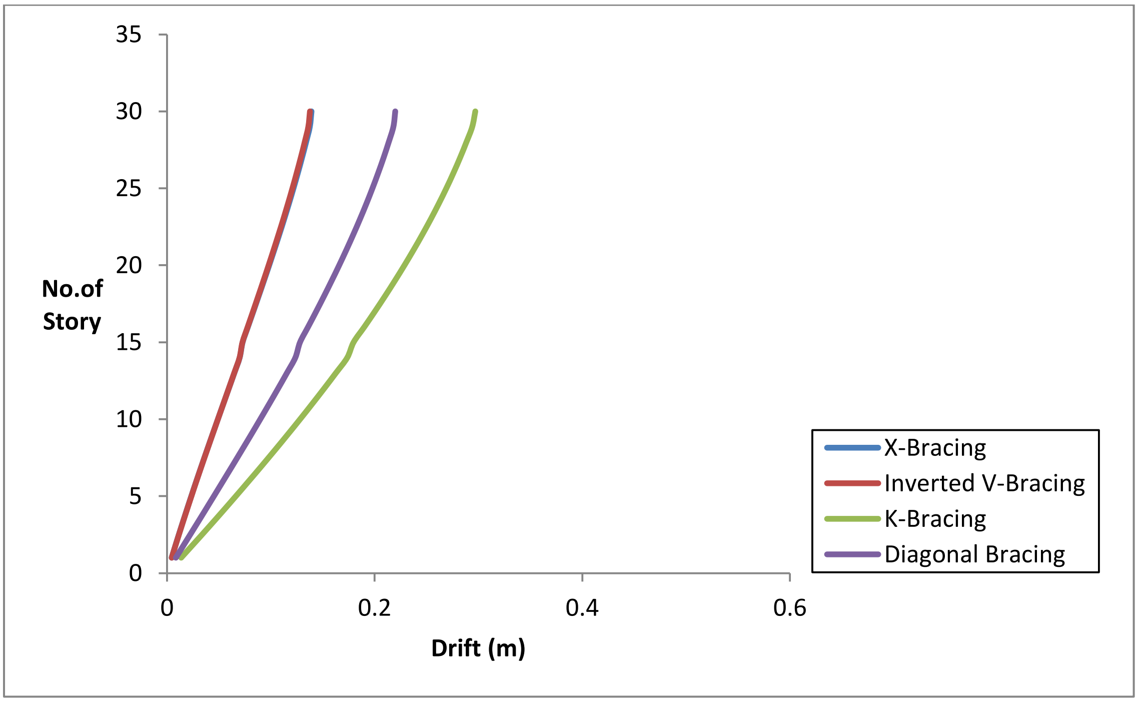


Figure 4.20: Comparison of 4 different types of bracing: Braced completely the outer bays and the 15 & 30th floors for model B1-19, B2-19, B3-19, and B4-19

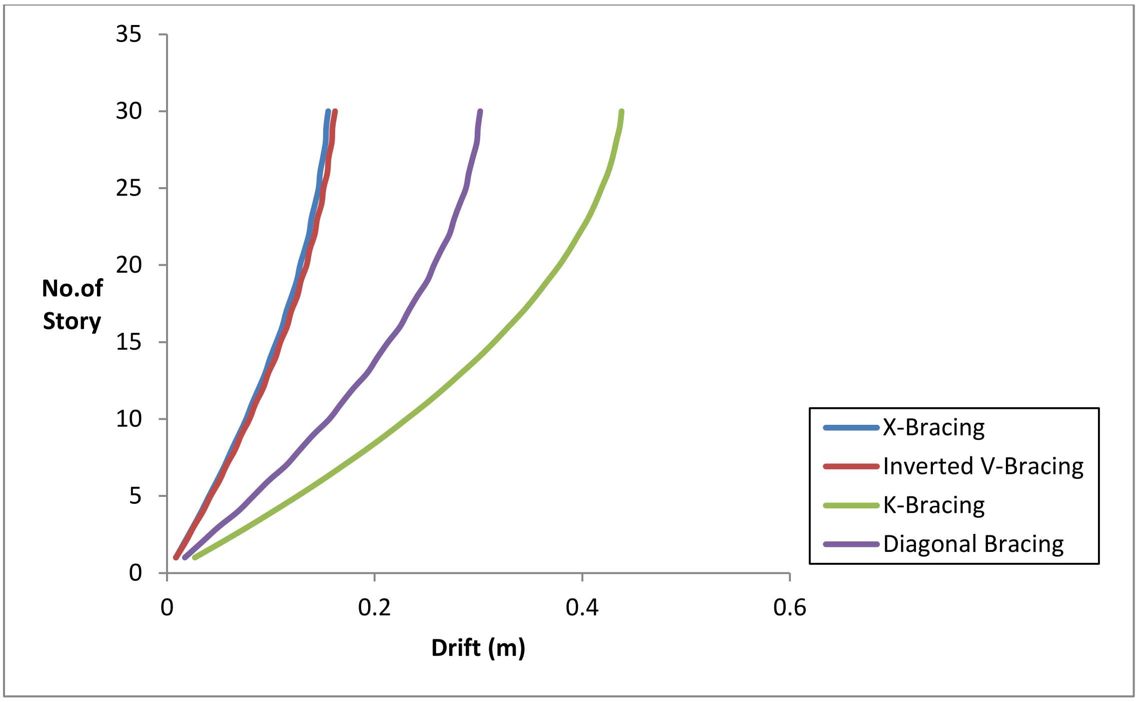


Figure 4.21: Comparison of 4 different types of bracing schemes spread across the buildings width for model B1-20, B2-20, B3-20, and B4-20

Basically, braces buckles in compression and yields in tension. The initial compressive buckling capacity is smaller than the tensile yield force. Later on, in subsequent buckling cycles, the buckling capacity is further reduced by the prior inelastic excursion (Rafael Sabelli, Charles W. Roeder, and Jerome F. Hajjar, 2013). The general idea of any bracing system is that in any plane of bracing, the compression diagonal braces should balance the tension diagonal braces at each bracing level so that the lateral resistance in tension and compression is similar in both directions. (T.RangaRajan, 2014). Although each bracing type has its pros and cons, there is certainly a type/s that prevails over the others for a majority of the scenarios. Concerning this study, it is worth mentioning that X-bracing and Inverted V-bracing stand up to be a most efficient bracing type in resisting lateral drift as compared to K-bracing and single diagonal bracing in all cases.

This was probably due to characteristics of X-bracing that has bracing members in tension (assuming that the compression braces do not contribute stiffness or strength) and under the lateral loading it developed ductility when these were sized to yield before the columns or beams fail (T.RangaRajan, 2014). X-Bracing also introduces extra restraint into the frame that can cater the wind loading. Moreover, it tends to increase brace rotation requirements in flexural buckling because of the increased number of connections and the corresponding reduced of buckling length (Rafael Sabelli, Charles W. Roeder, and Jerome F. Hajjar, 2013).

Inverted V-bracing deals with both tensile and compression at same time and since that tensile member has plastic hardening effect, the bearing capacity of structure system did not reduce before the braces broken under the wind actions (Qin Xuedong, Liu Chungang, Zhang Wenyuan, 2014). According to Nicholas Mcewen, 2011 the important criteria of the Inverted V-bracing system is that it likely requires less material weight than X-bracing and it allows for much greater openings in each bay (architectural insight) and although heavier than single-diagonal bracing it performs much better at reducing drift, which makes it optimal bracing type in out of all other bracing type in most cases.

Under substantial wind forces, K-bracing imposes the out-of-balance force between the tension brace and buckled compression brace, not on the horizontal beam but on the column when the braces reach their capacity. The large unbalanced forces and bending moments occurs in K-bracing due to the fact that buckling load is smaller than the tensile yield resistance and it decreases with increasing damage, and certainly the bending moment increases as the compressive resistance deteriorates (Rafael Sabelli, Charles W. Roeder, and Jerome F. Hajjar, 2013). K-bracing has been engaging with the potential for collapse of the columns when the compression brace buckles as the bending moments and inelastic deformation will occur in the column or simply due to irregularity in shape of the structure (Doshi and Jagadish, 2013). Owing to force imbalance between the tension and compression braces in K-bracing, the plastic hinge formation does not occur in the column, which has affected the behavior of the braces by deforming the column to increase contraction and limit elongation of the brace (Taichiro Okazaki, Dimitrios G. Lignos, Tsuyoshi Hikino, and Koichi Kajiwara, 2013). As a result, K-bracing is not permitted in high-rise structure.

Under the action of wind loading, single diagonal bracing was much weaker and flexible in the direction causing compression in the braces, leading to the possibility of soft-story formation, which is definitely not satisfactory (T.RangaRajan, 2014). Diagonal bracing must have both tensile and compressive pairs in order to attain the balance so that the lateral resistance in tension and compression is identical in both directions (Rafael Sabelli, Charles W. Roeder, and Jerome F. Hajjar, 2013). The drift attained by the diagonal bracing is quite large due to the fact that it takes the full tension and compression loads at a time using its single member, and thus provision of larger bracing size is a must to cater the lateral loading, as per explained by Nicholas Mcewen, 2011. Similarly, when the single diagonal bracing is used, there is a marked tendency towards the accumulation of inelastic drift in the direction corresponding to brace compression (Khatib et al.1988).

4.3 ANALYSIS ON THE EFFECT OF DIFFERENT BRACING LAYOUTS/CONFIGURATIONS ON LATERAL DRIFT OF STEEL FRAME

Apart from bracing center bay only, bracing exterior floor/floors does increase the stiffness of the structure in terms of reduction in lateral drift. Throughout the study, the maximum drift difference out of all floors of the structure as a percentage of the drift for the case of bracing the center bay only has been analyzed and used as an indicator to determine the best means of limiting the lateral drift in the structure. The drift difference was calculated by means of taking the drift difference between the bracing the center bay (as a control parameter) with other associated layouts of each model and then divided it by the corresponding drift for the bracing the center bay only condition. Generally, in all the 84 models, it is interesting to note that lateral drift was small towards the bottom of the structure, but increases steadily with the buildings height. As shown in Table 4.5 and Table 4.6, at the location or floor/ floors of applied bracing, there is no significant increase of lateral drift can be notified due to bracing that ignores the deflection from taking place.

As the comparison is made between the first seven models of each bracing type, it has to be seen that bracing multiple floors did provide a better resistance to lateral drift, but it all depends on the location the bracings were applied. For instance, bracing the top floor: 30th floor (models no.1) could reduce the floor drift and thus increase the maximum drift difference as compared to bracing center bay only by 13.37%, 12.33%, 4.128%, and 6.551% for X-bracing (B1-1), Inverted V-bracing (B2-1), K-bracing (B3-1), and single diagonal bracing (B4-1) respectively. Meanwhile, in models no.2 (B1-2, B2-2, B3-2, and B4-2) the bracing was applied at the second top floor (29th floor) and the results gained were good as some minor floor drift difference and increase in percentage of drift difference could be notified as compared to bracing to center bay only or bracing at top floor by the percentage of drift difference of 13.75%, 12.70%, 4.347% and 6.845% for X-bracing (B1-2), Inverted V-bracing (B2-2), K-bracing (B3-2), and single diagonal bracing (B4-2) respectively. However, if the bracing was located at the middle of the frame: 15th floor (models no.3), an increase in maximum floor drift was obtained, thus the maximum drift difference got reduced compared to the two previous models. The maximum drift difference as compared with the case of bracing the center bay only was 11.69%, 10.91%, 5.341%, and 7.122% for X-bracing (B1-3), Inverted V-bracing (B2-3), K-bracing (B3-3), and single diagonal bracing (B4-3) respectively. Furthermore, the next comparison of the models no.4, which was braced at the first floor were analyzed and it was found that the maximum floor drift showed a tremendous increase although the maximum drift difference was found higher such that 68.79%, 67.71%, 99.70%, and 69.63% for X-bracing (B1-4), Inverted V-bracing (B2-4), K-bracing (B3-4), and single diagonal bracing (B4-4) respectively. Thereafter, the analysis was made by bracing more than one floor, as in model no.5, which has been braced at the 15th and 30th floors. The results were found that maximum floor drift were smaller and hence maximum drift difference with the case of bracing the center bay only was 22.15%, 20.17%, 9.0%, and 12.71% for X-bracing (B1-5), Inverted V-bracing (B2-5), K-bracing (B3-5), and single diagonal bracing (B4-5) respectively. The next analysis was about model no.6, which has been braced on the 14th and 30th floors. It however shows a slight increase in maximum floor drift and slight decline in maximum drift difference as compared to model no.5. The maximum drift difference for this case was 21.84%, 20.38%, 8.963%, and 12.60% for X-bracing (B1-6), Inverted V-bracing (B2-6), K-bracing (B3-6), and single diagonal bracing (B4-6) respectively. In the models no.7, which was braced at 16th and 30th floors, reduction in floor drift and increase in drift difference was notified as compared to model no.5 and no.6. The maximum drift difference as regard to the case the center bay only was found to be

22.48%, 20.94%, 9.042%, and 12.84% for X-bracing (B1-7), Inverted V-bracing (B2-7), K-bracing (B3-7), and single diagonal bracing (B4-7) respectively. As shown in Graph 1, throughout the first seven models, it was worth noting that bracing the bottom floor (model no.4) of the frame structure is not beneficial at all (although the maximum drift difference was higher), as it contribute to increase in floor drift and it is vice versa if the bracing was applied at top floor (model no.1 & 2). Nevertheless, bracing multiple top floors as in case of model no.5 and 6, has been found to minimal the floor drift and thus increase the drift difference as compared to bracing the center bay only. The order or sequence of increase in frame stiffness by means of reduction in floor drift as can be seen in Figure 4.22 was model no.4, model no.3, model no.1, model no.2, model no.6, model no.5, and model no.7.

On the other hand, the comparison was made with regards to model no.8 until model no.13. In models no.8 (B1-8, B2-8, B3-8, and B4-8) the bracing were applied at the 30th, 16th and 17th floors of the frame. The results found was encouraging as the maximum floor drift is lower and the maximum drift difference is higher such that 29.86%, 28.0%, 13.61%, and 18.25% for X-bracing (B1-8), Inverted V-bracing (B2-8), K-bracing (B3-8), and single diagonal bracing (B4-8) respectively. Subsequently, in models no.9 (B1-9, B2-9, B3-9, and B4-9) which the bracing positioned at the 30th, 15th, and 16th floors, the results gained were satisfactory, however there is slight increase in floor drift and slight decrease in maximum drift difference as compared to model no.8 that was 29.36%, 27.60%, 13.57%, and 18.08% for X-bracing (B1-9), Inverted V-bracing (B2-9), K-bracing (B3-9), and single diagonal bracing (B4-9) respectively. In model no.10, the models were configured by means of applying bracing at 30th, 14th and 15th floors. The maximum floor drift was found higher and the maximum drift difference was found lower compared to model no.8 and 9. The maximum drift difference for this case was 28.90%, 27.22%, 13.53%, and 17.91% for X-bracing (B1-10), Inverted V-bracing (B2-10), K-bracing (B3-10), and single diagonal bracing (B4-10) respectively. Meanwhile, in models no.11 the bracing was applied at the top two floors: 30th and 29th floors. However, it was found that the results obtained are not very encouraging as the maximum floor drift obtained was higher and the maximum drift difference was lower that was about 20.52%, 19.17%, 7.54%, and 11.15% for X-bracing (B1-11), Inverted V-bracing (B2-11), K-bracing (B3-11), and single diagonal bracing (B4-11) respectively. This was probably due to increase weight of steel that finds difficulty to counteract the wind forces. Besides that, in model no.12 at which the bracing was applied at the 15^{th} and 16^{th} floors, the maximum floor drift was lesser and maximum drift difference was higher as compared to previous model no.11. The maximum drift difference as compared to case of bracing center bay only was 21.17%, 19.82%, 10.83%, and 13.38% % for X-bracing (B1-12), Inverted V-bracing (B2-12), K-bracing (B3-12), and single diagonal bracing (B4-12) respectively. The next case is about model no.13 which has been configured by providing bracing at 1^{st} and 2^{nd} bottom floors of the frame, and it was found that the results were in similar pattern as model no.4. The maximum floor drift, for instance were higher although it did showed insignificance higher maximum drift difference that was about 69.64%, 68.41%, 67.64%, and 69.09% for X-bracing (B1-13), Inverted V-bracing (B2-13), K-bracing (B3-13), and single diagonal bracing (B4-13) respectively. In general by referring to Graph 2, it is interesting to note that bracing the top floors in a right way as in models no.8 and 9 could increase the maximum difference to a greater extent and the case is vice versa if bracing was provided at bottom floors as in case of models no.13. Moreover, it is redundant to provide double bracing at top two floors as in case of models no.11, which has not shown a significance result in terms of limiting the drift. Thus, the order of increase in frame stiffness by means of reduction in floor drift as can be seen in Figure 4.23 was model no.13, model no.11, model no.12, model no.10, model no.9, and model no.8.

Thereafter, the model no.14, no.15, no.16, and no.20 were brought to analysis in terms of both maximum floor drift and maximum drift difference for the case of bracing center bay only. Here in model no.14 (B1-14, B2-14, B3-14, and B4-14) which the bracing was configured in a zigzag pattern, it was found that there was a very minimal maximum floor drift and the maximum drift difference was tremendously higher, that was about 51.37%, 48.77%, 26.76%, and 40.94% for X-bracing (B1-14), Inverted V-bracing (B2-14), K-bracing (B3-14), and single diagonal bracing (B4-14) respectively. Similarly, in model no.15 (B1-15, B2-15, B3-15, and B4-15), the bracing was orientated in a perpendicular pattern along the bay such that the maximum floor drift was higher and the maximum drift difference of about 50.60%, 47.92%, 26.34%, and 35.34% for X-bracing (B1-13), Inverted V-bracing (B2-13), K-bracing (B3-13), and single diagonal bracing (B4-13) respectively, all of which comparatively smaller compared to previous model of no.14. In model no.16 (B1-16, B2-16, B3-16, and B4-16), the bracing was located at the first and third bay by means of one free after the other. It was found that the maximum floor drift was not sufficiently good as the drift was higher and subsequently the maximum drift difference was lower of about 23.65%, 22.05%, 11.66%, and 17.76% for X-bracing (B1-16), Inverted V-bracing (B2-16), K-bracing (B3-16), and single diagonal bracing (B4-16) respectively. Furthermore, in model no.20 (B1-20, B2-10, B3-20, and B4-20) the bracing was used across all the three bays along the building height. It was found that maximum floor drift was significantly lower and thus the maximum drift difference was potentially higher of about 54.29%, 51.06%, 29.63%, and 38.10% for X-bracing (B1-20), Inverted V-bracing (B2-20), K-bracing (B3-20), and single diagonal bracing (B4-20) respectively. In general, as showed in Figure 4.24, it can be seen that model no.20 shows a minimal floor drift as compared to model no.14, no.15, and no.16. This was probably due to bracing member stretched across the entire bays, which creating more resistance for drift to occur. Likewise, model no.14 and no.15 were showing significant results of increased stiffness with enormous benefit in terms of drift reduction. By the way, model no.16 did not show significant drift reduction and might not consider the best compared to others. Thus, the order of increase in frame stiffness by means of reduction in floor drift as can be seen in Figure 4.24 was model no.16, model no.15, model no.14, and model no.20.

Another method for increasing the structure stiffness is to brace the exterior bays. Thus, the analysis of drift results was made regarding bracing completely the exterior bays: model no.17, no.18, and no.19. In model no.17 (B1-17, B2-17, B3-17, and B4-17) the bracing was braced completely the exterior bays and the 30th floor. Staggering results with very little maximum floor drift was found and thus the maximum drift difference was 55.65%, 50.0%, 51.64%, and 52.72% for X-bracing (B1-17), Inverted V-bracing (B2-17), K-bracing (B3-17), and single diagonal bracing (B4-17) respectively. Then, in model no.18, it is worth to mention that maximum floor drift did show some slight increase and the maximum drift did show some slight drop compared to model no.17 which was about 54.56%, 54.20%, 51.80%, and 52.59% for X-bracing (B1-18), Inverted V-bracing (B2-18), K-bracing (B3-18), and single diagonal bracing (B4-18) respectively. Lastly, in model no.19, the completely braced exterior bays were provided bracing at 15th and 30th floor that seems the maximum floor drift was sufficiently lower and the maximum drift difference was tremendously higher of about 59.04%, 58.38%, 52.28%, and 54.90% for X-bracing (B1-19), Inverted V-bracing (B2-19), K-bracing (B3-19), and single diagonal bracing (B4-19) respectively. With regards to these three models, it is worth mentioning that bracing exterior bays could decrease the lateral drift to greater extent but of course it is an expensive approach after all. Thus, fully bracing the exterior two bays provides significantly more resistance to drift, but the issue becomes one of cost versus benefit. The order of increase in frame stiffness by means of reduction in lateral drift as shown in Figure 4.25 was model no.18, model no.17, and model no.19. The lateral drift patterns for different bracing orientations for Inverted V-bracing, K-bracing, and single-diagonal bracing were shown in Appendix D1, D2, and D3 respectively.

Table 4.5: Comparison of different bracing layouts on lateral drift of X-bracing and Inverted V-bracing

Frame	Max. Floor Drift	Max. Drift Difference	Max. % of Drift Diff.	Frame	Max. Floor Drift	Max. Drift Difference	Max. % of Drift Diff.
B1	0.33974	-	-	**B2**	0.33074	-	-
B1-1	0.29432	0.04542	13.37	**B2-1**	0.28997	0.04077	12.33
B1-2	0.29303	0.04671	13.75	**B2-2**	0.28875	0.04199	12.70
B1-3	0.30001	0.03973	11.69	**B2-3**	0.29465	0.03609	10.91
B1-4	0.33303	0.00671	1.975	**B2-4**	0.32486	0.006053	1.778
B1-5	0.26448	0.07526	22.15	**B2-5**	0.26229	0.06845	20.70
B1-6	0.26554	0.0742	21.84	**B2-6**	0.26333	0.06741	20.38
B1-7	0.26337	0.07637	22.48	**B2-7**	0.26147	0.06927	20.94
B1-8	0.23828	0.10146	29.86	**B2-8**	0.23813	0.09261	28.00
B1-9	0.24001	0.09973	29.36	**B2-9**	0.23945	0.09129	27.60
B1-10	0.24157	0.09817	28.90	**B2-10**	0.24073	0.09001	27.22
B1-11	0.27003	0.06971	20.52	**B2-11**	0.26734	0.0634	19.17
B1-12	0.26783	0.07191	21.17	**B2-12**	0.2652	0.06554	19.82
B1-13	0.32437	0.01537	4.524	**B2-13**	0.31709	0.01365	4.127
B1-14	0.16521	0.17453	51.37	**B2-14**	0.16945	0.16129	48.77
B1-15	0.16784	0.1719	50.60	**B2-15**	0.17225	0.15849	47.92
B1-16	0.25939	0.08035	23.65	**B2-16**	0.25783	0.07291	22.05
B1-17	0.15068	0.18906	55.65	**B2-17**	0.16538	0.16536	50.00
B1-18	0.15439	0.18535	54.56	**B2-18**	0.15147	0.17927	54.20
B1-19	0.13917	0.20057	59.04	**B2-19**	0.13765	0.19309	58.38
B1-20	0.15528	0.18446	54.29	**B2-20**	0.16186	0.16888	51.06

Table 4.6: Comparison of different bracing layouts on lateral drift of K-bracing and single diagonal bracing

Frame	Max. Floor Drift	Max. Drift Difference	Max. % of Drift Diff.	Frame	Max. Floor Drift	Max. Drift Difference	Max. % of Drift Diff.
B3	0.62231	-	-	**B4**	0.48738	-	-
B3-1	0.59662	0.02569	4.128	**B4-1**	0.45545	0.03193	6.551
B3-2	0.59526	0.02705	4.347	**B4-2**	0.45402	0.03336	6.845
B3-3	0.58907	0.03324	5.341	**B4-3**	0.45267	0.03471	7.122
B3-4	0.59474	0.02757	4.430	**B4-4**	0.47442	0.01296	2.659
B3-5	0.5663	0.05601	9.000	**B4-5**	0.42542	0.06196	12.71
B3-6	0.56653	0.05578	8.963	**B4-6**	0.42598	0.0614	12.60
B3-7	0.56604	0.05627	9.042	**B4-7**	0.42481	0.06257	12.84
B3-8	0.5376	0.08471	13.61	**B4-8**	0.39845	0.08893	18.25
B3-9	0.53786	0.08445	13.57	**B4-9**	0.39926	0.08812	18.08
B3-10	0.53811	0.0842	13.53	**B4-10**	0.40008	0.0873	17.91
B3-11	0.57539	0.04692	7.540	**B4-11**	0.43304	0.05434	11.15
B3-12	0.55781	0.0645	10.83	**B4-12**	0.42241	0.06497	13.38
B3-13	0.58348	0.03883	6.240	**B4-13**	0.45973	0.02765	5.673
B3-14	0.45579	0.16652	26.76	**B4-14**	0.28783	0.19955	40.94
B3-15	0.45838	0.16393	26.34	**B4-15**	0.31513	0.17225	35.34
B3-16	0.54974	0.07257	11.66	**B4-16**	0.40082	0.08656	17.76
B3-17	0.30097	0.32134	51.64	**B4-17**	0.23042	0.25696	52.72
B3-18	0.29997	0.32234	51.80	**B4-18**	0.23107	0.25631	52.59
B3-19	0.29694	0.32537	52.28	**B4-19**	0.21982	0.26756	54.90
B3-20	0.43791	0.1844	29.63	**B4-20**	0.30168	0.1857	38.10

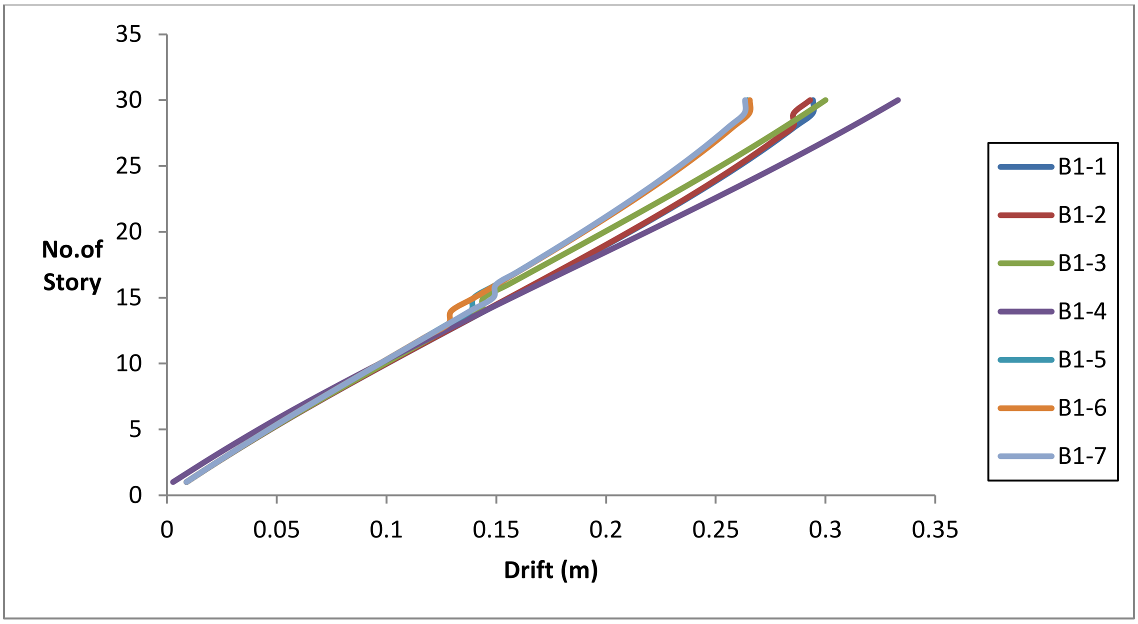


Figure 4.22: Lateral drift pattern of X-bracing configurations of model no.1 to no.7

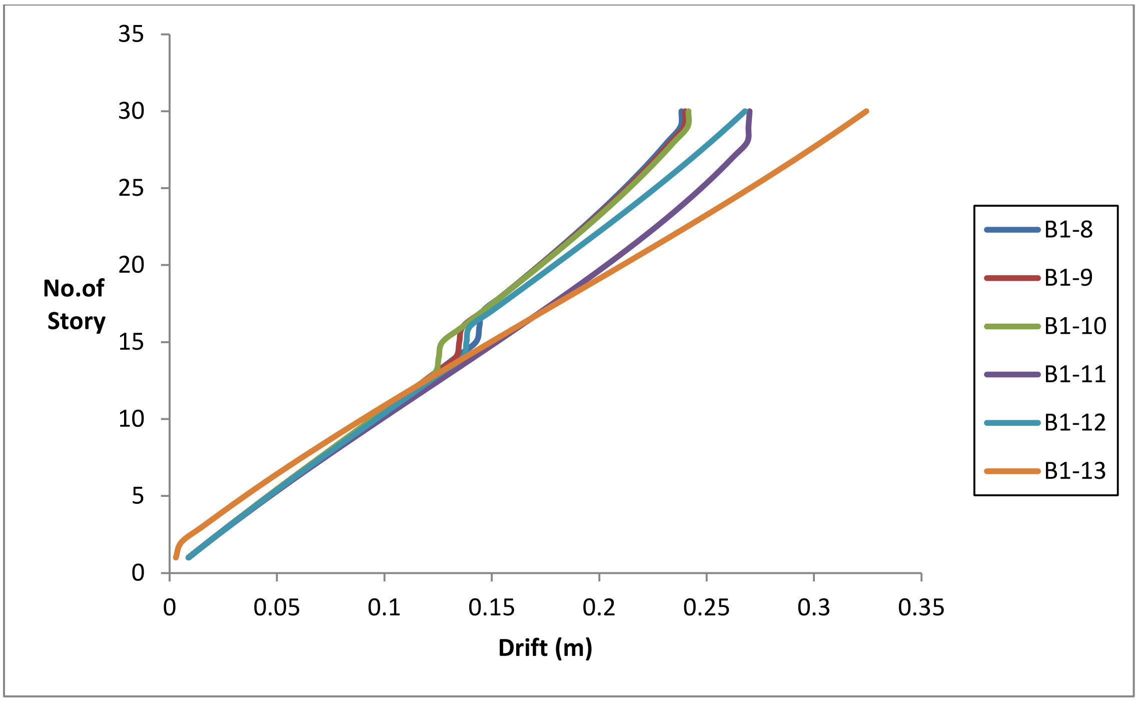


Figure 4.23: Lateral drift pattern of X-bracing configurations of model no.8 to no.13

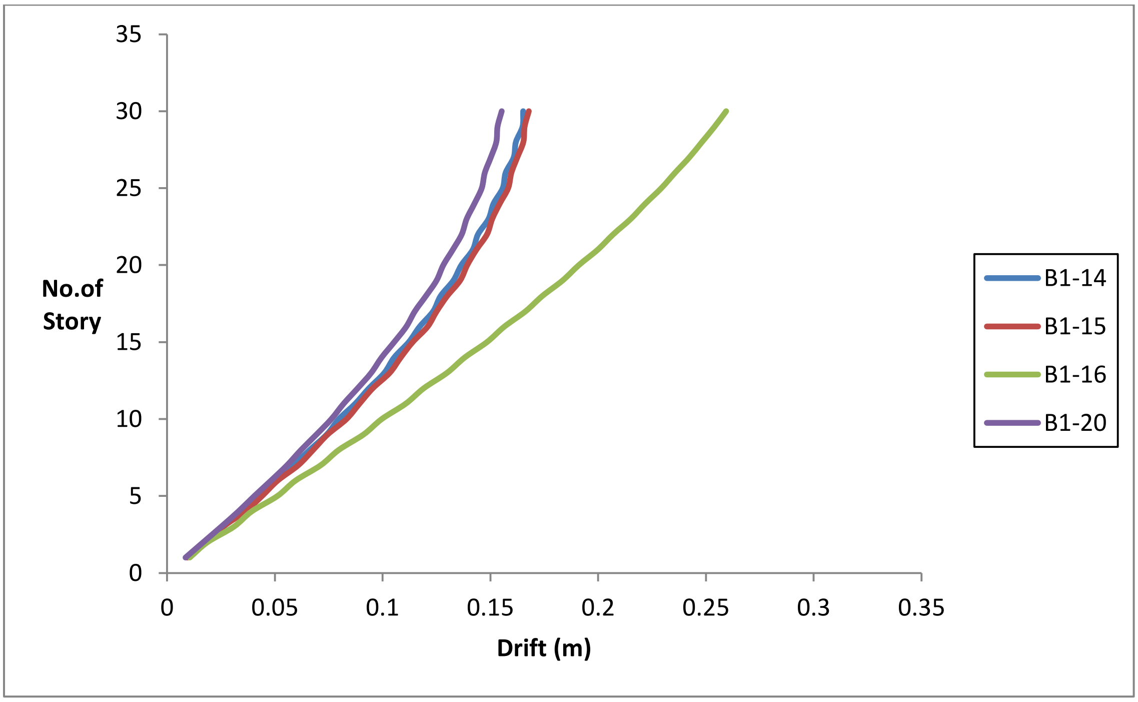


Figure 4.24: Lateral drift pattern of X-bracing configurations of model no.14 to no.16 & no.20

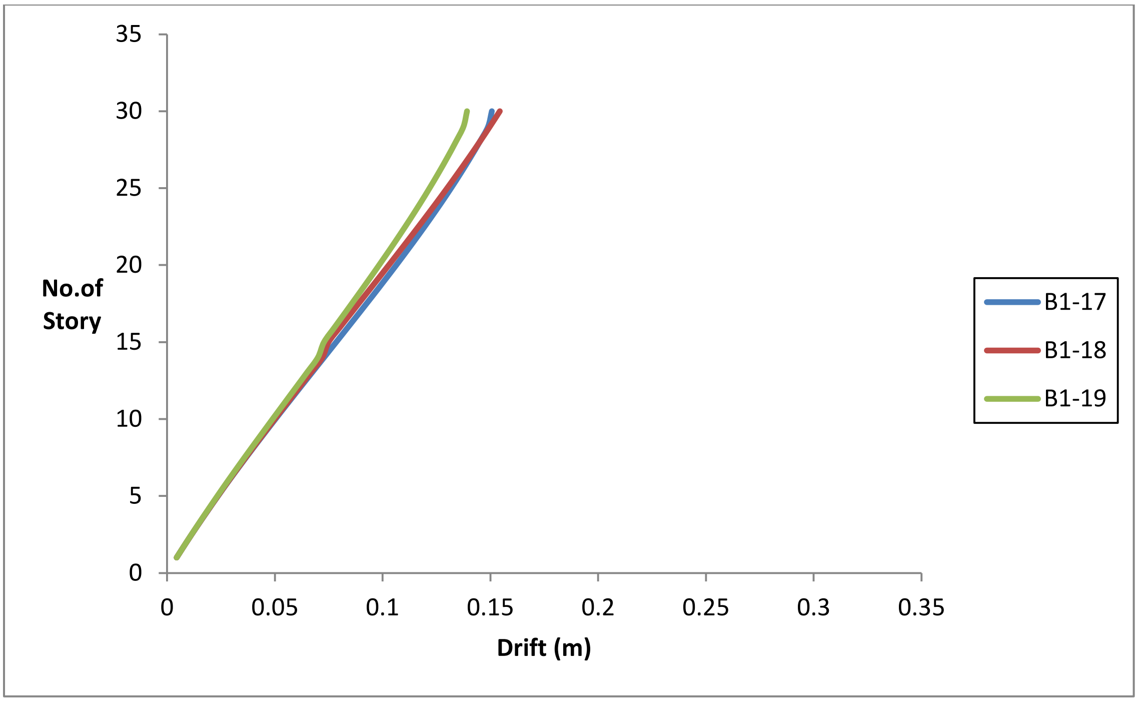


Figure 4.25: Lateral drift pattern of X-bracing configurations of model no.17 to no.19

Basically, frame configurations can affect building performance. As per stated in American Institute of Steel Construction (AISC) 341, the beam design must resist flexural forces in the post-elastic condition that is one brace buckled in compression and the other one with yielding in tension, does not ensure a high post-buckling that can affect frame stiffness. Pertaining to the analysis on the implications of various bracing orientations along the frame structure on the lateral drift, it was interesting to note that several layouts can induce greater amount of lateral stiffness and thus reducing substantial amount of lateral drift, while others not. Nonetheless, bracing the upper floor of the steel frame could trigger more resistance to drift compared to providing bracing at ground floors of the model frame. It was typically due to the fact that high-wind loading and the associated lateral drift occur at the top most of the building. Very minimal drift could be expected at the ground floors and hence provision of bracing is less significance here, compared to providing bracing at upper floors. It was deemed very important to establish the basic parameters for the analysis of the bracing center bay only steel frame, recognizing that this was the frame that formed the basic one for the evaluation of the other frame response.

4.3.1 Bracing the center bays vs. Bracing multiple bays

It is convenient to brace multiple bays rather than bracing center bay only to reduce overturning demands. For instance, concerning the complete load path for both the elastic and post-elastic conditions for the case of bracing the bays in a zigzag or perpendicular patterns as in model no.14 and 15 will have lower column and foundation forces, compared to bracing center bay only which have to bear higher beam and connection forces at the discontinuity (Rafael Sabelli, Charles W. Roeder, and Jerome F. Hajjar, 2013). With the increase in number of braced bays, the yield displacement or drift in models decreases due to increase of initial lateral stiffness of the model (P. Shademan Heidari, R. Ahmady Jazany, H. Kayhani, 2010).

4.3.2 Bracing schemes spread over the frame width

Among the various layouts, it was found that providing bracing in a zigzag or diagonal patterns as in the model no.14 and 15 or providing bracing across the full width of the frame as in model no.20 triggered greater reduction of drift difference as compared to the case of bracing center bay only in the context of lateral drift. When providing the bracing in a zigzag and diagonal patterns the lateral stiffness increased around 27% to 52% and 27% to 51% respectively depending on the type of bracing used in this study. The interesting fact of these layouts is it proved that minor amount of bracing could enhance the design enough to be considered an effective layout. According to Nicholas Mcewen, 2011 on his findings on these layouts shows an increase of lateral stiffness by 53% to 79% as a percent of original design's story drift and thus pointed out that such layouts increased the stiffness with enormous benefit in terms of drift reduction at an exceedingly low cost. Additionally, under these layouts the drifts were immediately improved as compared to bracing the center bay only, meanwhile the drift only continues to decrease as the building height increases. It was very clear that this method of bracing is one of the most efficient and effective ways in which to brace steel frame (Nicholas Mcewen, 2011).

Apart from that, braced across the full width of the frame as in model no.20 caused an increase in lateral stiffness in the range of 30% to 55% depending on the bracing type used. It literally shows that as long as the bracing elements spanning along the frame width, the lateral drift generated could be overcome by the interconnected bracing components.

4.3.3 Bracing the center bay vs. Bracing the exterior bays

Another method notified in this study to reduce the substantial lateral drift was bracing the exterior bays as in the model no.17, 18, and 19. Certainly if all exterior bays are braced, the lateral drift induced in the structure is lesser; however the issue becomes one of cost versus benefit. This method of bracing is overly expensive as compared to the case of bracing center bay only due to the increased weight and number of steel and correspondingly the number of extra joints needed. In this study, bracing completely the exterior bays increased frame stiffness around 50% to 60% as compared to the case of bracing center bay only. This was actually in accordance with Nicholas Mcewen, 2011, who explained bracing the exterior bays could increase the lateral stiffness of around 38% to 47% depending on the type of bracing used and of course it provides significantly more resistance to drift. Besides that, bracing that was considered for the exterior bays at alternating floors on each exterior bay in a staggered pattern such that each floor was braced by one bay as in model no.16, but the results revealed that it were not as good as in the case of completely bracing the exterior bays due to discontinuity of adjacent bracing member in the same bay. On occasion, when the distance between two braced bays increases, the ultimate displacement or drift of structures would also increase, and vice versa (P. Shademan Heidari, R. Ahmady Jazany, H. Kayhani, 2010).

4.4 ANALYSIS ON THE EFFECT OF USING SIMPLE PIN CONNECTION VS. COMBINED PIN AND MOMENT CONNECTION

Apart from varying the bracing type and layout, another parameter which was highlighted in this study is the use of a pin or pin-moment connection in reducing the lateral drift of 30-storey steel frame structure. There are certain advantages and disadvantages of using either a pin or combined pin and moment connection. Pin connection, for instance works essentially like a lapped joint, which it transfers vertical and horizontal shear loads and cannot resist any bending (rotational) forces. Apparently, the construction process becomes simplified as it consuming less time and it requires less skilled labor and the significance reduction in the complexity of the structural design and analysis can be notified when using pin connection. On the contrary, pin and moment connection although variant depending on the bracing layout, it always deals with the fact that there is a certain reduction in drift. Moment connections are basically designed to transfer bending moments and shear forces of the structure and the design strength and stiffness of the connection can be defined in relation to its strength and stiffness of the connected members. In this regard, moment connections deliver redundancy in the structure, and thus producing a safer building. Commonly, the method of modeling of combined pin and moment connection involves releasing the moment between the beam and the column at every point where a bracing member ties into a beam joint.

Ideally, it becomes very clear that largest savings in drift can be realized as the height of the building increases, upon which the differences in drift between the layouts with pin connections and those with combined pin and moment connections were compared. This was illustrated in the Table 4.7 and Table 4.8 which shows the drift results of all the bracing used. Meanwhile, Figure 4.38, Figure 4.39, Figure 4.40 and Figure 4.41 were displaying the drift differences between pin connections and pin-moment connections of X-bracing, Inverted V-bracing, K-bracing, and single diagonal bracing respectively. It is worth noting that in all designed 84 models of steel frame, the maximum drift difference was at the top floor (30^{th} floor). Moreover, in regards to drifting trend, it can be noticed that slowing of the drift difference occurred at the top of this particular building.

Once finished comparing the differences in drift between pin connections and those in the combined pin and moment connections, the average maximum drift difference for each layout and each bracing type were recorded. The average maximum drift difference as a percent of the original story drift was calculated by means of taking the drift difference between the pin connection and a combined pin and moment connection for each floor of each layout and then divided it by the corresponding drift for the pin condition only. The percentage of drift reduction was taken into account for both the type of bracing and its layouts. From the analysis obtained, it was found that the percentage of drift reduction for X-bracing, Inverted V-bracing, K-bracing, and single diagonal bracing were 47.75%, 45.66%, 25.95%, and 33.02% respectively, as shown in Table 4.7 and Table 4.8. Other results governing pin and pin-moment connections can be referred in Appendices E.

Table 4.7: Drift difference between pin connections and combined pin-moment connections of X-bracing and Inverted V-bracing

Frame	Max.Drift		Drift Diff.	Frame	Max.Drift		Drift Diff.
	Pin Connection	Pin Moment Connection			Pin Connection	Pin-Moment Connection	
B1	0.33974	0.13234	0.61047	**B2**	0.33074	0.13794	0.58294
B1-1	0.29432	0.13214	0.55103	**B2-1**	0.28997	0.13774	0.52499
B1-2	0.29303	0.13196	0.54967	**B2-2**	0.28875	0.13755	0.52364
B1-3	0.30001	0.12936	0.56881	**B2-3**	0.29465	0.13484	0.54237
B1-4	0.33303	0.1267	0.61955	**B2-4**	0.32486	0.13206	0.59349
B1-5	0.26448	0.12917	0.51161	**B2-5**	0.26229	0.13464	0.48668
B1-6	0.26554	0.12898	0.51427	**B2-6**	0.26333	0.13444	0.48946
B1-7	0.26337	0.12935	0.50887	**B2-7**	0.26147	0.13483	0.48434
B1-8	0.23828	0.12669	0.46831	**B2-8**	0.23813	0.13206	0.44543
B1-9	0.24001	0.12632	0.47369	**B2-9**	0.23945	0.13167	0.45011
B1-10	0.24157	0.12594	0.47866	**B2-10**	0.24073	0.13128	0.45466
B1-11	0.27003	0.13176	0.51205	**B2-11**	0.26734	0.13735	0.48623
B1-12	0.26783	0.12651	0.52765	**B2-12**	0.2652	0.13187	0.50275
B1-13	0.32437	0.12119	0.62638	**B2-13**	0.31709	0.12632	0.60163
B1-14	0.16521	0.13988	0.15332	**B2-14**	0.16945	0.14571	0.14010
B1-15	0.16784	0.14478	0.13739	**B2-15**	0.17225	0.15055	0.12598
B1-16	0.25939	0.15568	0.39982	**B2-16**	0.25783	0.16129	0.37443
B1-17	0.15068	0.06613	0.56112	**B2-17**	0.16538	0.068978	0.58291
B1-18	0.15439	0.065431	0.57620	**B2-18**	0.15147	0.068203	0.54973
B1-19	0.13917	0.065386	0.53017	**B2-19**	0.13765	0.068156	0.50486
B1-20	0.15528	0.13232	0.14786	**B2-20**	0.16186	0.13893	0.14167
∑	-	-	10.02692	**∑**	-	-	9.58839
Avg. Drift	-	-	0.47747	**Avg. Drift**	-	-	0.45659
% Drift Diff.	-	-	47.75%	**% Drift Diff.**	-	-	45.66%

Table 4.8: Drift reduction between pin connections and combined pin-moment connections of K-bracing and diagonal-bracing

Frame	Max.Drift		Drift Diff.	Frame	Max.Drift		Drift Diff.
	Pin Connection	Pin-Moment Connection			Pin Connection	Pin-Moment Connection	
B3	0.62231	0.4149	0.33329	**B4**	0.48738	0.27968	0.42616
B3-1	0.59662	0.41431	0.30557	**B4-1**	0.45545	0.27927	0.38683
B3-2	0.59526	0.41374	0.30494	**B4-2**	0.45402	0.27886	0.38580
B3-3	0.58907	0.40563	0.31141	**B4-3**	0.45267	0.27312	0.39665
B3-4	0.59474	0.38883	0.34622	**B4-4**	0.47442	0.26781	0.43550
B3-5	0.5663	0.40503	0.28478	**B4-5**	0.42542	0.27271	0.35896
B3-6	0.56653	0.40445	0.28609	**B4-6**	0.42598	0.2723	0.36077
B3-7	0.56604	0.40561	0.28343	**B4-7**	0.42481	0.27312	0.35708
B3-8	0.5376	0.39728	0.26101	**B4-8**	0.39845	0.26748	0.32870
B3-9	0.53786	0.39611	0.26354	**B4-9**	0.39926	0.26667	0.33209
B3-10	0.53811	0.39493	0.26608	**B4-10**	0.40008	0.26586	0.33548
B3-11	0.57539	0.41313	0.28200	**B4-11**	0.43304	0.27846	0.35696
B3-12	0.55781	0.3967	0.28883	**B4-12**	0.42241	0.26709	0.36770
B3-13	0.58348	0.38003	0.34868	**B4-13**	0.45973	0.25616	0.44280
B3-14	0.45579	0.43045	0.05560	**B4-14**	0.28783	0.26458	0.08078
B3-15	0.45838	0.4353	0.05035	**B4-15**	0.31513	0.29146	0.07511
B3-16	0.54974	0.44604	0.18863	**B4-16**	0.40082	0.29683	0.25944
B3-17	0.30097	0.20732	0.31116	**B4-17**	0.23042	0.13948	0.39467
B3-18	0.29997	0.20515	0.31610	**B4-18**	0.23107	0.13794	0.40304
B3-19	0.29694	0.205	0.30962	**B4-19**	0.21982	0.13784	0.37294
B3-20	0.43791	0.41484	0.05268	**B4-20**	0.30168	0.27861	0.07647
∑	-	-	5.45002	**∑**	-	-	6.93393
Avg. Drift	-	-	0.25952	**Avg. Drift**	-	-	0.33019
% Drift Diff	-	-	25.95%	**% Drift Diff.**	-	-	33.02%

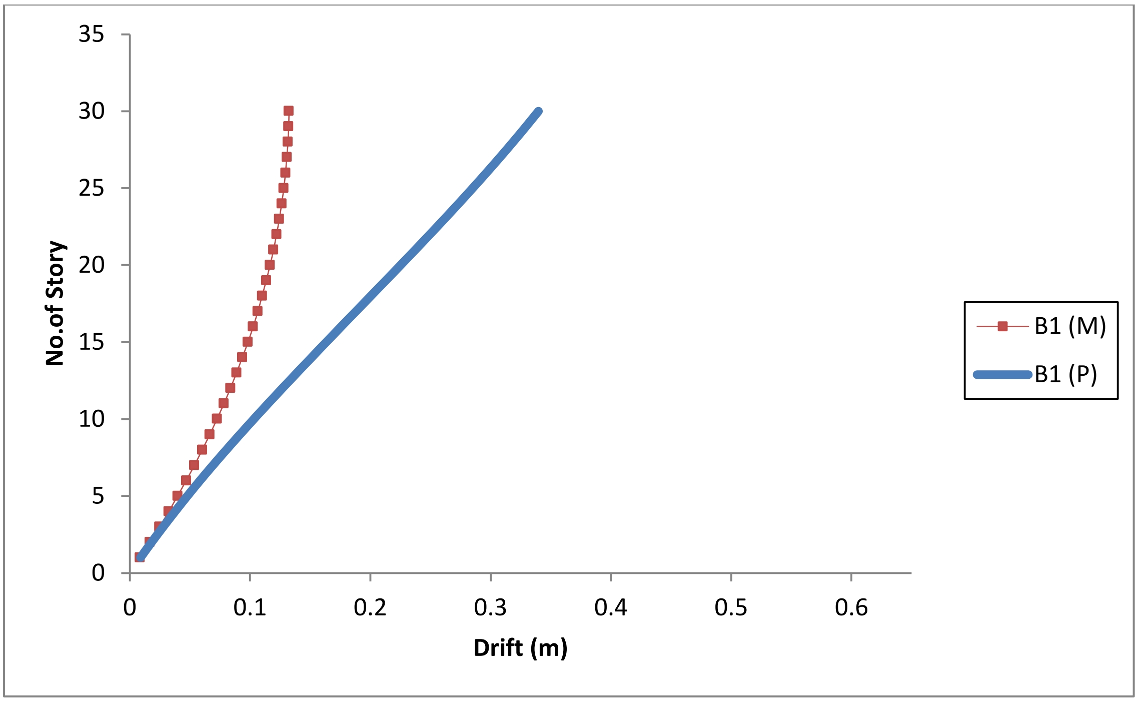


Figure 4.26: Pin connection vs. Pin-moment connection of model B1

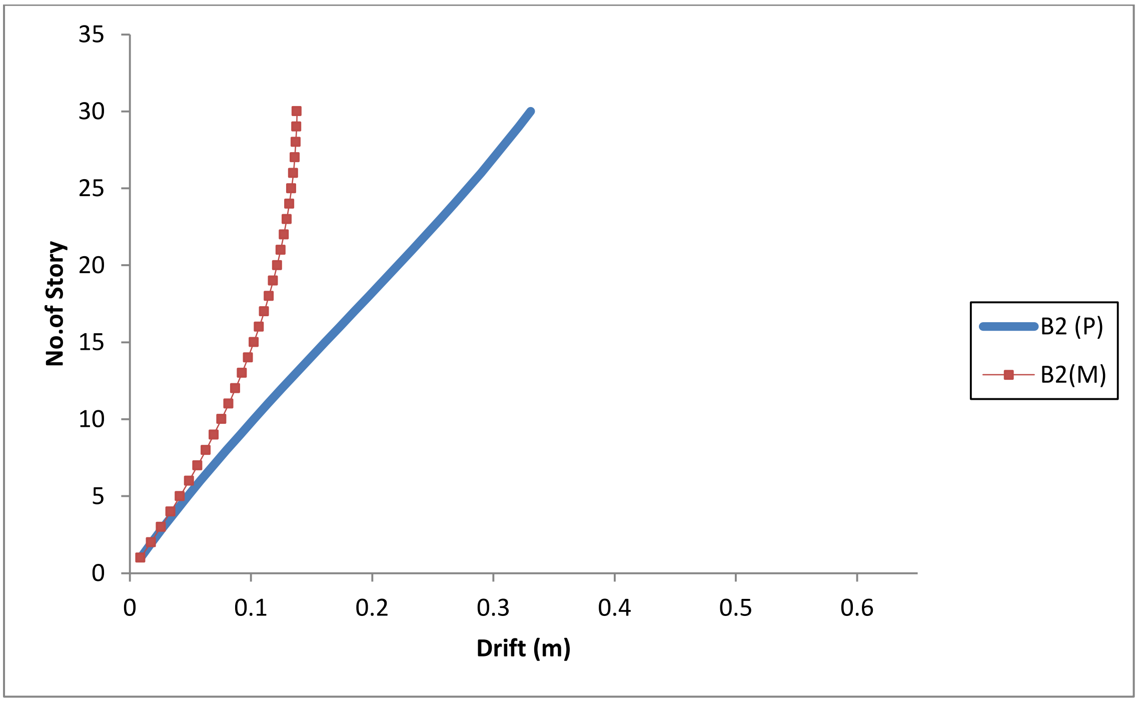


Figure 4.27: Pin connection vs. Pin-moment connection of model B2

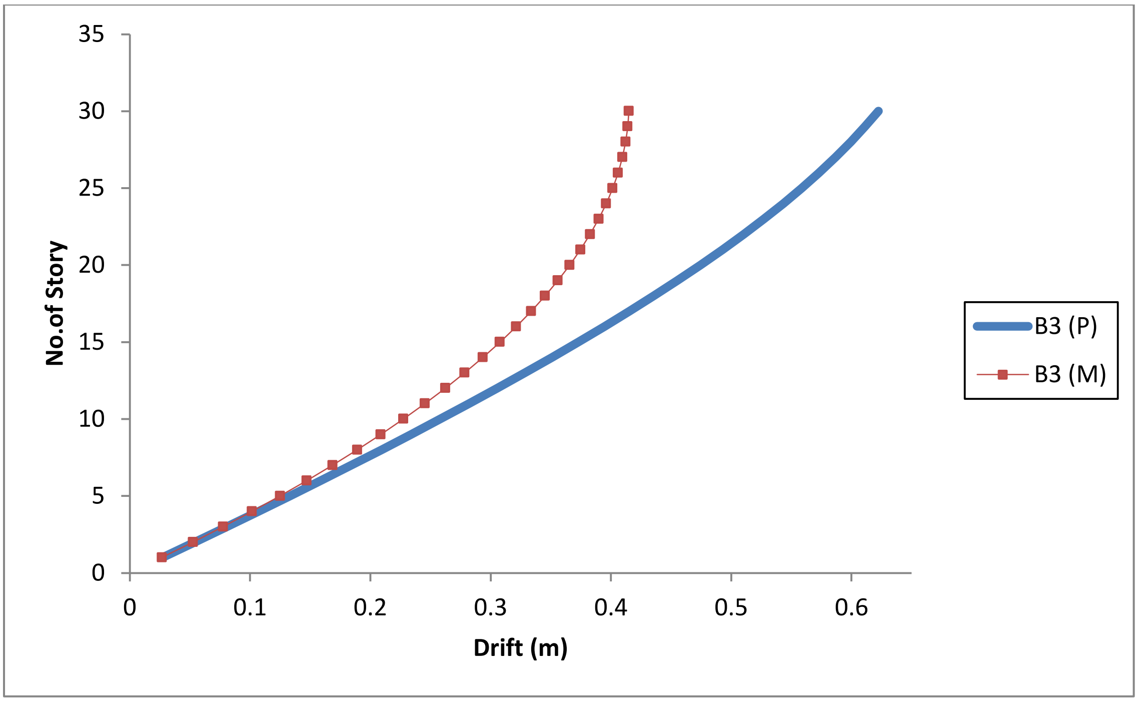


Figure 4.28: Pin connection vs. Pin-moment connection of model B3

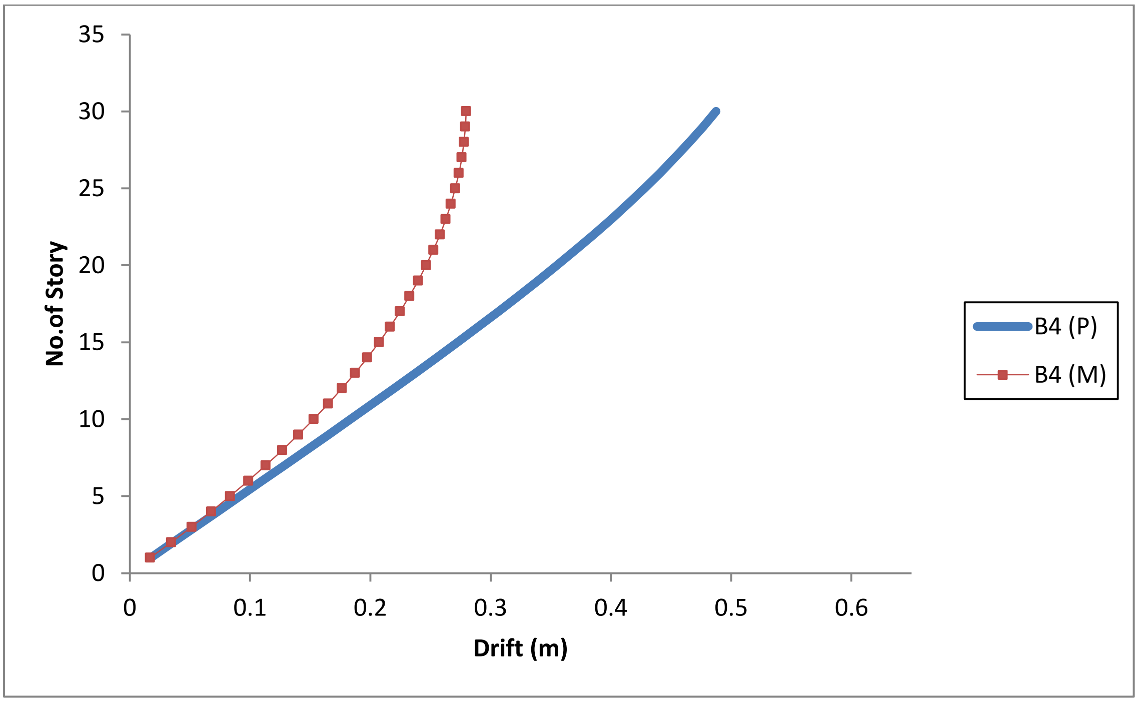


Figure 4.29: Pin connection vs. Pin-moment connection of model B4

Basically, pin-moment connections were developed with the intention of increasing the inelastic drift capacity that could be obtained based on brace buckling and yielding while maintaining lateral resistance. From the results obtained, it shows that significant reduction in drift can be obtained upon using pin-moment connections. This was actually in accordance with Nicholas Mcewen (2011), who defined that reduction of drift was between 8% to 13% can be realized depending on the type of bracing used in 17 stories steel frame building when changing from using pin connections to combined pin and moment connections. Thus, it can be reached to a consensus that changing from using all pin connections to combined pin-moment connections, a drift reduction can be found immensely in the range of 26% to 48% depending on the type of bracing used in the 30 stories steel frame structure. Additionally, it is worth to note that curve shifts to left and rotates it to a more vertical position when the combined pin-moment connections were used instead of pin connections as can be seen in Figure 4.38, Figure 4.39, Figure 4.40 and Figure 4.41. These changes tend to be beneficial as there is less drift in the structure and the change in drift from floor to floor has created less deviation. Although it shows a significant reduction in drift, but the financial matter regards the most, as the moment connections are highly expensive and time consuming.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL

This chapter is deliberating about the conclusions and recommendations on this study. The conclusions are based on the findings of the study and will indicate whether the conclusions meet the proposed objectives of the study, meanwhile the recommendation is about what are the necessary things that can be done in order to further improvise this study in the near future. Essentially, this study develop a list of ways in which a steel frame structure can be braced against wind together with an insight for an effective bracing type for which designers can quickly look to see the best design options.

5.2 CONCLUSIONS

As per on basis of this study, following conclusions were drawn:

i. X-bracing and Inverted V-bracing can provide better lateral stiffness to steel frame structure as compared to K-bracing and single diagonal bracing in terms of maximum lateral drift, interstory drift index, and total drift index. Numerically, the results of maximum lateral drift of various bracing orientations revealed that the maximum drift range lies between 0.33074 (in Inverted V-bracing) to 0.62231 (in K-bracing) and the minimum drift range lies between 0.13765 (in Inverted V-bracing) to 0.29694 (in K-bracing). As for interstory drift index, its' maximum value was in the range of 0.00358 (in Inverted V-bracing) to 0.00968 (in K-bracing). Meanwhile, considering the total drift index, the maximum value was in the range of 0.00367 (in Inverted V-bracing) to 0.00691 (in K-bracing), all of which less than the maximum allowable drift index of 0.009525m set by American Society Civil Engineers ASCE 7-05 (2006). Theoretically, force imbalance between tension and compression braces or the irregularity in the shape of the structure has turn out to causing poor performance of K-bracing, meanwhile the existence of extra restrains in X-bracing or Inverted V-bracing has caused them to work out well to resist lateral drift in structures.

ii. Ideally, different bracing positioning can induce different drift values on the steel frame. Bracing the upper floor could trigger more resistance to drift as compared to providing bracing at ground floors. Moreover, providing bracing in zigzag or diagonal patterns across the bays, as in model no.14 and no.15 looks promising, as it can increase the lateral stiffness as compared to the case of bracing the center bay only in the range of 27% to 52% for model no.14 and 27% to 51% for model no.15 respectively. Likewise, providing bracing across the entire frame width, as in model no. 20 also enhance the lateral stiffness of the steel frame in the range of 30% to 55%, when compared to the case of bracing the center bay only. Out of all bracing configurations, fully bracing the exterior bays (model no.17, 18, and 19) allows the lateral stiffness to increase to a greater extent when compared to the case of bracing the center bay only of about 50% to 60% depending on the bracings location in the exterior bays.

iii. Finally, changing the course of pin connection to a combined pin-moment connection triggered the reduction of drift on the associated steel frame of about 26% to 48% depending on the type of bracing used.

5.3 RECOMMENDATIONS

As a final note, it is important to have some necessary suggestions in which this study could be brought to another level in the near future. The following recommendations could be undertaken for the future endeavor:

i. A series of investigation is encouraged to look at a different building with different wind loads (triangular loads) and tributary areas to see if in fact these results hold up.

ii. A series of investigation or parametric study to determine more efficient and economical bracing layouts, considering criteria like lesser number and weight of steel, lesser number of joints, or minimum cost.

iii. A study to look at the provision of cap truss, belt truss, or gusset plate into the steel frame to corporate with bracing members, and to find out whether these have any effects on limiting the lateral drift of the structure.

In a nutshell, all the **conclusions that were drawn met the proposed objectives** of this study.

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APPENDIX A

Wind Load Calculations Procedure:

1) Determination of basic wind velocity:

$V_b = C_{dir} \times C_{season} \times, V_{b,0}$

Where V_b is the basic wind velocity

C_{dir} is the directional factor

C_{season} is the seasonal factor

$V_{b,0}$ is the fundamental value of the basic wind velocity

2) **Determination of peak velocity pressure, $q_p(z)$**

$$\boldsymbol{q_p(z) = [1 + \frac{7k_1}{c_o(z) \times In\left(\frac{z}{z_0}\right)}] \times \frac{1}{2} \times p \times v_b{}^2 \times (k_T \times In\left(\frac{z}{z_0}\right))}$$

Where: k_1 is the turbulence factor = 1.0

$c_o(z)$ is the orography factor = 1.0

p is the air density = 1.25 kg/m^3

k_T is the terrain factor = $0.19 \times \frac{z_O}{z_{o,II}} = 0.234$, where $z_{o=}$ 0.0616, $z_{o,II}$ = 0.05

Thereafter, the wind loadings per unit length, w (kN/m^2) can be calculated as:

w = (c_{pe} + c_{pi}) x q_p,

where C_{pe} = pressure coefficient for the external pressure depending on the size of the loaded area A = +0.8 (windward direction).

C_{pi} = internal pressure coefficient (depends on the size and distribution of the openings in the building envelope and it should be in the range of 0.2 to 0.3) = +0.2 (leeward direction).

Therefore, Wind Load, w = (C_{pe} + C_{pi}) x q_p = q_p = **0.969 kN/m^2** (for 30 stories = 90 m).

Wind Load: 0.969 kN/m^2 x 3m x 6m = **17.442 kN**

APPENDICES B (ANSYS Figures)

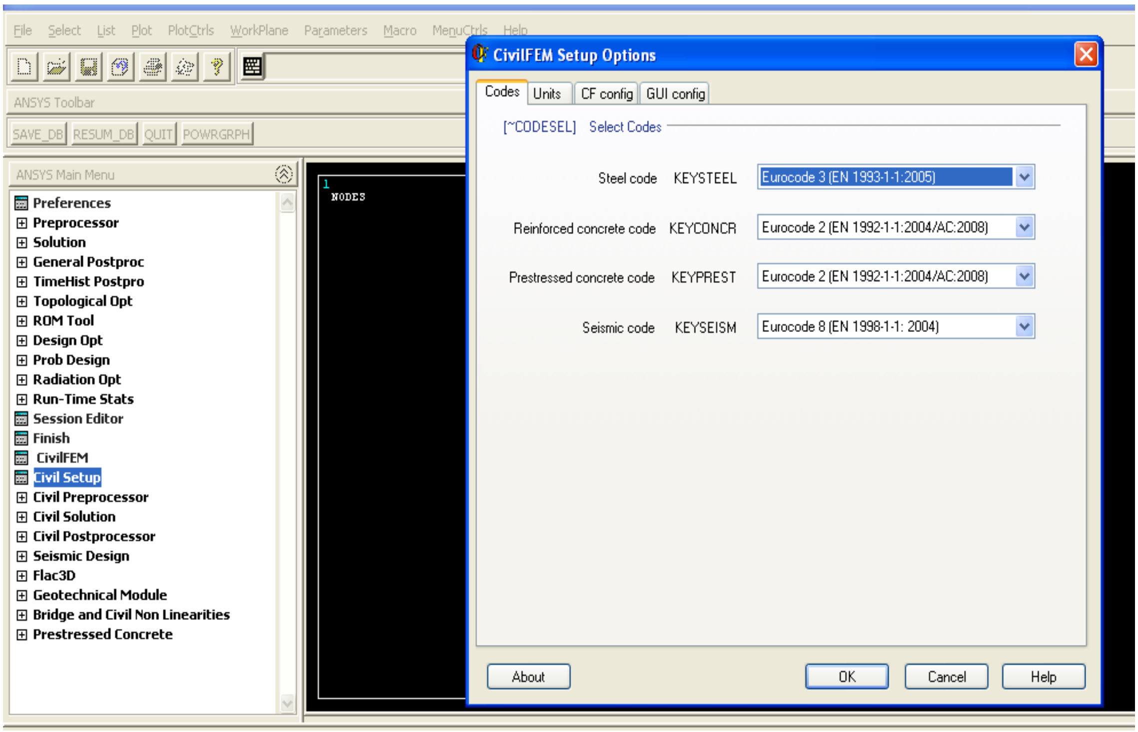


Figure 1: Set-up the Code

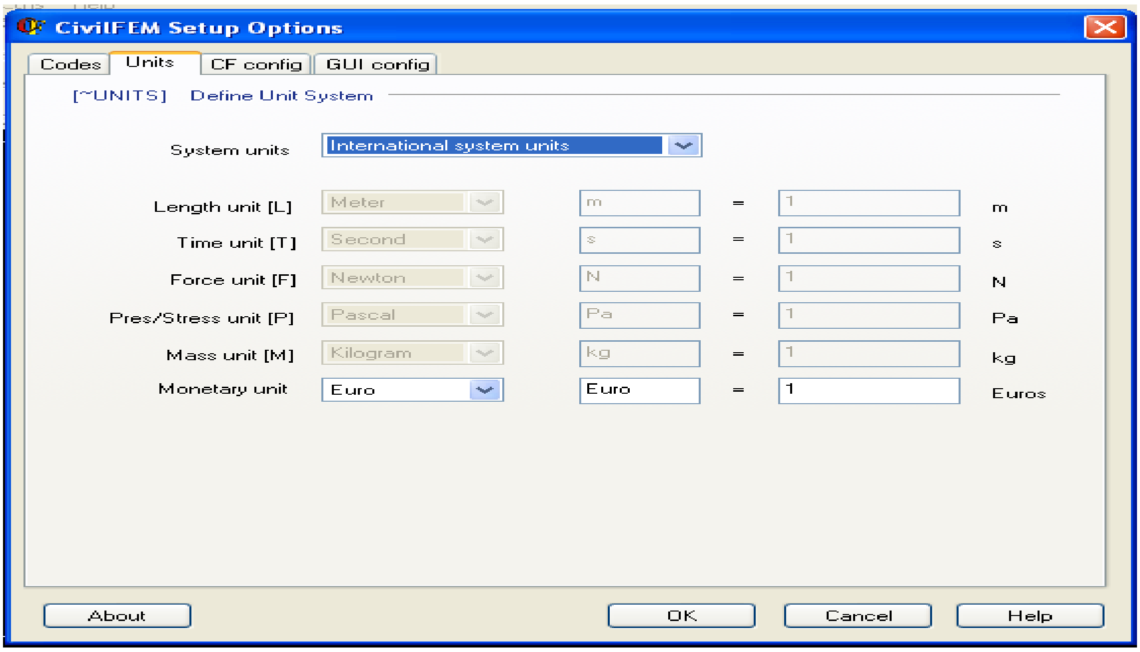


Figure 2: Define the units

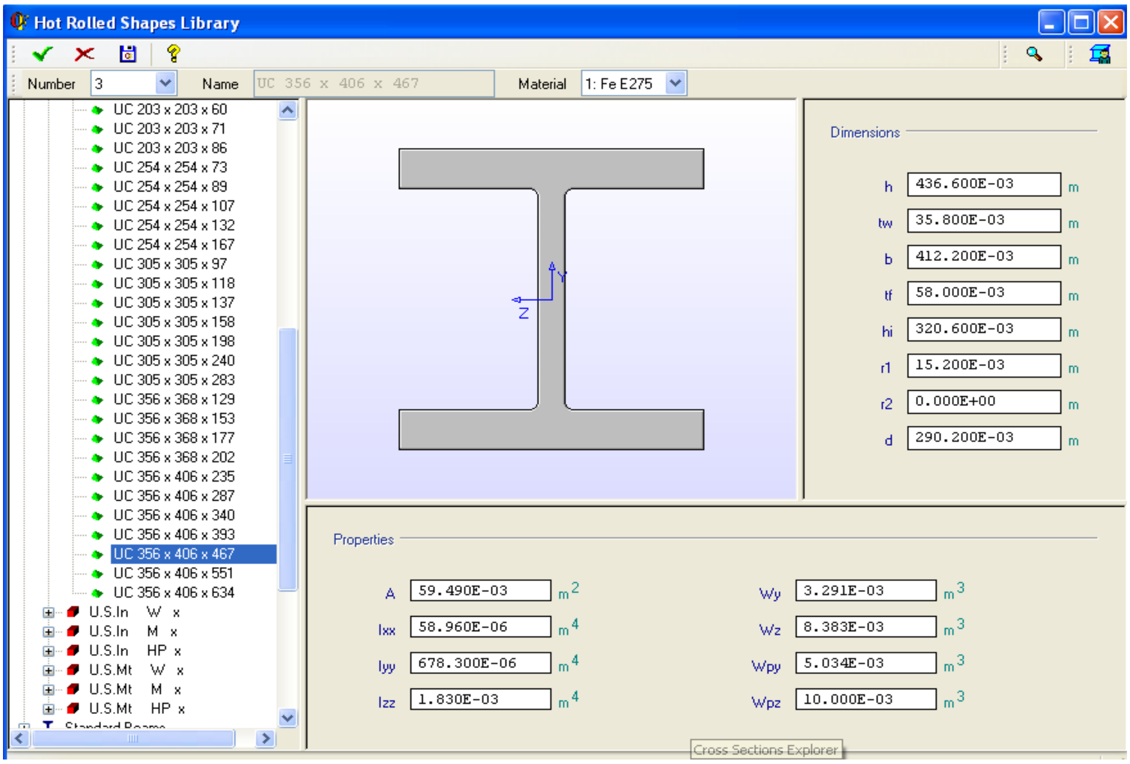


Figure 3: Column cross-section properties for 6^{th}-10^{th} floor

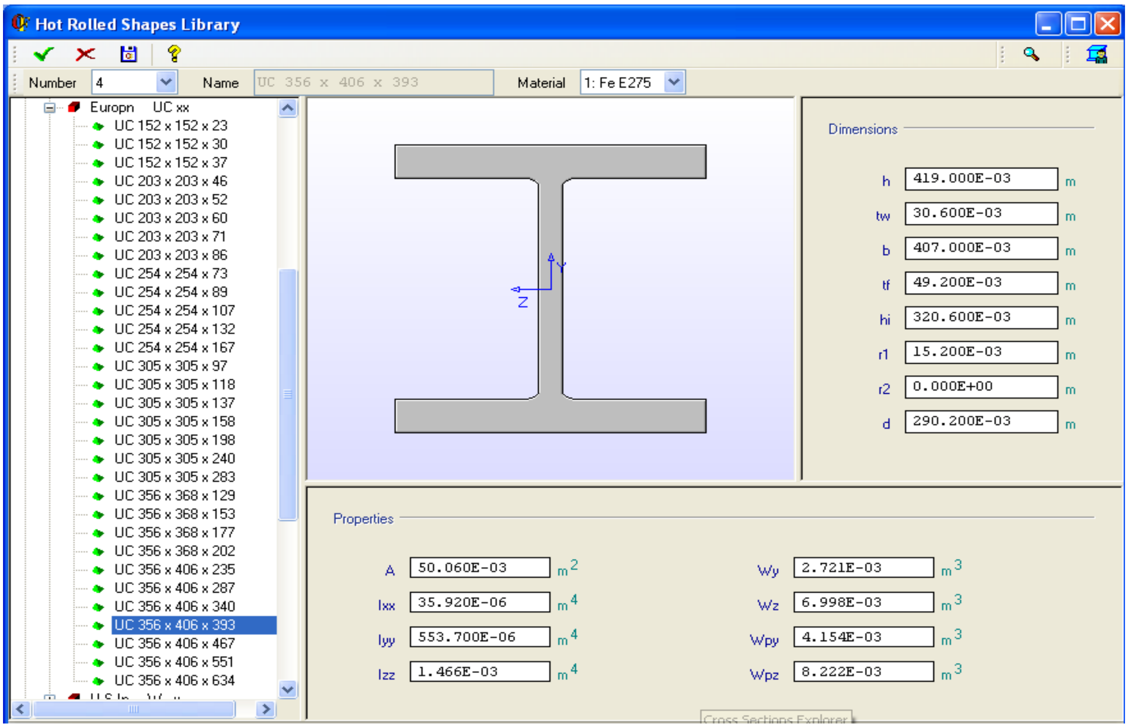


Figure 4: Column cross-section properties for 11^{th}-15^{th} floor

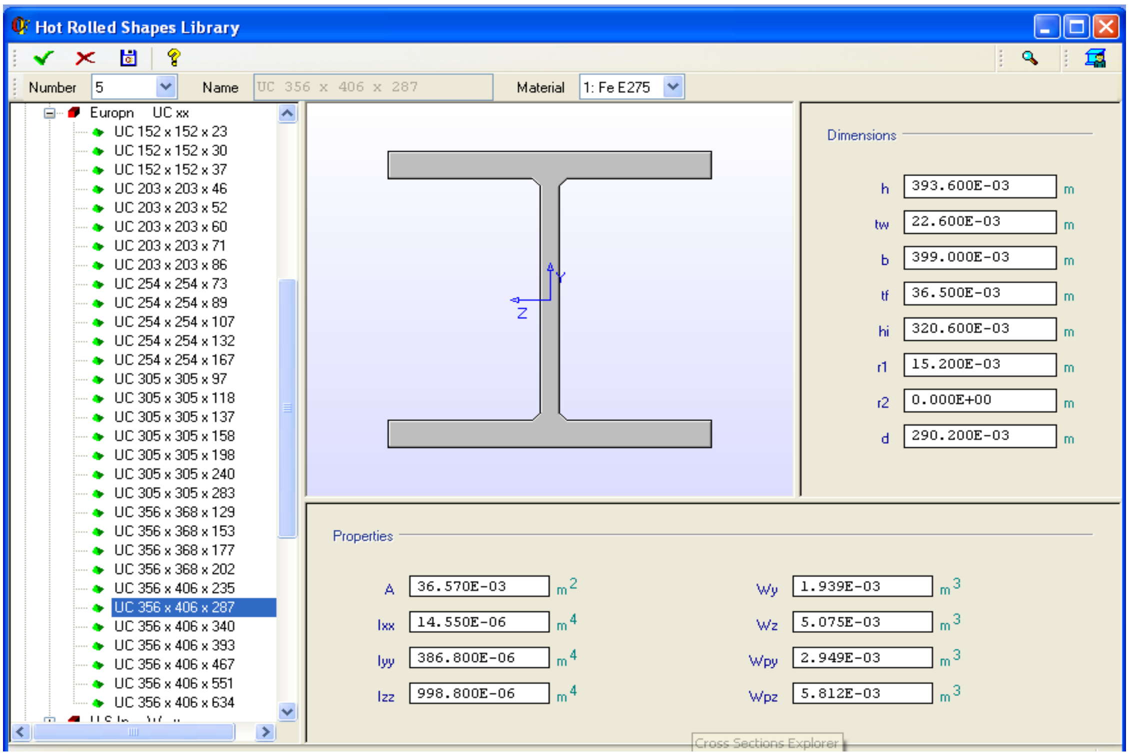


Figure 5: Column cross-section properties for 16th-20th floor

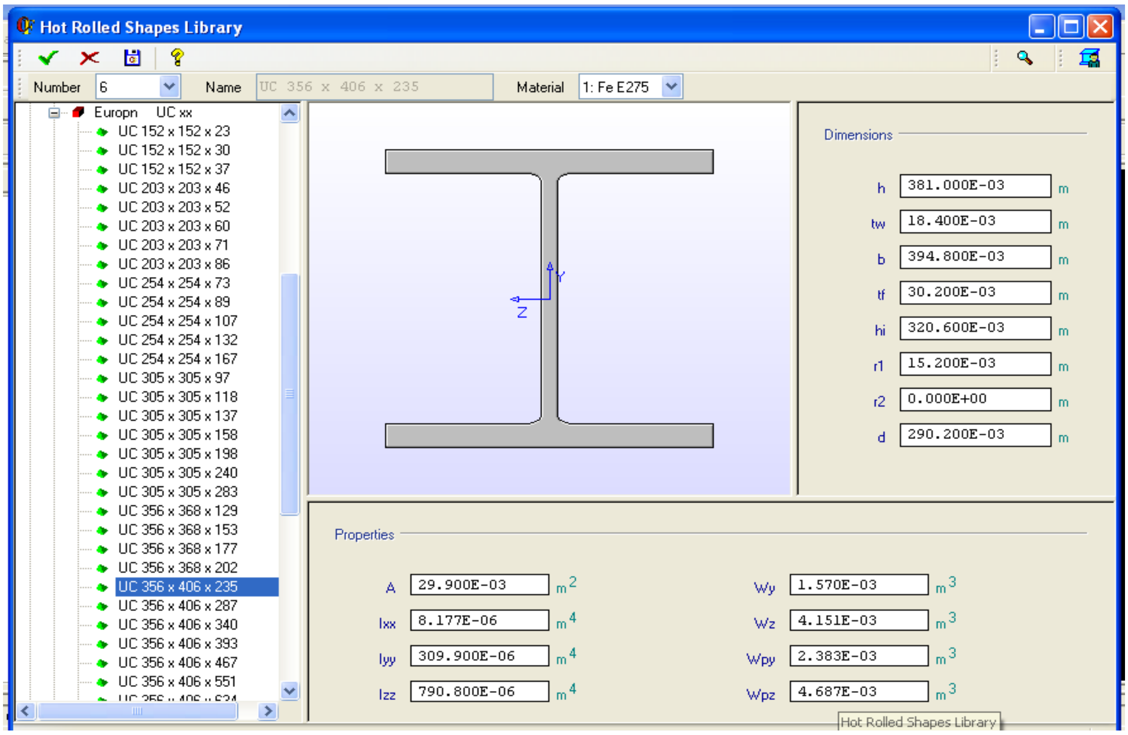


Figure 6: Column cross-section properties for 21st-25th floor

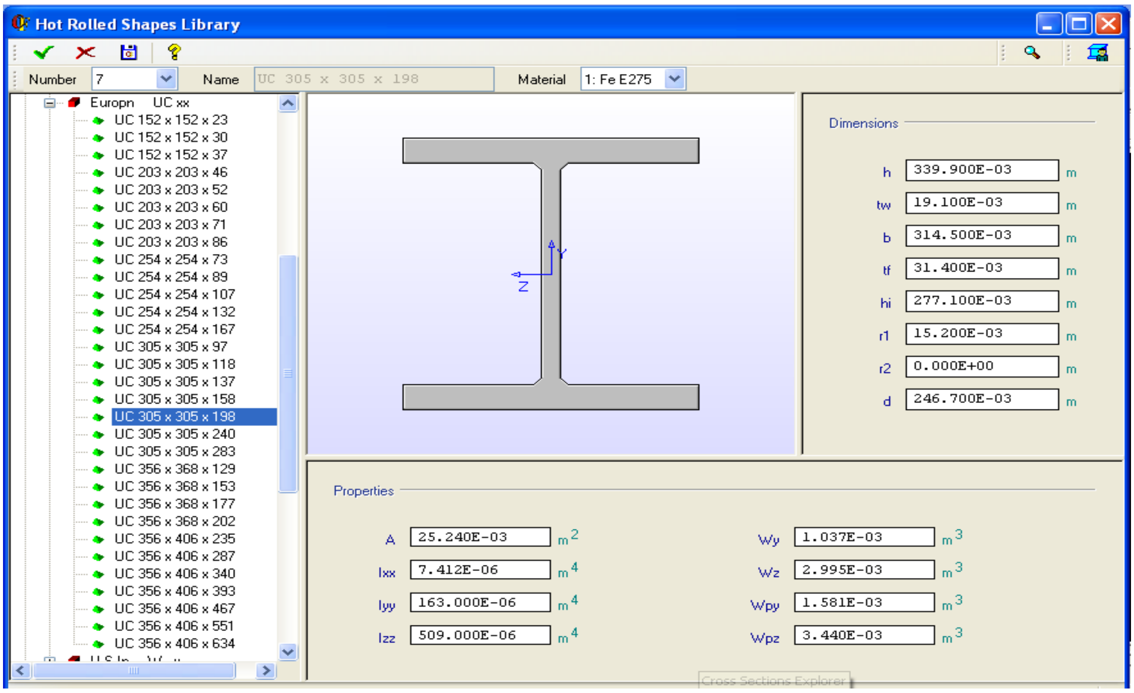


Figure 7: Column cross-section properties for 26th-30th floor

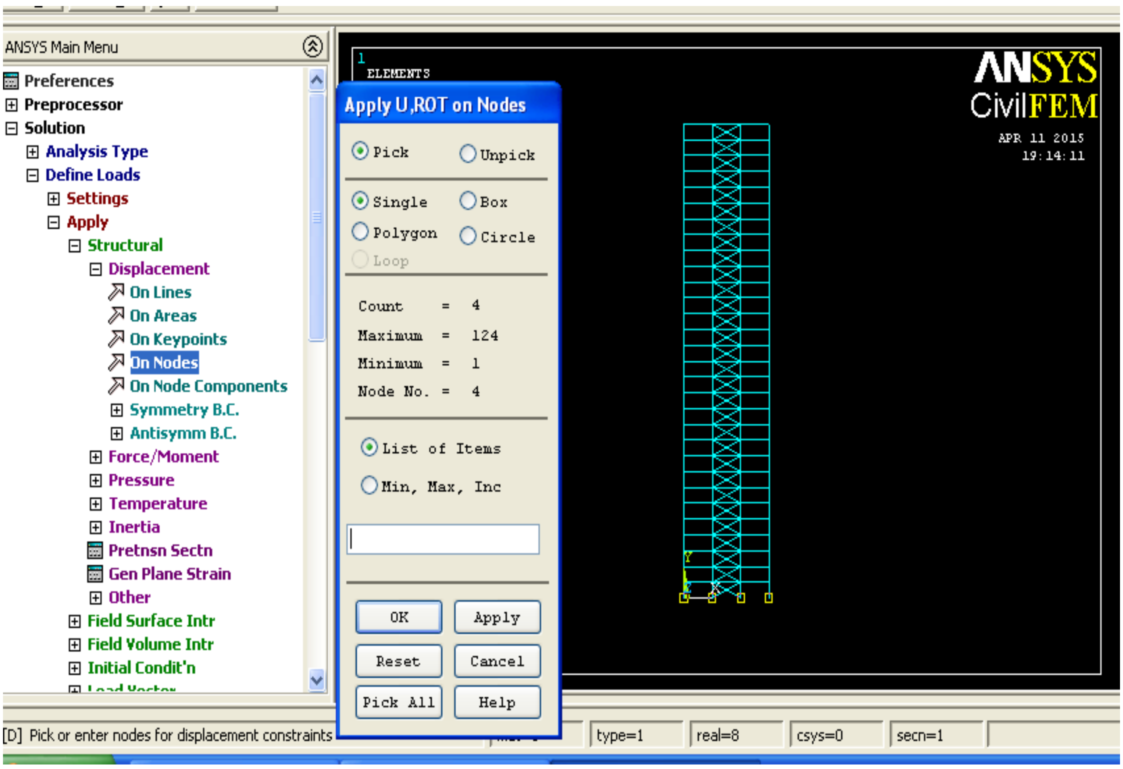


Figure 8: Constrained all DOF the bottom nodes

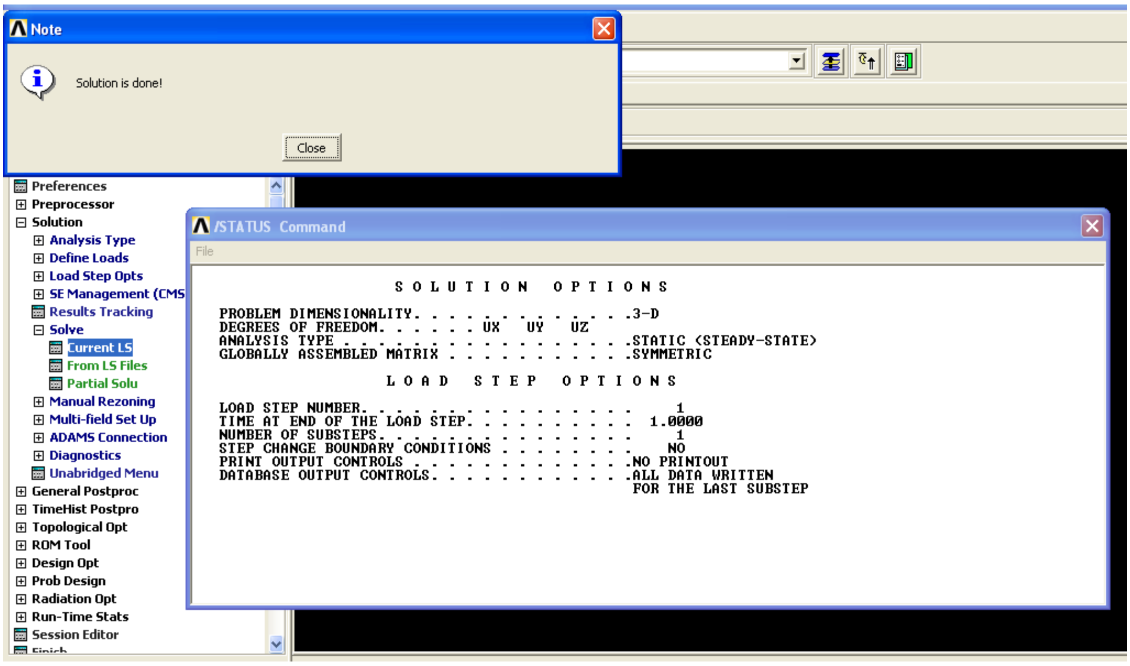


Figure 9: Solving the model

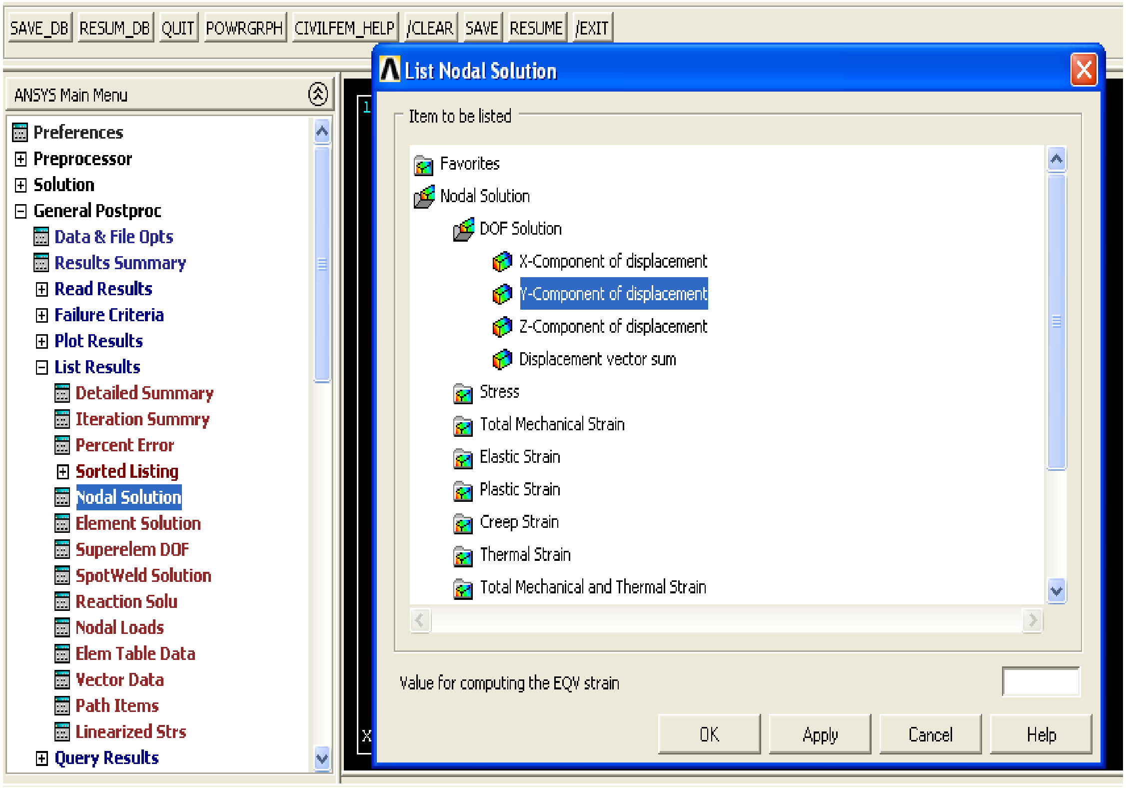


Figure 10: Listing out the y-direction drift result of the model

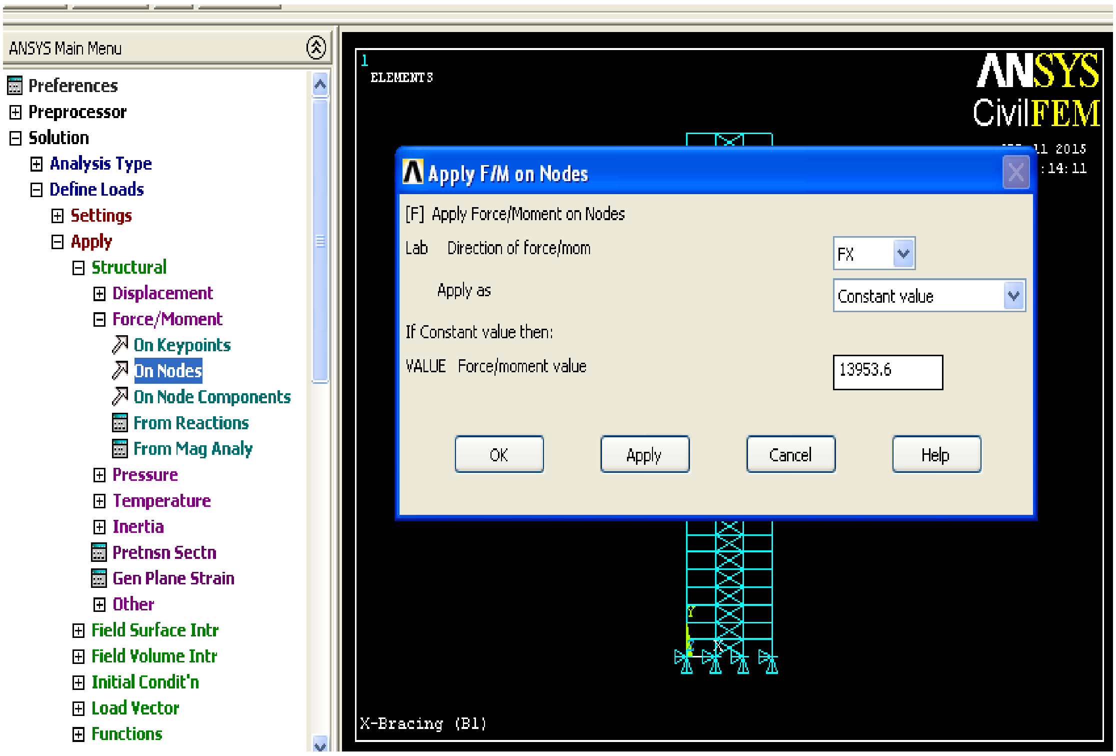


Figure 11: Apply 13953.6 N horizontal loads in windward direction

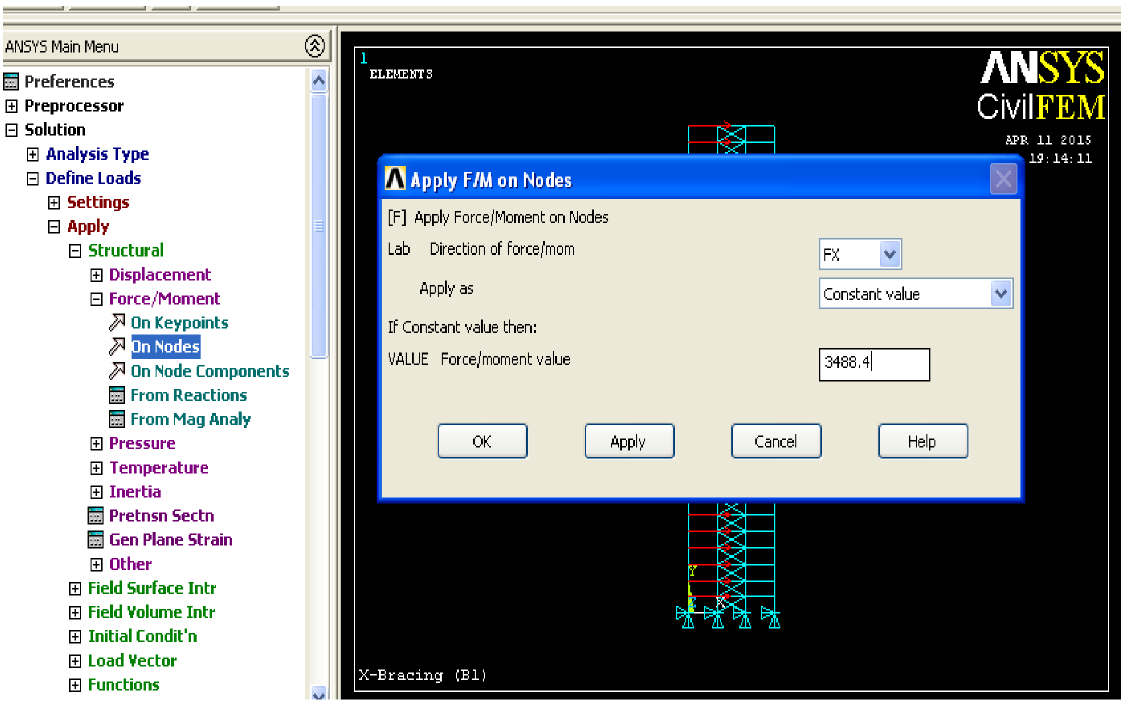


Figure 12: Apply 3488.4 N horizontal loads in leeward direction

APPENDIX C1: Comparison of 4 different types of bracing: Braced along the center bay only

	X-Bracing (B1)		Inverted V-Bracing (B2)		K-Bracing (B3)		Diagonal-Bracing (B4)	
Floor	Floor Drift (m)	Drift Diff. per floor (m)	Floor Drift (m)	Drift Diff. per floor (m)	Floor Drift (m)	Drift Diff per floor (m)	Floor Drift (m)	Drift Diff. per floor (m)
1	0.00892	0.00892	0.00894	0.00894	0.02718	0.02718	0.01746	0.01746
2	0.01819	0.00927	0.01821	0.00927	0.05406	0.02689	0.03600	0.01854
3	0.02781	0.00961	0.02781	0.00960	0.08068	0.02662	0.05456	0.01856
4	0.03772	0.00991	0.03770	0.00989	0.10700	0.02632	0.07309	0.01854
5	0.04788	0.01017	0.04783	0.01013	0.13296	0.02596	0.09157	0.01848
6	0.05836	0.01047	0.05817	0.01034	0.15862	0.02566	0.11003	0.01846
7	0.06917	0.01082	0.06884	0.01067	0.18402	0.02540	0.12852	0.01849
8	0.08028	0.01111	0.07979	0.01095	0.20910	0.02508	0.14698	0.01846
9	0.09164	0.01136	0.09097	0.01118	0.23382	0.02472	0.16537	0.01839
10	0.10319	0.01155	0.10234	0.01137	0.25814	0.02432	0.18364	0.01827
11	0.11494	0.01175	0.11386	0.01152	0.28204	0.02390	0.20178	0.01814
12	0.12688	0.01194	0.12555	0.01169	0.30553	0.02349	0.21980	0.01802
13	0.13896	0.01208	0.13737	0.01182	0.32854	0.02301	0.23764	0.01784
14	0.15114	0.01218	0.14927	0.01190	0.35105	0.02251	0.25525	0.01761
15	0.16337	0.01223	0.16122	0.01195	0.37301	0.02196	0.27260	0.01735
16	0.17567	0.01230	0.17317	0.01195	0.39442	0.02141	0.28970	0.01710
17	0.18805	0.01238	0.18518	0.01201	0.41530	0.02088	0.30655	0.01685
18	0.20045	0.01240	0.19720	0.01202	0.43560	0.02030	0.32311	0.01656
19	0.21283	0.01238	0.20919	0.01199	0.45528	0.01968	0.33933	0.01622
20	0.22515	0.01232	0.22111	0.01192	0.47429	0.01901	0.35517	0.01584
21	0.23740	0.01225	0.23292	0.01181	0.49261	0.01832	0.37062	0.01545
22	0.24955	0.01215	0.24462	0.01170	0.51023	0.01762	0.38565	0.01503
23	0.26156	0.01201	0.25618	0.01156	0.52711	0.01688	0.40023	0.01458
24	0.27341	0.01185	0.26755	0.01137	0.54321	0.01610	0.41432	0.01409
25	0.28507	0.01166	0.27872	0.01117	0.55851	0.01530	0.42790	0.01358
26	0.29650	0.01143	0.28965	0.01093	0.57299	0.01448	0.44093	0.01303
27	0.30771	0.01121	0.30034	0.01069	0.58663	0.01364	0.45342	0.01249
28	0.31866	0.01095	0.31076	0.01042	0.59940	0.01277	0.46533	0.01191
29	0.32934	0.01068	0.32089	0.01013	0.61130	0.01190	0.47665	0.01132
30	0.33974	0.01040	0.33074	0.00985	0.62231	0.01101	0.48738	0.01073
Max	**0.33974**	**0.01240**	**0.33074**	**0.01202**	**0.62231**	**0.02689**	**0.48738**	**0.01856**

APPENDIX C2: Comparison of 4 different types of bracing: Braced along the center bay and at the top floor

	X-Bracing (B1-1)			Inverted V-Bracing (B2-1)			K-Bracing (B3-1)			Single Diagonal Bracing (B4-1)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00890	0.00003	0.30	0.00894	0.00000	0.00	0.02717	0.00001	0.04	0.01745	0.00002	0.09
2	0.01809	0.00011	0.60	0.01816	0.00005	0.28	0.05402	0.00005	0.09	0.03593	0.00007	0.18
3	0.02756	0.00024	0.88	0.02766	0.00015	0.54	0.08058	0.00010	0.13	0.05441	0.00015	0.27
4	0.03728	0.00044	1.15	0.03740	0.00030	0.80	0.10681	0.00019	0.18	0.07283	0.00026	0.36
5	0.04721	0.00068	1.42	0.04733	0.00050	1.05	0.13267	0.00029	0.22	0.09116	0.00041	0.45
6	0.05737	0.00099	1.69	0.05742	0.00075	1.29	0.15820	0.00042	0.27	0.10943	0.00060	0.55
7	0.06780	0.00137	1.98	0.06777	0.00107	1.56	0.18343	0.00059	0.32	0.12769	0.00083	0.65
8	0.07846	0.00183	2.27	0.07833	0.00146	1.83	0.20832	0.00078	0.37	0.14587	0.00111	0.76
9	0.08928	0.00235	2.57	0.08906	0.00192	2.11	0.23281	0.00101	0.43	0.16394	0.00143	0.87
10	0.10023	0.00296	2.87	0.09991	0.00243	2.38	0.25687	0.00127	0.49	0.18185	0.00179	0.98
11	0.11130	0.00364	3.17	0.11083	0.00303	2.66	0.28048	0.00156	0.55	0.19958	0.00220	1.09
12	0.12247	0.00441	3.48	0.12185	0.00370	2.95	0.30363	0.00190	0.62	0.21712	0.00268	1.22
13	0.13369	0.00527	3.79	0.13291	0.00446	3.25	0.32628	0.00226	0.69	0.23444	0.00320	1.35
14	0.14492	0.00622	4.12	0.14398	0.00529	3.54	0.34839	0.00266	0.76	0.25148	0.00377	1.48
15	0.15612	0.00725	4.44	0.15501	0.00621	3.85	0.36990	0.00311	0.83	0.26821	0.00439	1.61
16	0.16728	0.00839	4.78	0.16597	0.00720	4.16	0.39082	0.00360	0.91	0.28462	0.00508	1.75
17	0.17840	0.00965	5.13	0.17687	0.00831	4.49	0.41117	0.00413	0.99	0.30071	0.00584	1.91
18	0.18942	0.01103	5.50	0.18767	0.00953	4.83	0.43087	0.00473	1.09	0.31643	0.00668	2.07
19	0.20031	0.01252	5.88	0.19833	0.01086	5.19	0.44991	0.00537	1.18	0.33175	0.00758	2.23
20	0.21101	0.01414	6.28	0.20882	0.01229	5.56	0.46822	0.00607	1.28	0.34661	0.00856	2.41
21	0.22151	0.01589	6.69	0.21908	0.01384	5.94	0.48579	0.00682	1.38	0.36100	0.00962	2.60
22	0.23176	0.01779	7.13	0.22909	0.01553	6.35	0.50260	0.00763	1.50	0.37488	0.01077	2.79
23	0.24173	0.01983	7.58	0.23883	0.01735	6.77	0.51860	0.00851	1.61	0.38822	0.01201	3.00
24	0.25139	0.02202	8.05	0.24824	0.01931	7.22	0.53377	0.00944	1.74	0.40099	0.01333	3.22
25	0.26071	0.02436	8.55	0.25732	0.02140	7.68	0.54807	0.01044	1.87	0.41315	0.01475	3.45
26	0.26965	0.02685	9.06	0.26602	0.02363	8.16	0.56147	0.01152	2.01	0.42468	0.01625	3.69
27	0.27818	0.02953	9.60	0.27432	0.02602	8.66	0.57396	0.01267	2.16	0.43555	0.01787	3.94
28	0.28629	0.03237	10.16	0.28219	0.02857	9.19	0.58551	0.01389	2.32	0.44574	0.01959	4.21
29	0.29415	0.03519	10.69	0.28980	0.03109	9.69	0.59629	0.01501	2.46	0.45523	0.02142	4.49
30	0.29432	0.04542	13.37	0.28997	0.04077	12.33	0.59662	0.02569	4.13	0.45545	0.03193	6.55
Max	**0.29432**	**0.04542**	**13.37**	**0.28997**	**0.04077**	**12.33**	**0.59662**	**0.02569**	**4.13**	**0.45545**	**0.03193**	**6.55**

APPENDIX C3: Comparison of 4 different types of bracing: Braced along the center bay and at the 2nd top floor

	X-Bracing (B1-2)			Inverted V-Bracing (B2-2)			K-Bracing (B3-2)			Diagonal-Bracing (B4-2)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00890	0.00003	0.32	0.00894	0.00000	0.00	0.02716	0.00001	0.04	0.01745	0.00002	0.10
2	0.01808	0.00011	0.62	0.01816	0.00005	0.29	0.05401	0.00005	0.09	0.03593	0.00007	0.19
3	0.02755	0.00025	0.91	0.02766	0.00016	0.56	0.08057	0.00011	0.14	0.05440	0.00016	0.29
4	0.03727	0.00045	1.20	0.03739	0.00031	0.83	0.10680	0.00020	0.19	0.07282	0.00028	0.38
5	0.04718	0.00070	1.47	0.04731	0.00052	1.09	0.13265	0.00031	0.23	0.09114	0.00043	0.47
6	0.05733	0.00102	1.76	0.05739	0.00078	1.34	0.15817	0.00045	0.28	0.10940	0.00063	0.57
7	0.06775	0.00142	2.05	0.06773	0.00111	1.62	0.18339	0.00063	0.34	0.12765	0.00087	0.68
8	0.07839	0.00189	2.36	0.07827	0.00152	1.90	0.20827	0.00083	0.40	0.14582	0.00116	0.79
9	0.08919	0.00244	2.67	0.08899	0.00199	2.19	0.23275	0.00107	0.46	0.16387	0.00150	0.91
10	0.10012	0.00307	2.98	0.09981	0.00253	2.47	0.25679	0.00135	0.52	0.18176	0.00188	1.02
11	0.11117	0.00377	3.28	0.11071	0.00315	2.77	0.28038	0.00166	0.59	0.19947	0.00231	1.15
12	0.12231	0.00457	3.60	0.12170	0.00385	3.07	0.30351	0.00202	0.66	0.21699	0.00281	1.28
13	0.13350	0.00546	3.93	0.13274	0.00463	3.37	0.32614	0.00240	0.73	0.23428	0.00336	1.41
14	0.14469	0.00645	4.27	0.14378	0.00549	3.68	0.34822	0.00283	0.81	0.25130	0.00395	1.55
15	0.15585	0.00752	4.60	0.15477	0.00645	4.00	0.36970	0.00331	0.89	0.26799	0.00461	1.69
16	0.16697	0.00870	4.95	0.16569	0.00748	4.32	0.39060	0.00382	0.97	0.28437	0.00533	1.84
17	0.17804	0.01001	5.32	0.17655	0.00863	4.66	0.41090	0.00440	1.06	0.30042	0.00613	2.00
18	0.18901	0.01144	5.71	0.18730	0.00990	5.02	0.43058	0.00502	1.15	0.31610	0.00701	2.17
19	0.19984	0.01299	6.10	0.19791	0.01128	5.39	0.44957	0.00571	1.25	0.33138	0.00795	2.34
20	0.21049	0.01466	6.51	0.20834	0.01277	5.78	0.46784	0.00645	1.36	0.34619	0.00898	2.53
21	0.22092	0.01648	6.94	0.21854	0.01438	6.17	0.48536	0.00725	1.47	0.36053	0.01009	2.72
22	0.23110	0.01845	7.39	0.22849	0.01613	6.59	0.50212	0.00811	1.59	0.37435	0.01130	2.93
23	0.24099	0.02057	7.86	0.23815	0.01803	7.04	0.51807	0.00904	1.72	0.38763	0.01260	3.15
24	0.25057	0.02284	8.35	0.24749	0.02006	7.50	0.53317	0.01004	1.85	0.40033	0.01399	3.38
25	0.25980	0.02527	8.86	0.25649	0.02223	7.98	0.54741	0.01110	1.99	0.41242	0.01548	3.62
26	0.26865	0.02785	9.39	0.26510	0.02455	8.48	0.56074	0.01225	2.14	0.42388	0.01705	3.87
27	0.27708	0.03063	9.95	0.27331	0.02703	9.00	0.57316	0.01347	2.30	0.43467	0.01875	4.14
28	0.28529	0.03337	10.47	0.28127	0.02949	9.49	0.58482	0.01458	2.43	0.44477	0.02056	4.42
29	0.28554	0.04380	13.30	0.28152	0.03937	12.27	0.58544	0.02586	4.23	0.44518	0.03147	6.60
30	0.29303	0.04671	13.75	0.28875	0.04199	12.70	0.59526	0.02705	4.35	0.45402	0.03336	6.85
Max	**0.29303**	**0.04671**	**13.75**	**0.28875**	**0.04199**	**12.70**	**0.59526**	**0.02705**	**4.35**	**0.45402**	**0.03336**	**6.85**

APPENDIX C4: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th floor

	X-Bracing (B1-3)			Inverted V-Bracing (B2-3)			K-Bracing (B3-3)			Diagonal-Bracing (B4-3)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00889	0.00004	0.41	0.00894	0.00000	0.00	0.02716	0.00002	0.07	0.01744	0.00003	0.14
2	0.01805	0.00015	0.81	0.01814	0.00007	0.38	0.05398	0.00008	0.15	0.03590	0.00010	0.28
3	0.02748	0.00033	1.19	0.02761	0.00021	0.74	0.08050	0.00019	0.23	0.05433	0.00023	0.42
4	0.03713	0.00059	1.56	0.03729	0.00041	1.10	0.10667	0.00033	0.31	0.07269	0.00041	0.56
5	0.04697	0.00092	1.92	0.04715	0.00069	1.44	0.13244	0.00052	0.39	0.09093	0.00064	0.70
6	0.05702	0.00133	2.28	0.05714	0.00103	1.77	0.15787	0.00075	0.47	0.10910	0.00093	0.85
7	0.06732	0.00185	2.67	0.06737	0.00147	2.13	0.18298	0.00104	0.57	0.12723	0.00129	1.00
8	0.07782	0.00247	3.07	0.07779	0.00200	2.50	0.20771	0.00139	0.67	0.14526	0.00172	1.17
9	0.08846	0.00318	3.47	0.08835	0.00262	2.88	0.23203	0.00179	0.77	0.16315	0.00222	1.34
10	0.09920	0.00399	3.87	0.09901	0.00333	3.26	0.25589	0.00225	0.87	0.18086	0.00278	1.51
11	0.11003	0.00491	4.27	0.10971	0.00415	3.65	0.27927	0.00277	0.98	0.19836	0.00342	1.70
12	0.12092	0.00596	4.70	0.12048	0.00507	4.04	0.30217	0.00336	1.10	0.21565	0.00415	1.89
13	0.13184	0.00712	5.12	0.13127	0.00610	4.44	0.32453	0.00401	1.22	0.23268	0.00496	2.09
14	0.14302	0.00812	5.37	0.14229	0.00698	4.68	0.34663	0.00442	1.26	0.24940	0.00585	2.29
15	0.14432	0.01905	11.66	0.14367	0.01755	10.89	0.35127	0.02174	5.83	0.25246	0.02014	7.39
16	0.15550	0.02017	11.48	0.15462	0.01855	10.71	0.37220	0.02222	5.63	0.26860	0.02110	7.28
17	0.16648	0.02157	11.47	0.16538	0.01980	10.69	0.39230	0.02300	5.54	0.28448	0.02207	7.20
18	0.17748	0.02297	11.46	0.17615	0.02105	10.67	0.41181	0.02379	5.46	0.30007	0.02304	7.13
19	0.18846	0.02437	11.45	0.18689	0.02230	10.66	0.43070	0.02458	5.40	0.31532	0.02401	7.08
20	0.19939	0.02576	11.44	0.19755	0.02356	10.66	0.44892	0.02537	5.35	0.33019	0.02498	7.03
21	0.21024	0.02716	11.44	0.20811	0.02481	10.65	0.46646	0.02615	5.31	0.34467	0.02595	7.00
22	0.22099	0.02856	11.45	0.21856	0.02606	10.65	0.48329	0.02694	5.28	0.35873	0.02692	6.98
23	0.23161	0.02995	11.45	0.22886	0.02732	10.66	0.49938	0.02773	5.26	0.37233	0.02790	6.97
24	0.24206	0.03135	11.47	0.23899	0.02856	10.68	0.51470	0.02851	5.25	0.38545	0.02887	6.97
25	0.25232	0.03275	11.49	0.24890	0.02982	10.70	0.52921	0.02930	5.25	0.39805	0.02985	6.98
26	0.26236	0.03414	11.51	0.25858	0.03107	10.73	0.54290	0.03009	5.25	0.41012	0.03081	6.99
27	0.27217	0.03554	11.55	0.26801	0.03233	10.76	0.55575	0.03088	5.26	0.42163	0.03179	7.01
28	0.28172	0.03694	11.59	0.27718	0.03358	10.81	0.56774	0.03166	5.28	0.43257	0.03276	7.04
29	0.29101	0.03833	11.64	0.28606	0.03483	10.85	0.57885	0.03245	5.31	0.44292	0.03373	7.08
30	0.30001	0.03973	11.69	0.29465	0.03609	10.91	0.58907	0.03324	5.34	0.45267	0.03471	7.12
Max	**0.30001**	**0.03973**	**11.69**	**0.29465**	**0.03609**	**10.91**	**0.58907**	**0.03324**	**5.34**	**0.45267**	**0.03471**	**7.12**

APPENDIX C5: Comparison of 4 different types of bracing: Braced along the center bay and at the 1st floor

	X-Bracing (B1-4)			Inverted V-Bracing (B2-4)			K-Bracing (B3-4)			Diagonal-Bracing (B4-4)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00277	0.00616	68.97	0.00289	0.00605	67.71	0.00008	0.02709	99.70	0.00530	0.01216	69.63
2	0.01218	0.00601	33.04	0.01233	0.00588	32.29	0.02746	0.02660	49.21	0.02374	0.01226	34.06
3	0.02177	0.00604	21.71	0.02193	0.00588	21.14	0.05405	0.02664	33.01	0.04227	0.01228	22.52
4	0.03166	0.00606	16.07	0.03182	0.00588	15.60	0.08033	0.02667	24.93	0.06079	0.01231	16.84
5	0.04180	0.00609	12.71	0.04195	0.00588	12.29	0.10626	0.02670	20.08	0.07924	0.01233	13.47
6	0.05224	0.00611	10.47	0.05229	0.00588	10.11	0.13188	0.02674	16.86	0.09767	0.01236	11.23
7	0.06304	0.00614	8.87	0.06296	0.00588	8.54	0.15724	0.02678	14.55	0.11614	0.01238	9.63
8	0.07412	0.00616	7.67	0.07391	0.00588	7.37	0.18229	0.02681	12.82	0.13457	0.01241	8.44
9	0.08545	0.00619	6.75	0.08509	0.00588	6.46	0.20698	0.02684	11.48	0.15294	0.01243	7.52
10	0.09698	0.00621	6.02	0.09647	0.00588	5.74	0.23126	0.02688	10.41	0.17118	0.01246	6.79
11	0.10871	0.00623	5.42	0.10798	0.00588	5.16	0.25513	0.02691	9.54	0.18930	0.01248	6.19
12	0.12062	0.00626	4.93	0.11967	0.00588	4.68	0.27858	0.02695	8.82	0.20729	0.01251	5.69
13	0.13268	0.00628	4.52	0.13149	0.00588	4.28	0.30156	0.02698	8.21	0.22510	0.01254	5.28
14	0.14483	0.00631	4.18	0.14339	0.00588	3.94	0.32404	0.02701	7.69	0.24269	0.01256	4.92
15	0.15704	0.00633	3.88	0.15534	0.00588	3.65	0.34596	0.02705	7.25	0.26002	0.01258	4.62
16	0.16931	0.00636	3.62	0.16729	0.00588	3.40	0.36734	0.02708	6.87	0.27709	0.01261	4.35
17	0.18166	0.00639	3.40	0.17930	0.00588	3.18	0.38819	0.02711	6.53	0.29392	0.01263	4.12
18	0.19404	0.00641	3.20	0.19132	0.00588	2.98	0.40845	0.02715	6.23	0.31045	0.01266	3.92
19	0.20639	0.00644	3.03	0.20331	0.00588	2.81	0.42809	0.02719	5.97	0.32665	0.01268	3.74
20	0.21869	0.00646	2.87	0.21523	0.00588	2.66	0.44706	0.02723	5.74	0.34247	0.01270	3.58
21	0.23091	0.00649	2.73	0.22704	0.00588	2.52	0.46535	0.02726	5.53	0.35789	0.01273	3.44
22	0.24304	0.00651	2.61	0.23874	0.00588	2.40	0.48294	0.02729	5.35	0.37290	0.01275	3.31
23	0.25503	0.00653	2.50	0.25030	0.00588	2.30	0.49978	0.02733	5.19	0.38745	0.01278	3.19
24	0.26685	0.00656	2.40	0.26167	0.00588	2.20	0.51585	0.02736	5.04	0.40151	0.01281	3.09
25	0.27848	0.00659	2.31	0.27284	0.00588	2.11	0.53112	0.02739	4.90	0.41506	0.01284	3.00
26	0.28989	0.00661	2.23	0.28377	0.00588	2.03	0.54556	0.02743	4.79	0.42808	0.01285	2.91
27	0.30107	0.00664	2.16	0.29446	0.00588	1.96	0.55916	0.02747	4.68	0.44054	0.01288	2.84
28	0.31200	0.00666	2.09	0.30488	0.00588	1.89	0.57190	0.02750	4.59	0.45242	0.01291	2.77
29	0.32265	0.00669	2.03	0.31501	0.00588	1.83	0.58377	0.02753	4.50	0.46372	0.01293	2.71
30	0.33303	0.00671	1.98	0.32486	0.00588	1.78	0.59474	0.02757	4.43	0.47442	0.01296	2.66
Max	**0.33303**	**0.00671**	**68.97**	**0.32486**	**0.00605**	**67.71**	**0.59474**	**0.02757**	**99.70**	**0.47442**	**0.01296**	**69.63**

APPENDIX C6: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 30th floors

	X-Bracing (B1-5)			Inverted V-Bracing (B2-5)			K-Bracing (B3-5)			Diagonal-Bracing (B4-5)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00887	0.00006	0.64	0.00894	0.00000	0.00	0.02715	0.00003	0.11	0.01742	0.00004	0.22
2	0.01797	0.00023	1.25	0.01810	0.00011	0.59	0.05394	0.00012	0.23	0.03584	0.00016	0.44
3	0.02730	0.00051	1.83	0.02749	0.00032	1.15	0.08041	0.00028	0.34	0.05420	0.00035	0.65
4	0.03681	0.00091	2.41	0.03706	0.00064	1.70	0.10650	0.00050	0.47	0.07247	0.00063	0.86
5	0.04647	0.00142	2.96	0.04677	0.00106	2.22	0.13219	0.00077	0.58	0.09059	0.00098	1.07
6	0.05629	0.00206	3.53	0.05657	0.00160	2.75	0.15750	0.00112	0.71	0.10860	0.00143	1.30
7	0.06631	0.00286	4.14	0.06657	0.00227	3.30	0.18246	0.00156	0.85	0.12654	0.00198	1.54
8	0.07647	0.00381	4.75	0.07670	0.00310	3.88	0.20703	0.00207	0.99	0.14434	0.00264	1.80
9	0.08672	0.00492	5.37	0.08691	0.00406	4.46	0.23115	0.00267	1.14	0.16197	0.00340	2.06
10	0.09701	0.00618	5.99	0.09717	0.00517	5.05	0.25478	0.00336	1.30	0.17936	0.00428	2.33
11	0.10734	0.00760	6.61	0.10743	0.00643	5.65	0.27791	0.00413	1.46	0.19652	0.00526	2.61
12	0.11767	0.00921	7.26	0.11770	0.00785	6.25	0.30051	0.00502	1.64	0.21342	0.00638	2.90
13	0.12795	0.01101	7.92	0.12792	0.00945	6.88	0.32256	0.00598	1.82	0.23002	0.00762	3.21
14	0.13840	0.01274	8.43	0.13829	0.01098	7.36	0.34429	0.00676	1.93	0.24626	0.00899	3.52
15	0.13983	0.02354	14.41	0.13977	0.02145	13.31	0.34898	0.02403	6.44	0.24940	0.02320	8.51
16	0.15012	0.02555	14.54	0.14994	0.02323	13.42	0.36948	0.02494	6.32	0.26496	0.02474	8.54
17	0.16014	0.02791	14.84	0.15984	0.02534	13.68	0.38910	0.02620	6.31	0.28019	0.02636	8.60
18	0.17009	0.03036	15.15	0.16966	0.02754	13.97	0.40809	0.02751	6.32	0.29507	0.02804	8.68
19	0.17991	0.03292	15.47	0.17935	0.02984	14.27	0.42640	0.02888	6.34	0.30955	0.02978	8.78
20	0.18957	0.03558	15.80	0.18887	0.03224	14.58	0.44401	0.03028	6.38	0.32358	0.03159	8.89
21	0.19903	0.03837	16.16	0.19819	0.03473	14.91	0.46087	0.03174	6.44	0.33714	0.03348	9.03
22	0.20828	0.04127	16.54	0.20728	0.03734	15.26	0.47698	0.03325	6.52	0.35021	0.03544	9.19
23	0.21726	0.04430	16.94	0.21611	0.04007	15.64	0.49228	0.03483	6.61	0.36274	0.03749	9.37
24	0.22595	0.04746	17.36	0.22464	0.04291	16.04	0.50676	0.03645	6.71	0.37471	0.03961	9.56
25	0.23432	0.05075	17.80	0.23284	0.04588	16.46	0.52037	0.03814	6.83	0.38608	0.04182	9.77
26	0.24234	0.05416	18.27	0.24069	0.04896	16.90	0.53309	0.03990	6.96	0.39682	0.04411	10.00
27	0.24997	0.05774	18.76	0.24815	0.05219	17.38	0.54491	0.04172	7.11	0.40692	0.04650	10.26
28	0.25719	0.06147	19.29	0.25521	0.05555	17.88	0.55579	0.04361	7.28	0.41635	0.04898	10.53
29	0.26417	0.06517	19.79	0.26200	0.05889	18.35	0.56589	0.04541	7.43	0.42510	0.05155	10.82
30	0.26448	0.07526	22.15	0.26229	0.06845	20.70	0.56630	0.05601	9.00	0.42542	0.06196	12.71
Max	**0.26448**	**0.07526**	**22.15**	**0.26229**	**0.06845**	**20.70**	**0.56630**	**0.05601**	**9.00**	**0.42542**	**0.06196**	**12.71**

APPENDIX C7: Comparison of 4 different types of bracing: Braced along the center bay and at the 14th and 30th floors

	X-Bracing (B1-6)			Inverted V-Bracing (B2-6)			K-Bracing (B3-6)			Diagonal-Bracing (B4-6)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00887	0.00006	0.64	0.00894	0.00000	0.00	0.02715	0.00003	0.11	0.01742	0.00004	0.23
2	0.01797	0.00023	1.26	0.01810	0.00011	0.59	0.05394	0.00013	0.23	0.03584	0.00016	0.44
3	0.02729	0.00051	1.85	0.02749	0.00032	1.16	0.08040	0.00028	0.35	0.05420	0.00036	0.66
4	0.03680	0.00092	2.43	0.03706	0.00064	1.71	0.10650	0.00050	0.47	0.07246	0.00064	0.87
5	0.04646	0.00143	2.98	0.04676	0.00107	2.24	0.13218	0.00078	0.59	0.09058	0.00099	1.09
6	0.05628	0.00208	3.56	0.05656	0.00161	2.77	0.15748	0.00114	0.72	0.10859	0.00144	1.31
7	0.06629	0.00288	4.17	0.06655	0.00229	3.33	0.18244	0.00158	0.86	0.12652	0.00200	1.56
8	0.07644	0.00384	4.79	0.07667	0.00312	3.91	0.20700	0.00210	1.00	0.14431	0.00267	1.82
9	0.08668	0.00496	5.41	0.08688	0.00409	4.50	0.23111	0.00271	1.16	0.16192	0.00345	2.09
10	0.09697	0.00622	6.03	0.09713	0.00521	5.09	0.25473	0.00341	1.32	0.17931	0.00433	2.36
11	0.10728	0.00766	6.66	0.10738	0.00648	5.69	0.27784	0.00420	1.49	0.19646	0.00532	2.64
12	0.11759	0.00929	7.32	0.11764	0.00791	6.30	0.30043	0.00510	1.67	0.21334	0.00646	2.94
13	0.12812	0.01084	7.80	0.12808	0.00929	6.76	0.32277	0.00577	1.76	0.22992	0.00772	3.25
14	0.12962	0.02152	14.24	0.12965	0.01962	13.14	0.32774	0.02331	6.64	0.23324	0.02201	8.62
15	0.14003	0.02334	14.29	0.13997	0.02125	13.18	0.34887	0.02414	6.47	0.24917	0.02343	8.60
16	0.15017	0.02550	14.52	0.14999	0.02318	13.39	0.36912	0.02530	6.41	0.26478	0.02492	8.60
17	0.16027	0.02778	14.77	0.15998	0.02520	13.61	0.38879	0.02651	6.38	0.28008	0.02647	8.64
18	0.17030	0.03015	15.04	0.16988	0.02732	13.85	0.40782	0.02778	6.38	0.29502	0.02809	8.69
19	0.18021	0.03262	15.33	0.17965	0.02954	14.12	0.42618	0.02910	6.39	0.30955	0.02978	8.78
20	0.18995	0.03520	15.63	0.18926	0.03185	14.41	0.44383	0.03046	6.42	0.32364	0.03153	8.88
21	0.19950	0.03790	15.97	0.19865	0.03427	14.71	0.46075	0.03186	6.47	0.33726	0.03336	9.00
22	0.20883	0.04072	16.32	0.20782	0.03680	15.04	0.47690	0.03333	6.53	0.35039	0.03526	9.14
23	0.21789	0.04367	16.70	0.21673	0.03945	15.40	0.49225	0.03486	6.61	0.36298	0.03725	9.31
24	0.22666	0.04675	17.10	0.22533	0.04222	15.78	0.50677	0.03644	6.71	0.37500	0.03932	9.49
25	0.23511	0.04996	17.53	0.23360	0.04512	16.19	0.52042	0.03809	6.82	0.38643	0.04147	9.69
26	0.24320	0.05330	17.98	0.24153	0.04812	16.61	0.53319	0.03980	6.95	0.39723	0.04370	9.91
27	0.25090	0.05681	18.46	0.24906	0.05128	17.07	0.54505	0.04158	7.09	0.40738	0.04604	10.15
28	0.25820	0.06046	18.97	0.25618	0.05458	17.56	0.55598	0.04342	7.24	0.41687	0.04846	10.41
29	0.26525	0.06409	19.46	0.26305	0.05784	18.03	0.56612	0.04518	7.39	0.42567	0.05098	10.70
30	0.26554	0.07420	21.84	0.26333	0.06741	20.38	0.56653	0.05578	8.96	0.42598	0.06140	12.60
Max	**0.26554**	**0.07420**	**21.84**	**0.26333**	**0.06741**	**20.38**	**0.56653**	**0.05578**	**8.96**	**0.42598**	**0.06140**	**12.60**

APPENDIX C8: Comparison of 4 different types of bracing: Braced along the center bay and at the 16th and 30th floors

	X-Bracing (B1-7)			Inverted V-Bracing (B2-7)			K-Bracing (B3-7)			Diagonal-Bracing (B4-7)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00887	0.00006	0.63	0.00894	0.00000	0.00	0.02715	0.00003	0.11	0.01742	0.00004	0.22
2	0.01797	0.00023	1.24	0.01811	0.00011	0.58	0.05394	0.00012	0.22	0.03584	0.00016	0.43
3	0.02730	0.00051	1.82	0.02750	0.00032	1.14	0.08041	0.00027	0.34	0.05421	0.00035	0.64
4	0.03682	0.00090	2.38	0.03707	0.00063	1.68	0.10651	0.00049	0.46	0.07247	0.00062	0.85
5	0.04648	0.00141	2.93	0.04678	0.00105	2.20	0.13220	0.00076	0.57	0.09060	0.00097	1.06
6	0.05631	0.00204	3.50	0.05659	0.00158	2.72	0.15752	0.00110	0.69	0.10862	0.00141	1.28
7	0.06634	0.00283	4.10	0.06659	0.00225	3.27	0.18249	0.00153	0.83	0.12656	0.00196	1.53
8	0.07650	0.00378	4.71	0.07673	0.00307	3.84	0.20706	0.00204	0.98	0.14438	0.00260	1.77
9	0.08676	0.00487	5.32	0.08695	0.00402	4.42	0.23119	0.00263	1.13	0.16201	0.00336	2.03
10	0.09707	0.00612	5.93	0.09722	0.00512	5.00	0.25483	0.00331	1.28	0.17942	0.00422	2.30
11	0.10741	0.00753	6.55	0.10750	0.00636	5.59	0.27797	0.00407	1.44	0.19659	0.00519	2.57
12	0.11775	0.00913	7.20	0.11777	0.00778	6.20	0.30060	0.00493	1.61	0.21350	0.00630	2.87
13	0.12805	0.01091	7.85	0.12801	0.00936	6.81	0.32266	0.00588	1.79	0.23011	0.00753	3.17
14	0.13827	0.01287	8.52	0.13816	0.01111	7.44	0.34411	0.00694	1.98	0.24638	0.00887	3.48
15	0.14862	0.01475	9.03	0.14842	0.01280	7.94	0.36520	0.00781	2.09	0.26225	0.01035	3.80
16	0.14997	0.02570	14.63	0.14982	0.02335	13.48	0.36960	0.02482	6.29	0.26520	0.02450	8.46
17	0.16013	0.02792	14.85	0.15988	0.02530	13.66	0.38946	0.02584	6.22	0.28038	0.02617	8.54
18	0.16997	0.03048	15.21	0.16962	0.02758	13.99	0.40840	0.02720	6.24	0.29519	0.02792	8.64
19	0.17969	0.03314	15.57	0.17923	0.02996	14.32	0.42666	0.02862	6.29	0.30959	0.02974	8.76
20	0.18925	0.03590	15.95	0.18868	0.03243	14.67	0.44421	0.03008	6.34	0.32355	0.03162	8.90
21	0.19862	0.03878	16.34	0.19792	0.03500	15.03	0.46102	0.03159	6.41	0.33705	0.03357	9.06
22	0.20777	0.04178	16.74	0.20693	0.03769	15.41	0.47707	0.03316	6.50	0.35005	0.03560	9.23
23	0.21666	0.04490	17.17	0.21569	0.04049	15.81	0.49232	0.03479	6.60	0.36251	0.03772	9.43
24	0.22526	0.04815	17.61	0.22415	0.04340	16.22	0.50674	0.03647	6.71	0.37441	0.03991	9.63
25	0.23354	0.05153	18.08	0.23228	0.04644	16.66	0.52030	0.03821	6.84	0.38571	0.04219	9.86
26	0.24146	0.05504	18.56	0.24006	0.04959	17.12	0.53298	0.04001	6.98	0.39640	0.04453	10.10
27	0.24901	0.05870	19.08	0.24745	0.05289	17.61	0.54474	0.04189	7.14	0.40643	0.04699	10.36
28	0.25615	0.06251	19.62	0.25445	0.05631	18.12	0.55557	0.04383	7.31	0.41580	0.04953	10.64
29	0.26305	0.06629	20.13	0.26118	0.05971	18.61	0.56562	0.04568	7.47	0.42448	0.05217	10.95
30	0.26337	0.07637	22.48	0.26147	0.06927	20.94	0.56604	0.05627	9.04	0.42481	0.06257	12.84
Max	**0.26337**	**0.07637**	**22.48**	**0.26147**	**0.06927**	**20.94**	**0.56604**	**0.05627**	**9.04**	**0.42481**	**0.06257**	**12.84**

APPENDIX C9: Comparison of 4 different types of bracing: Braced along the center bay and at the 16 &17th and 30th floors

	X-Bracing (B1-8)			Inverted V-Bracing (B2-8)			K-Bracing (B3-8)			Diagonal-Bracing (B4-8)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00884	0.00009	0.99	0.00894	0.00000	0.00	0.02713	0.00005	0.17	0.01741	0.00006	0.33
2	0.01786	0.00033	1.83	0.01806	0.00015	0.81	0.05388	0.00019	0.35	0.03577	0.00023	0.63
3	0.02707	0.00073	2.64	0.02737	0.00044	1.59	0.08026	0.00042	0.52	0.05404	0.00051	0.94
4	0.03643	0.00129	3.42	0.03681	0.00089	2.35	0.10624	0.00076	0.71	0.07218	0.00091	1.25
5	0.04588	0.00200	4.18	0.04635	0.00148	3.09	0.13178	0.00118	0.89	0.09014	0.00143	1.56
6	0.05546	0.00290	4.97	0.05595	0.00222	3.81	0.15691	0.00171	1.08	0.10796	0.00207	1.88
7	0.06516	0.00401	5.79	0.06568	0.00316	4.59	0.18165	0.00237	1.29	0.12564	0.00288	2.24
8	0.07495	0.00533	6.64	0.07549	0.00430	5.38	0.20594	0.00316	1.51	0.14315	0.00383	2.61
9	0.08478	0.00686	7.49	0.08534	0.00564	6.20	0.22975	0.00407	1.74	0.16043	0.00494	2.99
10	0.09459	0.00860	8.34	0.09517	0.00717	7.01	0.25301	0.00513	1.99	0.17743	0.00621	3.38
11	0.10436	0.01058	9.21	0.10494	0.00892	7.83	0.27573	0.00631	2.24	0.19414	0.00764	3.79
12	0.11408	0.01280	10.09	0.11465	0.01090	8.68	0.29788	0.00765	2.50	0.21053	0.00927	4.22
13	0.12368	0.01528	11.00	0.12425	0.01312	9.55	0.31941	0.00913	2.78	0.22657	0.01107	4.66
14	0.13313	0.01801	11.92	0.13370	0.01557	10.43	0.34028	0.01077	3.07	0.24220	0.01305	5.11
15	0.14259	0.02078	12.72	0.14316	0.01806	11.20	0.36072	0.01229	3.30	0.25737	0.01523	5.59
16	0.14423	0.03144	17.90	0.14483	0.02834	16.37	0.36531	0.02911	7.38	0.26052	0.02918	10.07
17	0.14580	0.04225	22.47	0.14642	0.03876	20.93	0.36961	0.04569	11.00	0.26354	0.04301	14.03
18	0.15483	0.04562	22.76	0.15543	0.04177	21.18	0.38805	0.04755	10.92	0.27750	0.04561	14.12
19	0.16354	0.04929	23.16	0.16412	0.04507	21.55	0.40554	0.04974	10.93	0.29106	0.04827	14.23
20	0.17211	0.05304	23.56	0.17266	0.04845	21.91	0.42233	0.05196	10.96	0.30419	0.05098	14.35
21	0.18051	0.05689	23.96	0.18101	0.05191	22.29	0.43838	0.05423	11.01	0.31686	0.05376	14.50
22	0.18870	0.06085	24.38	0.18915	0.05547	22.68	0.45368	0.05655	11.08	0.32905	0.05660	14.68
23	0.19666	0.06490	24.81	0.19704	0.05914	23.09	0.46818	0.05893	11.18	0.34070	0.05953	14.87
24	0.20434	0.06907	25.26	0.20466	0.06289	23.51	0.48186	0.06135	11.29	0.35181	0.06251	15.09
25	0.21172	0.07335	25.73	0.21196	0.06676	23.95	0.49468	0.06383	11.43	0.36232	0.06558	15.33
26	0.21877	0.07773	26.22	0.21893	0.07072	24.42	0.50662	0.06637	11.58	0.37222	0.06871	15.58
27	0.22547	0.08224	26.73	0.22554	0.07480	24.91	0.51766	0.06897	11.76	0.38149	0.07193	15.86
28	0.23178	0.08688	27.26	0.23176	0.07900	25.42	0.52777	0.07163	11.95	0.39009	0.07524	16.17
29	0.23784	0.09150	27.78	0.23772	0.08317	25.92	0.53709	0.07421	12.14	0.39803	0.07862	16.49
30	0.23828	0.10146	29.86	0.23813	0.09261	28.00	0.53760	0.08471	13.61	0.39845	0.08893	18.25
Max	**0.23828**	**0.10146**	**29.86**	**0.23813**	**0.09261**	**28.00**	**0.53760**	**0.08471**	**13.61**	**0.39845**	**0.08893**	**18.25**

APPENDIX C10: Comparison of 4 different types of bracing: Braced along the center bay and at the 15 &16th and 30th floors

	X-Bracing (B1-9)			Inverted V-Bracing (B2-9)			K-Bracing (B3-9)			Diagonal-Bracing (B4-9)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00885	0.00008	0.89	0.00894	0.00000	0.00	0.02713	0.00005	0.18	0.01741	0.00006	0.33
2	0.01788	0.00032	1.75	0.01806	0.00015	0.83	0.05387	0.00019	0.36	0.03577	0.00023	0.65
3	0.02709	0.00072	2.57	0.02736	0.00045	1.62	0.08025	0.00043	0.54	0.05403	0.00053	0.96
4	0.03644	0.00127	3.37	0.03680	0.00090	2.40	0.10623	0.00077	0.72	0.07216	0.00093	1.28
5	0.04590	0.00199	4.15	0.04633	0.00151	3.15	0.13176	0.00120	0.90	0.09011	0.00146	1.59
6	0.05547	0.00289	4.95	0.05591	0.00226	3.88	0.15687	0.00175	1.10	0.10791	0.00212	1.93
7	0.06516	0.00401	5.79	0.06563	0.00321	4.67	0.18159	0.00243	1.32	0.12558	0.00294	2.29
8	0.07494	0.00534	6.66	0.07542	0.00438	5.48	0.20586	0.00324	1.55	0.14307	0.00391	2.66
9	0.08474	0.00689	7.52	0.08523	0.00574	6.31	0.22965	0.00417	1.78	0.16032	0.00505	3.05
10	0.09453	0.00866	8.39	0.09504	0.00730	7.14	0.25289	0.00525	2.03	0.17730	0.00634	3.45
11	0.10428	0.01066	9.27	0.10478	0.00908	7.98	0.27558	0.00646	2.29	0.19398	0.00780	3.87
12	0.11396	0.01292	10.18	0.11445	0.01110	8.84	0.29769	0.00784	2.57	0.21034	0.00946	4.30
13	0.12353	0.01543	11.10	0.12401	0.01336	9.73	0.31919	0.00935	2.85	0.22634	0.01130	4.76
14	0.13315	0.01799	11.90	0.13363	0.01564	10.48	0.34031	0.01074	3.06	0.24192	0.01333	5.22
15	0.13486	0.02851	17.45	0.13537	0.02585	16.03	0.34517	0.02784	7.46	0.24524	0.02736	10.04
16	0.13649	0.03918	22.30	0.13704	0.03613	20.86	0.34975	0.04467	11.33	0.24845	0.04125	14.24
17	0.14577	0.04228	22.48	0.14627	0.03891	21.01	0.36893	0.04637	11.17	0.26288	0.04367	14.25
18	0.15478	0.04567	22.78	0.15523	0.04197	21.28	0.38719	0.04841	11.11	0.27698	0.04613	14.28
19	0.16367	0.04916	23.10	0.16408	0.04511	21.56	0.40479	0.05049	11.09	0.29067	0.04866	14.34
20	0.17242	0.05273	23.42	0.17277	0.04834	21.86	0.42168	0.05261	11.09	0.30393	0.05124	14.43
21	0.18099	0.05641	23.76	0.18126	0.05166	22.18	0.43784	0.05477	11.12	0.31672	0.05390	14.54
22	0.18936	0.06019	24.12	0.18955	0.05507	22.51	0.45324	0.05699	11.17	0.32903	0.05662	14.68
23	0.19748	0.06408	24.50	0.19758	0.05860	22.88	0.46785	0.05926	11.24	0.34081	0.05942	14.85
24	0.20533	0.06808	24.90	0.20534	0.06221	23.25	0.48163	0.06158	11.34	0.35204	0.06228	15.03
25	0.21287	0.07220	25.33	0.21278	0.06594	23.66	0.49455	0.06396	11.45	0.36267	0.06523	15.24
26	0.22008	0.07642	25.77	0.21988	0.06977	24.09	0.50659	0.06640	11.59	0.37269	0.06824	15.48
27	0.22692	0.08079	26.26	0.22662	0.07372	24.55	0.51773	0.06890	11.75	0.38208	0.07134	15.73
28	0.23338	0.08528	26.76	0.23297	0.07779	25.03	0.52794	0.07146	11.92	0.39080	0.07453	16.02
29	0.23959	0.08975	27.25	0.23906	0.08183	25.50	0.53736	0.07394	12.10	0.39885	0.07780	16.32
30	0.24001	0.09973	29.36	0.23945	0.09129	27.60	0.53786	0.08445	13.57	0.39926	0.08812	18.08
Max	**0.24001**	**0.09973**	**29.36**	**0.23945**	**0.09129**	**27.60**	**0.53786**	**0.08445**	**13.57**	**0.39926**	**0.08812**	**18.08**

APPENDIX C11: Comparison of 4 different types of bracing: Braced along the center bay and at the 14 &15th and 30th floors

	X-Bracing (B1-10)			Inverted V-Bracing (B2-10)			K-Bracing (B3-10)			Diagonal-Bracing (B4-10)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00884	0.00008	0.90	0.00894	0.00000	0.00	0.02713	0.00005	0.18	0.01740	0.00006	0.34
2	0.01787	0.00032	1.78	0.01806	0.00015	0.84	0.05387	0.00020	0.36	0.03576	0.00024	0.66
3	0.02708	0.00073	2.62	0.02735	0.00046	1.65	0.08024	0.00044	0.55	0.05402	0.00054	0.98
4	0.03642	0.00129	3.43	0.03678	0.00092	2.44	0.10621	0.00079	0.74	0.07214	0.00095	1.30
5	0.04587	0.00202	4.22	0.04630	0.00153	3.20	0.13173	0.00123	0.93	0.09009	0.00148	1.62
6	0.05542	0.00294	5.03	0.05588	0.00229	3.94	0.15683	0.00179	1.13	0.10787	0.00216	1.96
7	0.06510	0.00407	5.89	0.06557	0.00327	4.74	0.18153	0.00249	1.35	0.12553	0.00299	2.33
8	0.07485	0.00543	6.76	0.07534	0.00445	5.57	0.20579	0.00331	1.58	0.14299	0.00399	2.72
9	0.08463	0.00700	7.64	0.08514	0.00583	6.41	0.22955	0.00427	1.83	0.16023	0.00514	3.11
10	0.09440	0.00879	8.52	0.09492	0.00742	7.25	0.25277	0.00537	2.08	0.17718	0.00646	3.52
11	0.10411	0.01083	9.42	0.10463	0.00923	8.11	0.27543	0.00661	2.34	0.19383	0.00795	3.94
12	0.11376	0.01312	10.34	0.11427	0.01128	8.98	0.29751	0.00802	2.63	0.21016	0.00964	4.39
13	0.12350	0.01546	11.13	0.12401	0.01336	9.73	0.31927	0.00927	2.82	0.22612	0.01152	4.85
14	0.12528	0.02586	17.11	0.12583	0.02344	15.70	0.32441	0.02664	7.59	0.22963	0.02562	10.04
15	0.12698	0.03639	22.28	0.12757	0.03365	20.87	0.32928	0.04373	11.72	0.23301	0.03959	14.52
16	0.13644	0.03923	22.33	0.13697	0.03620	20.90	0.34913	0.04529	11.48	0.24787	0.04183	14.44
17	0.14566	0.04239	22.54	0.14613	0.03905	21.09	0.36812	0.04718	11.36	0.26243	0.04412	14.39
18	0.15482	0.04563	22.76	0.15522	0.04198	21.29	0.38648	0.04912	11.28	0.27663	0.04648	14.39
19	0.16387	0.04896	23.00	0.16420	0.04499	21.51	0.40417	0.05111	11.23	0.29044	0.04889	14.41
20	0.17277	0.05238	23.26	0.17302	0.04809	21.75	0.42115	0.05314	11.20	0.30381	0.05136	14.46
21	0.18149	0.05591	23.55	0.18164	0.05128	22.02	0.43740	0.05521	11.21	0.31672	0.05390	14.54
22	0.19000	0.05955	23.86	0.19005	0.05457	22.31	0.45289	0.05734	11.24	0.32913	0.05652	14.66
23	0.19826	0.06330	24.20	0.19821	0.05797	22.63	0.46759	0.05952	11.29	0.34102	0.05921	14.79
24	0.20625	0.06716	24.56	0.20608	0.06147	22.98	0.48146	0.06175	11.37	0.35236	0.06196	14.96
25	0.21393	0.07114	24.96	0.21364	0.06508	23.35	0.49447	0.06404	11.47	0.36310	0.06480	15.14
26	0.22127	0.07523	25.37	0.22086	0.06879	23.75	0.50660	0.06639	11.59	0.37323	0.06770	15.35
27	0.22824	0.07947	25.83	0.22771	0.07263	24.18	0.51782	0.06881	11.73	0.38271	0.07071	15.60
28	0.23483	0.08383	26.31	0.23416	0.07660	24.65	0.52812	0.07128	11.89	0.39154	0.07379	15.86
29	0.24117	0.08817	26.77	0.24036	0.08053	25.10	0.53763	0.07367	12.05	0.39969	0.07696	16.15
30	0.24157	0.09817	28.90	0.24073	0.09001	27.22	0.53811	0.08420	13.53	0.40008	0.08730	17.91
Max	**0.24157**	**0.09817**	**28.90**	**0.24073**	**0.09001**	**27.22**	**0.53811**	**0.08420**	**13.53**	**0.40008**	**0.08730**	**17.91**

APPENDIX C12: Comparison of 4 different types of bracing: Braced along the center bay and at the 29th and 30th floors

	X-Bracing (B1-11)			Inverted V-Bracing (B2-11)			K-Bracing (B3-11)			Diagonal-Bracing (B4-11)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00888	0.00004	0.47	0.00894	0.00000	0.00	0.02716	0.00002	0.08	0.01744	0.00003	0.16
2	0.01803	0.00017	0.92	0.01813	0.00008	0.43	0.05398	0.00009	0.16	0.03589	0.00011	0.31
3	0.02743	0.00038	1.36	0.02758	0.00024	0.85	0.08049	0.00019	0.24	0.05430	0.00025	0.46
4	0.03705	0.00067	1.78	0.03723	0.00047	1.25	0.10666	0.00034	0.32	0.07264	0.00045	0.62
5	0.04684	0.00105	2.19	0.04705	0.00078	1.64	0.13243	0.00053	0.40	0.09087	0.00070	0.77
6	0.05683	0.00152	2.61	0.05699	0.00118	2.02	0.15784	0.00078	0.49	0.10901	0.00102	0.93
7	0.06706	0.00211	3.05	0.06717	0.00167	2.43	0.18294	0.00108	0.59	0.12710	0.00142	1.11
8	0.07747	0.00281	3.51	0.07751	0.00228	2.86	0.20767	0.00143	0.68	0.14509	0.00189	1.29
9	0.08801	0.00363	3.96	0.08798	0.00299	3.29	0.23197	0.00185	0.79	0.16293	0.00244	1.48
10	0.09863	0.00456	4.42	0.09854	0.00380	3.72	0.25581	0.00233	0.90	0.18058	0.00306	1.67
11	0.10933	0.00561	4.88	0.10913	0.00473	4.15	0.27917	0.00287	1.02	0.19802	0.00376	1.86
12	0.12008	0.00680	5.36	0.11977	0.00578	4.60	0.30205	0.00348	1.14	0.21524	0.00456	2.08
13	0.13084	0.00812	5.84	0.13041	0.00696	5.07	0.32439	0.00415	1.26	0.23219	0.00545	2.29
14	0.14156	0.00958	6.34	0.14101	0.00826	5.53	0.34616	0.00489	1.39	0.24882	0.00643	2.52
15	0.15219	0.01118	6.84	0.15153	0.00969	6.01	0.36730	0.00571	1.53	0.26511	0.00749	2.75
16	0.16274	0.01293	7.36	0.16192	0.01125	6.50	0.38782	0.00660	1.67	0.28103	0.00867	2.99
17	0.17317	0.01488	7.91	0.17220	0.01298	7.01	0.40771	0.00759	1.83	0.29658	0.00997	3.25
18	0.18345	0.01700	8.48	0.18232	0.01488	7.55	0.42692	0.00868	1.99	0.31172	0.01139	3.53
19	0.19352	0.01931	9.07	0.19223	0.01696	8.11	0.44542	0.00986	2.17	0.32640	0.01293	3.81
20	0.20335	0.02180	9.68	0.20191	0.01920	8.68	0.46315	0.01114	2.35	0.34057	0.01460	4.11
21	0.21290	0.02450	10.32	0.21129	0.02163	9.29	0.48010	0.01251	2.54	0.35421	0.01641	4.43
22	0.22213	0.02742	10.99	0.22036	0.02426	9.92	0.49622	0.01401	2.75	0.36728	0.01837	4.76
23	0.23099	0.03057	11.69	0.22907	0.02711	10.58	0.51149	0.01562	2.96	0.37975	0.02048	5.12
24	0.23946	0.03395	12.42	0.23739	0.03016	11.27	0.52587	0.01734	3.19	0.39158	0.02274	5.49
25	0.24751	0.03756	13.18	0.24529	0.03343	11.99	0.53933	0.01918	3.43	0.40274	0.02516	5.88
26	0.25510	0.04140	13.96	0.25274	0.03691	12.74	0.55184	0.02115	3.69	0.41320	0.02773	6.29
27	0.26219	0.04552	14.79	0.25969	0.04065	13.54	0.56338	0.02325	3.96	0.42293	0.03049	6.72
28	0.26890	0.04976	15.62	0.26628	0.04448	14.31	0.57408	0.02532	4.22	0.43190	0.03343	7.18
29	0.26949	0.05985	18.17	0.26684	0.05405	16.84	0.57487	0.03643	5.96	0.43253	0.04412	9.26
30	0.27003	0.06971	20.52	0.26734	0.06340	19.17	0.57539	0.04692	7.54	0.43304	0.05434	11.15
Max	**0.27003**	**0.06971**	**20.52**	**0.26734**	**0.06340**	**19.17**	**0.57539**	**0.04692**	**7.54**	**0.43304**	**0.05434**	**11.15**

APPENDIX C13: Comparison of 4 different types of bracing: Braced along the center bay and at the 15th and 16th floors

	X-Bracing (B1-12)			Inverted V-Bracing (B2-12)			K-Bracing (B3-12)			Diagonal-Bracing (B4-12)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00886	0.00006	0.72	0.00894	0.00000	0.00	0.02714	0.00004	0.14	0.01742	0.00005	0.27
2	0.01794	0.00026	1.42	0.01809	0.00012	0.67	0.05391	0.00016	0.29	0.03581	0.00019	0.52
3	0.02722	0.00058	2.09	0.02745	0.00037	1.32	0.08033	0.00035	0.44	0.05413	0.00042	0.77
4	0.03668	0.00104	2.74	0.03697	0.00073	1.94	0.10637	0.00063	0.59	0.07234	0.00075	1.03
5	0.04627	0.00162	3.38	0.04661	0.00122	2.55	0.13198	0.00098	0.74	0.09040	0.00117	1.28
6	0.05601	0.00235	4.03	0.05634	0.00183	3.14	0.15719	0.00143	0.90	0.10833	0.00170	1.55
7	0.06591	0.00326	4.71	0.06624	0.00260	3.78	0.18203	0.00199	1.08	0.12616	0.00236	1.84
8	0.07594	0.00435	5.41	0.07624	0.00355	4.44	0.20645	0.00265	1.27	0.14383	0.00315	2.14
9	0.08603	0.00561	6.12	0.08632	0.00465	5.11	0.23041	0.00341	1.46	0.16131	0.00406	2.46
10	0.09615	0.00704	6.82	0.09642	0.00592	5.78	0.25385	0.00429	1.66	0.17854	0.00510	2.78
11	0.10627	0.00867	7.54	0.10650	0.00736	6.46	0.27676	0.00528	1.87	0.19550	0.00628	3.11
12	0.11637	0.01051	8.28	0.11656	0.00899	7.16	0.29912	0.00641	2.10	0.21219	0.00761	3.46
13	0.12641	0.01255	9.03	0.12654	0.01083	7.88	0.32089	0.00765	2.33	0.22854	0.00910	3.83
14	0.13657	0.01457	9.64	0.13665	0.01262	8.45	0.34232	0.00873	2.49	0.24452	0.01073	4.20
15	0.13820	0.02517	15.41	0.13833	0.02289	14.20	0.34715	0.02586	6.93	0.24779	0.02481	9.10
16	0.13975	0.03592	20.45	0.13991	0.03326	19.21	0.35169	0.04273	10.83	0.25094	0.03876	13.38
17	0.14977	0.03828	20.36	0.14983	0.03535	19.09	0.37128	0.04402	10.60	0.26592	0.04063	13.25
18	0.15958	0.04087	20.39	0.15953	0.03767	19.10	0.39001	0.04559	10.47	0.28060	0.04251	13.16
19	0.16938	0.04345	20.42	0.16920	0.03999	19.12	0.40811	0.04717	10.36	0.29495	0.04438	13.08
20	0.17911	0.04604	20.45	0.17880	0.04231	19.14	0.42554	0.04875	10.28	0.30893	0.04624	13.02
21	0.18877	0.04863	20.48	0.18828	0.04464	19.17	0.44229	0.05032	10.22	0.32250	0.04812	12.98
22	0.19833	0.05122	20.53	0.19766	0.04696	19.20	0.45833	0.05190	10.17	0.33566	0.04999	12.96
23	0.20776	0.05380	20.57	0.20690	0.04928	19.24	0.47364	0.05347	10.14	0.34837	0.05186	12.96
24	0.21703	0.05638	20.62	0.21595	0.05160	19.29	0.48816	0.05505	10.13	0.36059	0.05373	12.97
25	0.22609	0.05898	20.69	0.22479	0.05393	19.35	0.50189	0.05662	10.14	0.37229	0.05561	13.00
26	0.23494	0.06156	20.76	0.23340	0.05625	19.42	0.51479	0.05820	10.16	0.38346	0.05747	13.03
27	0.24356	0.06415	20.85	0.24177	0.05857	19.50	0.52685	0.05978	10.19	0.39407	0.05935	13.09
28	0.25192	0.06674	20.94	0.24986	0.06090	19.60	0.53805	0.06135	10.24	0.40411	0.06122	13.16
29	0.26002	0.06932	21.05	0.25768	0.06321	19.70	0.54837	0.06293	10.29	0.41356	0.06309	13.24
30	0.26783	0.07191	21.17	0.26520	0.06554	19.82	0.55781	0.06450	10.37	0.42241	0.06497	13.33
Max	**0.26783**	**0.07191**	**21.17**	**0.26520**	**0.06554**	**19.82**	**0.55781**	**0.06450**	**10.83**	**0.42241**	**0.06497**	**13.38**

APPENDIX C14: Comparison of 4 different types of bracing: Braced along the center bay and at the 1st and 2nd floors

	X-Bracing (B1-13)			Inverted V-Bracing (B2-13)			K-Bracing (B3-13)			Diagonal-Bracing (B4-13)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00290	0.00602	67.46	0.00301	0.00593	66.35	0.00898	0.01820	66.96	0.00541	0.01205	69.00
2	0.00552	0.01267	69.64	0.00575	0.01246	68.41	0.01750	0.03657	67.64	0.01113	0.02487	69.09
3	0.01521	0.01259	45.28	0.01549	0.01232	44.31	0.04437	0.03631	45.00	0.02955	0.02500	45.83
4	0.02502	0.01269	33.66	0.02533	0.01237	32.82	0.07059	0.03641	34.03	0.04799	0.02510	34.34
5	0.03509	0.01280	26.73	0.03541	0.01242	25.97	0.09646	0.03650	27.45	0.06637	0.02520	27.52
6	0.04546	0.01290	22.10	0.04570	0.01247	21.44	0.12203	0.03659	23.07	0.08474	0.02529	22.99
7	0.05617	0.01300	18.80	0.05632	0.01252	18.19	0.14733	0.03669	19.94	0.10313	0.02539	19.76
8	0.06718	0.01311	16.33	0.06722	0.01257	15.75	0.17232	0.03678	17.59	0.12149	0.02549	17.34
9	0.07843	0.01321	14.41	0.07836	0.01262	13.87	0.19695	0.03687	15.77	0.13978	0.02559	15.47
10	0.08988	0.01331	12.90	0.08968	0.01266	12.37	0.22117	0.03697	14.32	0.15795	0.02569	13.99
11	0.10153	0.01341	11.67	0.10114	0.01272	11.17	0.24498	0.03706	13.14	0.17600	0.02578	12.78
12	0.11337	0.01351	10.65	0.11278	0.01277	10.17	0.26837	0.03716	12.16	0.19392	0.02588	11.77
13	0.12534	0.01362	9.80	0.12456	0.01281	9.33	0.29130	0.03724	11.34	0.21165	0.02599	10.94
14	0.13742	0.01372	9.08	0.13641	0.01286	8.62	0.31371	0.03734	10.64	0.22917	0.02608	10.22
15	0.14955	0.01382	8.46	0.14831	0.01291	8.01	0.33558	0.03743	10.04	0.24642	0.02618	9.60
16	0.16175	0.01392	7.92	0.16021	0.01296	7.48	0.35690	0.03752	9.51	0.26342	0.02628	9.07
17	0.17402	0.01403	7.46	0.17217	0.01301	7.03	0.37769	0.03761	9.06	0.28018	0.02637	8.60
18	0.18631	0.01414	7.05	0.18414	0.01306	6.62	0.39789	0.03771	8.66	0.29664	0.02647	8.19
19	0.19859	0.01424	6.69	0.19608	0.01311	6.27	0.41747	0.03781	8.31	0.31276	0.02657	7.83
20	0.21081	0.01434	6.37	0.20795	0.01316	5.95	0.43639	0.03790	7.99	0.32851	0.02666	7.51
21	0.22295	0.01445	6.09	0.21972	0.01320	5.67	0.45462	0.03799	7.71	0.34386	0.02676	7.22
22	0.23500	0.01455	5.83	0.23137	0.01325	5.42	0.47215	0.03808	7.46	0.35879	0.02686	6.97
23	0.24691	0.01465	5.60	0.24287	0.01331	5.20	0.48893	0.03818	7.24	0.37327	0.02696	6.74
24	0.25866	0.01475	5.40	0.25420	0.01335	4.99	0.50494	0.03827	7.05	0.38726	0.02706	6.53
25	0.27021	0.01486	5.21	0.26532	0.01340	4.81	0.52015	0.03836	6.87	0.40074	0.02716	6.35
26	0.28155	0.01495	5.04	0.27620	0.01345	4.64	0.53453	0.03846	6.71	0.41368	0.02725	6.18
27	0.29265	0.01506	4.89	0.28684	0.01350	4.50	0.54807	0.03856	6.57	0.42607	0.02735	6.03
28	0.30349	0.01517	4.76	0.29721	0.01355	4.36	0.56075	0.03865	6.45	0.43788	0.02745	5.90
29	0.31407	0.01527	4.64	0.30729	0.01360	4.24	0.57256	0.03874	6.34	0.44911	0.02754	5.78
30	0.32437	0.01537	4.52	0.31709	0.01365	4.13	0.58348	0.03883	6.24	0.45973	0.02765	5.67
Max	**0.32437**	**0.01537**	**69.64**	**0.31709**	**0.01365**	**68.41**	**0.58348**	**0.03883**	**67.64**	**0.45973**	**0.02765**	**69.09**

APPENDIX C15: Comparison of 4 different types of bracing schemes spread over buildings width (zigzag)

	X-Bracing (B1-14)			Inverted V-Bracing (B2-14)			K-Bracing (B3-14)			Diagonal-Bracing (B4-14)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00941	-0.00049	-5.47	0.00969	-0.00075	-8.43	0.02792	-0.00074	-2.74	0.01711	0.00036	2.05
2	0.01717	0.00102	5.61	0.01781	0.00040	2.18	0.05380	0.00026	0.49	0.03364	0.00236	6.55
3	0.02607	0.00174	6.25	0.02696	0.00085	3.06	0.08019	0.00049	0.61	0.04997	0.00459	8.41
4	0.03510	0.00262	6.95	0.03639	0.00131	3.47	0.10614	0.00086	0.80	0.06565	0.00744	10.18
5	0.04360	0.00428	8.94	0.04512	0.00271	5.67	0.13089	0.00207	1.56	0.08042	0.01115	12.18
6	0.05029	0.00806	13.81	0.05212	0.00605	10.40	0.15321	0.00541	3.41	0.09522	0.01482	13.47
7	0.05856	0.01061	15.33	0.06058	0.00826	12.00	0.17648	0.00754	4.10	0.10952	0.01900	14.78
8	0.06626	0.01402	17.47	0.06862	0.01117	14.00	0.19859	0.01051	5.03	0.12264	0.02434	16.56
9	0.07414	0.01750	19.10	0.07666	0.01432	15.74	0.22022	0.01360	5.82	0.13613	0.02924	17.68
10	0.07976	0.02343	22.71	0.08254	0.01980	19.35	0.23896	0.01918	7.43	0.14897	0.03467	18.88
11	0.08734	0.02760	24.01	0.09025	0.02361	20.74	0.25904	0.02300	8.16	0.16032	0.04146	20.55
12	0.09370	0.03318	26.15	0.09690	0.02865	22.82	0.27731	0.02822	9.24	0.17221	0.04759	21.65
13	0.10083	0.03813	27.44	0.10413	0.03324	24.20	0.29570	0.03284	10.00	0.18360	0.05404	22.74
14	0.10539	0.04575	30.27	0.10890	0.04037	27.05	0.31087	0.04018	11.45	0.19331	0.06194	24.27
15	0.11216	0.05121	31.35	0.11575	0.04547	28.20	0.32765	0.04536	12.16	0.20380	0.06880	25.24
16	0.11719	0.05848	33.29	0.12100	0.05217	30.13	0.34208	0.05234	13.27	0.21366	0.07604	26.25
17	0.12347	0.06458	34.34	0.12732	0.05786	31.25	0.35711	0.05819	14.01	0.22159	0.08496	27.72
18	0.12695	0.07350	36.67	0.13098	0.06622	33.58	0.36873	0.06687	15.35	0.23041	0.09270	28.69
19	0.13284	0.07999	37.58	0.13688	0.07231	34.57	0.38212	0.07316	16.07	0.23872	0.10061	29.65
20	0.13653	0.08862	39.36	0.14074	0.08037	36.35	0.39270	0.08159	17.20	0.24502	0.11015	31.01
21	0.14185	0.09555	40.25	0.14605	0.08687	37.30	0.40428	0.08833	17.93	0.25238	0.11824	31.90
22	0.14427	0.10528	42.19	0.14858	0.09604	39.26	0.41232	0.09791	19.19	0.25910	0.12655	32.82
23	0.14915	0.11241	42.98	0.15342	0.10276	40.11	0.42220	0.10491	19.90	0.26362	0.13661	34.13
24	0.15149	0.12192	44.59	0.15588	0.11167	41.74	0.42893	0.11428	21.04	0.26918	0.14514	35.03
25	0.15574	0.12933	45.37	0.16006	0.11866	42.57	0.43694	0.12157	21.77	0.27424	0.15366	35.91
26	0.15709	0.13941	47.02	0.16148	0.12817	44.25	0.44142	0.13157	22.96	0.27713	0.16380	37.15
27	0.16084	0.14687	47.73	0.16512	0.13522	45.02	0.44766	0.13897	23.69	0.28116	0.17226	37.99
28	0.16185	0.15681	49.21	0.16619	0.14457	46.52	0.45055	0.14885	24.83	0.28457	0.18076	38.85
29	0.16493	0.16441	49.92	0.16915	0.15174	47.29	0.45488	0.15642	25.59	0.28569	0.19096	40.06
30	0.16521	0.17453	51.37	0.16945	0.16129	48.77	0.45579	0.16652	26.76	0.28783	0.19955	40.94
Max	**0.16521**	**0.17453**	**51.37**	**0.16945**	**0.16129**	**48.77**	**0.45579**	**0.16652**	**26.76**	**0.28783**	**0.19955**	**40.94**

APPENDIX C16: Comparison of 4 different types of bracing schemes spread over buildings width (diagonal)

	X-Bracing (B1-15)			Inverted V-Bracing (B2-15)			K-Bracing (B3-15)			Diagonal-Bracing (B4-15)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00938	-0.00046	-5.13	0.00973	-0.00079	-8.81	0.02792	-0.00075	-2.75	0.01931	-0.00185	-10.58
2	0.01811	0.00008	0.45	0.01882	-0.00061	-3.33	0.05477	-0.00071	-1.32	0.03782	-0.00183	-5.07
3	0.02587	0.00194	6.98	0.02687	0.00094	3.39	0.08002	0.00066	0.82	0.05404	0.00052	0.96
4	0.03626	0.00146	3.86	0.03756	0.00014	0.38	0.10731	-0.00031	-0.29	0.07262	0.00048	0.65
5	0.04409	0.00380	7.93	0.04571	0.00213	4.45	0.13138	0.00158	1.19	0.08922	0.00235	2.57
6	0.05132	0.00703	12.05	0.05319	0.00498	8.57	0.15424	0.00438	2.76	0.10402	0.00601	5.46
7	0.06090	0.00827	11.96	0.06301	0.00583	8.47	0.17884	0.00518	2.82	0.12087	0.00765	5.95
8	0.06782	0.01246	15.52	0.07022	0.00957	11.99	0.20014	0.00896	4.29	0.13556	0.01142	7.77
9	0.07454	0.01709	18.65	0.07715	0.01382	15.19	0.22061	0.01321	5.65	0.14896	0.01641	9.92
10	0.08328	0.01991	19.30	0.08609	0.01625	15.88	0.24248	0.01566	6.07	0.16404	0.01960	10.67
11	0.08929	0.02565	22.31	0.09236	0.02150	18.89	0.26100	0.02104	7.46	0.17681	0.02497	12.38
12	0.09545	0.03143	24.77	0.09869	0.02687	21.40	0.27904	0.02649	8.67	0.18876	0.03104	14.12
13	0.10331	0.03565	25.66	0.10669	0.03068	22.33	0.29815	0.03039	9.25	0.20203	0.03561	14.99
14	0.10842	0.04272	28.27	0.11202	0.03725	24.96	0.31389	0.03716	10.59	0.21288	0.04237	16.60
15	0.11397	0.04940	30.24	0.11770	0.04352	26.99	0.32944	0.04357	11.68	0.22334	0.04926	18.07
16	0.12088	0.05479	31.19	0.12472	0.04845	27.98	0.34575	0.04867	12.34	0.23475	0.05495	18.97
17	0.12509	0.06296	33.48	0.12911	0.05607	30.28	0.35870	0.05660	13.63	0.24370	0.06285	20.50
18	0.13001	0.07044	35.14	0.13412	0.06308	31.99	0.37175	0.06385	14.66	0.25264	0.07047	21.81
19	0.13597	0.07686	36.11	0.14014	0.06905	33.01	0.38522	0.07006	15.39	0.26216	0.07717	22.74
20	0.13927	0.08588	38.14	0.14359	0.07752	35.06	0.39540	0.07889	16.63	0.26919	0.08598	24.21
21	0.14351	0.09389	39.55	0.14787	0.08505	36.52	0.40589	0.08672	17.60	0.27655	0.09407	25.38
22	0.14846	0.10109	40.51	0.15284	0.09178	37.52	0.41647	0.09376	18.38	0.28414	0.10151	26.32
23	0.15086	0.11070	42.32	0.15535	0.10083	39.36	0.42388	0.10323	19.58	0.28925	0.11098	27.73
24	0.15436	0.11905	43.54	0.15886	0.10869	40.62	0.43176	0.11145	20.52	0.29500	0.11932	28.80
25	0.15826	0.12681	44.48	0.16274	0.11598	41.61	0.43941	0.11910	21.33	0.30060	0.12730	29.75
26	0.15976	0.13674	46.12	0.16430	0.12535	43.28	0.44403	0.12896	22.51	0.30380	0.13713	31.10
27	0.16250	0.14521	47.19	0.16701	0.13333	44.39	0.44928	0.13735	23.41	0.30788	0.14554	32.10
28	0.16531	0.15335	48.12	0.16975	0.14101	45.38	0.45396	0.14544	24.26	0.31147	0.15386	33.07
29	0.16590	0.16344	49.63	0.17037	0.15052	46.91	0.45580	0.15550	25.44	0.31274	0.16391	34.39
30	0.16784	0.17190	50.60	0.17225	0.15849	47.92	0.45838	0.16393	26.34	0.31513	0.17225	35.34
Max	**0.16784**	**0.17190**	**50.60**	**0.17225**	**0.15849**	**47.92**	**0.45838**	**0.16393**	**26.34**	**0.31513**	**0.17225**	**35.34**

APPENDIX C17: Comparison of 4 different types of bracing schemes spread over the first and third bays

	X-Bracing (B1-16)			Inverted V-Bracing (B2-16)			K-Bracing (B3-16)			Diagonal-Bracing (B4-16)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.01053	-0.00161	-18.03	0.01073	-0.00179	-20.05	0.02905	-0.00187	-6.88	0.02037	-0.00291	-16.66
2	0.01879	-0.00060	-3.29	0.01918	-0.00097	-5.30	0.05542	-0.00136	-2.52	0.03743	-0.00143	-3.97
3	0.03097	-0.00317	-11.40	0.03152	-0.00371	-13.34	0.08510	-0.00442	-5.47	0.05804	-0.00348	-6.38
4	0.03930	-0.00159	-4.21	0.04001	-0.00231	-6.14	0.11030	-0.00330	-3.08	0.07456	-0.00147	-2.01
5	0.05124	-0.00335	-7.00	0.05209	-0.00425	-8.89	0.13848	-0.00552	-4.15	0.09432	-0.00275	-3.00
6	0.05960	-0.00124	-2.13	0.06054	-0.00237	-4.07	0.16246	-0.00384	-2.42	0.11027	-0.00024	-0.22
7	0.07133	-0.00216	-3.12	0.07234	-0.00350	-5.09	0.18919	-0.00517	-2.81	0.12922	-0.00070	-0.55
8	0.07976	0.00053	0.65	0.08084	-0.00105	-1.32	0.21199	-0.00289	-1.38	0.14464	0.00234	1.59
9	0.09123	0.00041	0.45	0.09236	-0.00139	-1.53	0.23721	-0.00339	-1.45	0.16273	0.00264	1.60
10	0.09963	0.00356	3.45	0.10081	0.00153	1.50	0.25873	-0.00059	-0.23	0.17752	0.00612	3.33
11	0.11077	0.00417	3.63	0.11196	0.00190	1.67	0.28238	-0.00034	-0.12	0.19467	0.00711	3.52
12	0.11912	0.00776	6.12	0.12030	0.00525	4.18	0.30260	0.00293	0.96	0.20880	0.01100	5.01
13	0.12990	0.00906	6.52	0.13106	0.00631	4.59	0.32462	0.00392	1.19	0.22499	0.01265	5.32
14	0.13812	0.01302	8.62	0.13925	0.01002	6.71	0.34346	0.00759	2.16	0.23838	0.01687	6.61
15	0.14844	0.01493	9.14	0.14953	0.01169	7.25	0.36379	0.00922	2.47	0.25351	0.01909	7.00
16	0.15647	0.01920	10.93	0.15749	0.01568	9.06	0.38119	0.01323	3.35	0.26611	0.02359	8.14
17	0.16634	0.02171	11.55	0.16726	0.01792	9.68	0.39982	0.01548	3.73	0.28019	0.02636	8.60
18	0.17417	0.02628	13.11	0.17499	0.02221	11.26	0.41577	0.01983	4.55	0.29199	0.03112	9.63
19	0.18352	0.02931	13.77	0.18421	0.02498	11.94	0.43262	0.02266	4.98	0.30493	0.03440	10.14
20	0.19106	0.03409	15.14	0.19163	0.02948	13.33	0.44704	0.02725	5.75	0.31584	0.03933	11.07
21	0.19981	0.03759	15.83	0.20022	0.03270	14.04	0.46204	0.03057	6.21	0.32758	0.04304	11.61
22	0.20702	0.04253	17.04	0.20727	0.03735	15.27	0.47487	0.03536	6.93	0.33755	0.04810	12.47
23	0.21513	0.04643	17.75	0.21520	0.04098	16.00	0.48798	0.03913	7.42	0.34804	0.05219	13.04
24	0.22193	0.05148	18.83	0.22182	0.04573	17.09	0.49916	0.04405	8.11	0.35701	0.05731	13.83
25	0.22933	0.05574	19.55	0.22901	0.04971	17.84	0.51031	0.04820	8.63	0.36619	0.06171	14.42
26	0.23568	0.06082	20.51	0.23514	0.05451	18.82	0.51979	0.05320	9.29	0.37409	0.06684	15.16
27	0.24233	0.06538	21.25	0.24155	0.05879	19.57	0.52894	0.05769	9.83	0.38191	0.07151	15.77
28	0.24819	0.07047	22.11	0.24717	0.06359	20.46	0.53667	0.06273	10.47	0.38872	0.07661	16.46
29	0.25405	0.07529	22.86	0.25276	0.06813	21.23	0.54378	0.06752	11.05	0.39515	0.08150	17.10
30	0.25939	0.08035	23.65	0.25783	0.07291	22.05	0.54974	0.07257	11.66	0.40082	0.08656	17.76
Max	**0.25939**	**0.08035**	**23.65**	**0.25783**	**0.07291**	**22.05**	**0.54974**	**0.07257**	**11.66**	**0.40082**	**0.08656**	**17.76**

APPENDIX C18: Comparison of 4 different types of bracing: Braced completely the outer bays and the 30th floor

	X-Bracing (B1-17)			Inverted V-Bracing (B2-17)			K-Bracing (B3-17)			Diagonal-Bracing (B4-17)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00446	0.00447	50.07	0.00448	0.00446	49.92	0.01360	0.01358	49.96	0.00849	0.00898	51.40
2	0.00906	0.00914	50.23	0.00911	0.00910	49.95	0.02703	0.02704	50.01	0.01771	0.01829	50.80
3	0.01380	0.01400	50.36	0.01392	0.01390	49.97	0.04031	0.04037	50.03	0.02696	0.02760	50.59
4	0.01867	0.01904	50.49	0.01886	0.01884	49.98	0.05343	0.05357	50.06	0.03617	0.03692	50.51
5	0.02365	0.02424	50.61	0.02393	0.02391	49.98	0.06637	0.06659	50.08	0.04535	0.04622	50.48
6	0.02875	0.02961	50.74	0.02909	0.02908	49.99	0.07914	0.07948	50.11	0.05450	0.05554	50.47
7	0.03399	0.03518	50.87	0.03443	0.03441	49.99	0.09177	0.09225	50.13	0.06364	0.06488	50.48
8	0.03934	0.04094	51.00	0.03990	0.03989	49.99	0.10423	0.10487	50.15	0.07275	0.07423	50.51
9	0.04478	0.04685	51.13	0.04550	0.04548	49.99	0.11649	0.11733	50.18	0.08180	0.08357	50.54
10	0.05029	0.05290	51.26	0.05118	0.05116	49.99	0.12853	0.12961	50.21	0.09077	0.09287	50.57
11	0.05587	0.05907	51.39	0.05694	0.05692	49.99	0.14035	0.14169	50.24	0.09966	0.10212	50.61
12	0.06150	0.06538	51.53	0.06278	0.06277	49.99	0.15195	0.15358	50.27	0.10847	0.11133	50.65
13	0.06716	0.07180	51.67	0.06869	0.06868	49.99	0.16330	0.16524	50.30	0.11716	0.12048	50.70
14	0.07283	0.07831	51.82	0.07465	0.07463	49.99	0.17437	0.17668	50.33	0.12571	0.12954	50.75
15	0.07849	0.08489	51.96	0.08062	0.08060	50.00	0.18516	0.18785	50.36	0.13411	0.13849	50.80
16	0.08413	0.09154	52.11	0.08659	0.08658	50.00	0.19565	0.19877	50.40	0.14236	0.14734	50.86
17	0.08976	0.09829	52.27	0.09260	0.09258	50.00	0.20586	0.20944	50.43	0.15045	0.15610	50.92
18	0.09535	0.10510	52.43	0.09861	0.09859	50.00	0.21575	0.21985	50.47	0.15836	0.16475	50.99
19	0.10088	0.11195	52.60	0.10460	0.10459	50.00	0.22530	0.22998	50.51	0.16607	0.17326	51.06
20	0.10633	0.11882	52.77	0.11056	0.11055	50.00	0.23450	0.23979	50.56	0.17356	0.18161	51.13
21	0.11167	0.12573	52.96	0.11647	0.11645	50.00	0.24334	0.24927	50.60	0.18082	0.18980	51.21
22	0.11691	0.13264	53.15	0.12232	0.12230	50.00	0.25179	0.25844	50.65	0.18783	0.19782	51.30
23	0.12201	0.13955	53.35	0.12810	0.12808	50.00	0.25984	0.26727	50.70	0.19458	0.20565	51.38
24	0.12697	0.14644	53.56	0.13379	0.13376	49.99	0.26748	0.27573	50.76	0.20104	0.21328	51.48
25	0.13176	0.15331	53.78	0.13937	0.13935	50.00	0.27470	0.28381	50.82	0.20720	0.22070	51.58
26	0.13637	0.16013	54.01	0.14484	0.14481	49.99	0.28146	0.29153	50.88	0.21306	0.22787	51.68
27	0.14079	0.16692	54.25	0.15018	0.15016	50.00	0.28778	0.29885	50.94	0.21859	0.23483	51.79
28	0.14501	0.17365	54.49	0.15539	0.15537	50.00	0.29363	0.30577	51.01	0.22379	0.24154	51.91
29	0.14895	0.18039	54.77	0.16046	0.16043	50.00	0.29901	0.31229	51.09	0.22857	0.24808	52.05
30	0.15068	0.18906	55.65	0.16538	0.16536	50.00	0.30097	0.32134	51.64	0.23042	0.25696	52.72
Max	**0.15068**	**0.18906**	**55.65**	**0.16538**	**0.16536**	**50.00**	**0.30097**	**0.32134**	**51.64**	**0.23042**	**0.25696**	**52.72**

APPENDIX C19: Comparison of 4 different types of bracing: Braced completely the outer bays and the 15th floor

	X-Bracing (B1-18)			Inverted V-Bracing (B2-18)			K-Bracing (B3-18)			Diagonal-Bracing (B4-18)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00445	0.00447	50.10	0.00448	0.00446	49.92	0.01360	0.01358	49.97	0.00848	0.00898	51.41
2	0.00904	0.00915	50.30	0.00909	0.00913	50.11	0.02702	0.02705	50.03	0.01770	0.01830	50.83
3	0.01377	0.01403	50.47	0.01383	0.01398	50.27	0.04029	0.04040	50.07	0.02693	0.02763	50.64
4	0.01862	0.01909	50.62	0.01869	0.01901	50.43	0.05339	0.05361	50.10	0.03613	0.03697	50.57
5	0.02357	0.02431	50.78	0.02364	0.02419	50.57	0.06630	0.06666	50.14	0.04528	0.04629	50.56
6	0.02863	0.02972	50.93	0.02867	0.02950	50.71	0.07904	0.07958	50.17	0.05439	0.05564	50.57
7	0.03383	0.03534	51.09	0.03383	0.03501	50.86	0.09163	0.09239	50.21	0.06349	0.06503	50.60
8	0.03913	0.04115	51.26	0.03908	0.04071	51.02	0.10404	0.10506	50.24	0.07256	0.07442	50.64
9	0.04451	0.04712	51.43	0.04442	0.04655	51.17	0.11624	0.11758	50.29	0.08155	0.08382	50.68
10	0.04995	0.05324	51.59	0.04981	0.05253	51.33	0.12822	0.12992	50.33	0.09047	0.09318	50.74
11	0.05545	0.05949	51.76	0.05524	0.05862	51.49	0.13998	0.14206	50.37	0.09929	0.10250	50.80
12	0.06099	0.06589	51.93	0.06070	0.06485	51.65	0.15149	0.15404	50.42	0.10801	0.11179	50.86
13	0.06655	0.07241	52.11	0.06619	0.07118	51.82	0.16275	0.16579	50.46	0.11660	0.12104	50.93
14	0.07203	0.07912	52.35	0.07159	0.07768	52.04	0.17373	0.17732	50.51	0.12496	0.13029	51.04
15	0.07495	0.08842	54.12	0.07450	0.08672	53.79	0.17984	0.19317	51.79	0.12954	0.14306	52.48
16	0.08044	0.09523	54.21	0.07988	0.09329	53.87	0.19024	0.20418	51.77	0.13759	0.15211	52.51
17	0.08605	0.10200	54.24	0.08537	0.09981	53.90	0.20038	0.21492	51.75	0.14564	0.16091	52.49
18	0.09167	0.10878	54.27	0.09087	0.10633	53.92	0.21023	0.22537	51.74	0.15354	0.16957	52.48
19	0.09729	0.11555	54.29	0.09635	0.11284	53.94	0.21977	0.23551	51.73	0.16126	0.17807	52.48
20	0.10287	0.12228	54.31	0.10180	0.11931	53.96	0.22897	0.24532	51.72	0.16880	0.18637	52.47
21	0.10841	0.12899	54.33	0.10719	0.12573	53.98	0.23783	0.25478	51.72	0.17614	0.19448	52.47
22	0.11391	0.13564	54.35	0.11252	0.13210	54.00	0.24634	0.26389	51.72	0.18327	0.20238	52.48
23	0.11934	0.14222	54.37	0.11779	0.13839	54.02	0.25448	0.27263	51.72	0.19018	0.21005	52.48
24	0.12469	0.14872	54.39	0.12296	0.14459	54.04	0.26223	0.28098	51.73	0.19684	0.21748	52.49
25	0.12994	0.15513	54.42	0.12803	0.15069	54.07	0.26958	0.28893	51.73	0.20325	0.22465	52.50
26	0.13508	0.16142	54.44	0.13298	0.15667	54.09	0.27652	0.29647	51.74	0.20938	0.23155	52.51
27	0.14011	0.16760	54.47	0.13781	0.16253	54.12	0.28303	0.30360	51.75	0.21524	0.23818	52.53
28	0.14501	0.17365	54.49	0.14251	0.16825	54.14	0.28912	0.31028	51.77	0.22082	0.24451	52.55
29	0.14977	0.17957	54.52	0.14706	0.17383	54.17	0.29476	0.31654	51.78	0.22609	0.25056	52.57
30	0.15439	0.18535	54.56	0.15147	0.17927	54.20	0.29997	0.32234	51.80	0.23107	0.25631	52.59
Max	**0.15439**	**0.18535**	**54.56**	**0.15147**	**0.17927**	**54.20**	**0.29997**	**0.32234**	**51.80**	**0.23107**	**0.25631**	**52.59**

APPENDIX C20: Comparison of 4 different types of bracing: Braced completely the outer bays and the 15 & 30th floors

	X-Bracing (B1-19)			Inverted V-Bracing (B2-19)			K-Bracing (B3-19)			Diagonal-Bracing (B4-19)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00444	0.00448	50.20	0.00448	0.00446	49.92	0.01360	0.01358	49.97	0.00848	0.00899	51.45
2	0.00901	0.00919	50.49	0.00907	0.00914	50.20	0.02702	0.02705	50.03	0.01768	0.01832	50.89
3	0.01369	0.01411	50.75	0.01378	0.01403	50.46	0.04028	0.04040	50.07	0.02687	0.02768	50.74
4	0.01848	0.01924	51.00	0.01859	0.01911	50.69	0.05338	0.05362	50.11	0.03603	0.03706	50.71
5	0.02335	0.02454	51.24	0.02347	0.02436	50.92	0.06628	0.06668	50.15	0.04512	0.04645	50.72
6	0.02831	0.03005	51.49	0.02842	0.02975	51.15	0.07902	0.07960	50.18	0.05417	0.05586	50.77
7	0.03338	0.03579	51.75	0.03347	0.03537	51.39	0.09160	0.09242	50.22	0.06319	0.06533	50.83
8	0.03853	0.04176	52.01	0.03859	0.04120	51.63	0.10399	0.10511	50.27	0.07215	0.07483	50.91
9	0.04373	0.04790	52.27	0.04378	0.04720	51.88	0.11619	0.11763	50.31	0.08103	0.08434	51.00
10	0.04898	0.05421	52.54	0.04899	0.05335	52.13	0.12816	0.12998	50.35	0.08980	0.09384	51.10
11	0.05424	0.06070	52.81	0.05422	0.05964	52.38	0.13989	0.14215	50.40	0.09847	0.10331	51.20
12	0.05953	0.06735	53.08	0.05946	0.06609	52.64	0.15139	0.15414	50.45	0.10702	0.11278	51.31
13	0.06481	0.07415	53.36	0.06469	0.07268	52.91	0.16263	0.16591	50.50	0.11542	0.12222	51.43
14	0.06998	0.08116	53.70	0.06982	0.07945	53.23	0.17359	0.17746	50.55	0.12357	0.13168	51.59
15	0.07282	0.09055	55.43	0.07266	0.08856	54.93	0.17969	0.19332	51.83	0.12811	0.14449	53.00
16	0.07794	0.09773	55.63	0.07770	0.09547	55.13	0.19007	0.20435	51.81	0.13590	0.15380	53.09
17	0.08312	0.10493	55.80	0.08281	0.10237	55.28	0.20018	0.21512	51.80	0.14366	0.16289	53.14
18	0.08827	0.11218	55.96	0.08788	0.10932	55.43	0.21000	0.22560	51.79	0.15125	0.17186	53.19
19	0.09336	0.11947	56.13	0.09290	0.11630	55.59	0.21950	0.23578	51.79	0.15863	0.18070	53.25
20	0.09838	0.12677	56.31	0.09783	0.12328	55.76	0.22866	0.24563	51.79	0.16579	0.18938	53.32
21	0.10331	0.13409	56.48	0.10266	0.13026	55.92	0.23748	0.25513	51.79	0.17273	0.19789	53.39
22	0.10813	0.14142	56.67	0.10739	0.13723	56.10	0.24594	0.26429	51.80	0.17942	0.20623	53.48
23	0.11283	0.14873	56.86	0.11200	0.14418	56.28	0.25403	0.27308	51.81	0.18585	0.21438	53.56
24	0.11739	0.15602	57.06	0.11646	0.15109	56.47	0.26173	0.28148	51.82	0.19200	0.22232	53.66
25	0.12179	0.16328	57.28	0.12076	0.15796	56.67	0.26902	0.28949	51.83	0.19785	0.23005	53.76
26	0.12602	0.17048	57.50	0.12489	0.16476	56.88	0.27590	0.29709	51.85	0.20340	0.23753	53.87
27	0.13007	0.17764	57.73	0.12884	0.17150	57.10	0.28235	0.30428	51.87	0.20863	0.24479	53.99
28	0.13393	0.18473	57.97	0.13259	0.17817	57.33	0.28837	0.31103	51.89	0.21353	0.25180	54.11
29	0.13753	0.19181	58.24	0.13608	0.18481	57.59	0.29400	0.31730	51.91	0.21803	0.25862	54.26
30	0.13917	0.20057	59.04	0.13765	0.19309	58.38	0.29694	0.32537	52.28	0.21982	0.26756	54.90
Max	**0.13917**	**0.20057**	**59.04**	**0.13765**	**0.19309**	**58.38**	**0.29694**	**0.32537**	**52.28**	**0.21982**	**0.26756**	**54.90**

APPENDIX C21: Comparison of 4 different types of bracing schemes spread over the buildings width

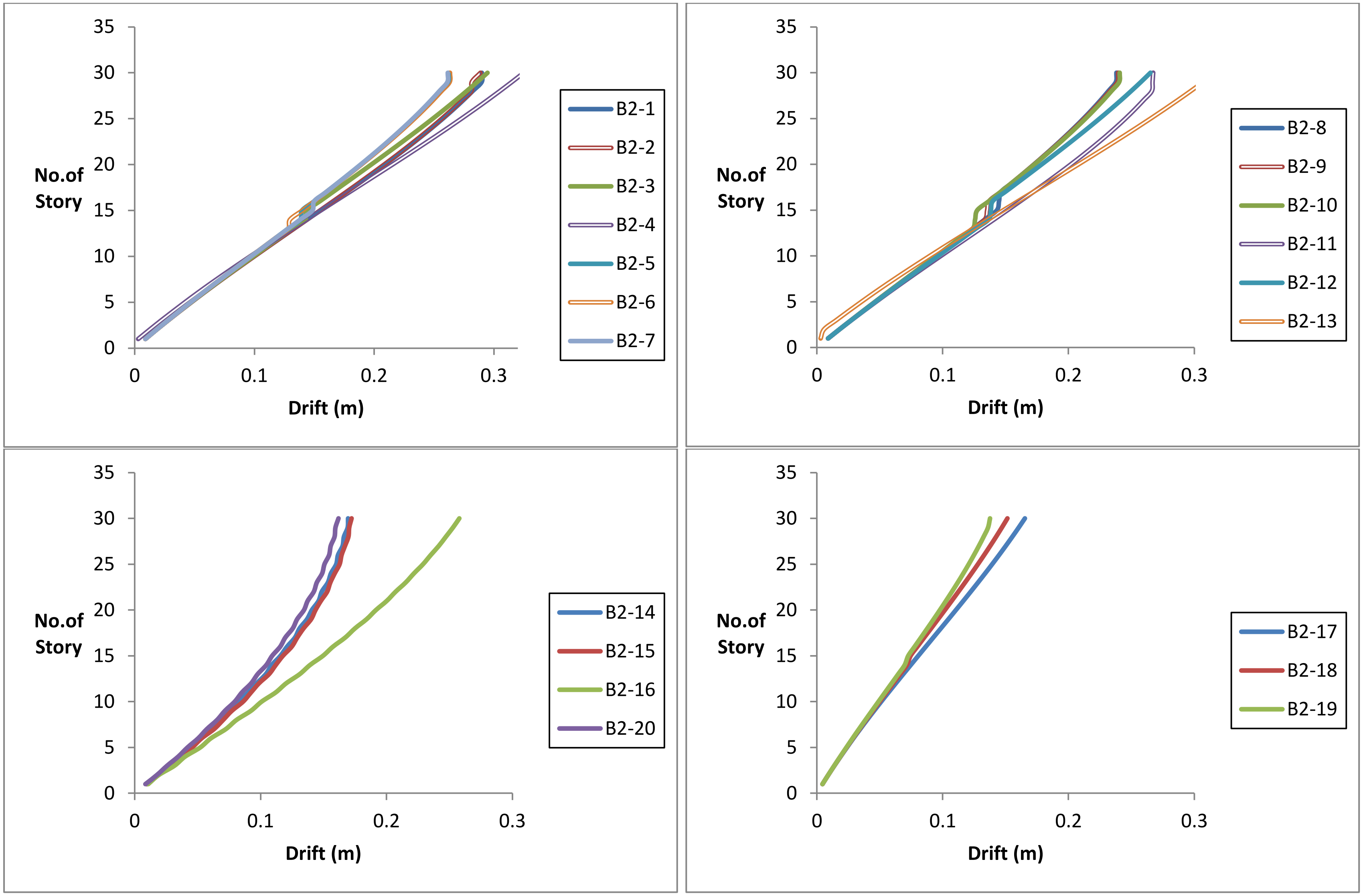
	X-Bracing (B1-20)			Inverted V-Bracing (B2-20)			K-Bracing (B3-20)			Diagonal-Bracing (B4-20)		
Floor	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff (m)	% of Drift Diff. (m)	Floor Drift (m)	Drift Diff. (m)	% of Drift Diff. (m)
1	0.00858	0.00035	3.89	0.00850	0.00044	4.95	0.02679	0.00039	1.42	0.01715	0.00032	1.81
2	0.01683	0.00137	7.50	0.01774	0.00047	2.57	0.05283	0.00123	2.28	0.03362	0.00238	6.60
3	0.02510	0.00271	9.73	0.02567	0.00214	7.71	0.07803	0.00265	3.29	0.04984	0.00472	8.65
4	0.03312	0.00459	12.18	0.03457	0.00313	8.31	0.10220	0.00480	4.49	0.06842	0.00468	6.40
5	0.04052	0.00736	15.37	0.04194	0.00589	12.31	0.12586	0.00710	5.34	0.08318	0.00839	9.16
6	0.04823	0.01013	17.35	0.05046	0.00772	13.26	0.14853	0.01009	6.36	0.09798	0.01205	10.95
7	0.05569	0.01348	19.49	0.05727	0.01157	16.81	0.17018	0.01384	7.52	0.11484	0.01368	10.64
8	0.06224	0.01804	22.48	0.06543	0.01436	18.00	0.19146	0.01764	8.44	0.12790	0.01908	12.98
9	0.06937	0.02227	24.30	0.07169	0.01928	21.20	0.21159	0.02223	9.51	0.14125	0.02412	14.59
10	0.07625	0.02694	26.11	0.07945	0.02289	22.36	0.23070	0.02744	10.63	0.15638	0.02726	14.84
11	0.08195	0.03300	28.71	0.08516	0.02870	25.20	0.24956	0.03248	11.52	0.16774	0.03404	16.87
12	0.08846	0.03842	30.28	0.09250	0.03305	26.32	0.26713	0.03840	12.57	0.17960	0.04020	18.29
13	0.09472	0.04424	31.84	0.09766	0.03971	28.90	0.28368	0.04486	13.65	0.19296	0.04468	18.80
14	0.09956	0.05158	34.13	0.10456	0.04471	29.95	0.30007	0.05098	14.52	0.20261	0.05264	20.62
15	0.10540	0.05797	35.48	0.10917	0.05205	32.29	0.31506	0.05795	15.54	0.21294	0.05966	21.89
16	0.11099	0.06468	36.82	0.11557	0.05760	33.26	0.32902	0.06540	16.58	0.22446	0.06524	22.52
17	0.11498	0.07307	38.86	0.11963	0.06555	35.40	0.34292	0.07238	17.43	0.23241	0.07414	24.19
18	0.12013	0.08032	40.07	0.12555	0.07165	36.33	0.35532	0.08028	18.43	0.24118	0.08193	25.36
19	0.12503	0.08780	41.25	0.12905	0.08014	38.31	0.36669	0.08859	19.46	0.25087	0.08846	26.07
20	0.12817	0.09698	43.07	0.13445	0.08666	39.19	0.37804	0.09625	20.29	0.25710	0.09807	27.61
21	0.13257	0.10483	44.16	0.13740	0.09552	41.01	0.38782	0.10479	21.27	0.26427	0.10635	28.70
22	0.13673	0.11282	45.21	0.14224	0.10238	41.85	0.39657	0.11366	22.28	0.27205	0.11360	29.46
23	0.13901	0.12255	46.85	0.14464	0.11154	43.54	0.40534	0.12177	23.10	0.27658	0.12365	30.89
24	0.14263	0.13078	47.83	0.14890	0.11865	44.35	0.41247	0.13074	24.07	0.28210	0.13222	31.91
25	0.14600	0.13907	48.78	0.15074	0.12798	45.92	0.41857	0.13994	25.06	0.28793	0.13997	32.71
26	0.14743	0.14907	50.28	0.15441	0.13524	46.69	0.42472	0.14827	25.88	0.29076	0.15017	34.06
27	0.15022	0.15749	51.18	0.15569	0.14465	48.16	0.42919	0.15744	26.84	0.29459	0.15883	35.03
28	0.15276	0.16590	52.06	0.15873	0.15203	48.92	0.43263	0.16677	27.82	0.29843	0.16690	35.87
29	0.15334	0.17600	53.44	0.15945	0.16144	50.31	0.43612	0.17518	28.66	0.29955	0.17710	37.16
30	0.15528	0.18446	54.29	0.16186	0.16888	51.06	0.43791	0.18440	29.63	0.30168	0.18570	38.10
Max	**0.15528**	**0.18446**	**54.29**	**0.16186**	**0.16888**	**51.06**	**0.43791**	**0.18440**	**29.63**	**0.30168**	**0.18570**	**38.10**

APPENDIX C22: Comparison of 4 different types in terms of maximum lateral drift, interstory drift index, and total drift index

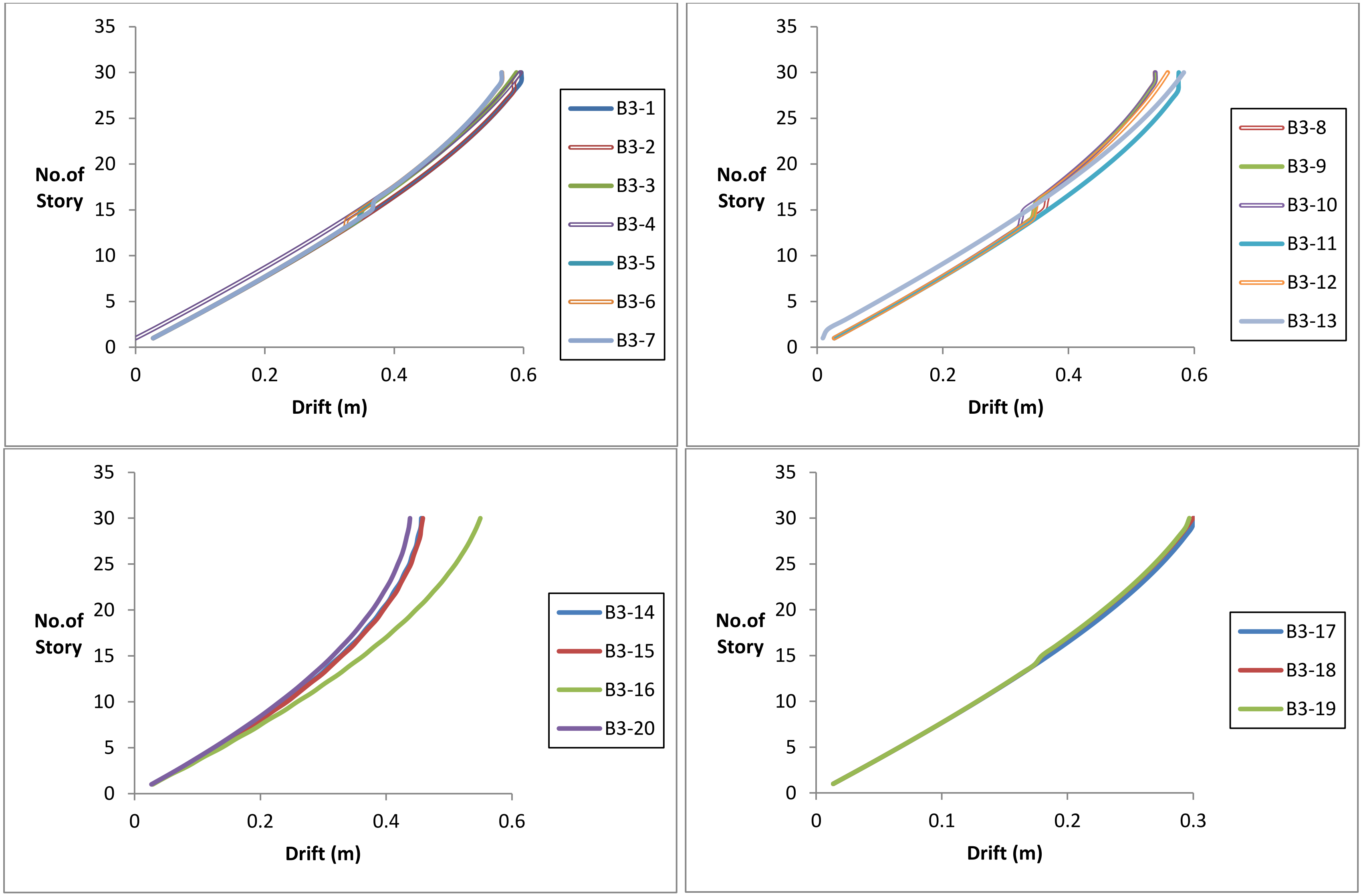
Frame	**X-Bracing (B1)**	**Inverted V-Bracing (B2)**	**K-Bracing (B3)**	**Diagonal-Bracing (B4)**	**X-Bracing (B1-6)**	**Inverted V-Bracing (B2-6)**	**K-Bracing (B3-6)**	**Diagonal-Bracing (B4-6)**
Max. Lateral Drift	0.33974	0.33074	0.62231	0.48738	0.26554	0.26333	0.56653	0.42598
Interstory Drift Index	0.00297	0.00298	0.00906	0.00582	0.00296	0.00298	0.00905	0.00581
Total Drift Index	0.00377	0.00367	0.00691	0.00542	0.00295	0.00293	0.00629	0.00473
Frame	**X-Bracing (B1-1)**	**Inverted V-Bracing (B2-1)**	**K-Bracing (B3-1)**	**Diagonal-Bracing (B4-1)**	**X-Bracing (B1-7)**	**Inverted V-Bracing (B2-7)**	**K-Bracing (B3-7)**	**Diagonal-Bracing (B4-7)**
Max. Lateral Drift	0.29432	0.28997	0.59662	0.45545	0.26337	0.26147	0.56604	0.42481
Interstory Drift Index	0.00297	0.00298	0.00906	0.00582	0.00905	0.00298	0.00296	0.00581
Total Drift Index	0.00327	0.00322	0.00663	0.00506	0.00293	0.00291	0.00629	0.00472
Frame	**X-Bracing (B1-2)**	**Inverted V-Bracing (B2-2)**	**K-Bracing (B3-2)**	**Diagonal-Bracing (B4-2)**	**X-Bracing (B1-8)**	**Inverted V-Bracing (B2-8)**	**K-Bracing (B3-8)**	**Diagonal-Bracing (B4-8)**
Max. Lateral Drift	0.29303	0.28875	0.59526	0.45402	0.23828	0.23813	0.53760	0.39845
Interstory Drift Index	0.00297	0.00298	0.00905	0.00582	0.00295	0.00298	0.00904	0.00580
Total Drift Index	0.00326	0.00321	0.00661	0.00504	0.00265	0.00265	0.00597	0.00443
Frame	**X-Bracing (B1-3)**	**Inverted V-Bracing (B2-3)**	**K-Bracing (B3-3)**	**Diagonal-Bracing (B4-3)**	**X-Bracing (B1-9)**	**Inverted V-Bracing (B2-9)**	**K-Bracing (B3-9)**	**Diagonal-Bracing (B4-9)**
Max. Lateral Drift	0.30001	0.29465	0.58907	0.45267	0.24001	0.23945	0.53786	0.39926
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581	0.00295	0.00298	0.00904	0.00580
Total Drift Index	0.00333	0.00327	0.00655	0.00503	0.00267	0.00266	0.00598	0.00444
Frame	**X-Bracing (B1-4)**	**Inverted V-Bracing (B2-4)**	**K-Bracing (B3-4)**	**Diagonal-Bracing (B4-4)**	**X-Bracing (B1-10)**	**Inverted V-Bracing (B2-10)**	**K-Bracing (B3-10)**	**Diagonal-Bracing (B4-10)**
Max. Lateral Drift	0.33303	0.32486	0.59474	0.47442	0.24157	0.24073	0.53811	0.40008
Interstory Drift Index	0.00092	0.00096	0.00003	0.00177	0.00295	0.00298	0.00904	0.00580
Total Drift Index	0.00370	0.00361	0.00661	0.00527	0.00268	0.00267	0.00598	0.00445
Frame	**X-Bracing (B1-5)**	**Inverted V-Bracing (B2-5)**	**K-Bracing (B3-5)**	**Diagonal-Bracing (B4-5)**	**X-Bracing (B1-11)**	**Inverted V-Bracing (B2-11)**	**K-Bracing (B3-11)**	**Diagonal-Bracing (B4-11)**
Max. Lateral Drift	0.26448	0.26229	0.56630	0.42542	0.27003	0.26734	0.57539	0.43304
Interstory Drift Index	0.00296	0.00298	0.00905	0.00581	0.00296	0.00298	0.00905	0.00581
Total Drift Index	0.00294	0.00291	0.00629	0.00473	0.00300	0.00297	0.00639	0.00481

Frame	**X-Bracing (B1-12)**	**Inverted V-- Bracing (B2-12)**	**K-Bracing (B3-12)**	**Diagonal- Bracing (B4-12)**	**X-Bracing (B1-17)**	**Inverted V- Bracing (B2-17)**	**K-Bracing (B3-17)**	**Diagonal- Bracing (B4-17)**
Max. Lateral Drift	0.26783	0.26520	0.55781	0.42241	0.15068	0.16538	0.30097	0.23042
Interstory Drift Index	0.00295	0.00298	0.00905	0.00581	0.00149	0.00149	0.00453	0.00283
Total Drift Index	0.00298	0.00295	0.00620	0.00469	0.00167	0.00184	0.00334	0.00256
Frame	**X-Bracing (B1-13)**	**Inverted V- Bracing (B2-13)**	**K-Bracing (B3-13)**	**Diagonal- Bracing (B4-13)**	**X-Bracing (B1-18)**	**Inverted V- Bracing (B2-18)**	**K-Bracing (B3-18)**	**Diagonal- Bracing (B4-18)**
Max. Lateral Drift	0.32437	0.31709	0.58348	0.45973	0.15439	0.17927	0.29997	0.23107
Interstory Drift Index	0.00097	0.00100	0.00299	0.00180	0.00148	0.00149	0.00453	0.00283
Total Drift Index	0.00360	0.00352	0.00648	0.00511	0.00172	0.00168	0.00333	0.00257
Frame	**X-Bracing (B1-14)**	**Inverted V- Bracing (B2-14)**	**K-Bracing (B3-14)**	**Diagonal- Bracing (B4-14)**	**X-Bracing (B1-19)**	**Inverted V- Bracing (B2-19)**	**K-Bracing (B3-19)**	**Diagonal- Bracing (B4-19)**
Max. Lateral Drift	0.16521	0.16945	0.45579	0.28783	0.13917	0.13765	0.29694	0.21982
Interstory Drift Index	0.00314	0.00323	0.00931	0.00570	0.00148	0.00149	0.00453	0.00283
Total Drift Index	0.00184	0.00188	0.00506	0.00320	0.00155	0.00153	0.00330	0.00244
Frame	**X-Bracing (B1-15)**	**Inverted V- Bracing (B2-15)**	**K-Bracing (B3-15)**	**Diagonal- Bracing (B4-15)**	**X-Bracing (B1-20)**	**Inverted V- Bracing (B2-20)**	**K-Bracing (B3-20)**	**Diagonal- Bracing (B4-20)**
Max. Lateral Drift	0.16784	0.17225	0.45838	0.31513	0.15528	0.16186	0.43791	0.30168
Interstory Drift Index	0.00313	0.00324	0.00931	0.00644	0.00286	0.00283	0.00893	0.00572
Total Drift Index	0.00186	0.00191	0.00509	0.00350	0.00173	0.00180	0.00487	0.00335
Frame	**X-Bracing (B1-16)**	**Inverted V- Bracing (B2-16)**	**K-Bracing (B3-16)**	**Diagonal- Bracing (B4-16)**				
Max. Lateral Drift	0.25939	0.25783	0.54974	0.40082				
Interstory Drift Index	0.00351	0.00358	0.00968	0.00679				
Total Drift Index	0.00288	0.00286	0.00611	0.00445				

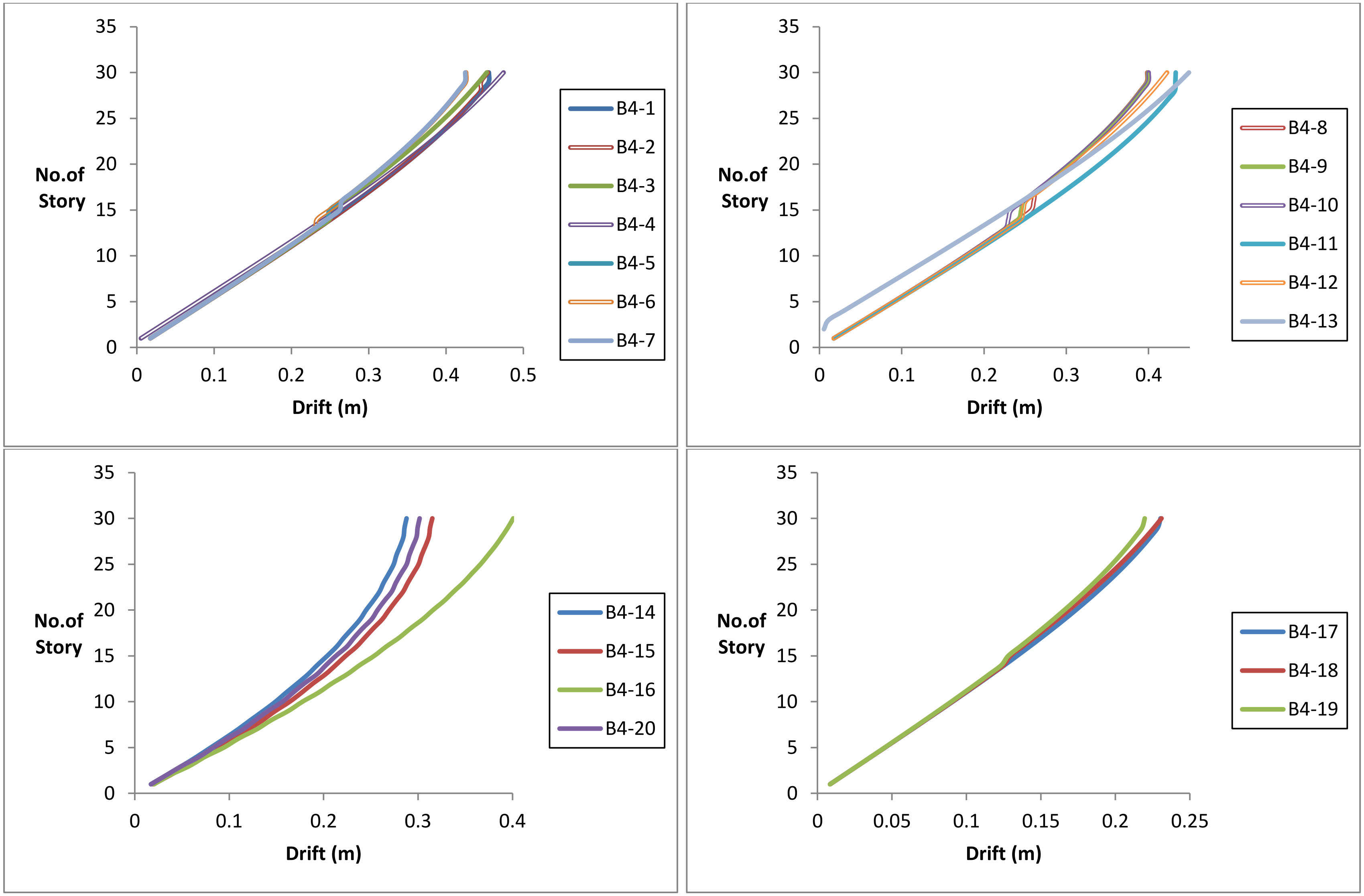
APPENDIX D1: Lateral Drift Pattern of Various Orientations of Inverted V-Bracing



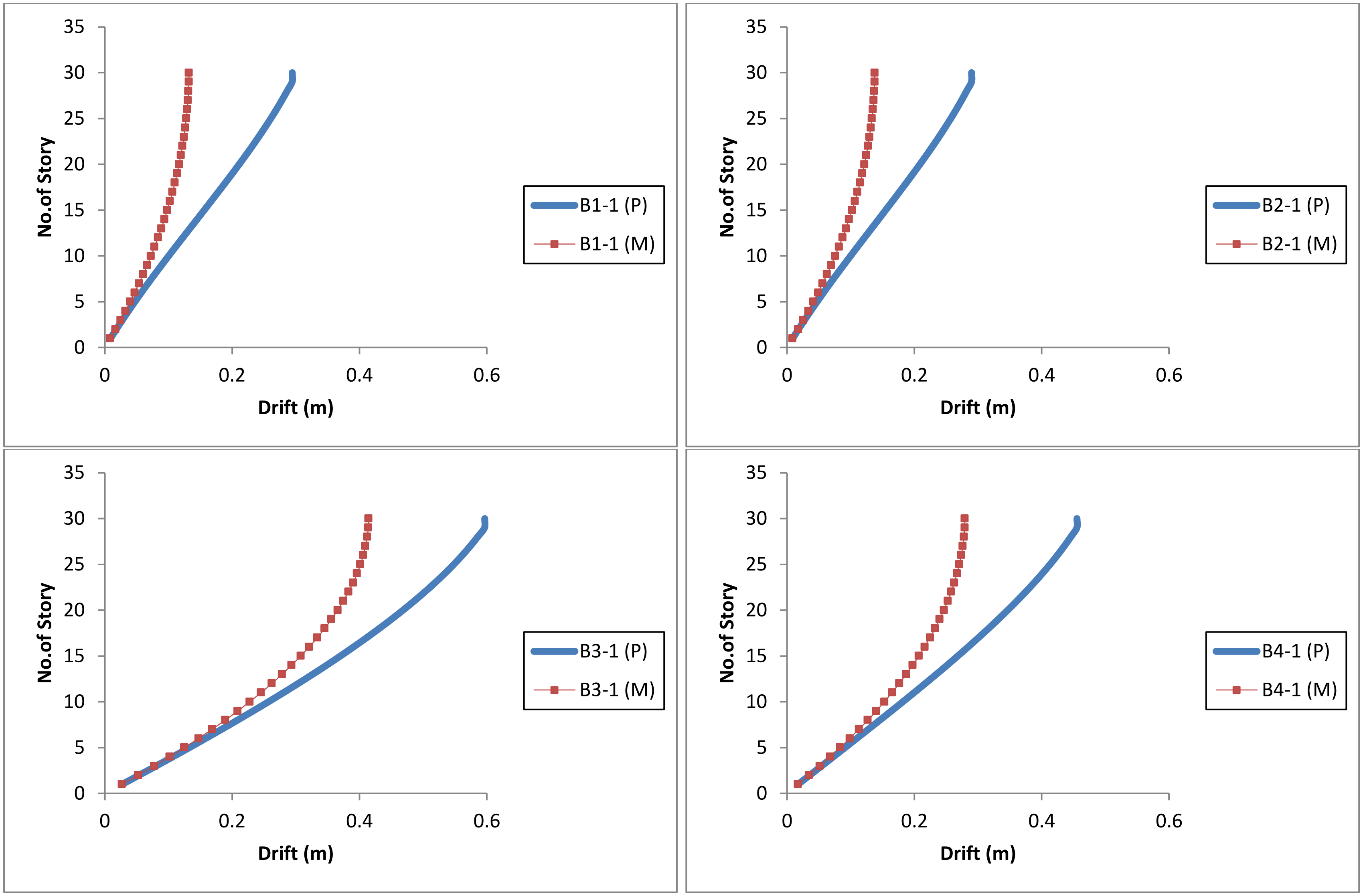
APPENDIX D2: Lateral Drift Pattern of Various Orientations of K-Bracing



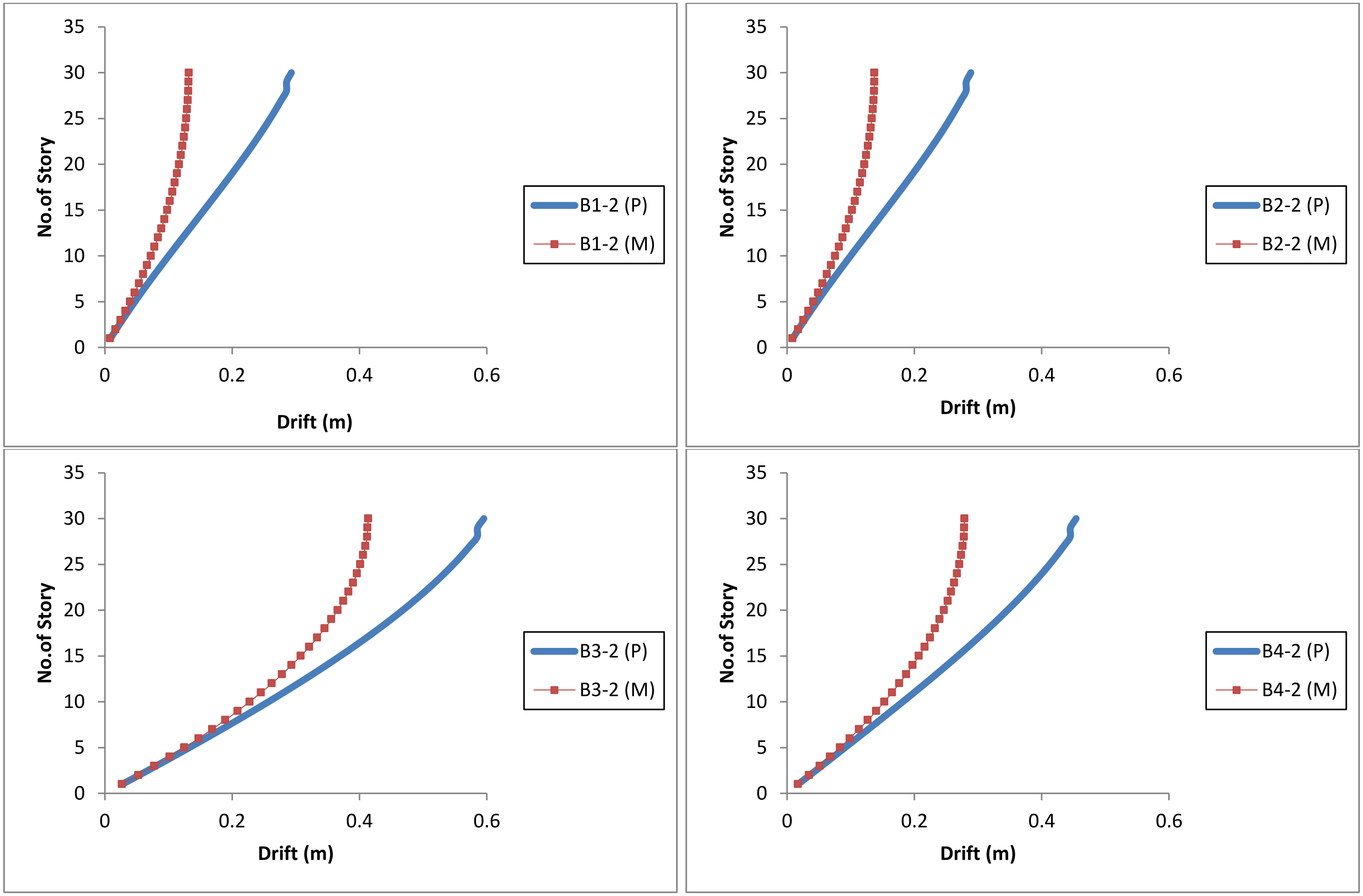
APPENDIX D3: Lateral Drift Pattern of Various Orientations of Single Diagonal Bracing



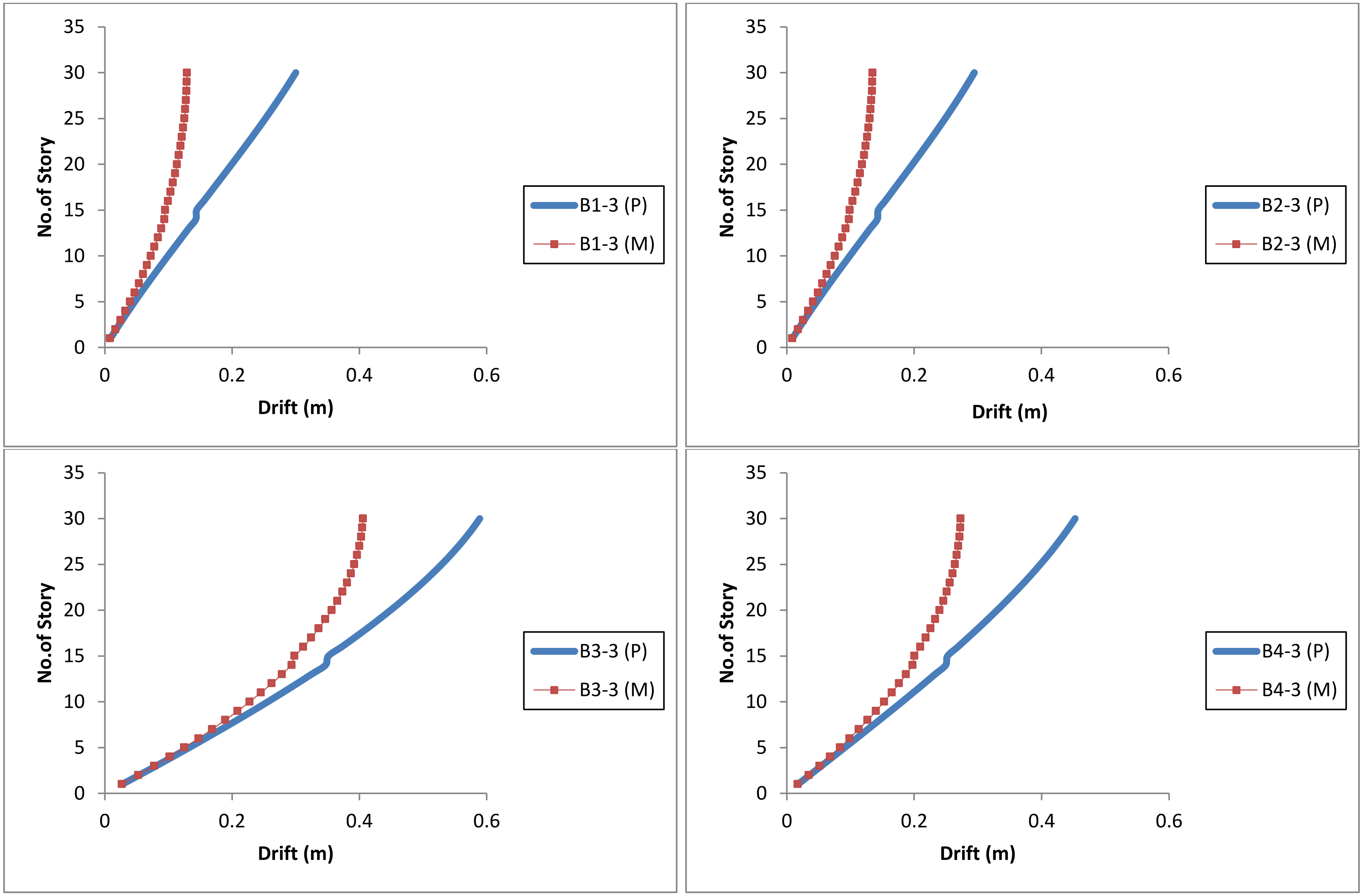
APPENDIX E1: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 30th floor



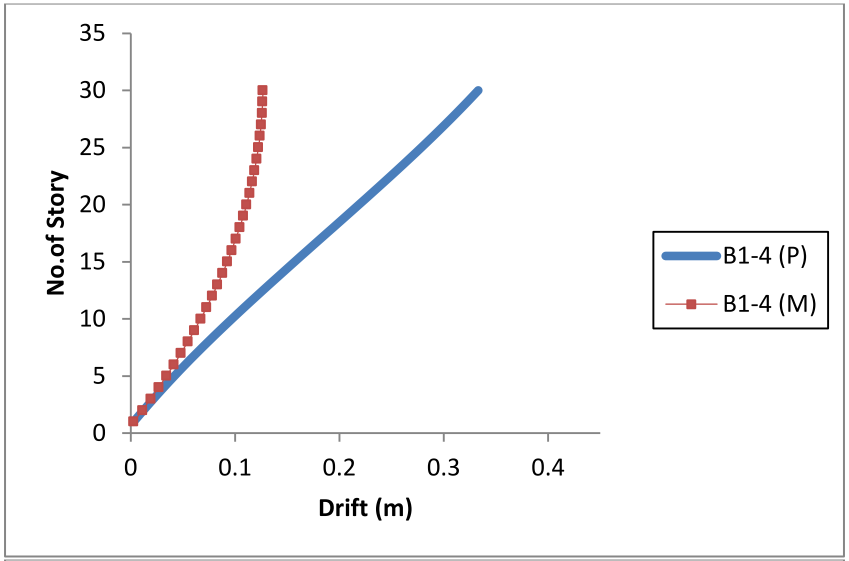
APPENDIX E2: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 2nd top floor

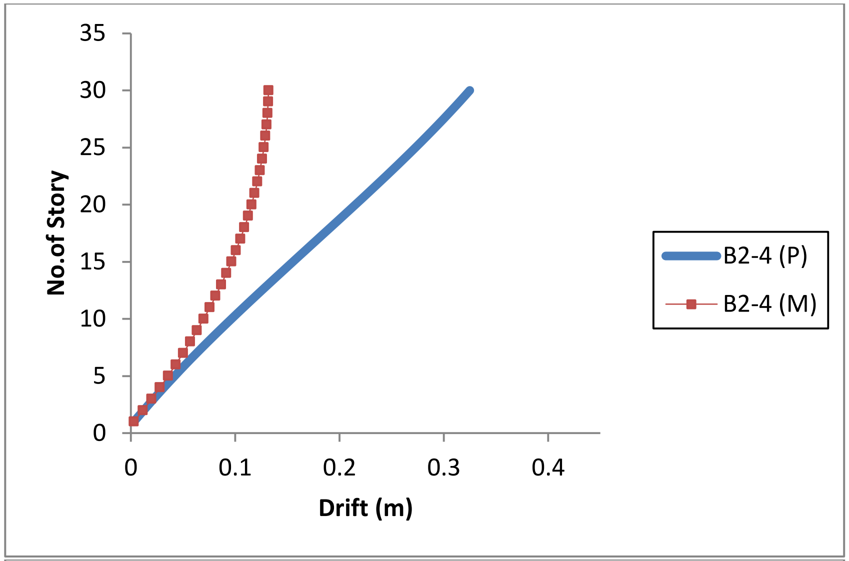


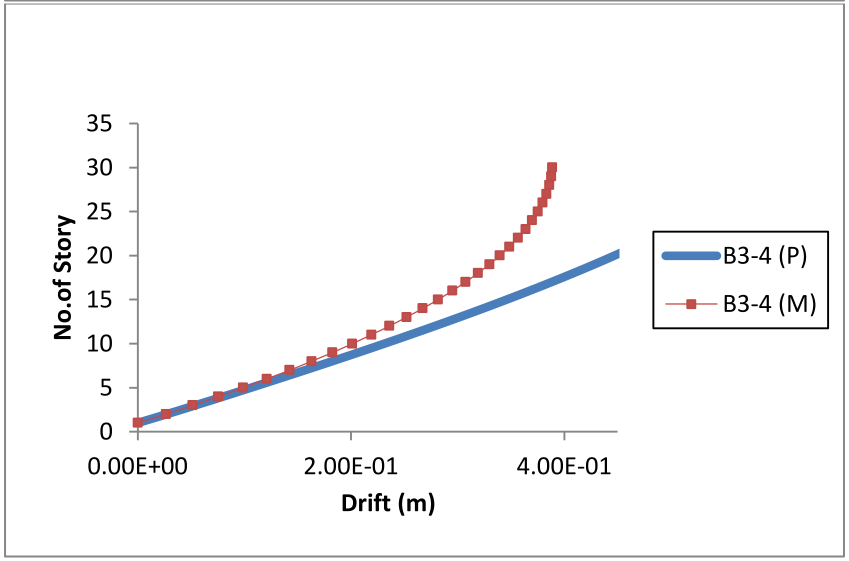
APPENDIX E3: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th floor

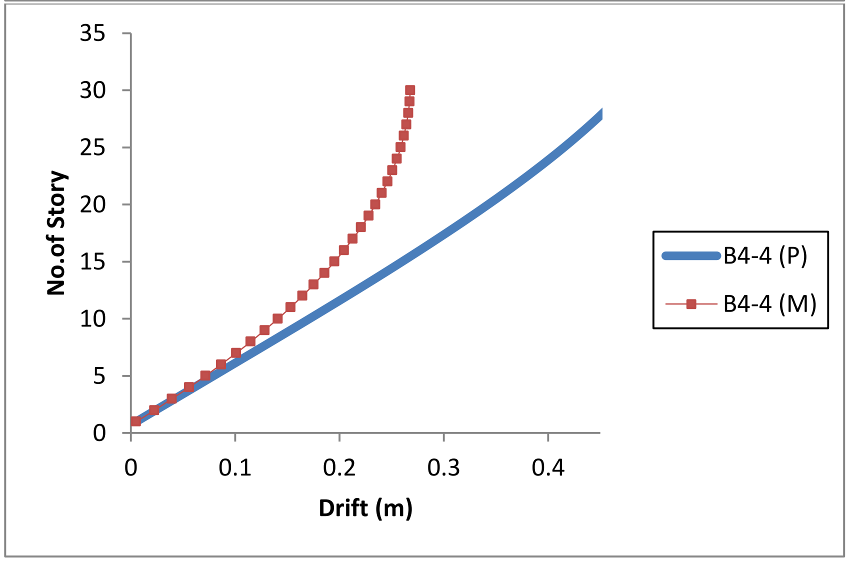


APPENDIX E4: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 1st floor

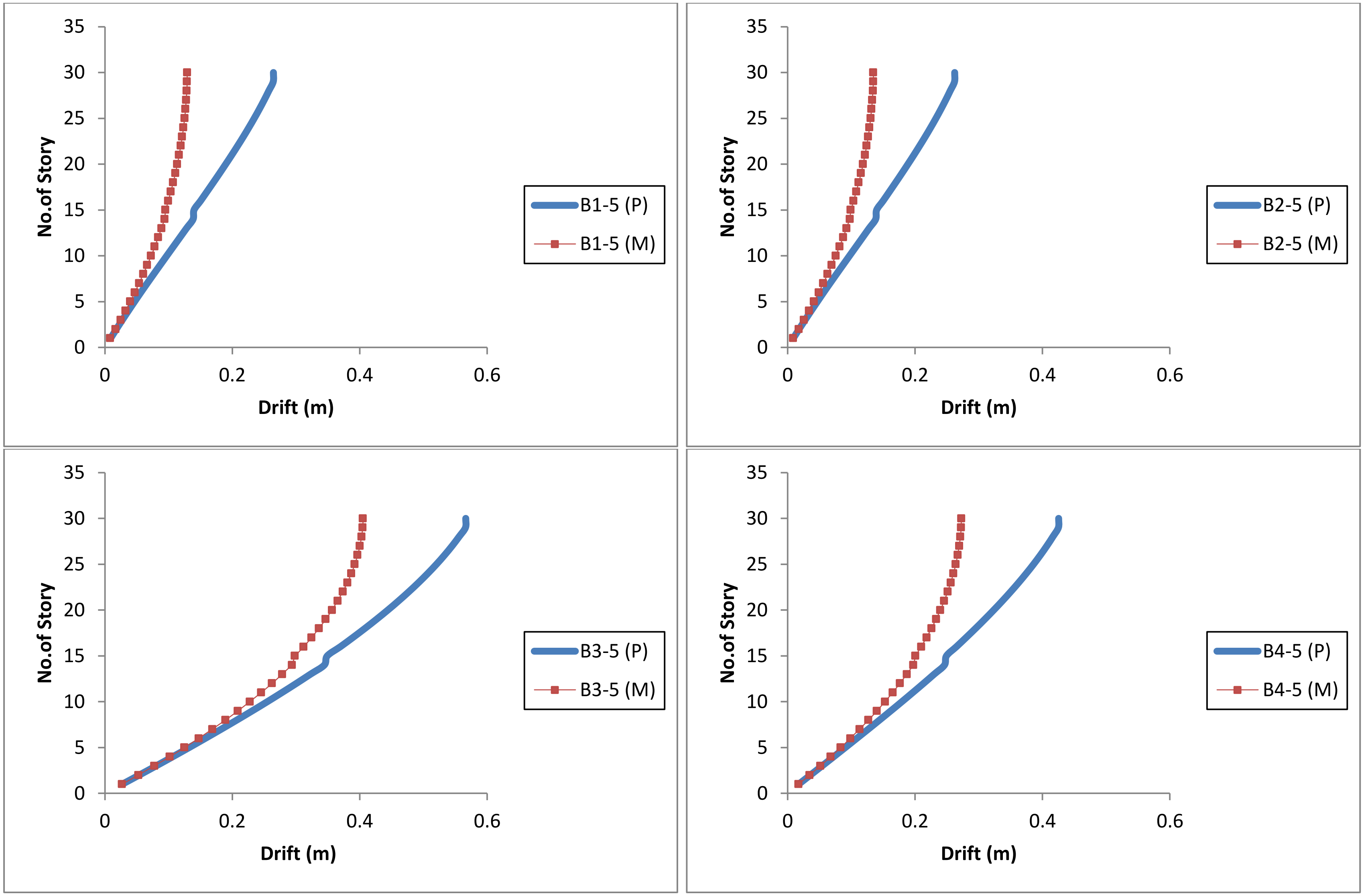




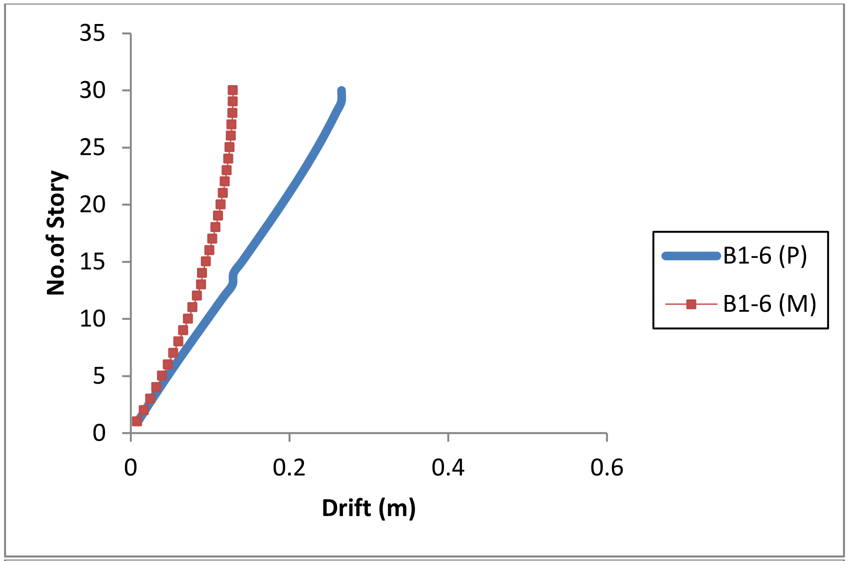


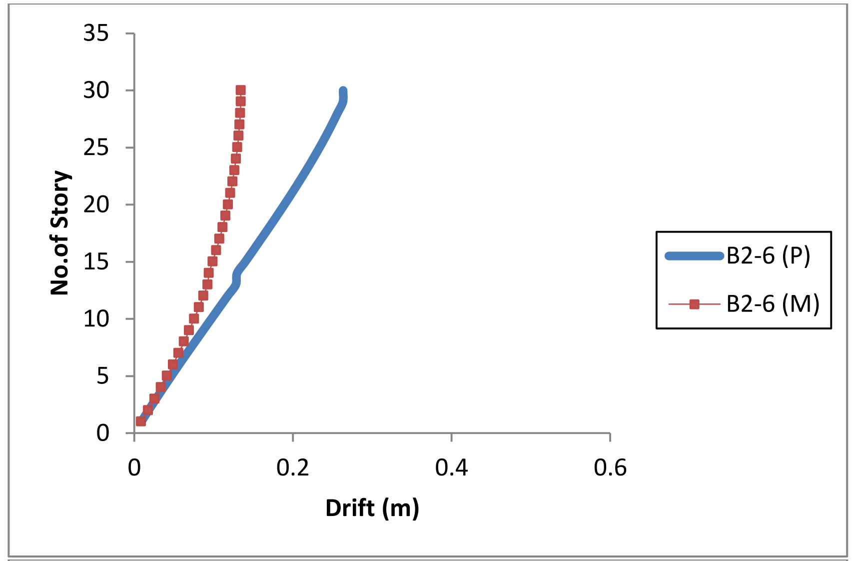


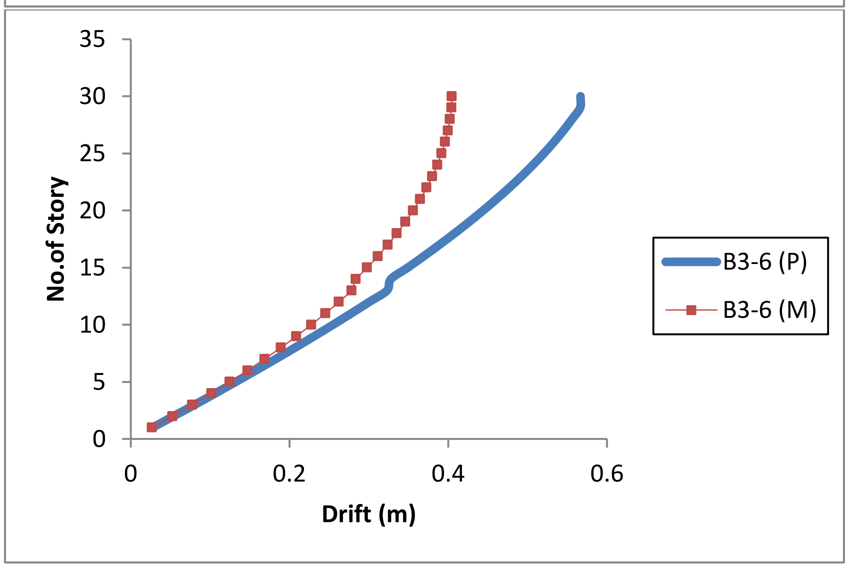
APPENDIX E5: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th and 30th floors

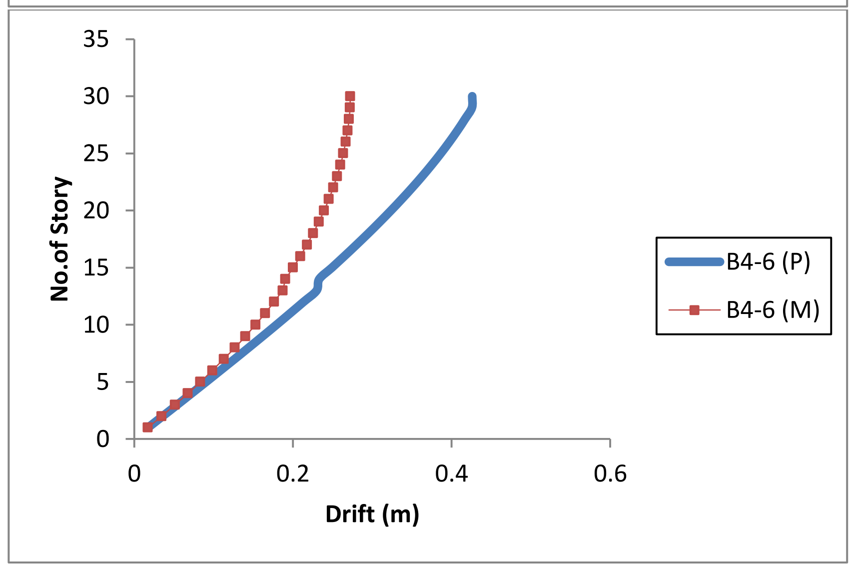


APPENDIX E6: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 14th and 30th floors

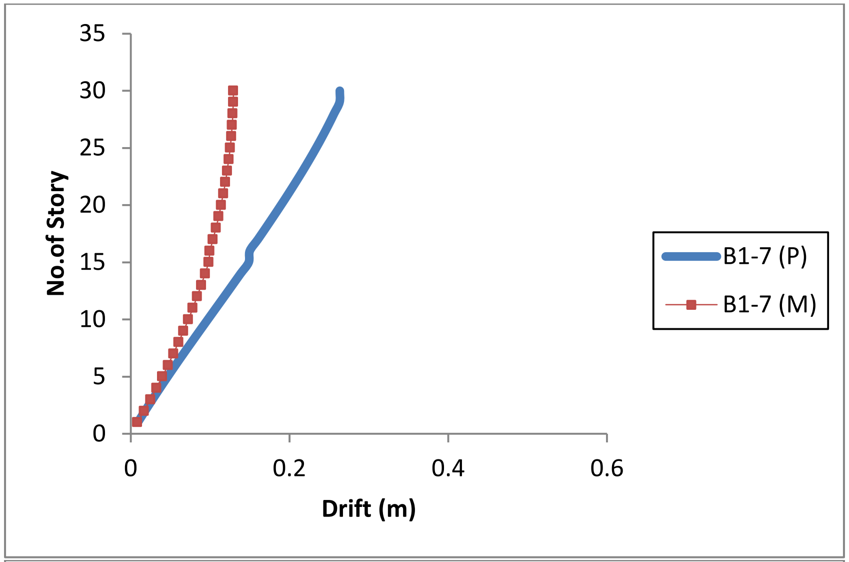


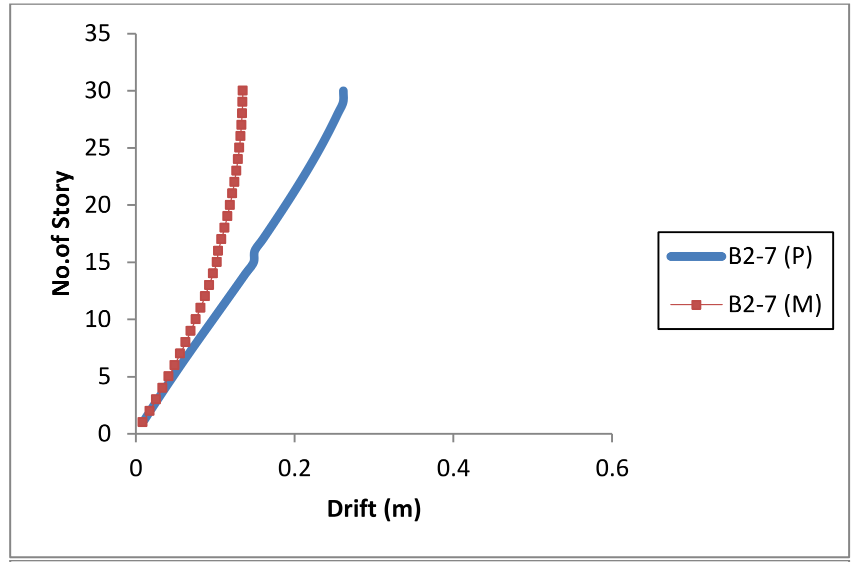


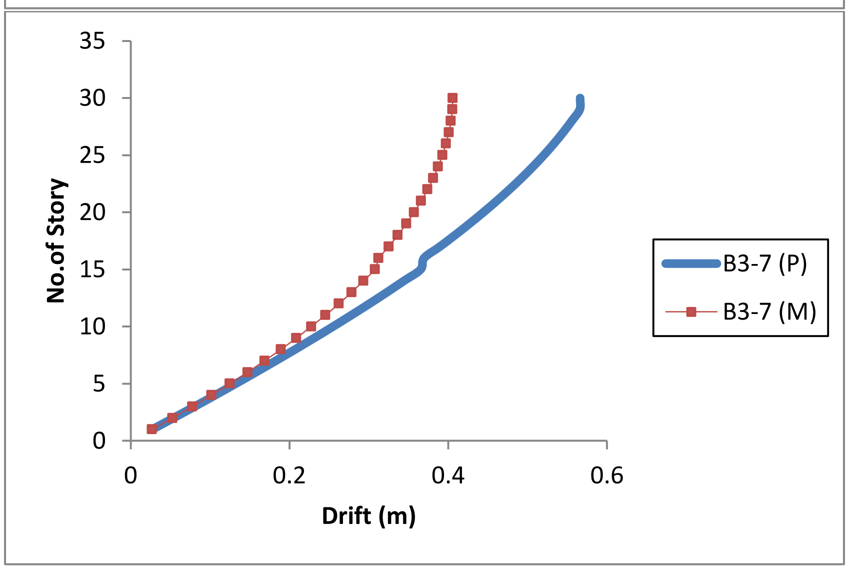


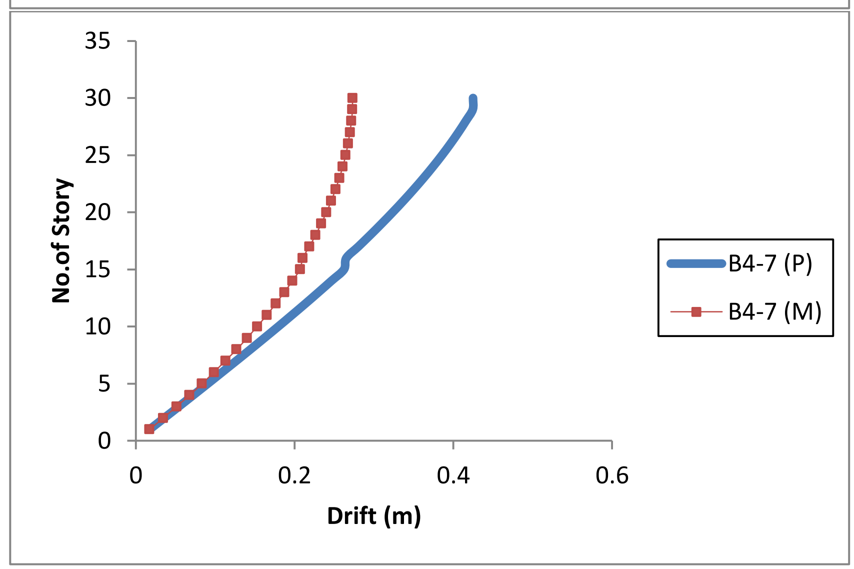


APPENDIX E7: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 16th and 30th floors

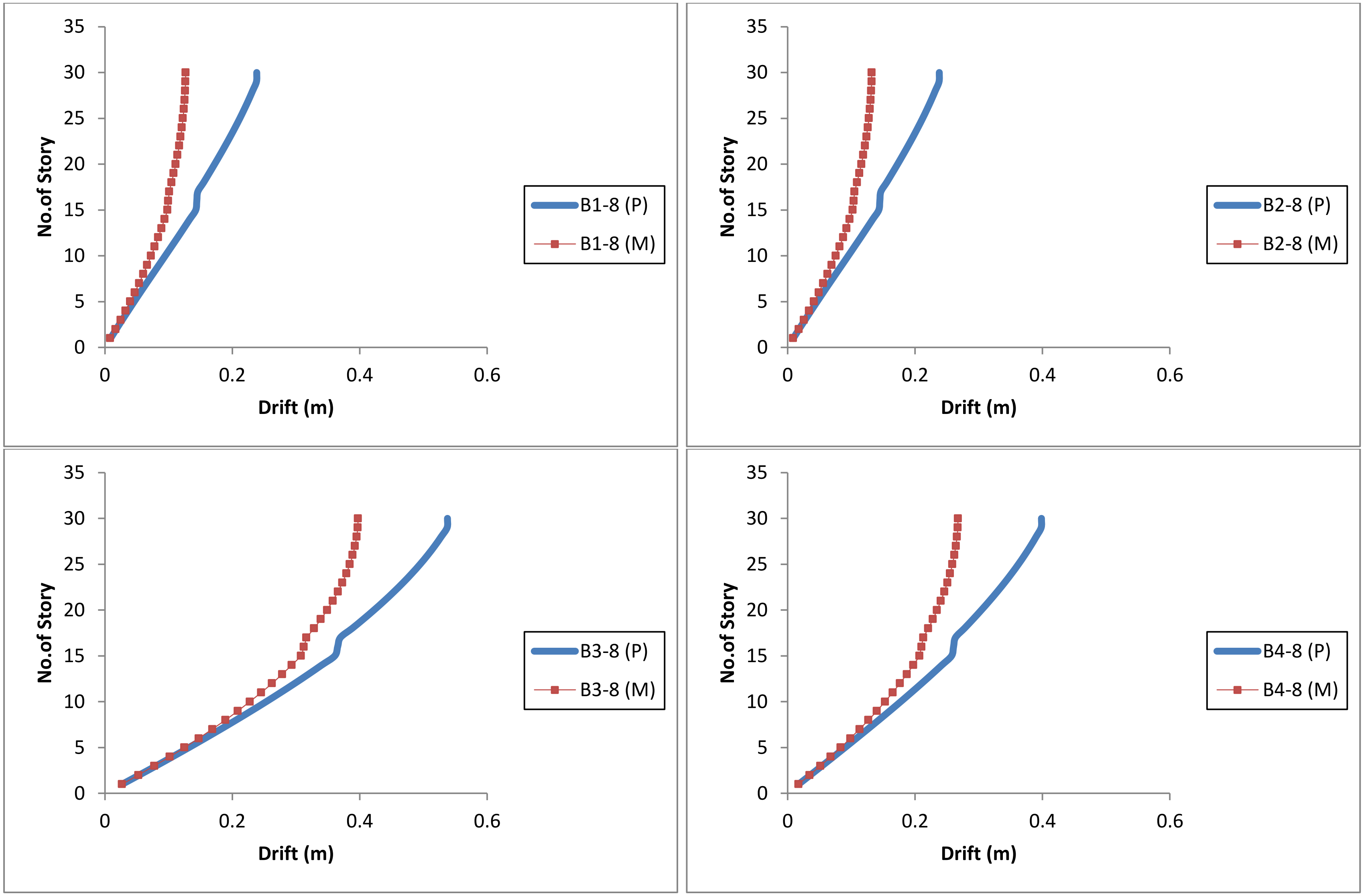




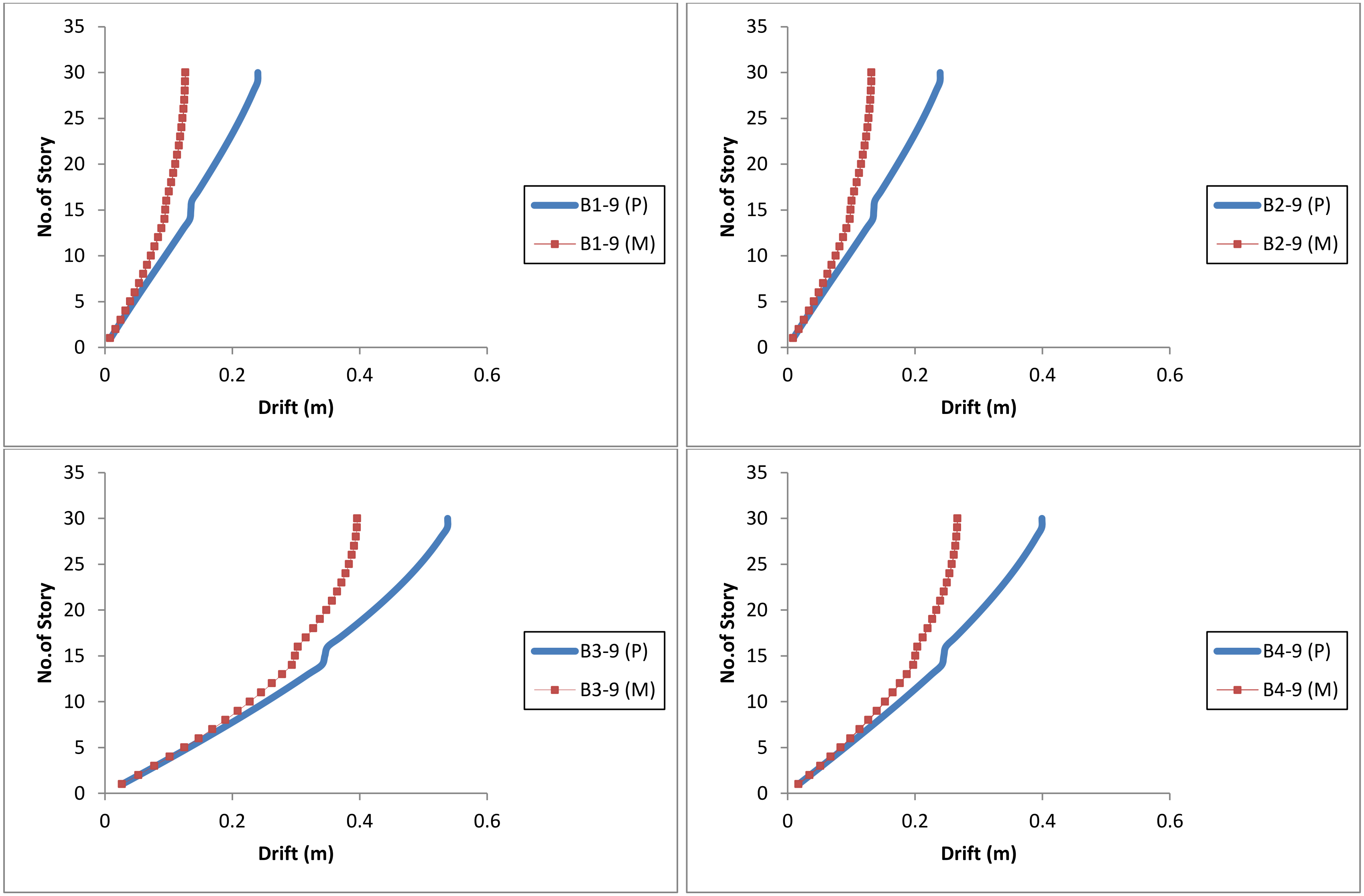




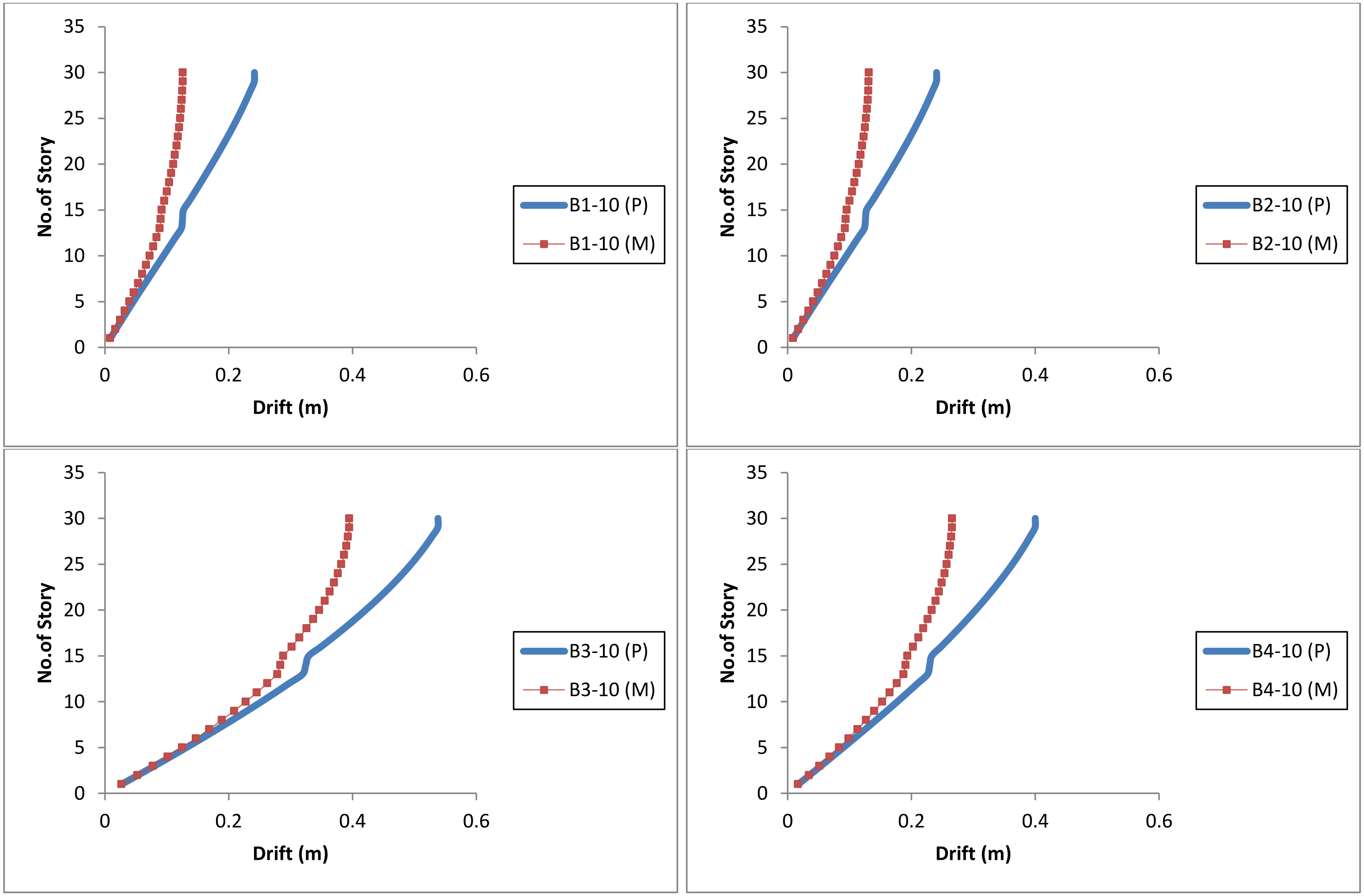
APPENDIX E8: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 16 &17th and 30th floors



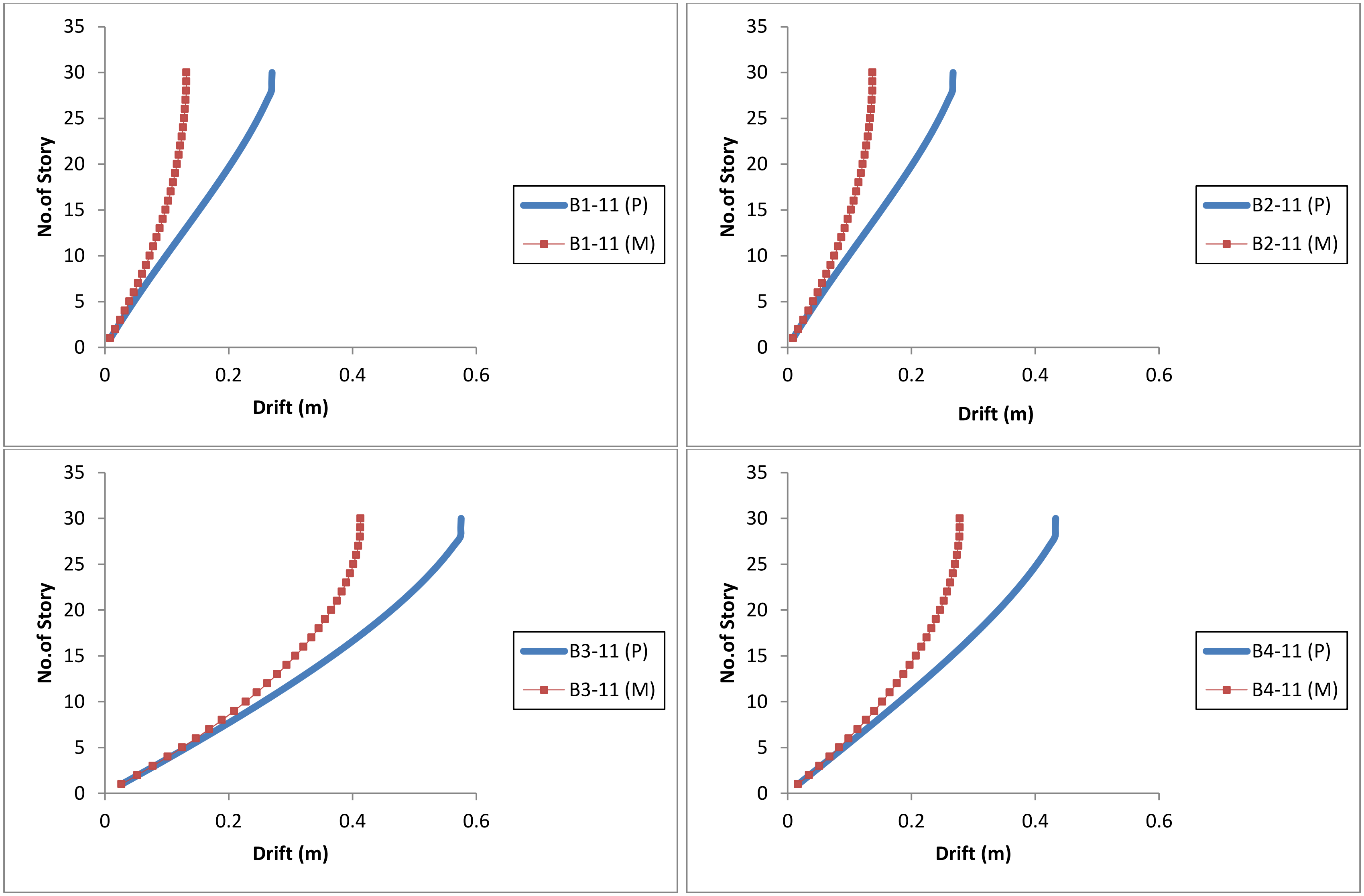
APPENDIX E9: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15 &16th and 30th floors



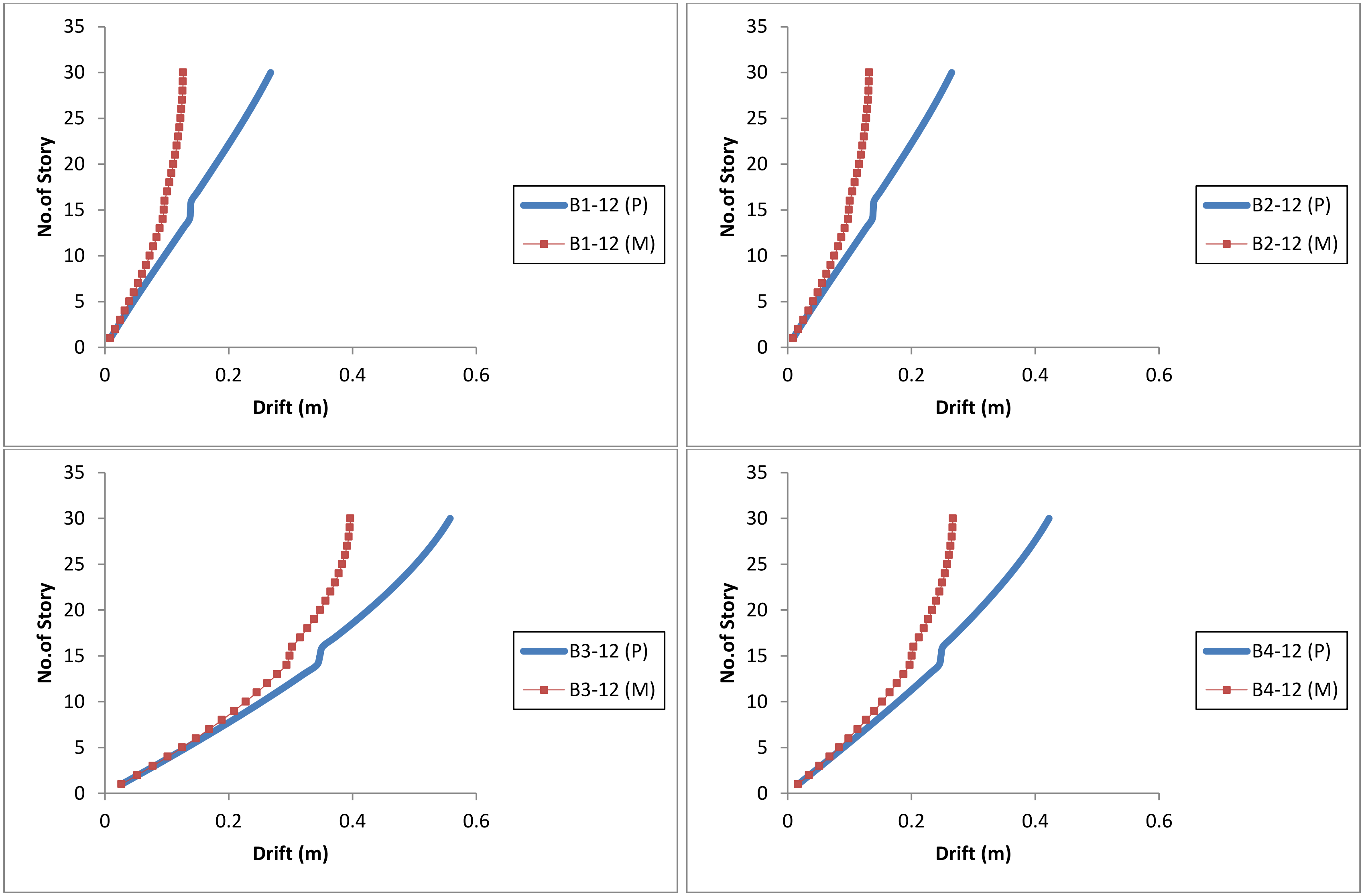
APPENDIX E10: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 14 &15th and 30th floors



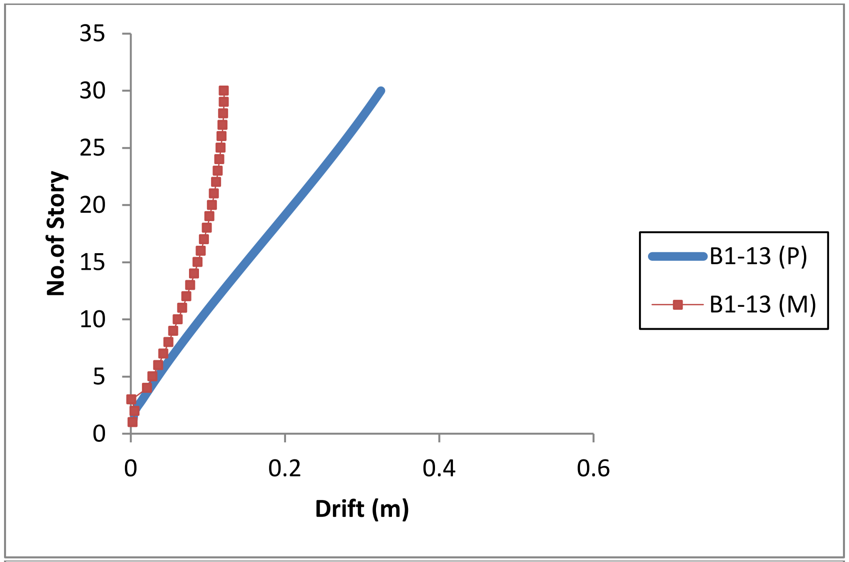
APPENDIX E11: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 29th and 30th floors

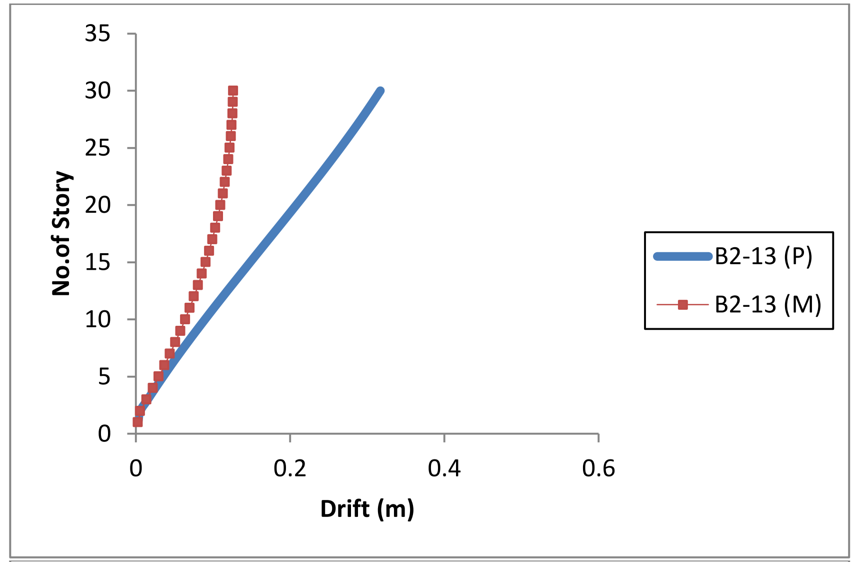


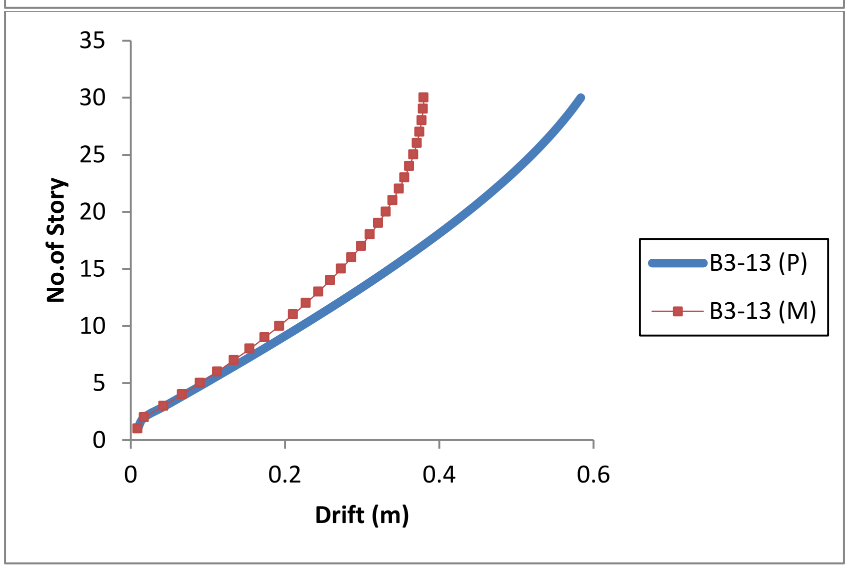
APPENDIX E12: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 15th and 16th floors

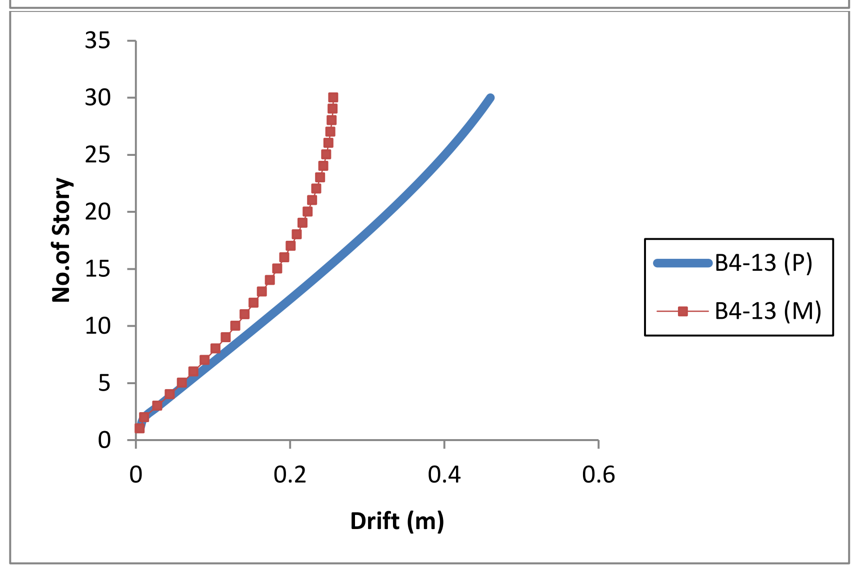


APPENDIX E13: Pin Connection vs. Pin-Moment Connection: Braced along the center bay and at the 1st and 2nd floors

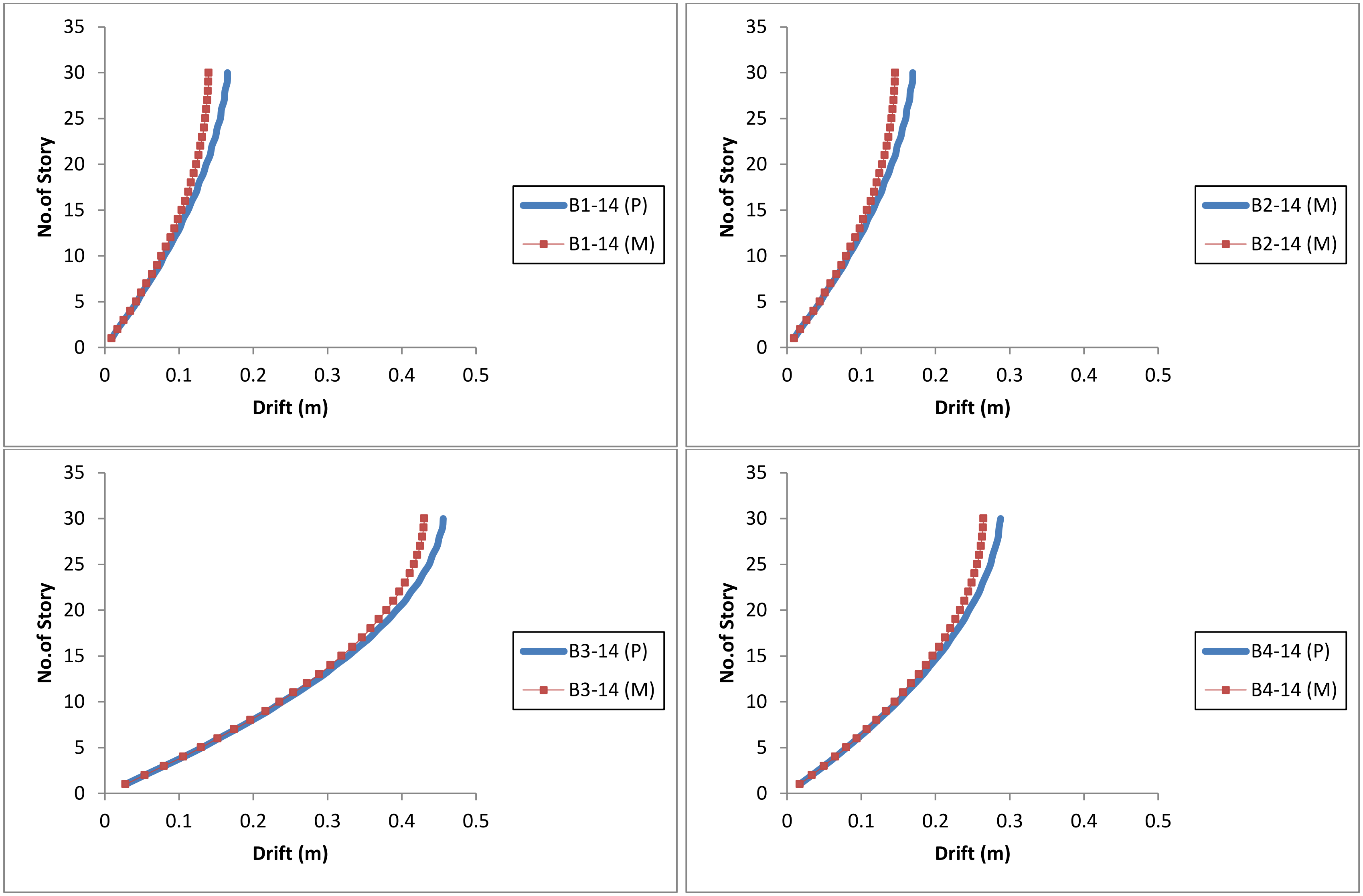




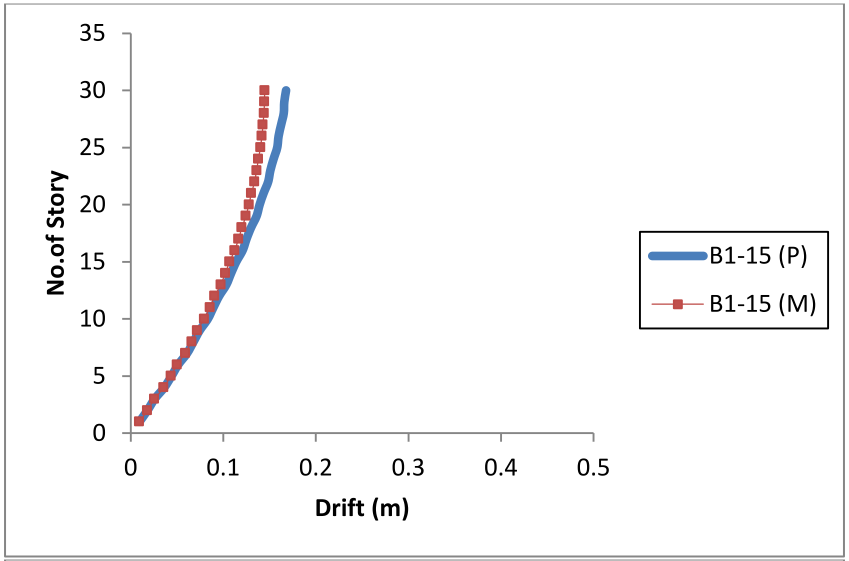


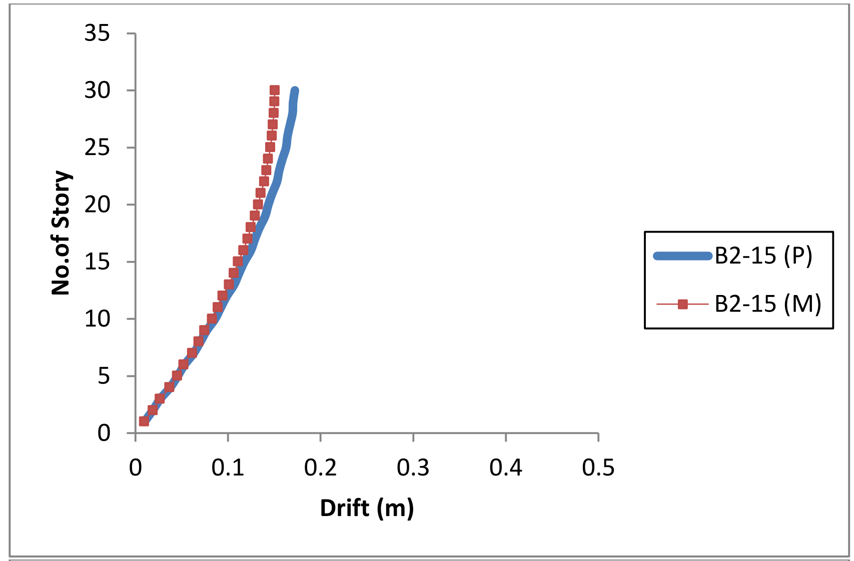


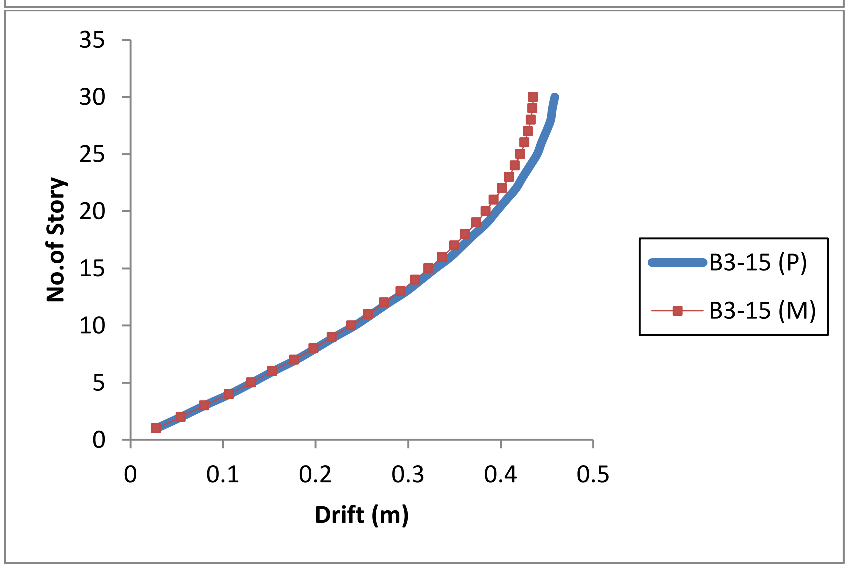
APPENDIX E14: Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over buildings width (zigzag)

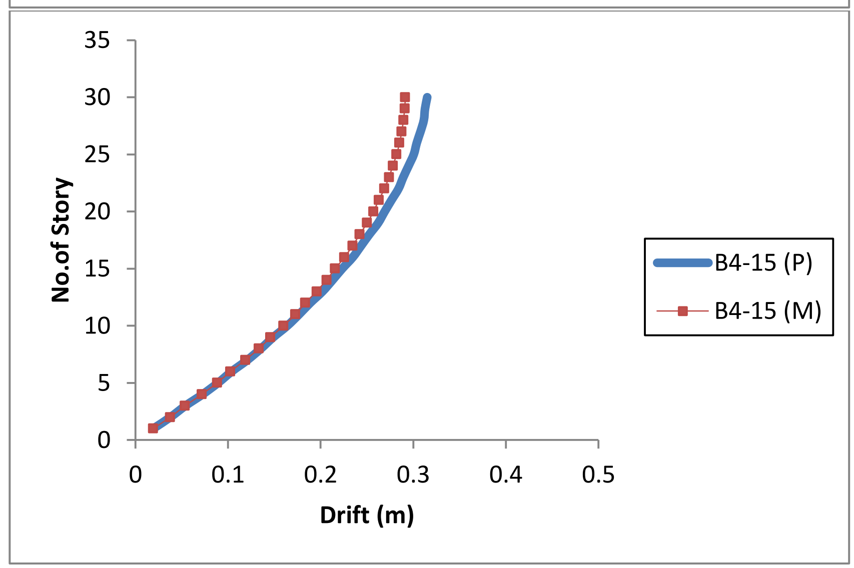


APPENDIX E15: Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over buildings width (diagonal)

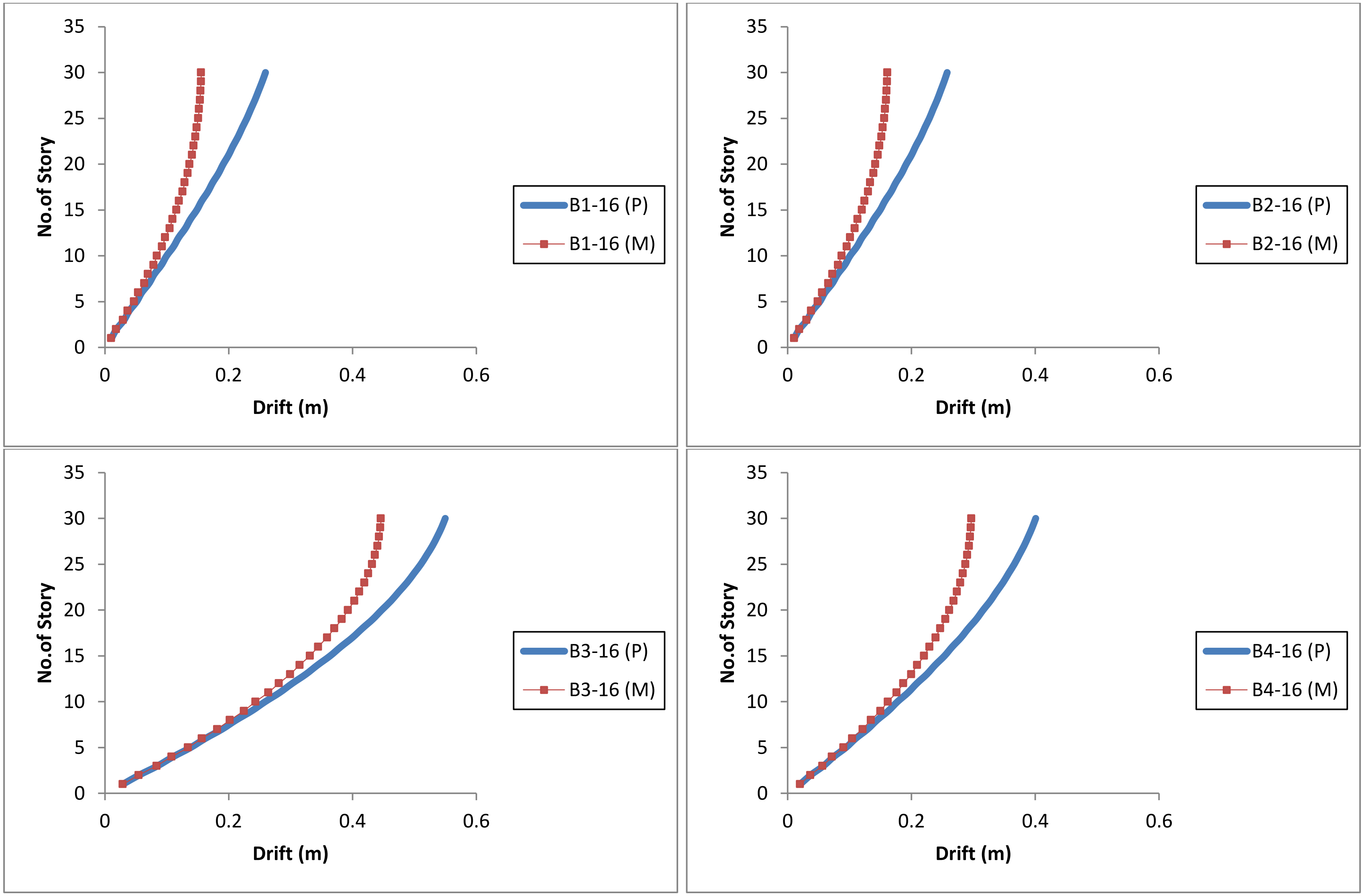




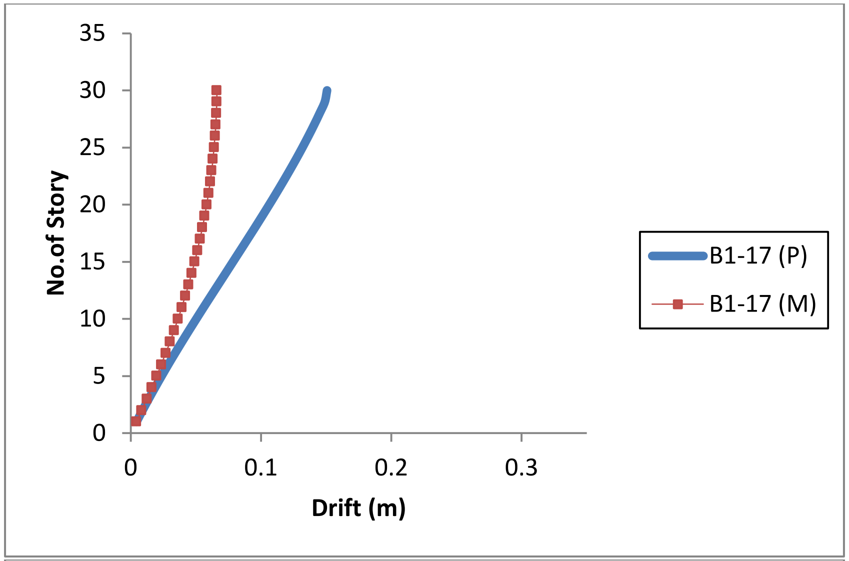


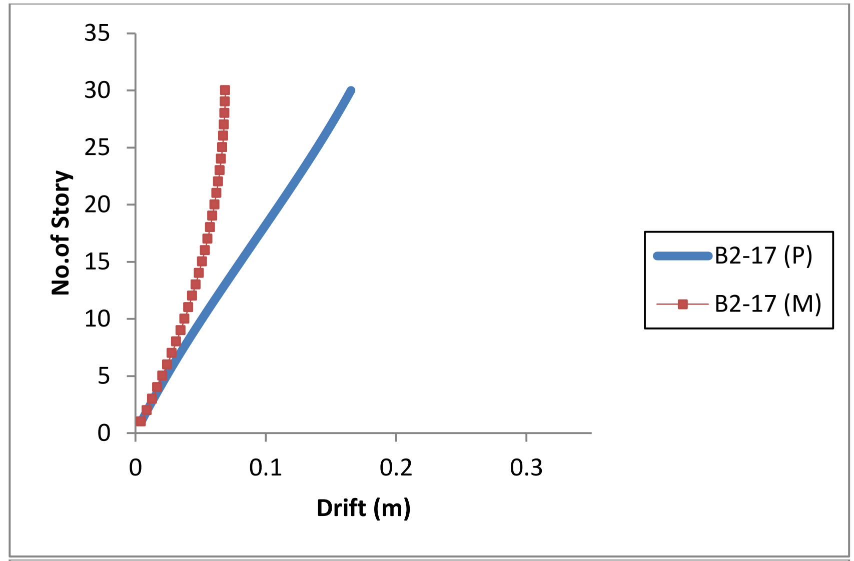


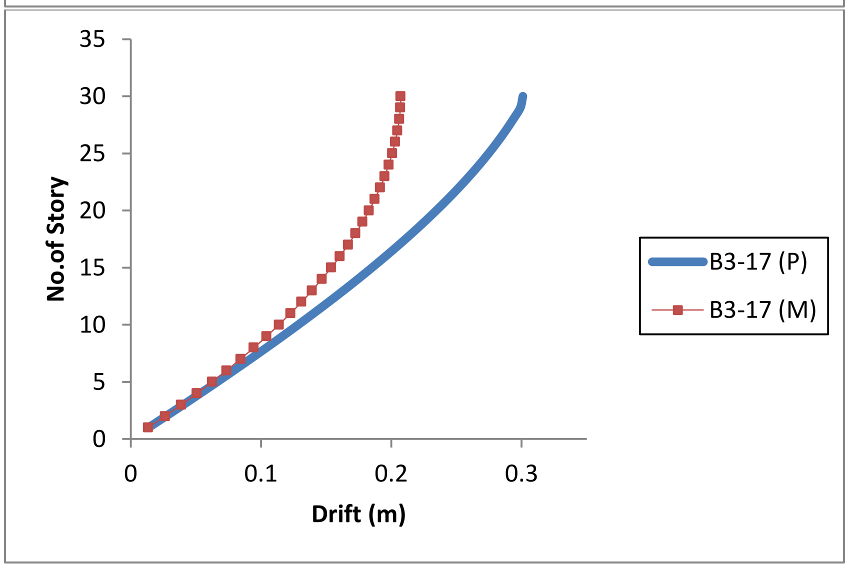
APPENDIX E16: Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over the first and third bays

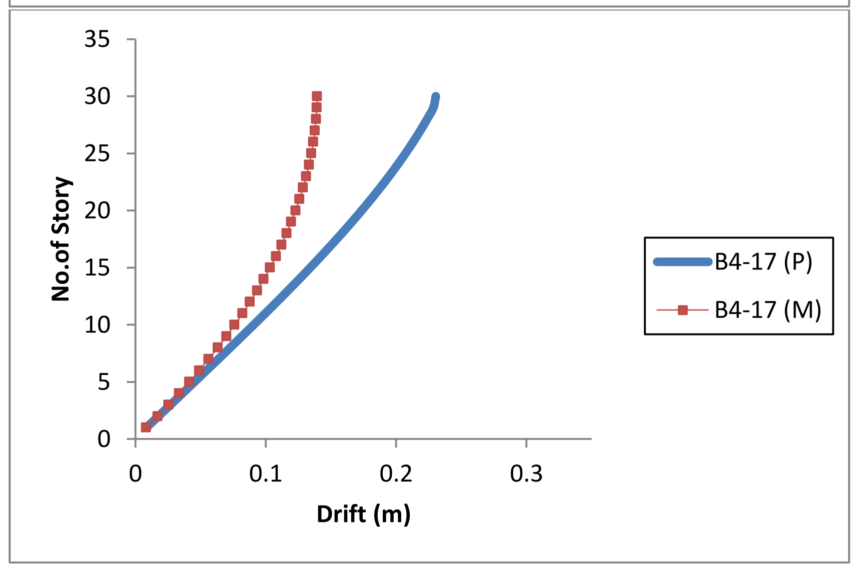


APPENDIX E17: Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 30th floor

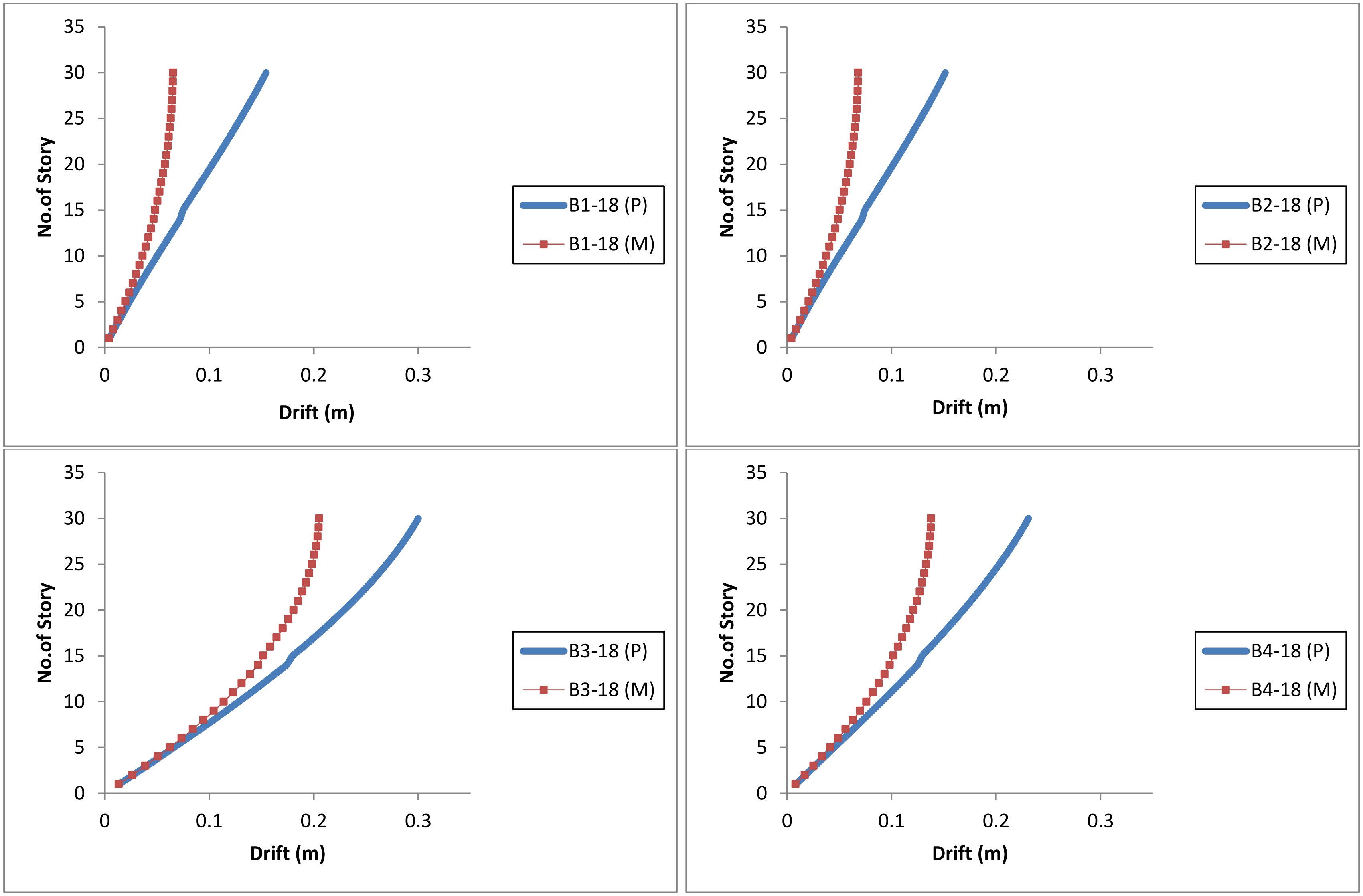




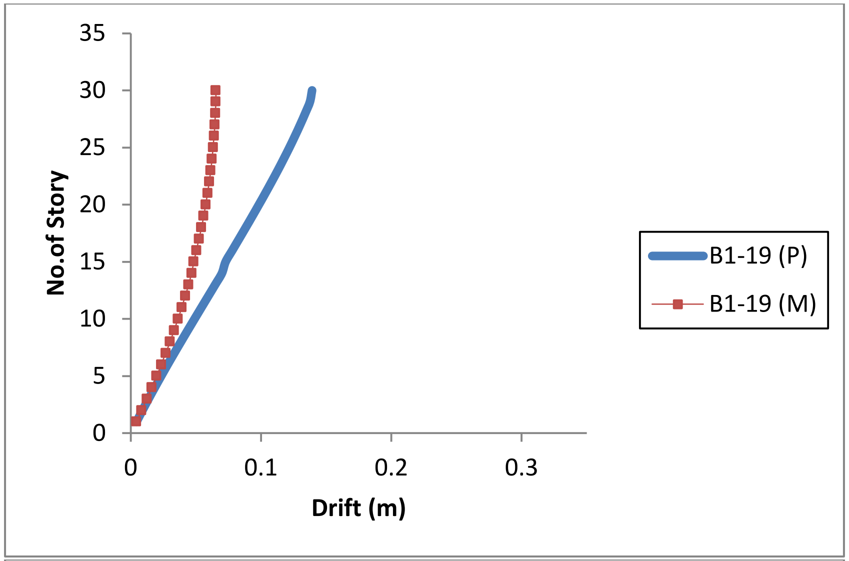


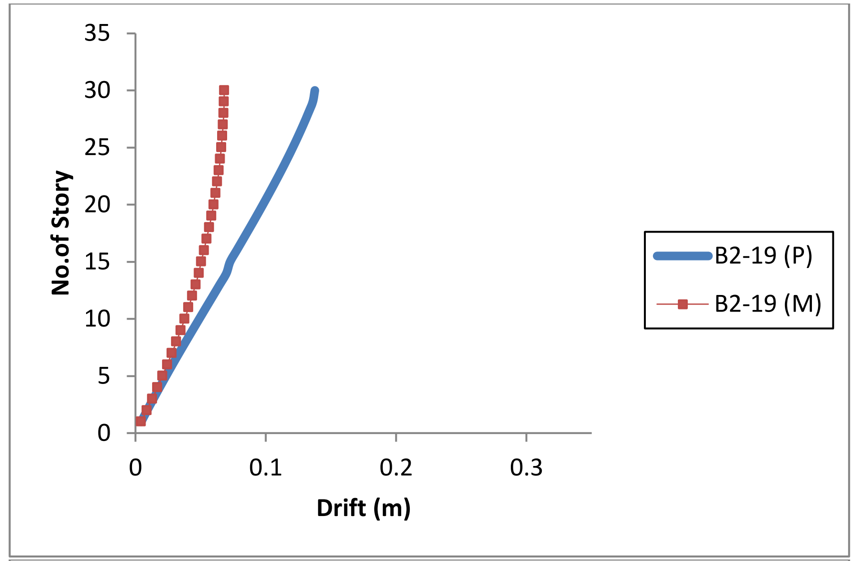


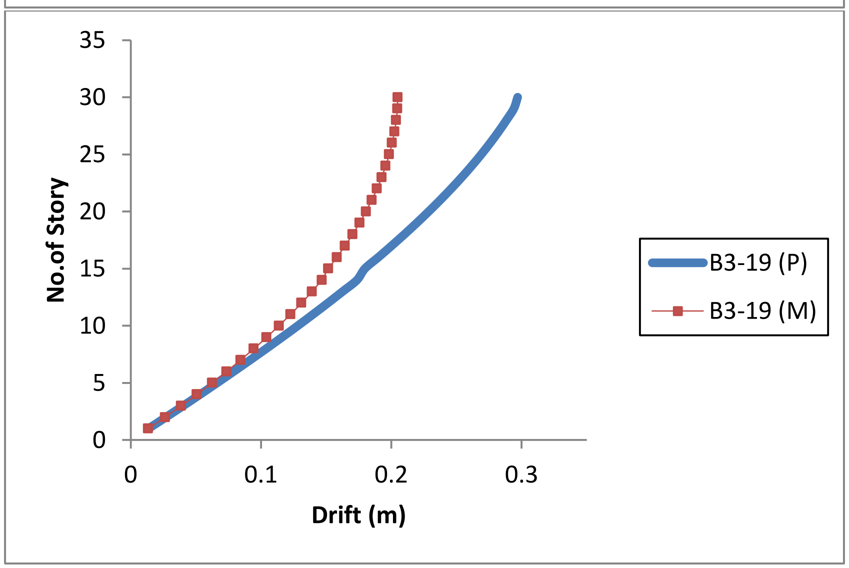
APPENDIX E18: Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 15th floor

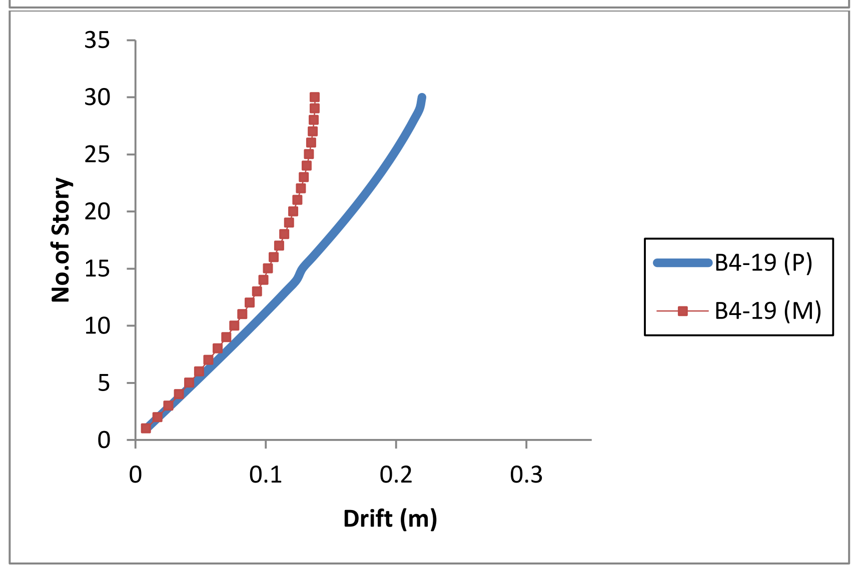


APPENDIX E19: Pin Connection vs. Pin-Moment Connection: Braced completely the outer bays and the 15 & 30th floors









APPENDIX E20: Pin Connection vs. Pin-Moment Connection: Bracing schemes spread over the buildings width