International Journal of Scientific Research and Engineering Development-– Volume 4 Issue 6, Nov-Dec 2021

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Evaluating Seismic Efficiency of K-Bracing in Steel Building Frames

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Abstract:

In moderate seismic zones the structural steel systems should be provided basic lateral resisting strength and stiffness which prevents the structure to be laterally unstable. The lateral instability of structures is resolved by providing appropriate bracings systems. In present study, K bracing will be provided the building frame around every bay to investigate the seismic efficiencies of structural systems under which K bracing type is configured in either concentrically or eccentrically k-bracing. In my study I observed 6 and 10 story steel building frames with the bracing systems will be analyzed using finite element analysis software called ETABS, the adopted code in the analysis is Eurocode 8 and Eurocode 3 for. Then, the lateral story displacement value under every bracing arrangement is assessed. The result of these bracing arrangement will determine the better bracing in terms of performance for lateral loading resistance. By considering the bracing location in steel building frames in either external or internal (around the core) of the steel building frames. From comparison of eccentrically k braced around the core and concentrically k braced at periphery bays lateral displacement of k braced around the core is increased by an average of 43.6%.. This shows that there great difference in lateral resistance and it is better to avoid it for six and ten story steel buildings.

Keywords: Steel frames; bracing: Eccentric; Concentric; Lateral displacement; Seismic.

I. INTRODUCTION

Bracings are usually used within steel building frames in order to establish resistance to a lateral loads acting on the building systems. Based on the arrangement and connection with other elements there are concentric and eccentric bracing. Concentric braces are the easiest and practically applied in construction industry because of its high axial stiffness and simplicity in application as compared to the eccentric bracing and this leads small lateral deformation. [1].

Eccentric bracing arrangements can always be considered to stabilize the building against lateral loads by providing a bending yield mechanism that tolerates for larger deformation in the steel building frame in the nonlinear region [2].

Depending on the size and shape of bracing, K, V, X, and inverted V type bracing are among them. The efficiency of bracing are depends on requirement of ductility, damping, shear and bending yield mechanisms at service and ultimate limit states [3].

By adding the bracing types, it would increases the natural period of vibration of the structure. In high-rise buildings, bracing system could decrease the acceleration of the structure and reduced the internal action caused by earthquake actions [4].

Therefore In this study we will be going to investigate the behavior of K-type bracing in reducing the seismic loads acting on the structure.

In highly seismic zone, the response of building subjected to dynamic load is greater than static load. The efficiency of seismic resistance of structures are dependent up on dynamic characteristics such as ductility, strength, stiffness. Those characteristics lead to reduce the base shear force and increases the energy dissipation [5].

Providing bracings to Structural building systems especially the steel buildings enhances lateral stability and stiffness of the high-rise buildings [6].

II.TYPES OF BRACING.

There are two arrangementsof bracing systems are 1) Concentric Bracing System and 2) Eccentric Bracing System. The steel braces are generally placed in vertically aligned spans. This system lets in to acquiring an amazing advance of stiffness with a minimal added weight.

1) Concentric bracings provide an additional lateral stiffness to the building systems hence will increase the natural frequency of the structure and also typically decreases the lateral storey displacement and drift. However, increase inside the stiffness may additionally attract a larger inertia force caused by seismic action, and reduce the bending moments and shear forces in columns besides they increase axial loading on columns.

2) Eccentric Bracings diminish the lateral stiffness of the building system and advance the energy dissipation capability. The vertical component of the bracing acts due to earthquake causes lateral point load on the beams at the connection point of the eccentric bracings. [7].

In addition to that, braced frames resist gravity loads in beam bending and column compression; and also lateral load in axial compression and tension. Braced frames are less stiff than moment resisting frames. Nevertheless, braced frames are flexible and are not as rigid as shear wall systems. There are numerous forms of braced frame like cross (X) bracing, chevron shape brace, V shape brace, and K bracing [8].

The figure below shows concentrically and eccentrically k-bracings:

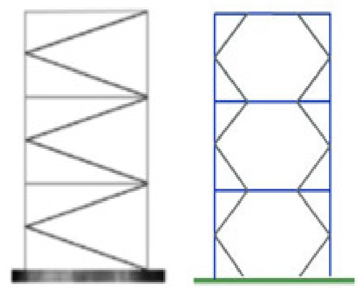

Fig 1.1: Concentric and Eccentric k bracing

III. LITERATURE

Steel building structures are perceptibly one of the most common adoptions for residential building and commercial constructions in the world-wide. Among these steel structures, various kinds of steel braced structures are perhaps the most favored kinds, because of its less skill requirement for joints and welding, and its likelihood to use lighter and common section for braces and beams. Braced steel frames categorize into two various types, concentric and eccentric braces, that have specific features and design requirements. In some research study, different kinds of bracings including X, inverted Chevron, K and diagonal concentric and eccentric two dimensional braced steel frames are analyzed using a finite element software and the differences and the merits of each kind is tried to be assessed. Although the method for this investigation does not cover all the aspects of the structures and models, this analysis still delivers a good comparison among all the common bracing types. The kind of loadings are derived from seismic code of Iranian, moreover the sections are the common Euro sections, which were checked and their design was performed by American Institute of Steel Construction (AISC) seismic provisions [9].

Structural steel is a multi-purpose construction material extensively used in the construction of medium to high rise building structures, airport hangers, bridges, shopping complex, recreational structures, steel arch, etc. It has high ductility and strength, which is the most important property under seismic action because the structure is required to absorb the vibration energy imparted to it during ground shaking. Duggal (2007) discussed on the high strength and large ductility to weight ratio of structural steel which makes it the best material for earthquake resistance [10].

The large ductility and the high strength-to-weight ratio of structural steel makes it the best construction material for earthquake resistance. In general, steel structures are more flexible than reinforced concrete structures, but also they exhibit larger lateral displacement than reinforced structures which can be controlled by providing lateral resistance mechanism such as bracing structures. Structural planning of steel buildings must obey to that the beams yield prior to the columns, and the strength of steel connection must be greater than the strength of beams and columns framing into the steel connection and the connections must guarantee high strength, ductility, and energy dissipation capacity, and too much lateral sway had to be avoided. Multi-storey buildings are usually constructed in steel materials as framed structures. A ductile frame can experience important inelastic deformations, localized in the neighborhood of sections having maximum bending moment. This ultimately leads to the formation and rotation of plastic hinges and redistribution of plastic moments, letting the structure to resist higher loads compared to those predicted by the elastic analysis [11].

IV. CAUSES AND FAILURE MODES OF STEEL STRUCTURES

Even though steel is highly ductile, inelastic ductility is not necessarily retained in the finished structure. Hence, precaution should be taken during design and construction to avoid losing this property. Significant care is also required to check structural failures due to instability and brittle fracture to guarantee the development of full ductility and energy dissipation capacity under earthquake loading [11].

The causes of instability are:

(i) Local buckling of plate elements (e.g., web, flange, etc.) with large width to-thickness ratios: A steel members comprising plate elements with a large width-to thickness ratio is incapable to reach its yield strength, because of prior local buckling. Even if the yield strength is reached, ductility will be insufficient. Under cyclic loading, it is observed that strength and ductility reduce with increasing width-to-thickness ratio, and local buckling of web causes additional degradation.

(ii) Flexural buckling of long columns and braces: Slender columns may fail by buckling. This mode of instability is quick and can happen when the axial load in a column may never reach the yield. Even a small lateral force in such situation will produce a significant deflection leading to instability and this phenomenon is termed as flexural buckling. The capability of slender columns is, hence, limited by the stiffness of the steel member rather than the strength of the material. The lateral stiffness of the steel frames, hence, is increased by providing bracing system to the frames. However, buckling of braces is a potential source of instability of steel frames. Steel bracing is considerable energy dissipative system by yielding under tension but buckle without much energy dissipation in compression. Therefore, the capacity of energy dissipation of concentrically braced frames is noticeable less, due to buckling of braces than that of the moment resisting frames.

(iii) Lateral-torsional buckling of beams: During moderate to strong shaking of the ground, additional forces are developed in numerous members of a structure. For a beam loaded in flexure, the load bearing side (generally the top of the member) carries the load in compression, whereas the non-load bearing side (generally the bottom of the member) will be in tension. If the beam is not supported in the opposite trend of bending, and the flexural load increases to a critical limit, the beam will fail due to local buckling on the compression side in wide-flange sections designed for flexure only.

If the top flange buckles laterally, the rest of the section will twist resulting in a failure mode termed as lateral-torsional buckling.

(iv) Connection failure: The failures of bolted and welded connections are to be avoided.

In this research study we are going to highlight both for concentrically and eccentrically type of steel bracing having two different types of geometrical configurations with similar steel cross section for assessment purpose.

Various researchers" worked out comparisons of the seismic efficiencies of various forms of steel bracings, but their criteria of constructing assumptions for the selected group are not similar. Mostly the comparison of bracing was made by assuming shape as the only criteria [12].

Preceding to the 1994 Northridge earthquake, comparatively little special concentrically braced steel building frames were built in California. It has normally been believed in the structural engineering community that the earthquake performance of concentric braced steel frames is lesser to that of moment resisting frames in steel building frames. Widespread damages have been reported in concentrically braced frames following numerous recent earthquakes, including the 1985 Mexico, 1994 Northridge and 1995 Hyogo-ken Nanbu events. For the reason that of these observations, building codes specify relatively low values for the response modification factor applied in design to account for the characteristic ductility of a system, and further restrictions are imposed for braced steel frames positioned in areas of high seismic risk. However, with the overview of more complex and rigorous guidelines for the design and construction of steel moment resisting frames following the Northridge earthquake, a quick increase in the use of special concentrically braced frames have happened, especially for low- and mid-rise construction [13].

V. METHODOLOGY

In this study ETABS (Extended Three-Dimensional Analysis of Building Systems) is used which is special purpose Software intended for the analysis and design which is specially developed for buildings.

The revolutionary and innovative new ETABS is the ultimate integrated software package for the structural analysis and design of building structures. Incorporating 40 years of continuous development and research, this latest ETABS offers unmatched 3 dimensional object based modeling and visualization tools, blazingly fast linear and nonlinear sophisticated analytical power and comprehensive design capacities for a large number of materials, and insightful graphic displays, schematic drawings and reports that allow users to rapidly and easily decipher and comprehend analysis and design results.

To study the seismic performance of K type bracing used to two block of G+6 and G+10 steel structure building. The geometry, material properties, loading were defined according Eurocode 3 and 8. Having those inputs were modelled in ETABS V-16 interface. The characteristic material properties used in themodel are stated in table 3.1

Table 3. 1Steel Grade Consideration

No.	Steel Grade	$f_y\,(MPa)$	$f_u\,(MPa)$
1.	S450	440	550

Table 3.2: Assumed Dead and Live load magnitudes acting on the Structure

Live Load	3kN/m^2
Load from fixed furniture (dead load)	1.15KN/m2
Earthquake load	As per of Eurocode 8

VI. ANALYSIS RESULT

Before analysis of the modelled structure, a lateral load acting to the steel building structure has been determined according to Eurocode 8.

A lateral load at the peak ground acceleration of seismic zone 4 which supposed to construct the building in Mekelle was determined using response spectrum method of analysis. And the lateral displacement can be determined using response spectrum for the same peak ground acceleration and ground condition. The loads were assumed to act in both principal direction.

In Eurocode-8, there are two type of response spectrum. Type 1 is recommended for high seismic area with great than earthquake magnitude of 5.5 Reciter scale and type 2 is used for relatively less seismic area with less than of earthquake magnitude of 5.5 Reciter scale [14].

Table 4.3: General Parameters considered during Analysis

S.No	Parameters	Values
1	Design Ground Acceleration, ag	0.15g
2	Design spectrum type	2
3	Ground type	B
4	Behavior factor	2 for K-bracing

Table 4.4: Values of Parameters describing the recommended Type 1 elastic response spectra

Ground type	S	T_B(S)	T_C(S)	T_D(S)
B	1.2	0.15	0.5	2

The results obtained from analysis of structures of each bracing configuration of the same story is plotted using excel sheet for comparison purpose and the corresponding result is tabulated and shown in the appendix for the above analysis results.

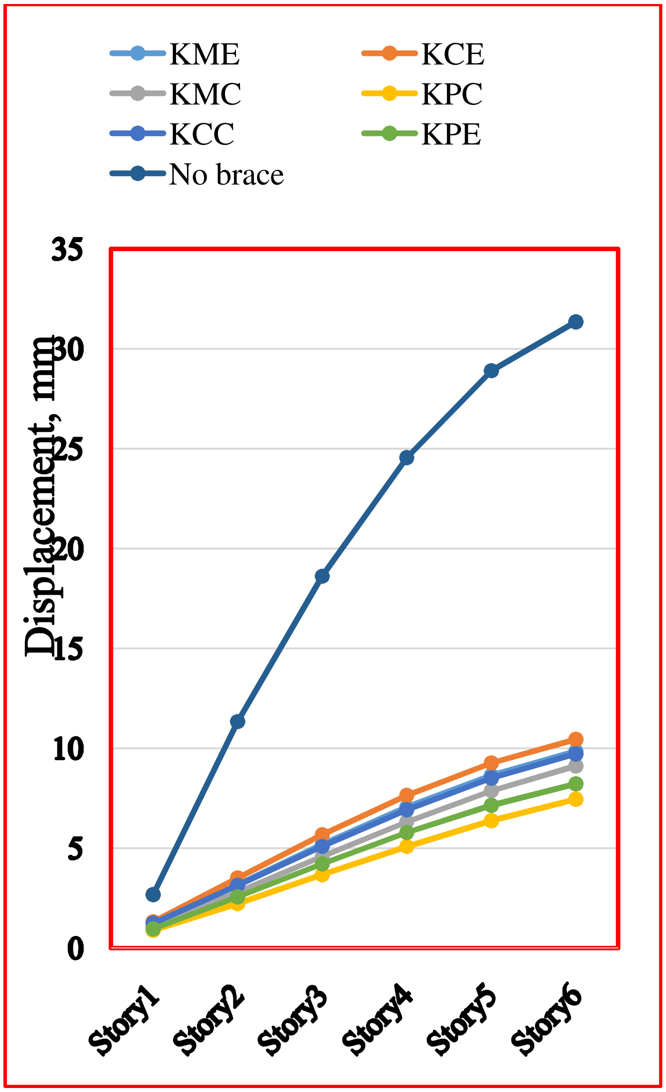

Figure 5.1: Plot of Lateral displacement values of each K bracing for six story Building

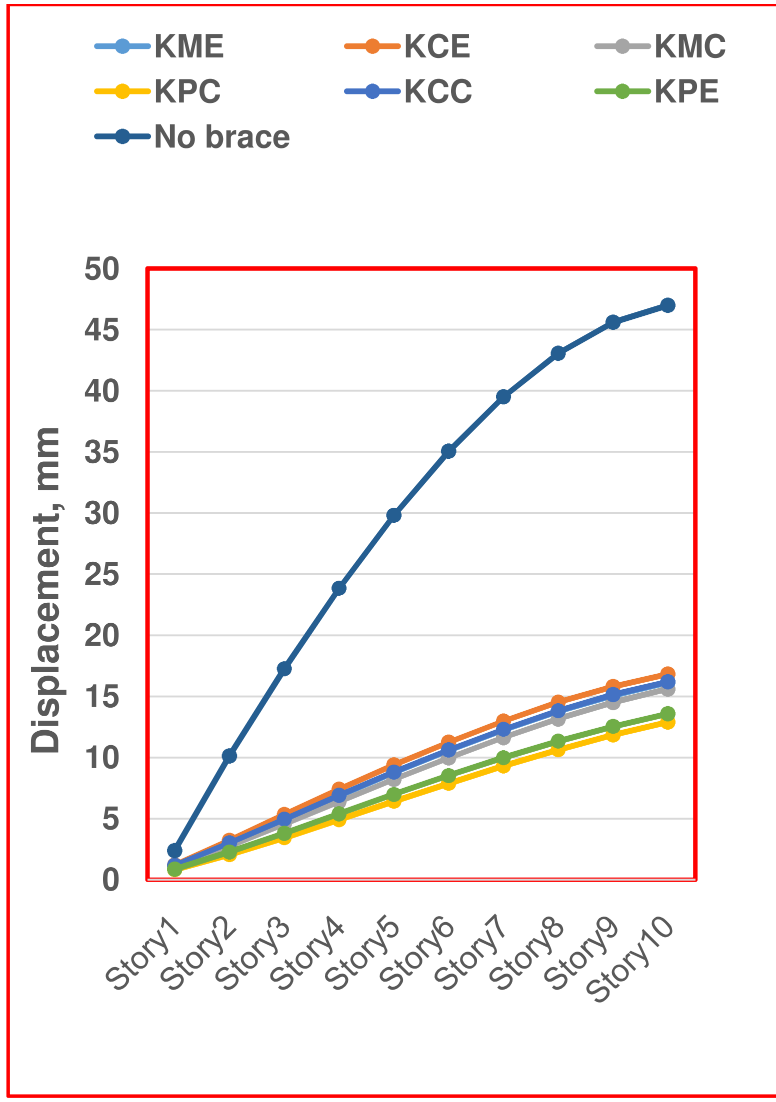

Figure 5.2: Plot of Lateral displacement values of each K bracing for ten story Building

Additional work on various k-bracing arrangement by varying bracing location with 10% connection offset (for the eccentric bracing) and considering fixed and pinned restraint condition.

a) Fixed restraint condition

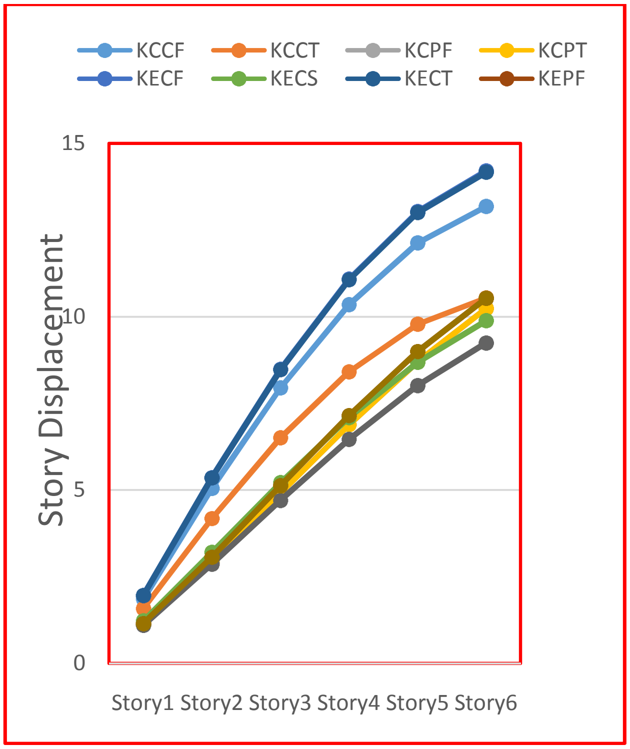

Figure 5.3: Plot of lateral displacement of six story steel building with various bracing location from bay to bay

b) Pinned restraint condition

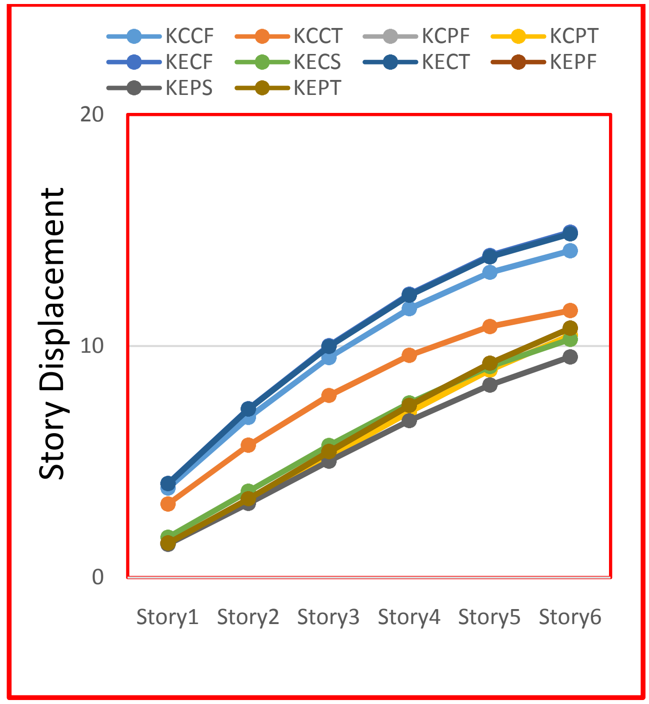

Figure 5.5: Plot of lateral displacement of six story steel building with various bracing location from bay to bay

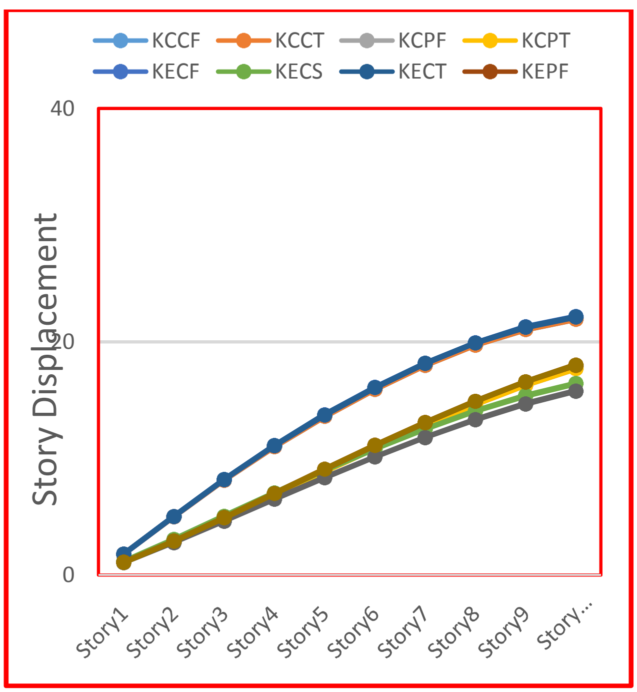

Figure 5.4: Plot of lateral displacement of ten story steel building with various bracing location from bay to bay

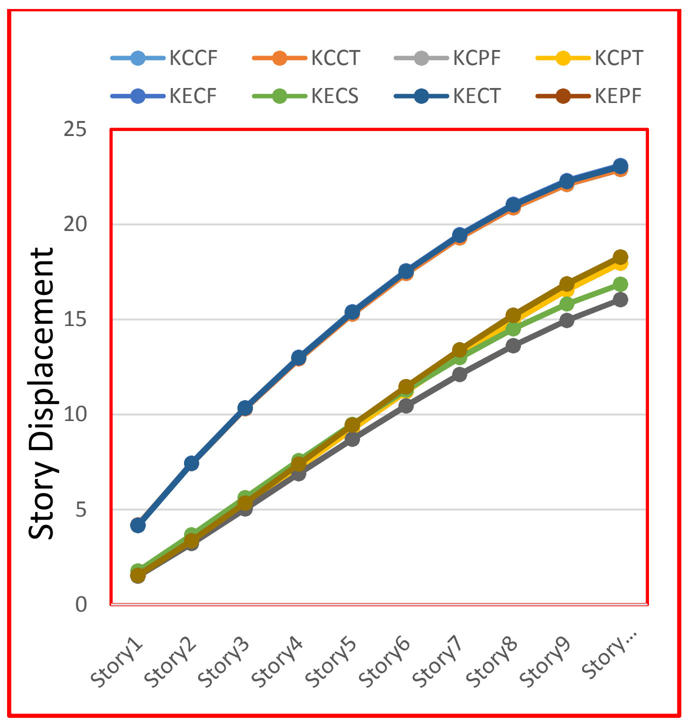

Figure 5.6: Plot of lateral displacement of ten story steel building with various bracing location from bay to bay

VII. DISCUSSION, CONCLUSION AND RECOMMANDATION

7.1 Discussion

The study of above mentioned frame geometry layout, story height of 3m and bay width is assumed to be investigated. This is due to high strength and ductility when compared to weight ratio of steel structures. In addition the presence of bracing gives an advantage to increase the stiffness the building.

From the Plot of lateral displacement values of each bracing types, it is discussed as follow:

- Generally the lateral displacement values of concentrically K-bracing always have smaller displacement than the eccentrically k-bracing which proofs that the concentric arrangement possess larger stiffness This is observed from the two lateral displacement.
- The unbraced building frame have the highest lateral displacement of all models investigated because of the lack provision lateral resisting system.
- The weakest bracing arrangement of all models is eccentrically k braced around the core (**K_{CE}**) and the strongest one is the concentrically k braced at periphery bays (**K_{PC}**)
- From comparison of eccentrically k braced around the core (**K_{CE}**) and concentrically k braced at periphery bays (**K_{PC}**), lateral displacement of **K_{CE}** bracing is increased by an average of 43.6%.. This shows that there great difference in lateral resistance and it is better to avoid **K_{CE}**For six and ten story steel buildings
- From comparison of each corresponding concentric and eccentric k bracing arrangement, concentrically k bracing at middle bay (**K_{MC}**) and eccentrically k bracing at middle bay (**K_{ME}**), the lateral displacement of **K_{ME}**is increased by an average of 7.8%, concentrically (K_{CC}) and eccentrically (K_{CE}) k bracing around the core, the lateral displacement of K_{CE} is increased by average of 7.33% and concentrically (K_{PC}) and eccentrically (K_{PE}) k bracing, the lateral displacement of K_{PE} is increased by an average of 9.8%. This shows that there is slight increment of lateral displacement in the corresponding bracing arrangements.
- It is noticed that the lateral displacement increases when the connection offset length increases, for instance in the first study 20% offset is used for eccentric and gives larger displacement value than the 10% offset connection.
- When considering the restraint condition, the lateral displacement increases for the pinned restraint condition case.

7.2 Conclusions

The following conclusions are drawn from the study;

- The lateral displacements of the structural steel building system for the corresponding k- bracing arrangement are determined from ETABS software analysis result specially version 2016. These lateral displacement values for the corresponding bracing arrangement are structured for steel buildings with six and ten stories.
- Comparisons is done firstly by considering lateral displacement values of each bracing arrangement obtained in a given story buildings separately. The plot of lateral displacement at each story level is made for each of two steel building structures. The main goal of considering two types of building with various number of stories is to identify the behavior of bracing arrangement as the building height varies.

- It is found that k bracing arranged in the two periphery bays performs better than the other arrangement of bracing .it gives higher lateral resistance mechanism for the overall building structures which have smaller value of horizontal displacement of the structure compared to other arrangement
- As it is shown from comparison graphs, the behavior of each bracing does not change as the number stories increase from six to ten stories. It means for the two types of building considered, k bracing provided at two periphery bays performs better than others. The next preference is the k bracing arranged at external middle bays, k bracing provided at first or the third external bays, then bracing at around the core. The graphs proofs all bracing behaves similarly even if the number of stories changes from four to ten stories.
- It is identified that from comparison plots of each graph, the structural system that contain with lesser offset bracing connection has less lateral displacement than that of larger offset bracing connection .And for the fixed and pinned restraint condition, the pinned condition exhibit larger lateral displacement .

7.3 Recommendations

This projects work is a step towards the complex phenomena to select the performance of various bracing arrangement. The main aim of this study is to investigate various bracing arrangement and identify the performance of each bracing.

Under this study one bracing type that I considered is classified under concentrically bracing and eccentrically bracing among the possibilities for future study, the following are the main points that deserve attention.

- In this study it is only considered K type of bracing. A study for other bracing type under similar criteria of comparison is left for future investigation.
- The analysis takes place by selecting a wide flange steel section for bracing cross section. The next researcher is expected to check the structural behavior under another cross-section like T section, angle section, tubular section, etc.
- It is also considered that the structure here considered fulfils plan and elevation regularity, the behaviors for irregular structures under this bracing type and also more than there by three bays can be considered for future study.
- In my study I considered linear analysis of the building but the nonlinear analysis is left for future study

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ACKNOWLEDGMENT

My sincere appreciation and thanks go toAllah who enabled to write this article and also to my dear wife Mrs. NajadHussein Yusufwho has inspired me in publishing this article.

