Klover Multidisciplinary Journal of Engineering
Volume 13 Issue 1, January-March 2025
ISSN:2995-4118
Impact Factor: 9.72
http://kloverjournals.org/journals/index.php/Engineering

STRUCTURAL VULNERABILITY OF ECCENTRICALLY BRACED HIGH-RISE STEEL FRAMES UNDER FIRE CONDITIONS

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DOI:https://doi.org/10.5281/zenodo.15488780

Abstract: In this research, the evaluation of progressive damage due to fire in high-rise steel structures with diverging braces has been done. For this purpose, a frame with two openings and one floor has been selected from the reference article, and the fire scenario was implemented in one of the openings, and the horizontal displacement of the middle of the structure and the top of the column with the displacement values obtained from the reference article, comparison and accuracy. was measured In the continuation of the research, 24 samples were analyzed in 3 categories. There are 15 floors in the first category of samples, 20 floors in the second category of samples, and 25 floors in the third category of samples. In each category, the first 4 samples are without braces and the second 4 samples are with divergent braces. In each category, the fire scenario was in the middle column of the first floor in the first sample, in the side column of the first floor in the second sample, in the middle column of the middle floor in the third sample, and in the side column of the middle floor in the fourth sample. The samples were subjected to static load and fire in the desired column, and the following results were obtained from this research.

Keywords: Progressive Collapse, Fire Loading, High-Rise Steel Structures, Eccentrically Braced Frames (EBF), Structural Fire Resistance, Diverging Braces

INTRODUCTION

1. Problem Statement

High-rise structures are among the structures that have been used in various countries with the advancement of science in the field of construction. In these structures, various solutions have been used to overcome the lateral loads on the structure, and one of these solutions is the use of divergent braces. By increasing the rigidity of the structure, the diverging braces prevent damage caused by lateral loads on the structure. Meanwhile, the behavior of these structures against fire is very important. Progressive failure means the removal of one of the columns in different parts of the structure, which causes the removal of columns in different parts of the structure due to the increase in temperature and the loss of the structure's resistance. Therefore, by removing the column, the possibility of the collapse of the structure will increase.

2. Thesis Objectives

- Simulation of high-rise steel structure with diverging brace under progressive damage caused by fire in the structure
- Investigating the effect of column removal in different positions and the behavior of the structure under the influence of heat on the amount of damage in the structure

- Comparison of the behavior of a high-rise steel structure with diverging braces compared to a high-rise steel structure without braces under progressive damage caused by heat

3. Methodology

The reference article was used to verify the results. The specifications of the model analyzed in this article are presented in Figure 1.

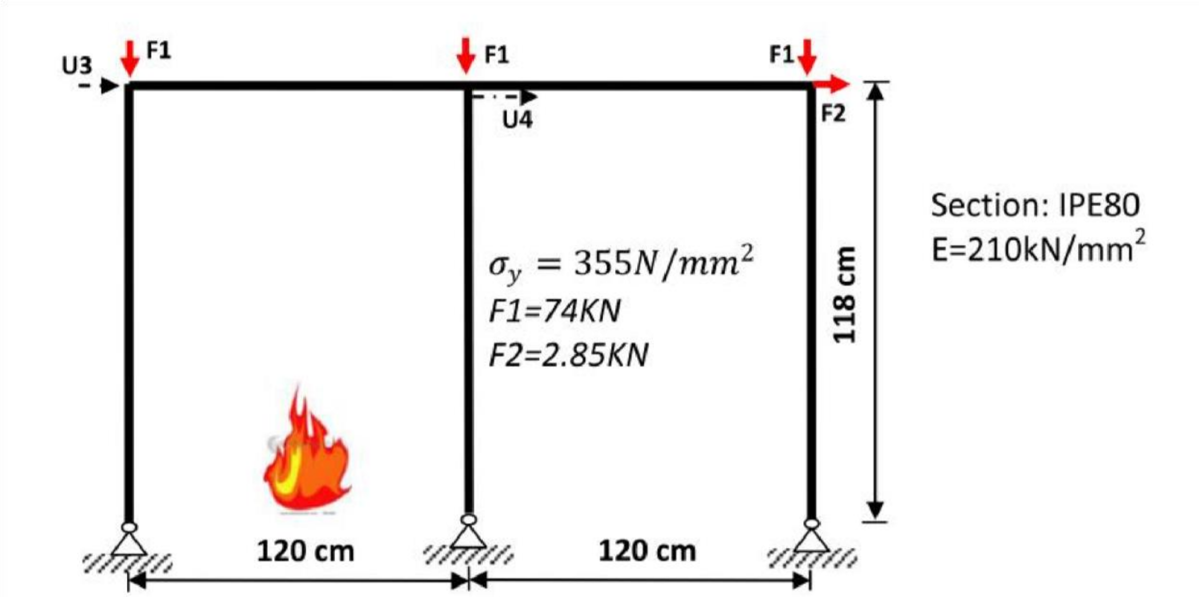

Figure 1: Specifications of the validation sample [1].

As seen in Figure 1, the verification sample is a frame with two openings and one floor, the dimensions of the opening are 120 cm and the height of each floor is 118 cm, and its cross section is IPE80 for It is a beam and a column. A fire has been made in the left opening. For modeling in the validation section, a two-dimensional beam model has been used in Abaqus, and a schematic of the drawing geometry in Abaqus software is presented in Figure 2.

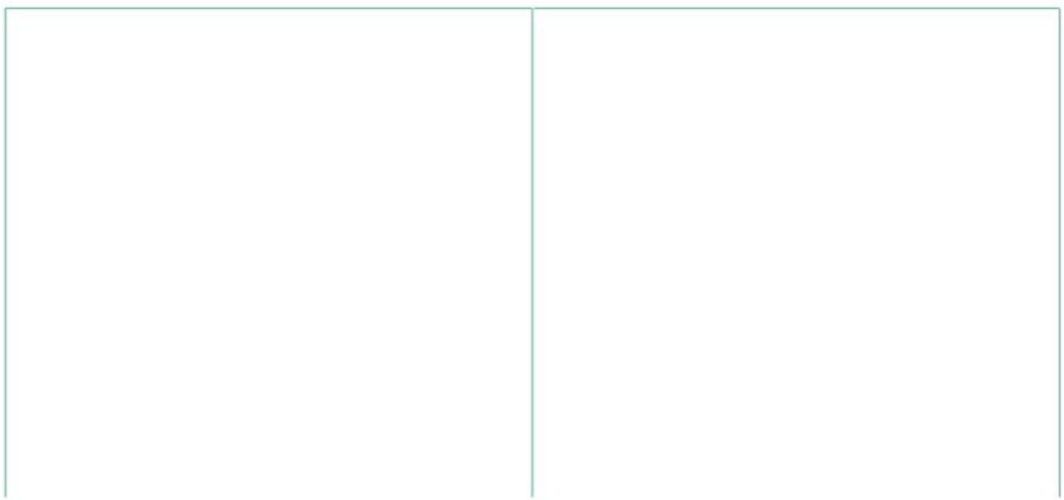

Figure 2: Geometry of drawing model in Abaqus software.

High-rise structures are among the structures that have been used in the development of science in the field of construction in different countries. In these structures, various strategies have been used to overcome the lateral loads on the structure, one of which is the use of eccentrically braces. eccentrically braces increase the stiffness of the structure to prevent damage due to lateral loads on the structure. Meanwhile, the behavior of these structures against fire is very important. Progressive collapse means the removal of one of the columns in different parts of the structure, which due to higher temperatures and loss of strength of the structure causes the removal of columns in different parts of the structure. Therefore, by removing the column, the probability of the collapse of the structure will increase. According to the cases mentioned in this study, by increasing the temperature of the structure based on the ISO834 scenario in the structure and removing the columns in different parts of high-rise steel structures with eccentrically bracing, the collapse and failure behavior of the structure under heat The simulation in Abaqus software should be investigated and its behavior compared to structures without eccentrically bracing.

4.1. Simulation of the main models in this research

The analyzed samples include 24 tall structure models, which are in three categories. The first category has 15 floors, the second category has 20 floors, and the third category has 25 floors. The first 4 samples in each category of 8 models are analyzed, the first 4 samples are related to the frame without braces and the second 4 samples are related to the frame with diverging braces. In all 4 models in each category, the location of the column that has been heated has changed, the first sample is the column of the lowest floor and in the middle of the plan, the second sample is the column of the lowest floor and on the right side of the plan, the third sample is in the middle and in the middle of the floors And the fourth example is the heated column on the side and middle of the floors, the specifications of the models are presented in Table 1.

Table 1: General characteristics of the models analyzed in this research.

Model number	number of floors	type of frame	location of the heated column
Model number 1	15	simple	In the middle of the first floor
Model number 2	15	simple	Next to the first floor
Model number 3	15	simple	In the middle of the middle floor
Model number 4	15	simple	Next to the middle floor
Model number 5	15	Divergent brace	In the middle of the first floor
Model number 6	15	Divergent brace	Next to the first floor
Model number 7	15	Divergent brace	In the middle of the middle floor
Model number 8	15	Divergent brace	Next to the middle floor
Model number 9	20	simple	In the middle of the first floor
Model number 10	20	simple	Next to the first floor
Model number 11	20	simple	In the middle of the middle floor
Model number 12	20	simple	Next to the middle floor
Model number 13	20	Divergent brace	In the middle of the first floor
Model number 14	20	Divergent brace	Next to the first floor
Model number 15	20	Divergent brace	In the middle of the middle floor
Model number 16	20	Divergent brace	Next to the middle floor
Model number 17	25	simple	In the middle of the first floor
Model number 18	25	simple	Next to the first floor
Model number 19	25	simple	In the middle of the middle floor
Model number 20	25	simple	Next to the middle floor

Model number 21	25	Divergent brace	In the middle of the first floor
Model number 22	25	Divergent brace	Next to the first floor
Model number 23	25	Divergent brace	In the middle of the middle floor
Model number 24	25	Divergent brace	Next to the middle floor

4.2. The results of other analyzed models

4.2.1. The results related to the simple 15-floor structure (models number 1 to 4)

A schematic of the deformation in models 1 to 4 is presented in Figures 3 to 6. In these models, the structure is 15 stories without braces, in model number 1, the fire place is on the first and middle floor column, in model number 2, the fire place is on the first floor column and side, in model number 3, The place of fire is on the column of the middle and middle floor, and in model number 4, the place of fire is on the column of the middle floor and on the side of the structure.

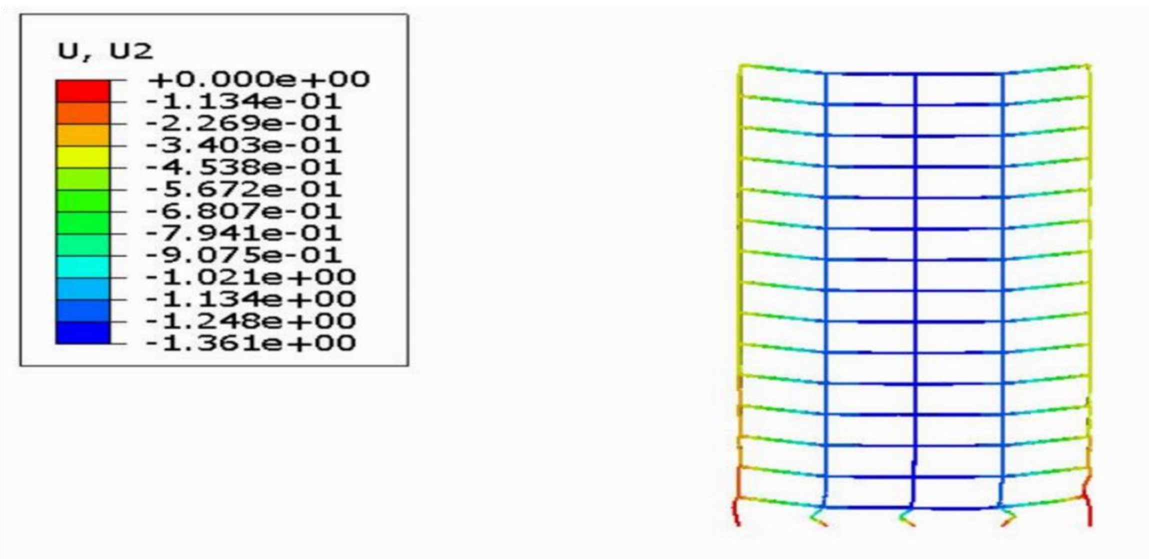

Figure 3: The largest displacement in thermal analysis in model number 1 (simple frame, 15-floor model, fire place in the middle of the first floor of the structure).

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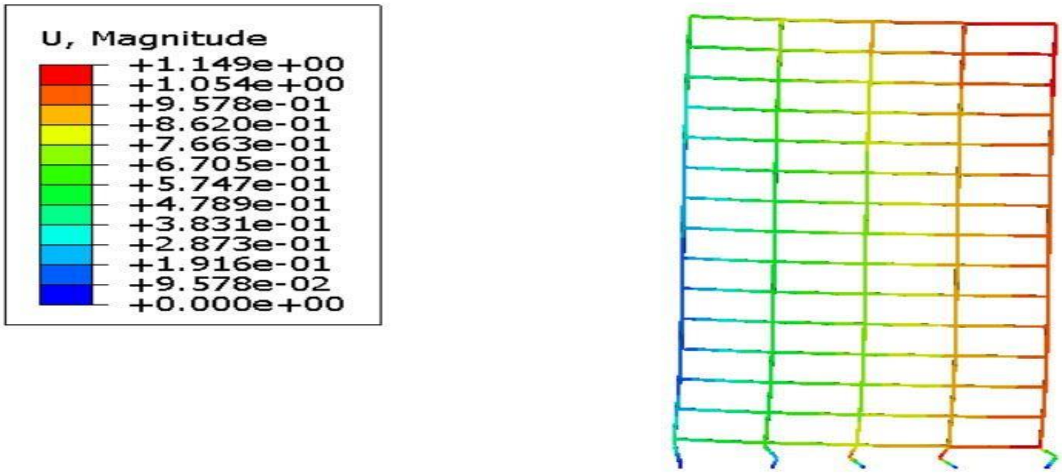

Figure 4: The largest displacement in thermal analysis in model number 2 (simple frame, 15-floor model, fire location next to the first floor of the structure)

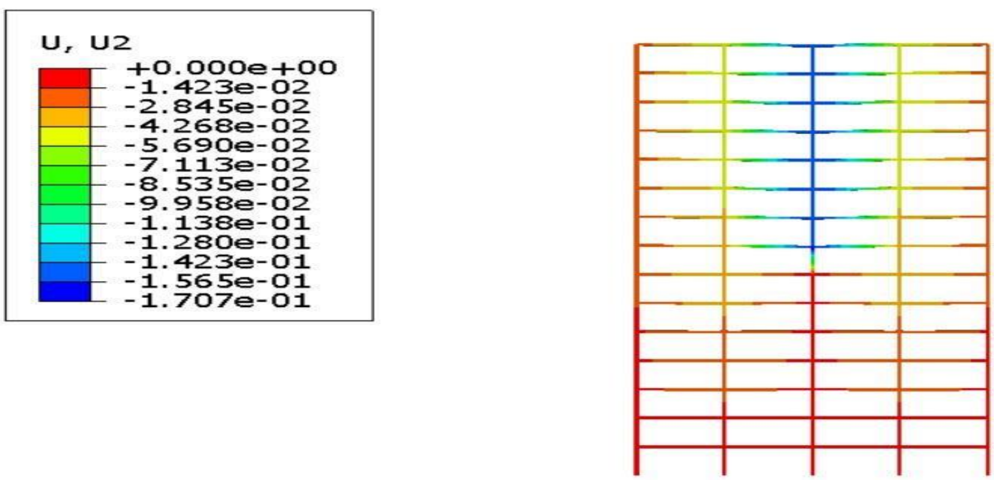

Figure 5: The largest displacement in thermal analysis in model number 3 (simple frame, 15-floor model, fire place in the middle of the middle floor of the structure)

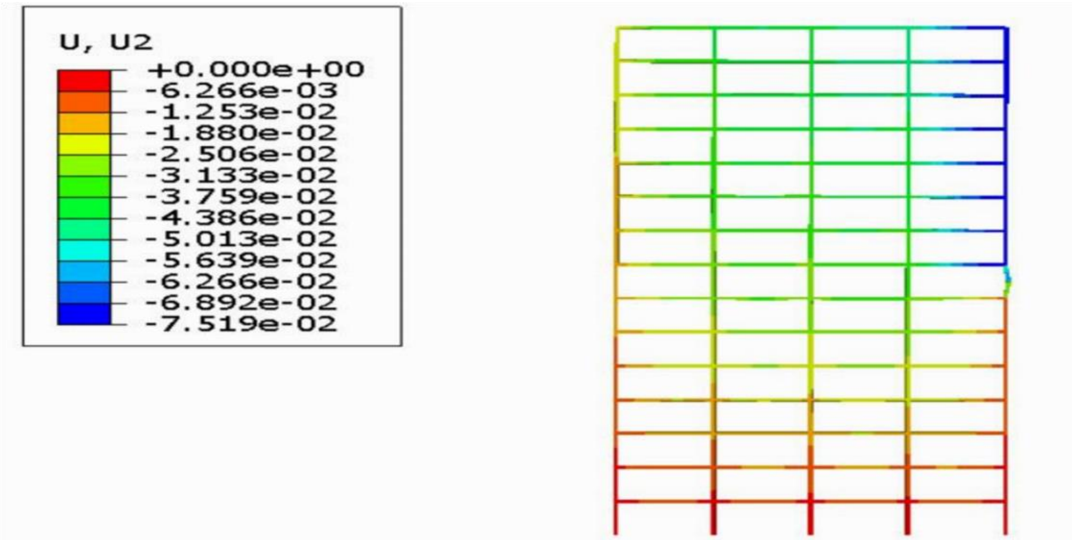

Figure 6: The highest displacement in thermal analysis in model number 4 (simple frame, 15-floor model, fire location next to the middle floor of the structure)

4.2.2. The results related to the 15-floor structure with braces (model number 5 to 8) A schematic of the deformation in models 5 to 8 is presented in Figure 7 to 10. In these models, the structure has 15 floors and has braces. In model number 5, the fire location is on the column of the first floor in the middle, in model number 6, the fire location is on the column of the first floor and on the side, in model number 7, the location The fire is on the column of the middle and middle floor and in model number 8, the place of fire is on the column of the middle floor and on the side of the structure.

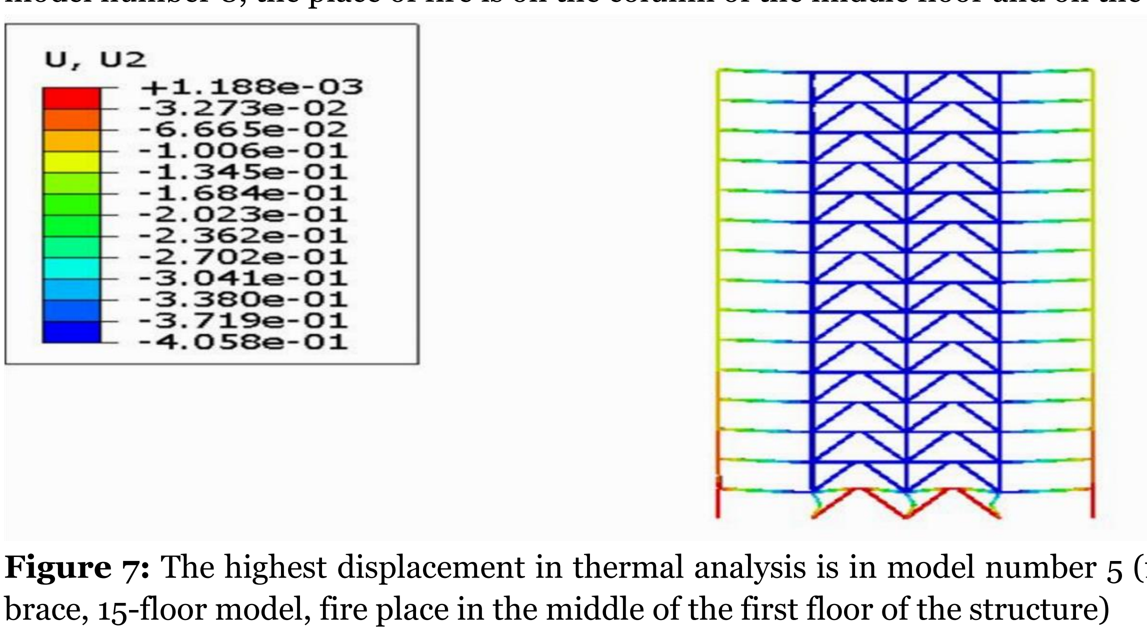

Figure 7: The highest displacement in thermal analysis is in model number 5 (frame with divergent brace, 15-floor model, fire place in the middle of the first floor of the structure)

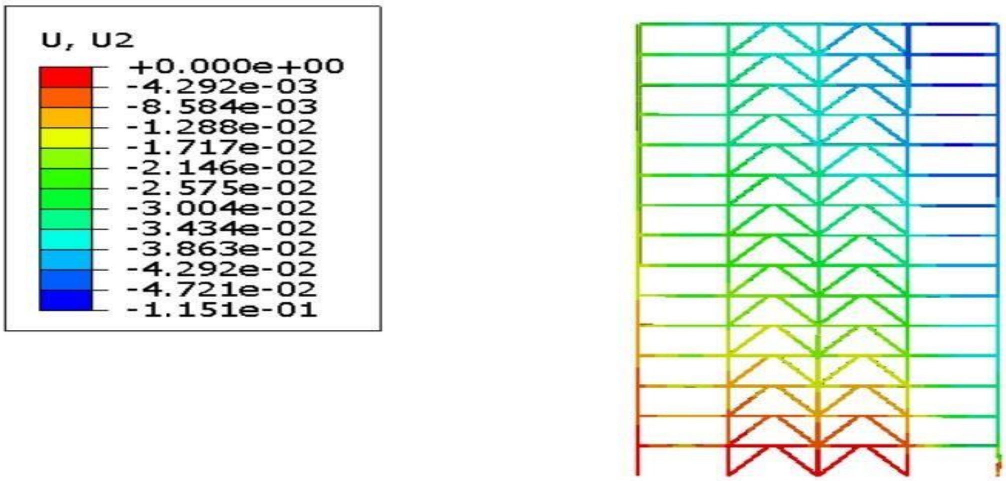

Figure 8: The highest displacement in thermal analysis in model number 6 (frame with divergent brace, 15-floor model, fire location next to the first floor of the structure)

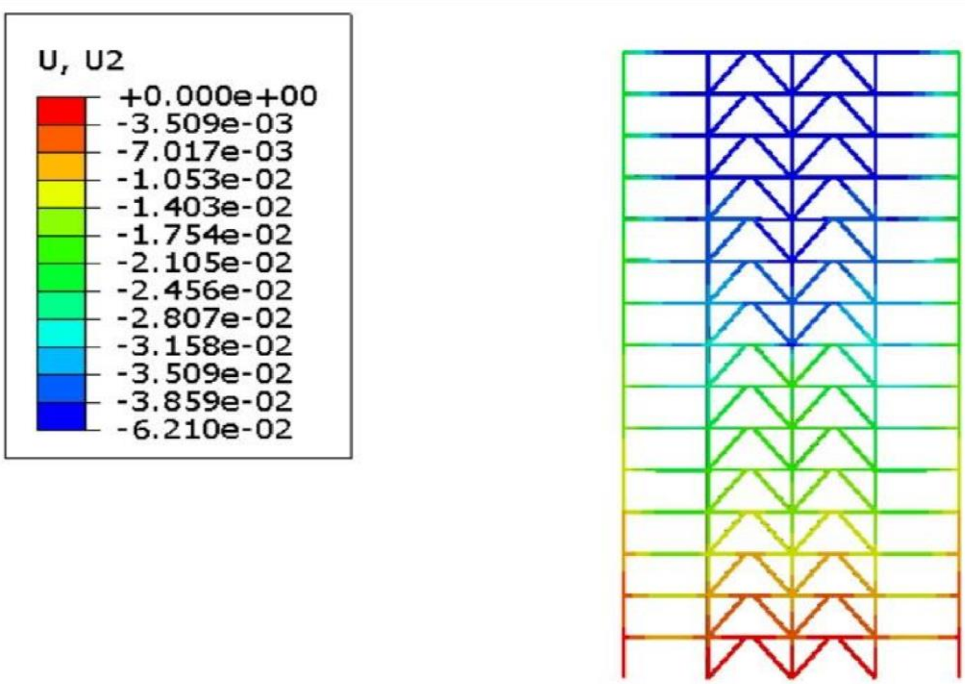

Figure 9: The highest displacement in thermal analysis in model number 7 (frame with divergent brace, 15-floor model, fire location in the middle of the middle floor of the structure)

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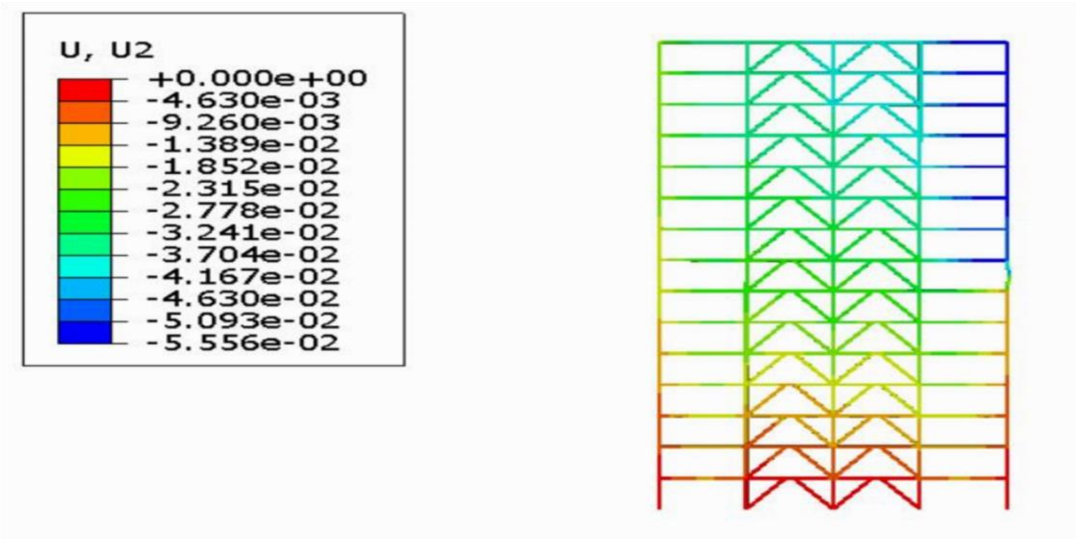

Figure 10: The highest displacement in thermal analysis is in model number 8 (frame with divergent brace, 15-floor model, fire location next to the middle floor of the structure).

4.2.3. The results related to the simple 20-floor structure (models No. 9 to 12)

A schematic of the deformation in models 9 to 12 is presented in Figure 11 to 14. In these models, there is a 20-floor structure without braces, on which 4 fire scenarios similar to models 1 to 4 have been applied, the first two samples of the column of the first floor and the second two samples of the column of the tenth floor are exposed to fire. is placed).

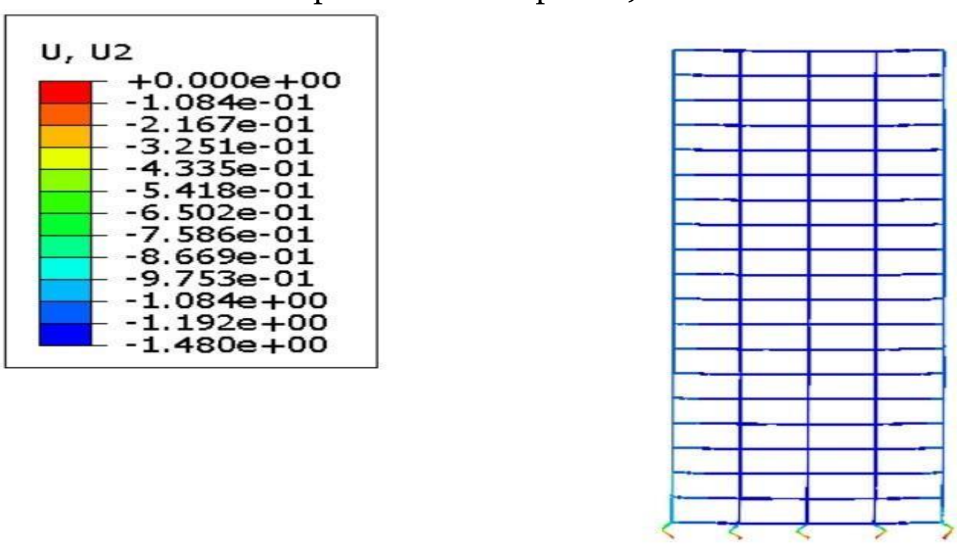

Figure 11: The highest displacement in thermal analysis in model number 9 (simple frame, 20-floor model, fire place in the middle of the first floor of the structure)

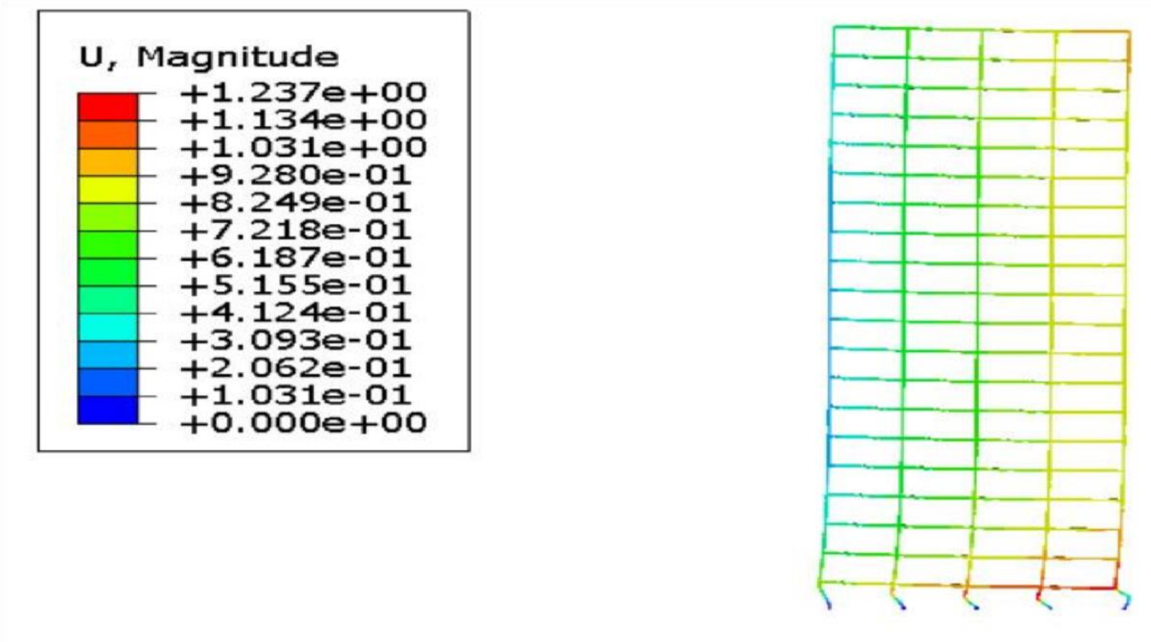

Figure 12: The highest displacement in thermal analysis in model number 10 (simple frame, 20-floor model, fire location next to the first floor of the structure)

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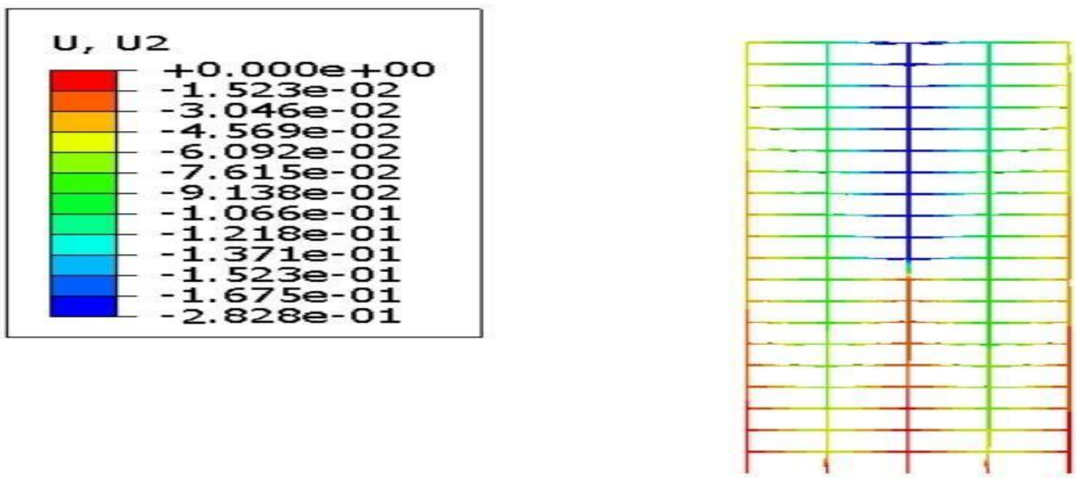

Figure 13: The highest displacement in thermal analysis in model number 11 (simple frame, 20-floor model, fire location in the middle of the middle floor of the structure)

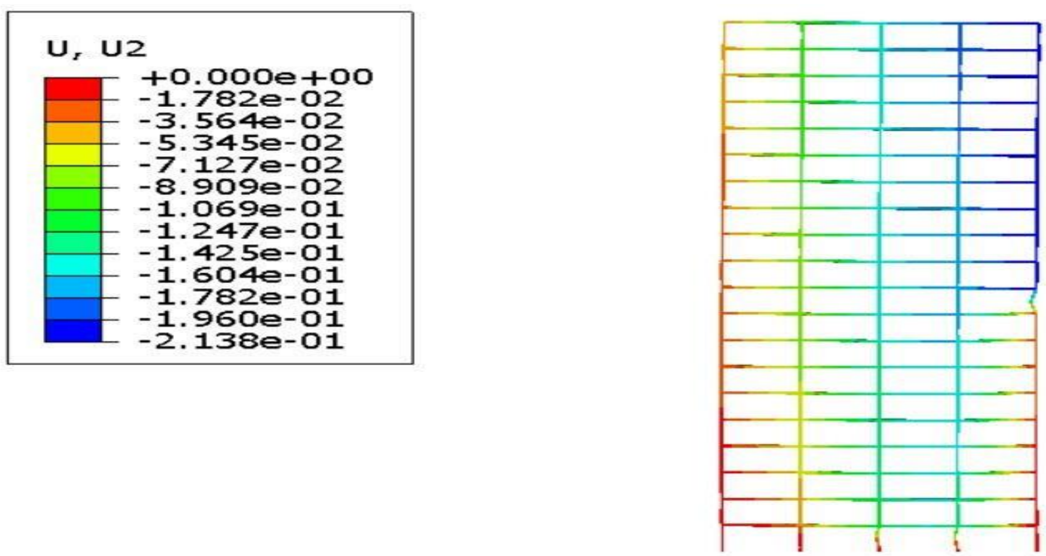

Figure 14: The highest displacement in thermal analysis in model number 12 (simple frame, 20-floor model, fire location next to the middle floor of the structure)

4.2.4. The results related to the 20-floor structure with braces (model number 13 to 16)

A schematic of the deformation in models 13 to 16 is presented in Figure 15 to 18. In these models, the structure has 20 floors and has braces. In model number 13, the fire location is on the column of the first floor in the middle, in model number 14, the fire location is on the column of the first floor and on the side, in model number 15, the location The fire is on the column of the middle and middle floor and in model number 16, the place of fire is on the column of the middle floor and on the side of the structure.

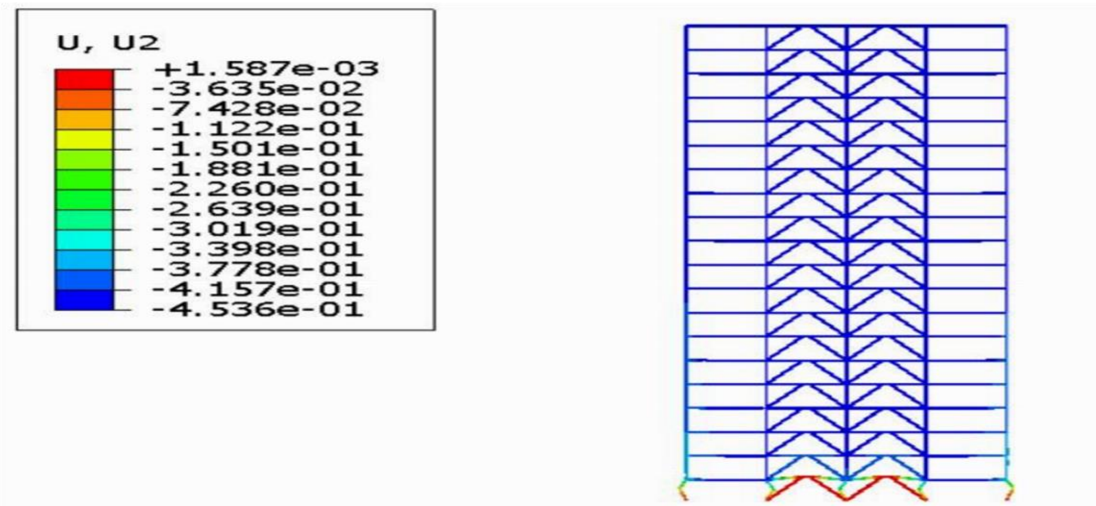

Figure 15: The highest displacement in thermal analysis in model number 13 (frame with diverging brace, 20-floor model, fire place in the middle of the first floor of the structure)

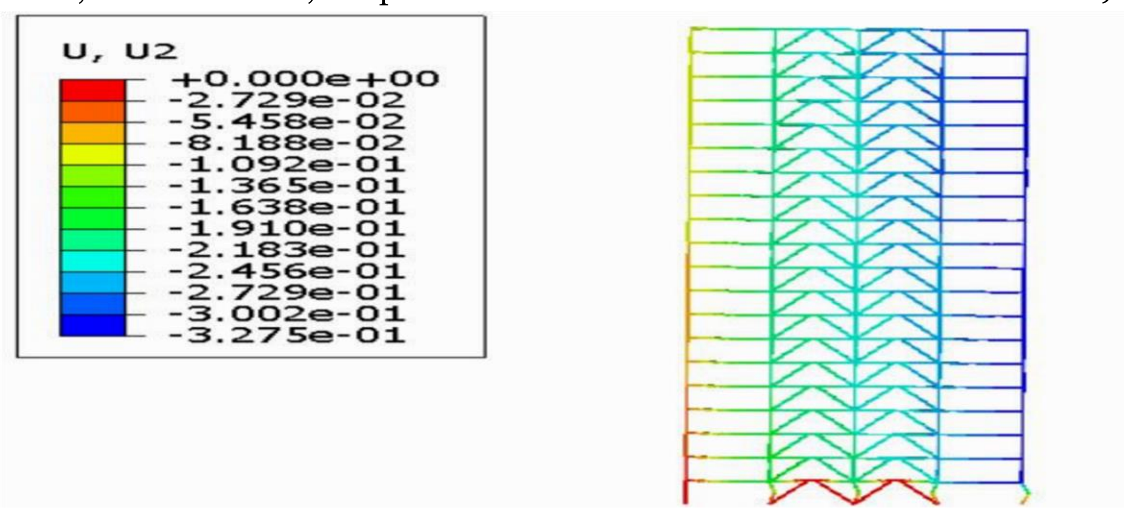

Figure 16: The largest displacement in thermal analysis in model number 14 (frame with divergent brace, 20-floor model, fire location next to the first floor of the structure)

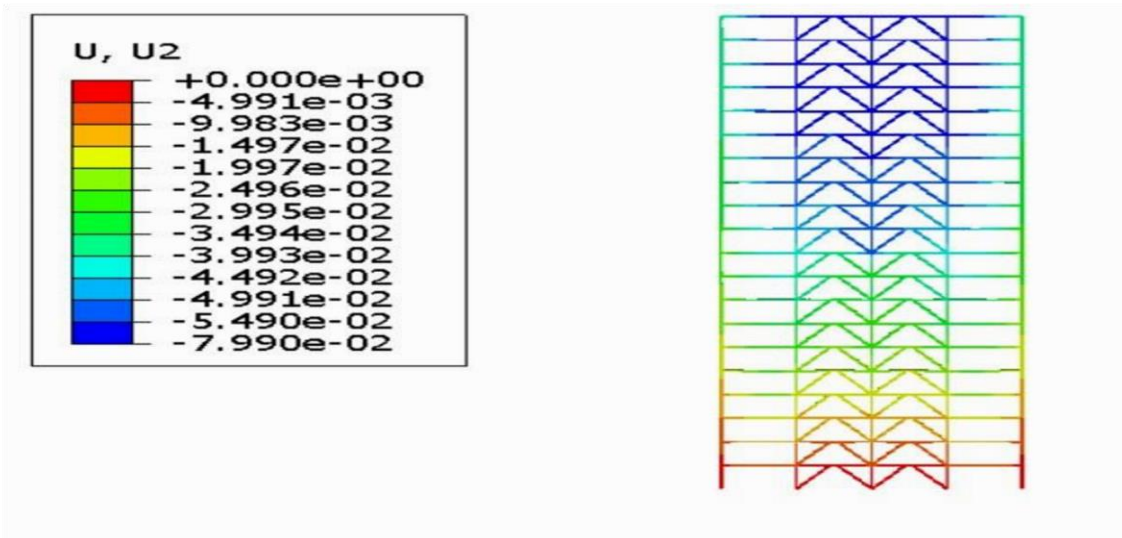

Figure17: The highest displacement in thermal analysis in model number 15 (frame with divergent brace, 20-floor model, fire place in the middle of the middle floor of the structure)

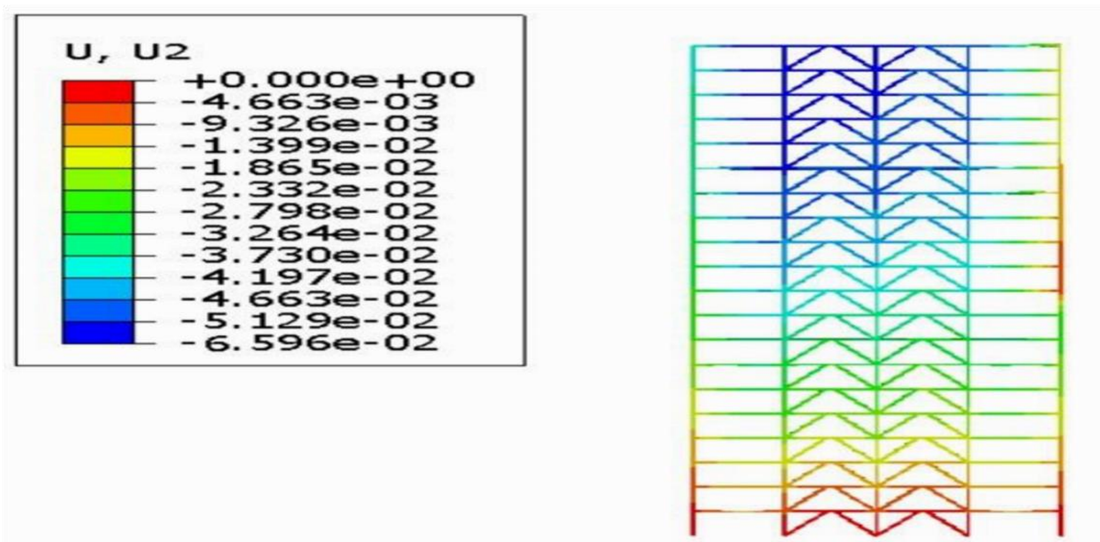

Figure 18: The highest displacement in thermal analysis in model number 16 (frame with divergent brace, 20-floor model, fire location next to the middle floor of the structure)

4.2.5. The results related to the simple 25-floor structure (models No. 17 to 20)

In this section, the results related to models 17 to 20 are presented. In these models, there is a 25-floor structure without braces, on which 4 fire scenarios similar to models 1 to 4 have been applied, the first two samples of the column of the first floor and the second two samples of the column of the thirteenth floor are exposed to fire. is placed). The results of the maximum displacement are presented in Figures 19 to 22.

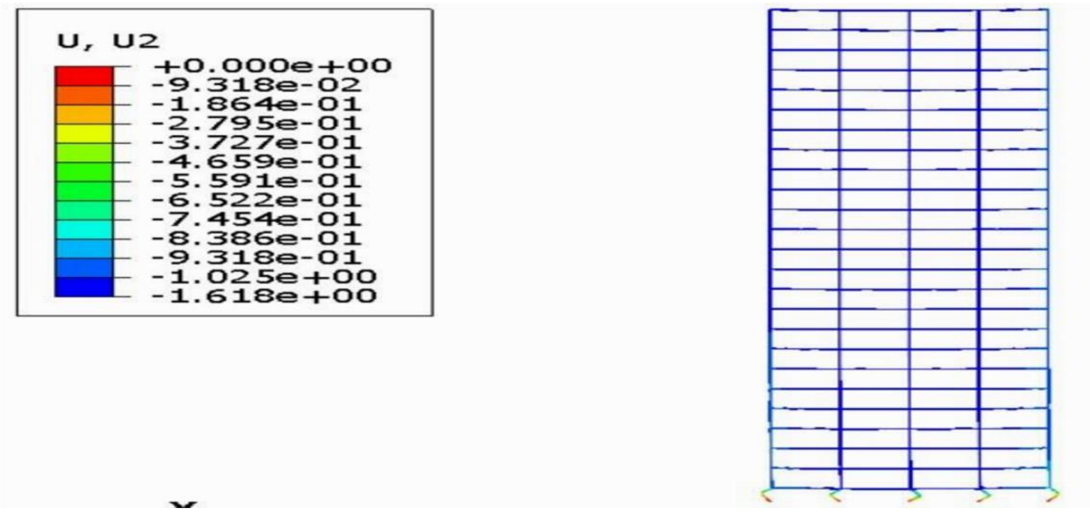

Figure 19: The highest displacement in thermal analysis is in model number 17 (simple frame, 25-floor model, fire place in the middle of the first floor of the structure).

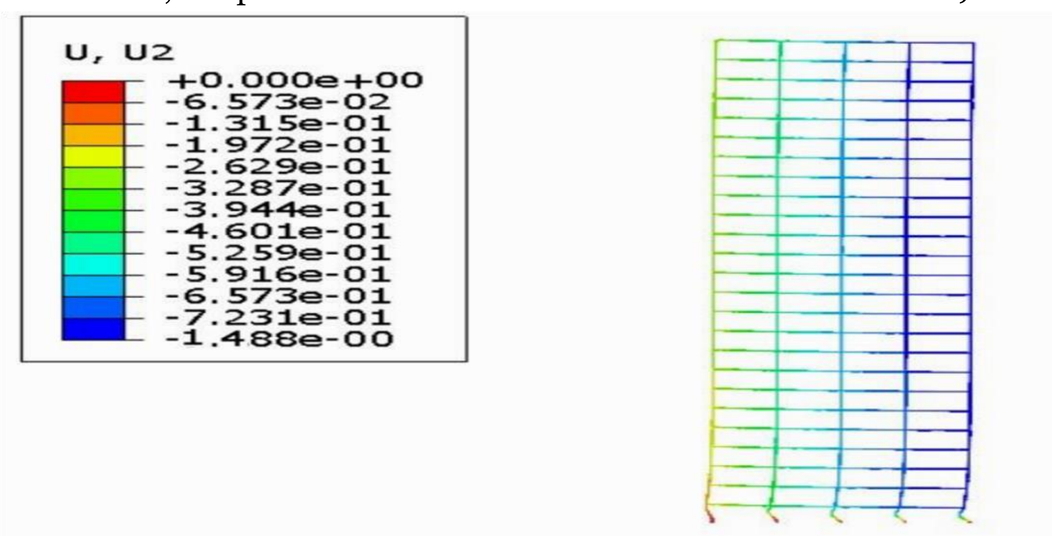

Figure 20: The highest displacement in thermal analysis in model number 18 (simple frame, 25-floor model, fire location next to the first floor of the structure)

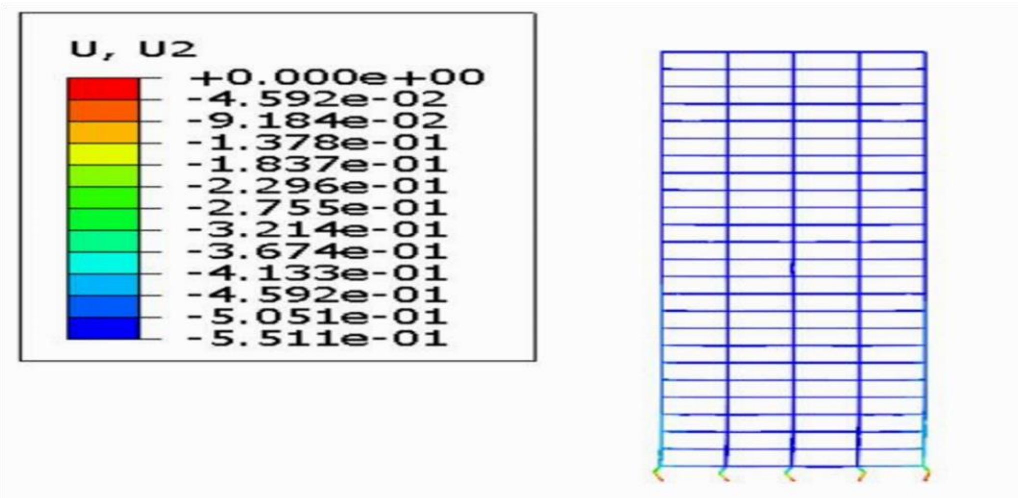

Figure 21 : The highest displacement in thermal analysis in model number 19 (simple frame, 25-floor model, fire place in the middle of the middle floor of the structure)

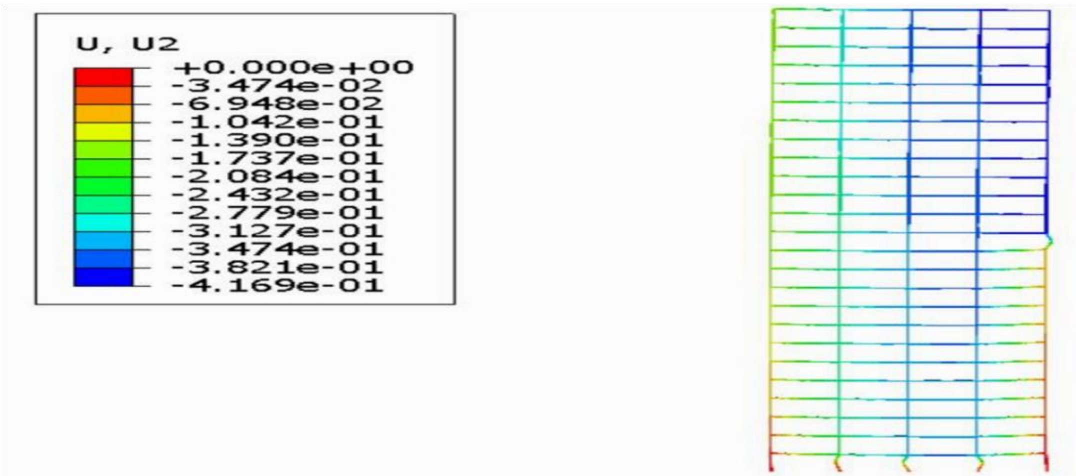

Figure 22: The highest displacement in thermal analysis in model number 20 (simple frame, 25-floor model, fire location next to the middle floor of the structure)

4.2.6. The results related to the 25-floor structure with braces (model number 21 to 24

A schematic of the deformation in models 21 to 24 is presented in Figure 23 to 26. In these models, the structure has 25 floors and has braces, in model number 21, the place of fire is on the column of the first floor in the middle, in model number 22, the place of fire is on the column of the first floor and on the side, in model number 23, the place The fire is on the column of the middle and middle floor and in model number 24, the place of fire is on the column of the middle floor and on the side of the structure.

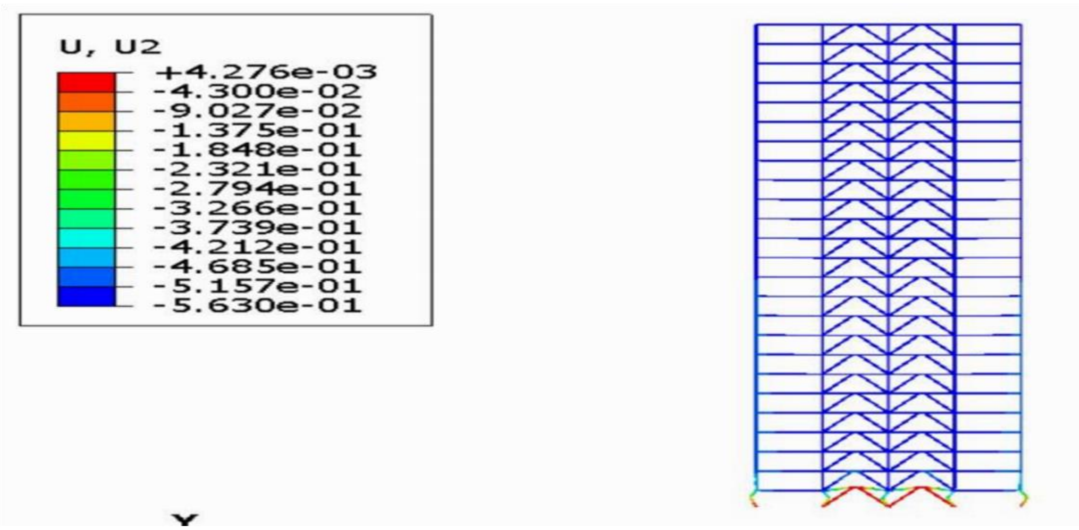

Figure 23: The highest displacement in thermal analysis in model number 21 (frame with divergent brace, 25-floor model, fire place in the middle of the first floor of the structure)

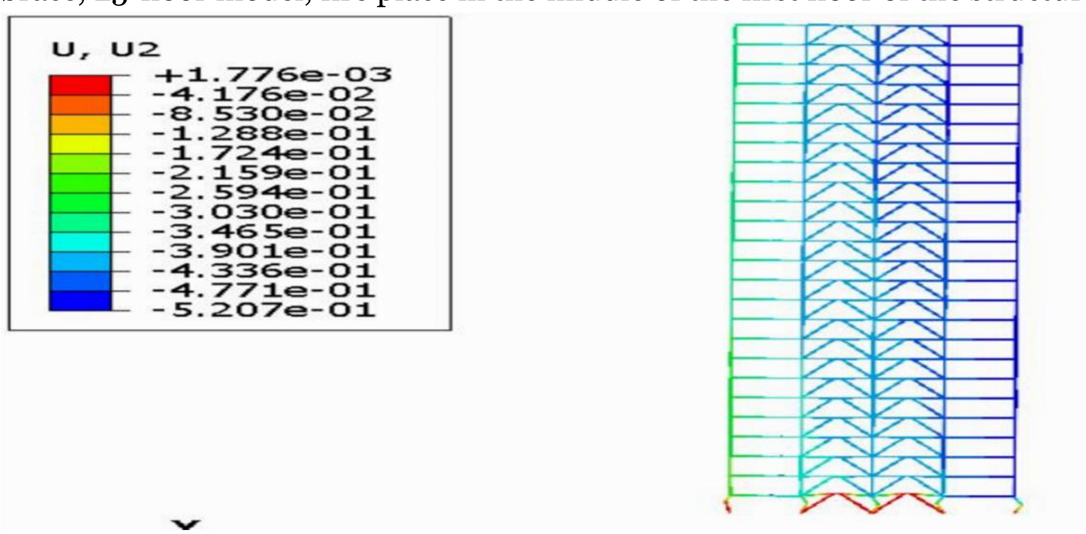

Figure 24: The highest displacement in thermal analysis in model number 22 (frame with divergent brace, 25-floor model, fire location next to the first floor of the structure)

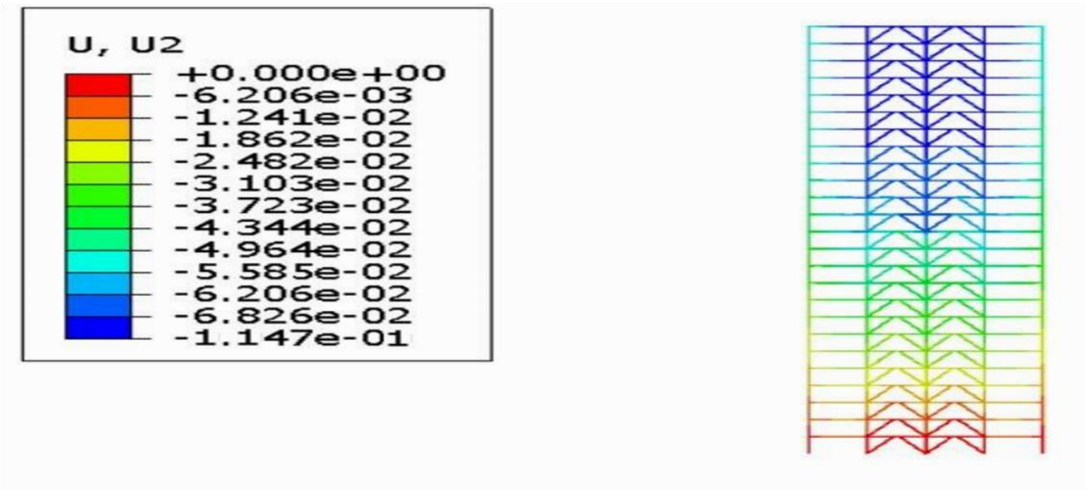

Figure 25: The highest displacement in thermal analysis in model number 23 (frame with divergent brace, 25-floor model, fire location in the middle of the middle floor of the structure)

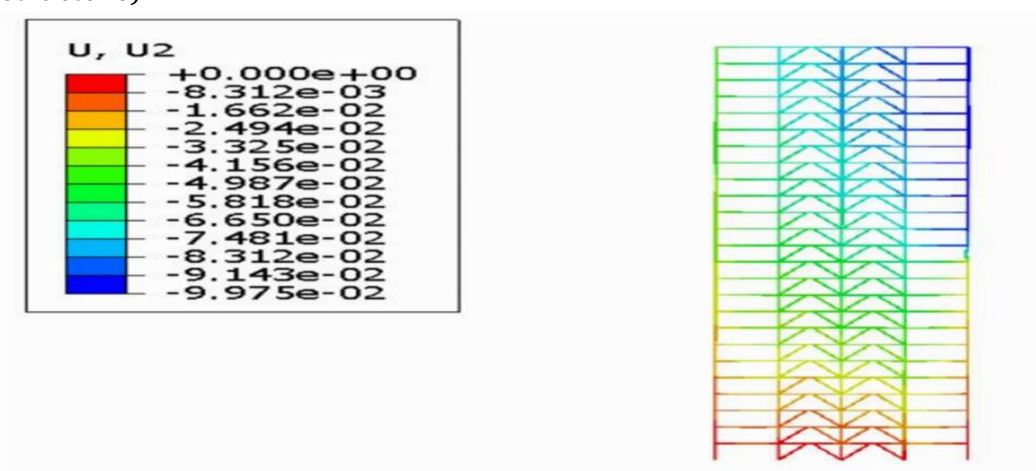

Figure 26: The highest displacement in thermal analysis is in model number 24 (frame with divergent brace, 25-floor model, fire location next to the middle floor of the structure)

5. Conclusion

In this research, the evaluation of progressive damage due to fire in high-rise steel structures with diverging braces has been done. For this purpose, a frame with two openings and one floor has been selected from the reference article, and the fire scenario was implemented in one of the openings, and the horizontal displacement of the middle of the structure and the top of the column with the displacement values obtained from the reference article, comparison and accuracy. was measured In the continuation of the research, 24 samples were analyzed in 3 categories. There are 15 floors in the first category of samples, 20 floors in the second category of samples, and 25 floors in the third category of samples. In each category, the first 4 samples are without braces and the second 4 samples are with divergent braces. In each category, the fire scenario was in the middle column of the first floor in the first sample, in the side column of the first floor in the second sample, in the middle column of the middle floor in the third sample, and in the side column of the middle floor in the fourth sample. The samples were subjected to static load and fire in the desired column, and the following results were obtained from this research.

1- In the 15-floor structure without braces (examples 1 to 4), the maximum displacement is related to model number 1 and 2, both of these structures are caused by fire and thermal load on its column. It has undergone many deformations and progressive deterioration. In model number 3 and 4, the structure has been able to resist the incoming loads to some extent and the reason for this is that the loads on the column in the middle floor are much less than the lower floor and for this reason by removing one column As a result of the fire, the structure has been able to withstand the loads with the help of the rest of the columns and the structure has not undergone many deformations. Therefore, in a 15-floor structure without the worst scenario, removing the column in the lower middle floor, then the lower side floor, and then the middle floor of the middle column, and finally, the least damage is related to the removal of the column in the middle and side floors.

2- In the samples analyzed in the 15-floor structure and with divergent braces in models 5 to 8, in all 4 models, the maximum amount of displacement due to the application of heat in the models compared to the simple frame without divergent braces with a decrease has been In this category, except for sample number 5, in the rest of the samples, the structure has been able to show good resistance, and with increasing temperature and removal of a column, progressive failure has occurred only in structure number 5.

3- In samples number 9 to 12, there were 20-floor structures without braces, and both structures 9 and 10, due to the fire and the thermal load on the column, suffered large deformations and progressive damage. has been In model number 11 and 12, the structure has been able to withstand the loads to a large extent and the reason for this is that the loads on the column in the middle floor are much less than the lower floor and for this reason by removing a Due to the fire of the structure, the column has been able to resist the loads with the help of the other columns and the structure did not undergo many deformations. In these models, compared to the 15-floor models, in all 4 models, the deformations have increased up to 40% due to the increase in loads on the structure due to the increase in height, and samples 11 and 12 also have displacements. They are a little upright, but they are prone to collapse due to progressive damage

4- In samples 13 to 16, in all 4 models of the 20-floor structure, the amount of maximum displacement due to the application of heat in the models compared to the simple frame without diverging braces was accompanied by a good reduction. In this category, except for sample number 13 and 14, in the rest of the samples, the structure has been able to show good resistance, and with the increase in temperature and the removal of a column, progressive failure has occurred in structures 13 and 14, and samples 15 and 16 have shown resistance. It has shown good resistance to progressive damage caused by fire. In this category, compared to the 15-floor samples with diverging braces, the amount of displacement has increased by 40%.

5- In the structures with 25 floors and without braces in all the samples, the structures have undergone many deformations and progressive damage due to the fire and the thermal load applied to its columns.

6- In the 25-floor structures with divergent braces, in all 4 models, the maximum amount of displacement due to the application of heat in the models compared to the simple frame without divergent braces was accompanied by a good reduction, except for sample number 21 and 22, in the rest of the samples, the structure has been able to show good resistance, and with the rise in temperature and the removal of a column, progressive damage has occurred in structures 21 and 22, and samples 23 and 24 have good resistance to progressive damage caused by fire from has shown itself. In this category, compared to the samples of 15 and 20 floors with diverging braces, the amount of displacement has increased by 30%.

7-

References

A. Saedi Daryan, H. Ketabdari, Mechanical properties of steel bolts with different diameters after exposure to high temperatures, Journal of Materials in Civil Engineering, 31(10) (2019) 04019221.

H. Ketabdari, A.S. Daryan, N. Hassani, Predicting post-fire mechanical properties of grade 8.8 and 10.9 steel bolts, Journal of Constructional Steel Research, 162, 2019.

A.S. Daryan, M. Yahyai, Behaviour of welded top-seat angle connections exposed to fire, Fire safety journal, 44(4) (2009) 603-611, 2009 .

saburi-Ghomi,S. ,Venture. ,kharrazi,M. "shear analysis and design of ductile steel shear walls" journal of structural Engineenig ,ASCE, 878-889, 2005.

Anne,B,Monnier, P,Anthony,P, Harasimowicz, P.E. " steel plate shear walls made this hospital expansion passible." modern steal construction. January, 2008 .

AISC, Steel plate shear wall Design, Guidezo, First printing American Institute Of Steel construction Inc. , chicago(, 2007.

X. Lu, X. Zeng, Z. Xu, H. Guan, Physics-based simulation and high-fidelity visualization of fire following earthquake considering building seismic damage, J. Earthq. Eng. 23 (7) (2019) 1173–1193 .

H.-H. Tsang, J.E. Daniell, F. Wenzel, A.C. Werner, A semi-probabilistic procedure for developing societal risk function, Nat. Hazards 92 (2) (2018) 943–969 .

T. Ma, L. Xu, W. Wang, Storey-based stability of steel frames subjected to postearthquake fire, Fire. Technol (2020) 1–31.

R. Suwondo, L. Cunningham, M. Gillie, C. Bailey, Progressive collapse analysis of composite steel frames subject to fire following earthquake, Fire Saf. J. 103 (2019) 49–58 .]11[G. Hou and Q. Li, “Firefighting capacity evaluation of water distribution system subjected to multi-ignitions of post-earthquake fires,” Struct. Saf., vol. 88, p. 102035 .

B. Faggiano, M. Esposto, R. Zaharia, D. Pintea, Structural analysis in case of fire after earthquake, Urban habitat Constr. under catastrophic events, COST Action C 26 (2008) 75– 80.

13 R. Rahnavard, R.J. Thomas, Numerical evaluation of the effects of fire on steel connections; Part 1: simulation techniques, Case Stud. Therm. Eng. 12 (2018) 445–453.]14[K. Himoto, Comparative analysis of post-earthquake fires in Japan from 1995 to 2017, Fire. Technol 55 (3) (2019) 935–961.

A.H. Buchanan, A.K. Abu, Structural design for fire safety, John Wiley & Sons, 2016. [16] S. Ni, A.C. Birely, Post-fire seismic behavior of reinforced concrete structural walls, Eng. Struct. 168 (2018) 163–178.