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Structure Behaviour under Seismic loads using X-Bracing, Inverted V-Bracing Systems and without Bracing

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Abstract:- This study aims to assess the seismic behaviour of different braced steel frames using nonlinear static analysis. The model consists of 11 stories, designed and analyzed with X-bracing, inverted V-bracing, and without bracing through ETABS. Therefore, the Maximum Story Drift, Stiffness Factor, and Displacement of all these seismic parameters were investigated and compared by implementing the pushover analysis method. The benefit of these parameters helps decide between rebuilding or repairing the affected structure after the earthquake. Even though these parameters are considered approximate methods to predict the displacement and drifts. The results of this study showed that the frames that are supported with X-bracing are more efficient and have the best seismic performance. In addition to that, the investigation was applied by installing braces in mid-span, and two different spans. However, installing braces in two spans has a slight advantage in performance.

***Keywords**:- Earthquakes, Pushover Analysis, Bracing systems, Non-Linear Static Analysis.*

I. INTRODUCTION

In some regions that are affected by earthquakes designing structures with considering seismic loads is important for both reinforced concrete structures and steel structures. In this model, the structure is a combination between steel and RC by using RC for both slabs and beams, while using steel for columns and braces, and as known, concrete resistance is very weak in tension stresses, [17] and strong in compression and steel in compression is susceptible to buckling. [9] However, if buckling happens in the braces after the earthquake, the braces will have permanent deformation and they won't be able to recover and return to their original shape. Nevertheless, during the earthquake, the braced frames compared to buckling, experience larger maximum story drifts [10]. Five different models are compared in this study, the first one is a structure without bracing, while the rest are X-bracing structures and inverted V-bracing structures, and the aim is to compare between drifts, stiffness, and displacement of these structures under a combination of loads include seismic loads, while the seismic excitation is considered as the most severe loading case. [12]

Generally, it's hard to find accurate results in the structure due to cyclic loads using the software,[4] Therefore, this study is focusing on using nonlinear static analysis, and the model is analyzed by using the pushover analysis method by placing connections between all members at each joint and applying a combination of dead, live, wind, and intensive seismic loads. The failure of connections under cyclic loads (seismic loads in the studied research) is considered as one of the structural failure reasons, while previously the failure of connections was considered as a structural failure reason but not directly attributed reason. [3] There are three collapse mechanisms to investigate if the structure is safe or not, gravity, sideway, and a combination of sideways and gravity. Recently, the design and analysis of structures became more advanced and can cover more critical details in the design also became simpler and easier to save more time, all that due to the high progress that scientists achieved.

The earthquakes movement can be classified into, low movement grade earthquake without causing non-structural and structural damages, moderate movement grade earthquake without causing structural damage and may include some non-structural damage, and intensive movement grade earthquake with a deformation possibility to non-structural and structural damage but collapse is unacceptable [8]

II. NUMERICAL MODELS

Different bracing systems are used to compare the seismic behaviour, and nonlinear and static analysis is implemented in to design.

High-rise symmetric structure includes 10 floors and 5 spans, the height of each floor is 3.3m and the length of each span is 5.5m, the structure consists of two parts.

A. Section Properties

- 3D framed structures have 5 spans of 5.5 m width in each direction.
- 10 floors structure and the height of each story is 3.35 m
- The bracing is placed in the mid-span for the first time and in the second and fourth span for the second time, and the considered braces are Cross bracing (X-bracing), Inverted V-bracing.
- 150 mm Solid slabs are used for all stories.
- The beams section is reinforced concrete, 600 mm depth, and 300 mm width.
- Columns and braces both are steel sections. For column design, HP18X204. For bracing design, steel tube 120X120X10

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- Connections between all members and braces have been used.
- For all slabs, dead load and live load are considered to be 5.5kN/m^2 and 2.5kN/m^2, respectively.
- For all beams, dead load coming from the walls is considered as 7kN/m
- Plastic hinges were placed at both ends of each member.
- Wind load is considered as 1kN in all directions. While Seismic load is considered as 100kN in X and Y directions.
- All models were analyzed using ETABS 18 software using AISC the American standard.
- The design sections were assigned to 5 models are shown in Figs. 1 to 5.

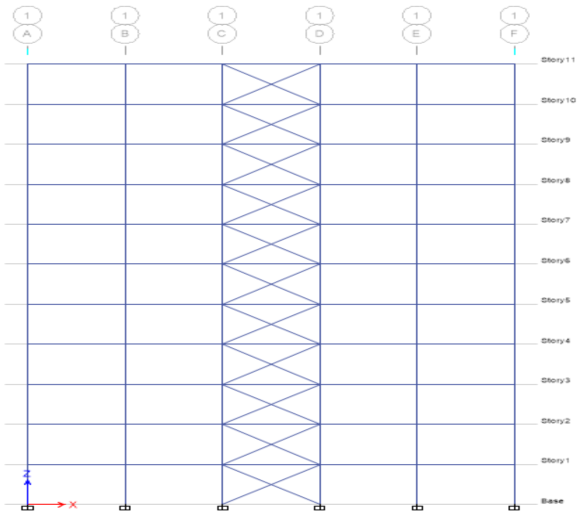

Fig. 1 X-bracing Mid-span model

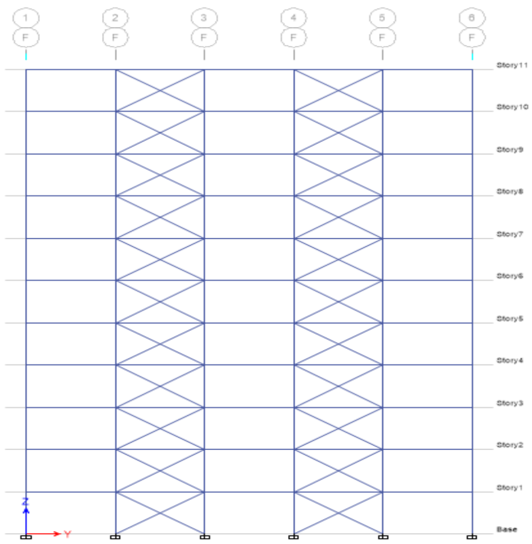

Fig. 2: X-bracing two-span model

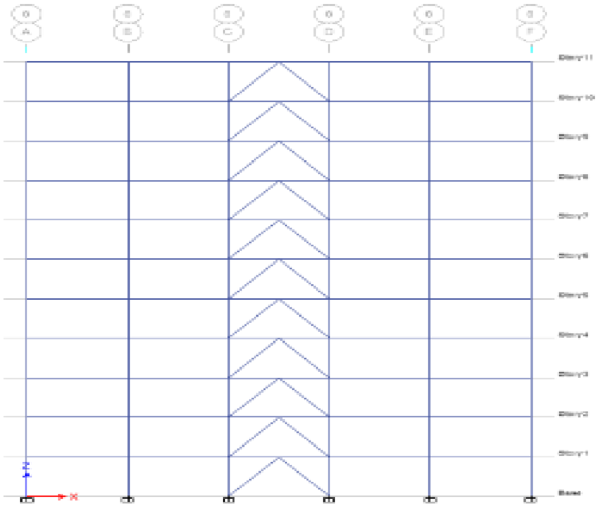

Fig. 3: Inverted V-bracing model mid-span

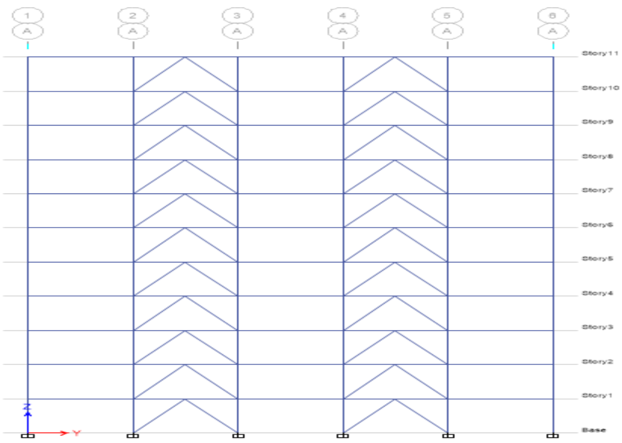

Fig. 4: Inverted V-bracing model two spans

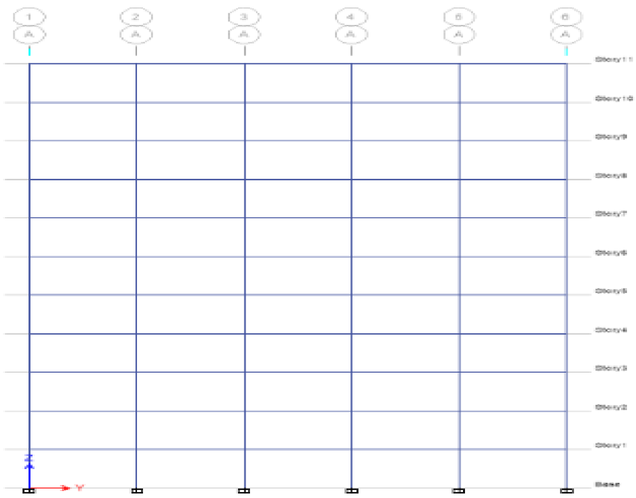

Fig. 5: Without bracing model

B. *Material Properties*

The main used materials are both steel for columns and bracings, and reinforced concrete for slabs and beams according to AISC Code. All the used materials are shown in table 1.

Type	Material	Property
Concrete	Modulus of Elasticity. E	24855.58 MPa
	Shear Modulus. G	10356.49 MPa
	Unit Weight	23.5631 kN/m3
	Compressive strength	27.58 MPa
Steel	Modulus of Elasticity. E	199947.98 MPa
	Shear Modulus. G	76903.07 MPa
	Unit Weight	76.9729 kN/m3
	Yield stress f_y	344.74 MPa
	Tensile Strength f_u	448.16 MPa
Reinforced bars	Modulus of Elasticity. E	199947.98 MPa
	Unit Weight	76.9729 kN/m3
	Yield stress f_y	413.69 MPa
	Tensile Strength f_u	620.53 MPa

Table 1: Materials properties of models

III. NON-LINEAR STATIC ANALYSIS

This approach is economical and imposed as a link and it is based on pushover analysis. [7] Non-Linear static analysis in other words pushover analysis where plastic hinges are assigned at both ends of each member. [2] The structure is exposed to a load combination consisting of live, dead, wind, and seismic loads. In each step, increasing gradually in force and lateral displacement, and decreasing gradually in the strength of elements and stiffness of plastic hinges. The building should have good performance, and the collapse mechanism should be investigated as well, and there must be no damage to the plastic hinges to ensure safety in the sideway mechanism of the structure

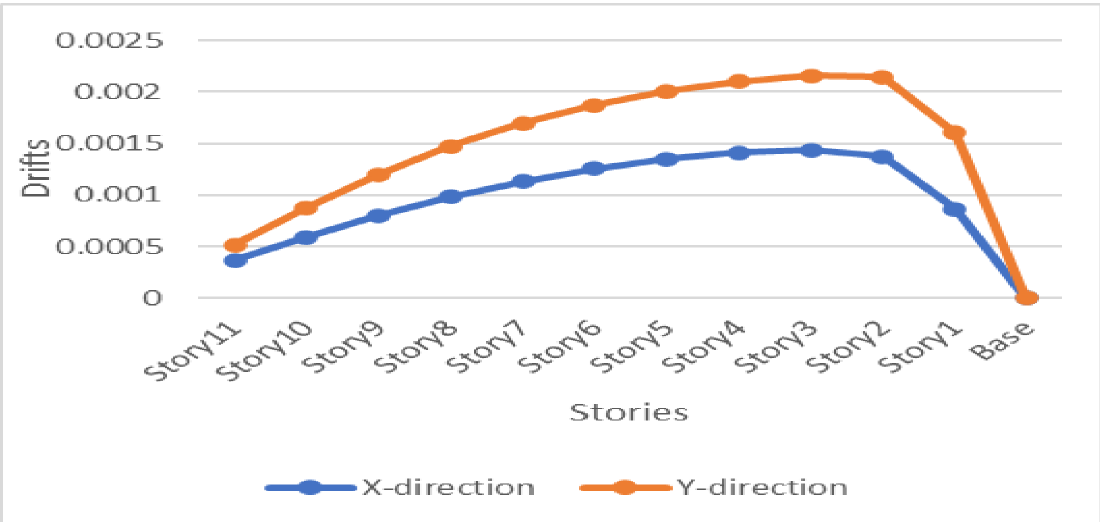

Fig. 6: Drifts without bracing structure

IV. RESULTS DISCUSSION

The used method is non-linear static analysis evaluated and the results are compared to explore which structure has the highest stiffness and the lowest displacement. The maximum story drifts, ductility factor, and stiffness factor of all these different seismic parameters can be compared after running a non-linear static analysis in the software

A. *Maximum Story Drifts*

Drifts are when directed forces are applied separately to the structure, forcing the structure to reach the maximum dynamic response value during an earthquake, and it can help to decide if the structure needs rebuilding or repairing [6].

Generally, the structure without bracing has very high story drifts compared to bracing structures and that leads to the importance of the braces [5] (the part of the structure that prevents the drifts is the braced frames and also it helps to use smaller column and beam sections. [11]). On the other hand, there is a big difference between the without-

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bracing model and the remaining models. While two-span bracing in both X-bracing and V inverted bracing can provide fewer drifts than mid-span bracing, X-bracing is more efficient compared to the position of the bracing. The models' drifts are presented in Figs. 6 to 10 according to each bracing system used. As shown in these figures the drifts in the basement are always zero in both the x and y direction, while the second, third, and fourth stories are the most affected stories by the drifts, and starting from the fourth, fifth, and sixth story the drifts start decreasing gradually until it reaches the minimum drifts at the highest story.

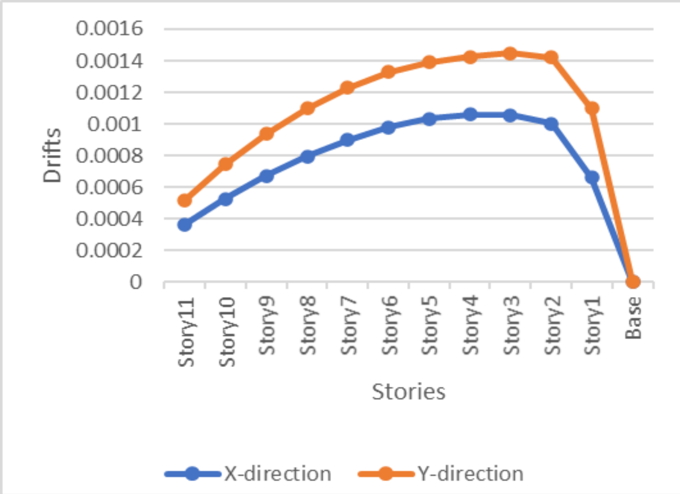

Fig. 7: Drifts X-bracing mid-span structure

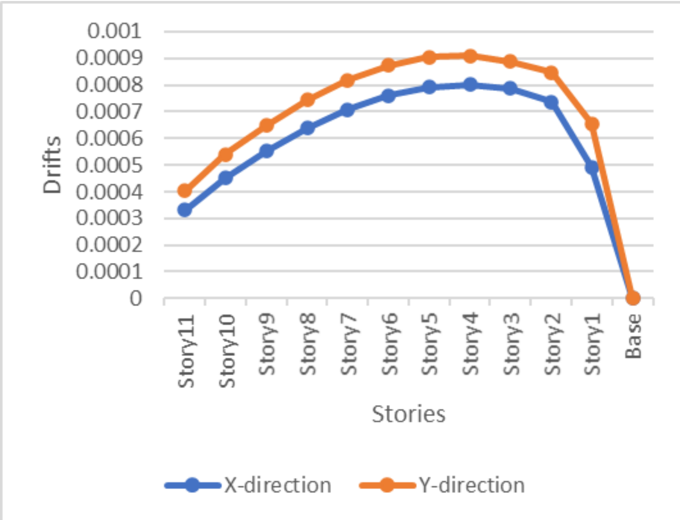

Fig. 8: Drifts X-bracing two-spans structure

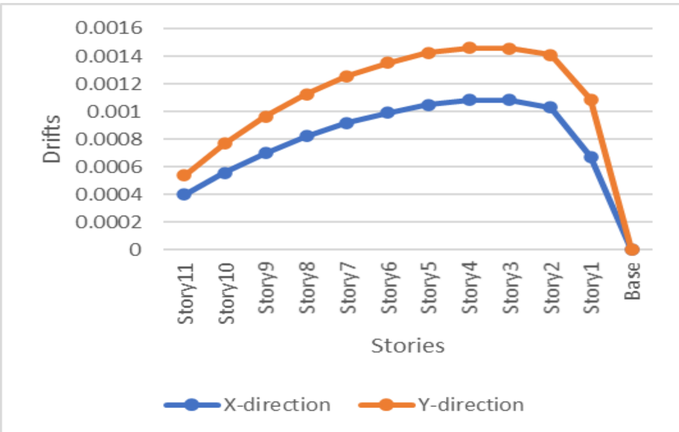

Fig. 9: Drifts Inverted V-bracing mid-span structure

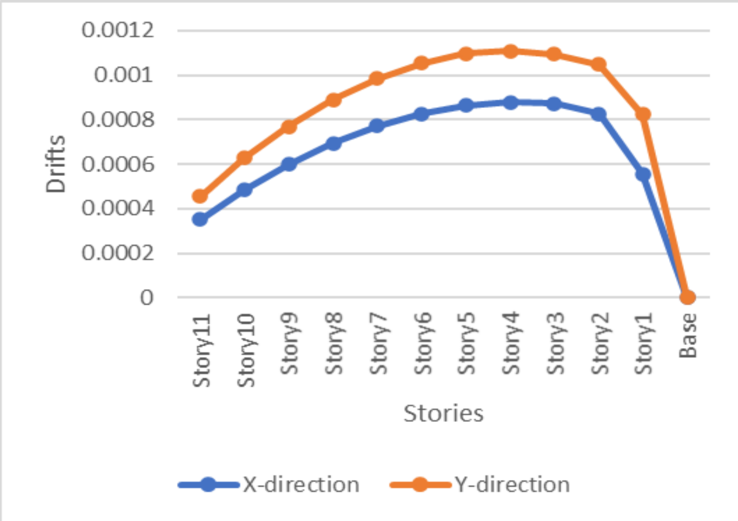

Fig. 10: Drifts Inverted V-bracing two-span structure

B. Stiffness factor

This factor describes the ability of the structure to withstand the applied loads without deformation of plastic hinges; also, this factor is helpful to define the collapse mechanism and the displacement of the structure under a specific load. The difference of stiffness factor differs according to the bracing system, and surely, the structure that has bracing in two spans has a higher stiffness factor. In addition to that, X-bracing has the advantage to use according to the higher stiffness factor it has. While there is an observed difference between the without-bracing structure and with-bracing structures as shown in Fig. 11.

The stiffness factor formula is as follows:

$$K = Ds/Vs$$

K: the stiffness factor
Ds: the displacement of the first plastic hinge
Vs: the base shear at the first plastic hinge.

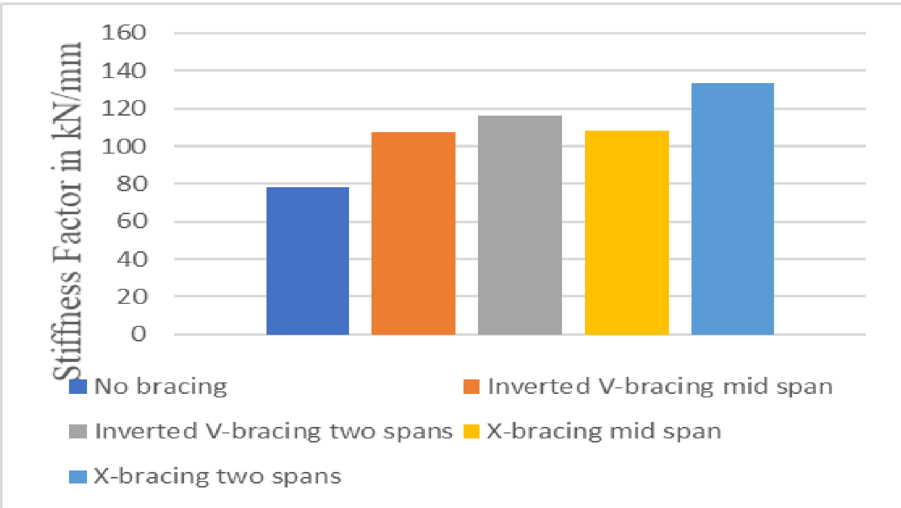

Fig. 11 Comparing the stiffness factor at various bracing frames

C. Lateral Displacement

Each structure should maintain a flexibility percentage to avoid brittle failure. Therefore, lateral displacement is depending on the stiffness of the structure which is the more stiffness there is the less displacement [15].

In general, the structure reaches the maximum displacement at the highest floor, while the stiffness reaches the minimum. Bracings play the main role to decrease displacement. In addition to that, as usual, X-bracing has the highest efficiency compared to V-bracing, and two spans are more efficient than one mid-span as shown in Fig. 8.

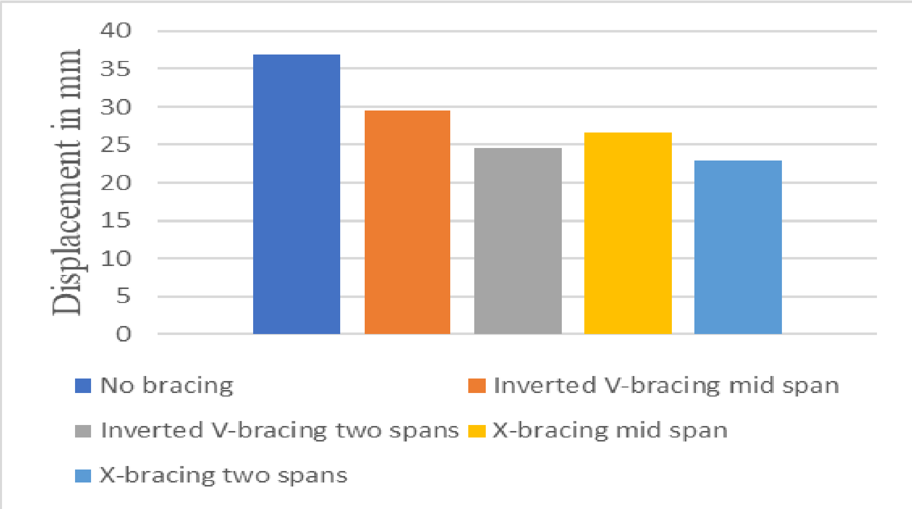

Fig. 12: Comparing the Displacement at various bracing frames

V. CONCLUSION

In this study, two types of braces were placed in two different positions in an 11-story building to compare four structures by using ETABS plus one structure that has no bracing to evaluate each structure's performance under seismic loads using non-linear static analysis. According to the study, the outcome can be evaluated as follows:

- After running different models, it is obvious that X-bracing is better to resist seismic loads than Inverted V-bracing.
- The use of braces is very important to minimize earthquake risk.
- The structures that are supported by braces are very much better and safe than structures with no braces.
- There is a slight difference between Installing bracing in two spans and only one span, but bracing in two spans is safer and better in resistance.
- The relation between stiffness factor and lateral displacement is an inverse relationship.
- From the basement to the highest story stiffness factor decreases gradually while lateral displacement increases gradually.
- At point zero in the basement, the drifts equal zero and then start increasing dramatically to reach the highest drifts in the second, third or fourth story, after those drifts start decreasing regularly to reach the lowest drifts in the last story.

REFERENCES

[1.] Ahmad. O., (2021). Evaluation of elastic stiffness factor of 2D reinforced concrete frame system with different parameters. International Journal of Advanced Engineering, Sciences and Applications, Vol. 2, No. 2.

[2.] Alkhattab. M., Resatoglu. R., Sadeghi. K., Alibrahim. B., (2019). Seismic performance of steel frames with inverted V-braces for North Cyprus. International Journal of Innovative Technology and Exploring Engineering. vol. 9, no. 1

[3.] Al sulayfani. B. J, Abdullah. M. M., (2007). Study of Bending Behavior of Reinforced Concrete Sections Under Cyclic Loads. Tikrit Journal of Engineering Sciences. Vol. 14, No. 1

[4.] Al-hachamee. E. K. S, Hussein. A. T., (2006). Elastic-Plastic Non-Linear Behavior of Suddenly Loaded Plane Steel Frames by ASI Technique. Tikrit Journal of Engineering Sciences. Vol. 13, No.4

[5.] Al-Safi. S, Alameri. I, Wasel. W, Al-Kadasi. A., (2021). Linear and Nonlinear Behavior of Steel Buildings with Different Bracing Systems. International Journal of Steel Structures. Vol. 22, No. 6.

[6.] Arab. R, Yakhchalian. M, (2022). Investigating Approximate Methods to Predict Residual Inter Story Drift Ratio Demands in Steel Eccentrically Braced Frames. International Journal of Steel Structures. Vol. 22, No. 6.

[7.] Causevic. M, Mitrovic. S, (2011). Comparison between non-linear dynamic and static seismic analysis of structures according to European and US provisions. Bulletin of Earthquake Engineering.

[8.] Haido. J. H., (2015). Prediction of RC multi-story construction performance with a new proposed design spectrum approach. Tikrit Journal of Engineering Sciences. Vol.22, No.1.

[9.] Ibrahim. A. M, Salman. W. D, Bahlol. F. M., (2019). Flexural Behavior of Concrete Composite Beams with New Steel Tube Section and Different Shear Connectors. Tikrit Journal of Engineering Sciences. Vol.26, No.1.

[10.] Kari. A, Ghassemieh. M, Abolmaali, A., (2011). A new dual bracing system for improving the seismic behavior of steel structures. Smart Materials and Structures.

[11.] Kharomi. M, Shariati. M, (2017). Evaluation of the seismic performance of special moment frames using incremental nonlinear dynamic analysis. Structural Engineering and Mechanics, Vol. 63, No. 2.

[12.] Mahmood. M. N, Ahmer. S. Y., (2006). Nonlinear Dynamic Analysis of Reinforced Concrete Framed Structures Including Soil-Structure Interaction

Effects. Tikrit Journal of Engineering Sciences. Vol. 13, No. 3

[13.] Metin Kose, M. and Kayadelen, C. (2013), "Effects of infill walls on RC buildings under time history loading using genetic programming and neuro-fuzzy", Struct. Eng. Mech., 47(3), 401- 419.

[14.] Santa-Ana P R and Miranda E 2000 Strength-reduction factors for multi-degree-of-freedom systems Proc. 12th World Conf. on Earth Engineering paper 1446

[15.] Sarhan. O, Raslan. M, (2020). Study of the elastic stiffness factor of steel structures with different lateral load resisting systems, International Journal of Advanced Engineering, Sciences and Applications, Vol. 1, No. 2.

[16.] Shakir. Q. M., Performance of high-strength concrete one-way slabs with embedded BFRP bar reinforcement. International Journal of Advanced Engineering, Sciences and Applications, Vol. 1, No. 3

[17.] Yahyapour. R, Seyedpoor. S,M, (2021). Comparing the Seismic Behavior of Various Knee Braced Steel Frames Based on Incremental Dynamic Analysis and Development of Fragility Curves. International Journal of Steel Structures. Vol. 22, No. 6.

[18.] Yakhchalian, M., Asgarkhani, N., & Yakhchalian, M. (2020). Evaluation of defection amplifcation factor for steel buckling restrained braced frames. Journal of Building Engineering, 30, 101228.

[19.] Yase. Z. J, Lateef. A. M, Khazaal. A. S., (2021). Structural Behavior of Simple Supported Two Layers Reinforced Concrete (Normal strength concrete & Mortar with 3-Dimension glass fiber), Beams. Tikrit Journal of Engineering Sciences. Vol.28, No.2

[20.] Vamvatsikos, D., & Cornell, C. A. (2002). Incremental dynamic analysis. Earthquake Engineering Structural Dynamics, 31(3), 491–514.

[21.] Zahrai, S. M., & Bolandi, H. (2019). Numerical study on the impact of out-of-plane eccentricity on lateral behavior of concentrically braced frames. International Journal of Steel Structures, 19(2), 341–350.