# Comparative Study on Thermal Stresses in Steel Structure and Steel with Different Bracing Configuration

Avinash A[1], Naveen Kumar D T[2]
*P G Student Department of civil engineering, ACSCE/VTU, Karnataka, India*
*Associate Professor, Department of civil engineering, ACSCE/VTU, Karnataka, India*

***Abstract*-Over the past few years steel structures are becoming a common feature in all manufacturing industrial buildings. Steel structures are particularly suitable for all buildings or industrial sheds. In some of manufacturing industries for conversion of raw material to usable material some machine operations are required in that processes, increases in the temperature will affect the steel frame structure. In order to study the performance of steel structures, different models were developed in STAAD Pro software by varying the types of bracings in structures. In which the horizontal beams connecting vertical elements are assumed as pinned connecting medium having equivalent distributed stiffness properties. Here the structure is analyzed for wind load and static analysis for different models by varying the temperature and the output of the models are evaluated to have a comparative study of their performance for thermal stresses. From the analysis results by compared to structures with other bracing configuration it is found that due to variation in temperature thermal stresses is less in Single diagonal bracing structure. Hence Single diagonal bracing structure is good type of bracing in resistivity of the structure.**

***Index Terms*-Thermal stresses, Deflection, Steel Bare Framed and Steel Braced Framed structure, Temperature Stresses, STAAD Pro.**

## I. INTRODUCTION

Now a days, Steel structure have become most popular in residential and industrial, because of its many advantages like light weight, fast execution and aesthetic appearance. Widely steel structure has been used in Stadium, sports, gymnastic, airport, industrial and factory buildings. To design steel structure, behavior of structure under gravity load, live load, wind load, seismic load and thermal load have to be analyzed.

### A .*Thermal Expansion*

As a solid material experiences an increase in temperature, the volume of the structure is ultimately impacted by increase in temperature resulting in a phenomenon known as thermal expansion. This process results from heat's ability to increase a material's kinetic energy.

Within solids, molecules are typically located in close proximity to one another, contributing to the defined shape of the structure. As the temperature rises, molecules begin to vibrate at a more rapid speed and push away from one another. This increased separation between the individual atoms causes the solid to expand, thus increasing the volume of the structure.

.

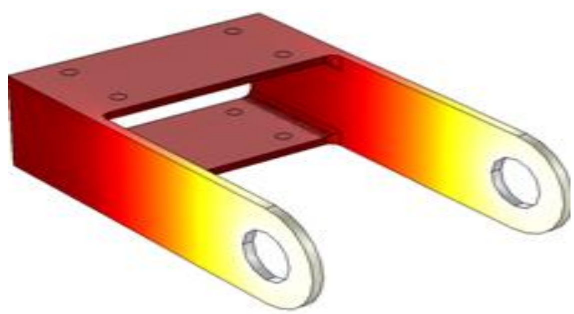

Fig*: Temperature distribution within the bracket*

### B .*With Expansion Comes Thermal Stresses*

With this volumetric enlargement, the elements of a solid undergo greater levels of stress. Thermal stresses can have a significant effect on a structure's strength and stability, potentially causing cracks or breaks within certain components. Such failures compromise the overall design of the structure, which can lead to possible weakening and deformation.

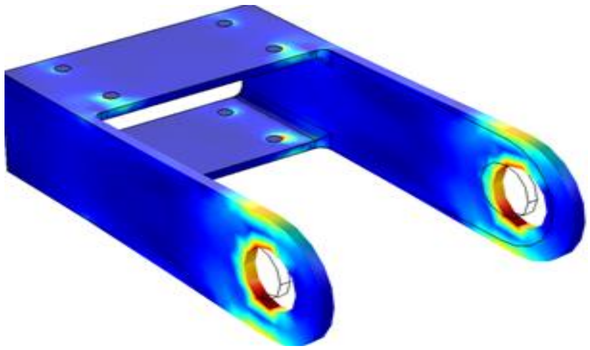

Fig: 2 *In the areas of greatest stress from the applied temperature (shown in red), the bracket experience deformation*

C .*Types of Bracings*

1) X-Bracing
2) Diagonal Bracing
3) K Bracing
4) Knee-Braced Frame

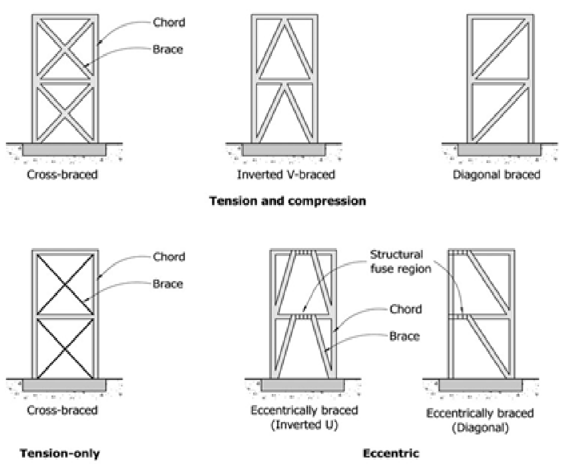


Fig 3: *Example of bracing schemes for concentrically braced frames (8)*

## II. LITERATURE REVIEW

Technical papers of various journals are studied to understand the importance and necessity of this research in consideration of wind and seismic resistant design. It presents a brief summary of the literature review. Following review of literature gives an outlook on the effect of thermal stresses in steel structures. Brahmanand V [1] Structural and Modal analysis of structural carbon steel member with point load under thermal loading is studied. Here theoretical calculations for deflection and stress of cantilever member and member with both end fixed are carried out. Effect of different cross section member with same cross section area on deflection and stress is also studied. While designing the structure, the effect of thermal stresses and deformation on the performance of structural members due to change in temperature during restrained condition has been not considered. Hemangi K.Patade [2] the effect of thermal stresses and deformation on the performance of structure due to increase in temperature is generally not treated in design codes and standards. This describes the behavior of structure when subjected to high temperature. The change in temperature makes material to expand and if this expansion is restrained, stresses are induced which affects expected performance of structure. The force generated by restrains is very large and its ignorance can lead to unsafe the design. When structure is subjected to high temperature, it results in reduction in stiffness and strength which significantly affects the structural performance. In this paper analysis of beam subjected to fire loading is done. Response of steel beam subjected to ISO834 fire with different types of restraining support condition is studies. Hongbo Liu ,Zhihua Chen [3] The change in temperature is very large for steel structures under solar radiations, and this temperature change can induced remarkable nodal displacement and member stress. In order to obtain the temperature distribution and thermal behavior of large span steel structures under solar radiations, a numerical simulation method was presented based on ASHRAE model. In order to provide into temperature distribution and provide data to verify the presented numerical simulation method, 10 steel plates' specimens with different aspect ratios and orientations were investigated by measuring their temperatures under solar radiations. The parameters values in the numerical simulation model were modified by the tests results. Using the temperature numerical simulation method, the temperature distribution and thermal behavior of a typical steel structure, the lattice shell structures were studied. The study shows that the solar radiations had a significant effect on the temperature distribution of steel structures. Considering the solar radiation, the temperature of steel structure is of $20^0$ C higher than the corresponding ambient air temperature. The temperature change is similar to sine curve from sunrise to sunset. The solar radiation has a remarkable effect on the member stress, nodal displacement and reactive force Milan Sapieta, Vladimir Dekys [4] Investigation of experimental thermal stress analysis of stainless steel which was loaded by 3 point bending. Loading took place cyclically with constant amplitude. The measurement was performed using contactless scanning of infrared radiations emitted during loading from the face of specimen. The results were evaluated according to the theory of thermo elasticity. After evaluation of the results we get stress distribution of first invariant of the front face of specimen. He Wang, Ao Wang [5] the working temperature of BIPV modules in high than ground mounted PV. Based on the theory of material mechanics and thermal stress analysis, the stress distribution of metallization interconnects system for crystalline silicon solar modules in BIPV were studies for the first time. The shear stress and normal stress distribution of soldered structure for crystalline silicon solar cell under thermal field were discussed. And the results show the stress distribution is not simply linier relationship as some results found. But there is stress concentration at the edge which was considered as the true reason the cost V-notch at the edge of soldered solar cell. The conclusion is to provide theoretical l basis for readability of silicon BIPV modules.

H.Saito, H.Useugi [6] The analyzing thermal stresses and deformations of a high rise steel structures, exposed to a comportment fire, it is convenient to divide the structure into the local substructure, directly fire exposed and the adjacent substructure, comprising the nearest floors and spans around the fire compartment and the remaining part of the structure. This paper presents a method for the calculation of the stress and deformation behavior of a high rise steel structure, exposed to a compartment of fire, based on a subdivision of a structure. In order to illustrate the structural fire behavior, 48 buildings have been analyzed according to this method. Here they concluded some of long span beams will get collapse mechanism if they designed according to allowable temperature $600^0$ C which is permitted in some Countries. And it is verified that the suggested calculation method based on divisions of structure into 3 types of substructures is suitable for high rise building structures exposed to compartment fire. A.S. Usmani, J.M.Rotter, [7] theoretical description of behavior of composite frame structure in fire. Behavior composite structure in fire as long been understood to be dominated by the effects of strength loss caused by thermal degradation, and the large deflection and runaway resulting from the action of imposed loading on a weakened structure. Thus strength and load are quite generally believed to be the key factors in determining structural response. In this project composite frame structures of the type tested at Cardington possess enormous reserves of strength through adopting large displacement configurations. It is thermally induced forces and displacement, and not material degradation that govern the structural response in fire. Degradation such as steel yielding and buckling can even be helpful in developing large displacement load carrying modes safely. However, because no clear failure of composite structures such as Cardington frames have been seen, it is not clear how for these structures are from failure in a given fire. This paper attempts to lay down some of the most important and fundamental principles that govern the behavior of composite frame structures in fire in a simple manner. This based upon the analysis of response of single structural elements under the combination of thermal actions and end restraints representing surrounding the structures.

## III. NEED FOR PRESENT STUDY

As the population is becoming more and more the necessity of tall buildings is much important. So the tall building construction has been rapidly increasing worldwide by introducing new challenges that need to be met through engineering judgment. As the height of the building increases, the stiffness and strength of the building decreases. Severe structural damages suffered by several modern buildings during recent earthquakes illustrate the importance of avoiding sudden changes in lateral stiffness. Different types of bracing configuration structures are nowadays very popular owing to their advantages over normal bare framed structures.

## IV. OBJECTIVES

1) Calculation of Stress and deflection in loaded member at different temperature considering combined effect of mechanical and thermal factor.
2) Study of effect of thermal stress at different temperature with different bracing configuration.
3) Compare thermal stresses between a steel bare framed structure and steel braced framed structure with different bracing configuration.

## V. STRUCTURAL MODELING AND LOADING

Table: 1 Building Modeling and Loading Data

| | | |
|---|---|---|
| 1 | Type Of Building | A multi-storeyed steel structure |
| 2 | Number of stories | G+4 |
| 3 | Gravity load factor | 1.5 |
| 4 | Floor height | 3m |
| 5 | Size of column | ISWL 350 |
| 6 | Size of beam | ISMB 200 |
| 7 | Size of bracings | ISA 200X200X25 |
| 8 | Imposed load | 4 KN/$m^2$ |
| 9 | Floor finish | 2 KN/$m^2$ |
| 10 | Number of bays | 04 |

### A. *Building Models*

Building is modeled using the software STAAD PRO. 4 building models were considered with different temperature, -$5^0$ C, -$10^0$ C,-$15^0$ C,-$20^0$ C, $0^0$ C, $5^0$ C, $10^0$ C, $15^0$ C, $20^0$ C.

MODEL I: Bare framed steel structure at temperature

MODEL II: X-Braced framed steel structure at temperature

MODEL III: Single Diagonal Braced framed steel structure at temperature.

## VI.MODELS FOR DIFFERENT BRACING CONFIGURATION

Model 1: Bare framed steel structure at temperature

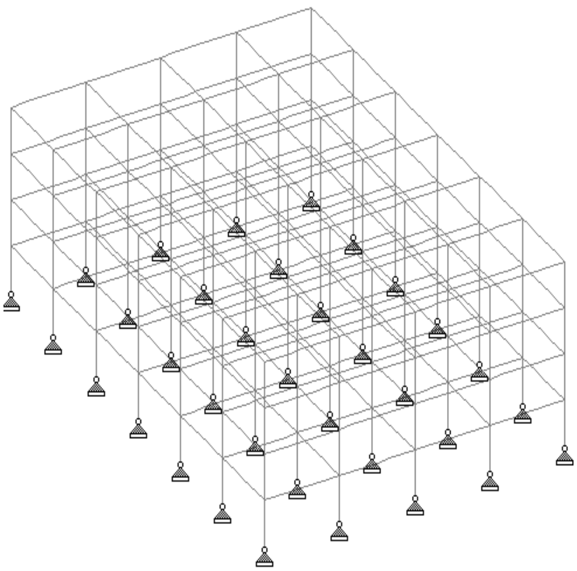

Fig4*3DModel*

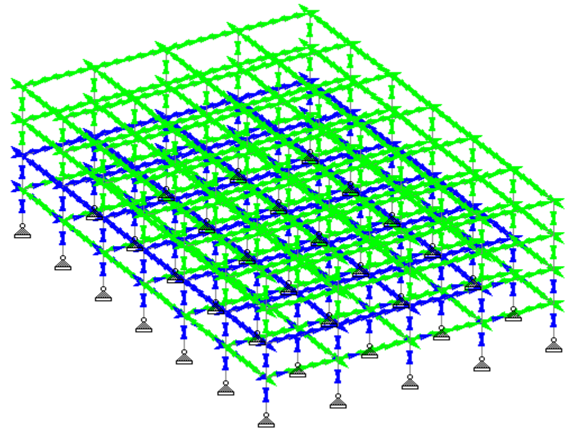

Fig.5 *Analysis Of Thermal Load*

Model 2: X-Braced framed steel structure at temperature

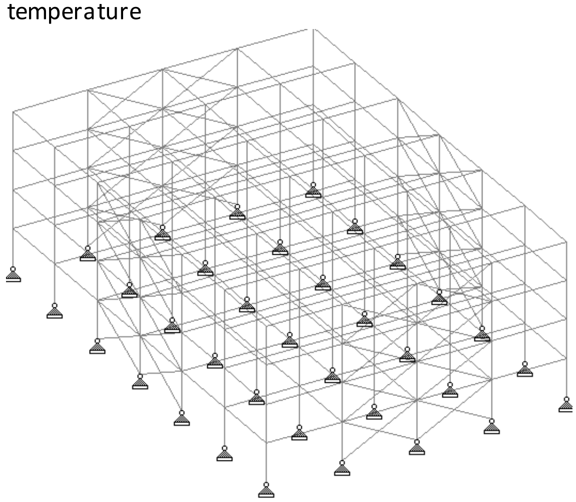

Fig: 6 *3DModel At $0^0C$*

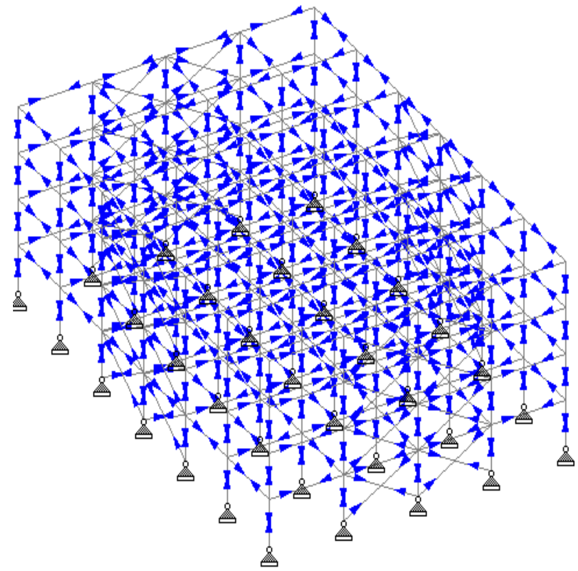

Fig: *7Analysis Of Temperature to X bracing At -$15^0C$*

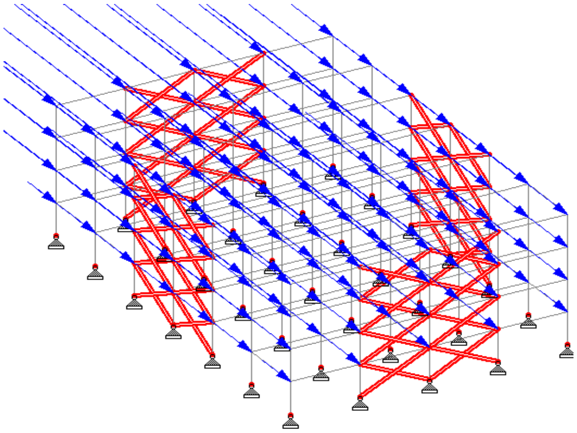

Fig: 8 *Analysis Of Load in Z Direction*

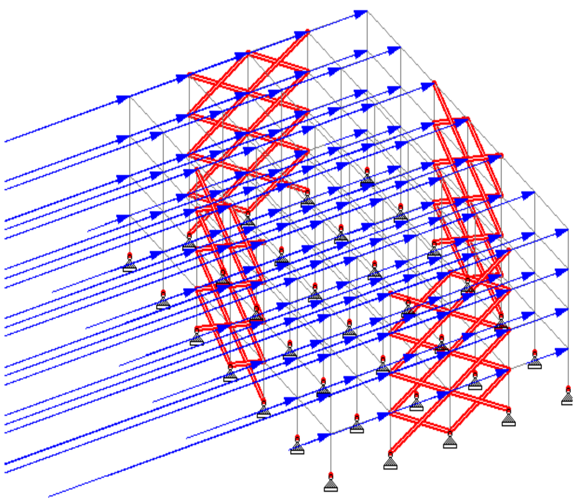

Fig: 9 *Analysis Of Load in X Direction*

Model 3: Single Diagonal Braced framed steel structure at temperature

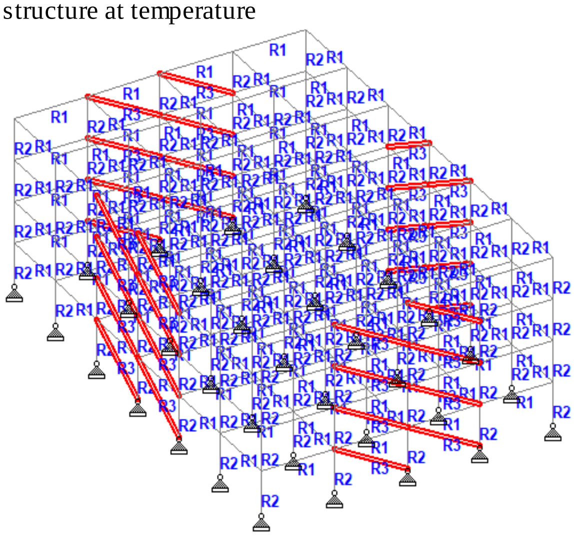

Fig: 10 *3DModel At $0^0C$*

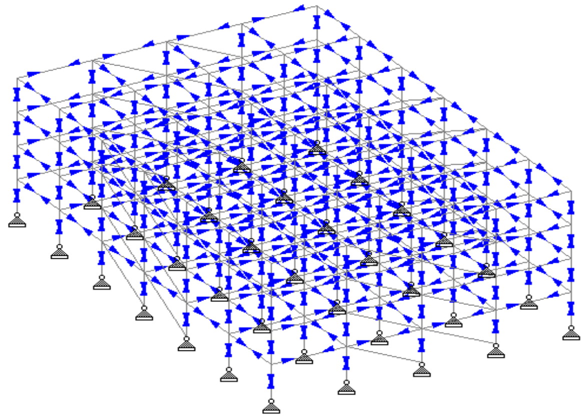

Fig: 11 *Analysis Of Temperature At $-15^0C$*

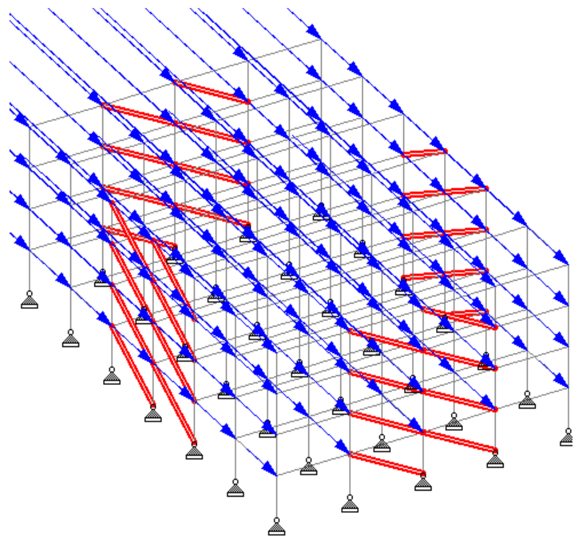

Fig: 12 *Analysis Of Load in Z Direction*

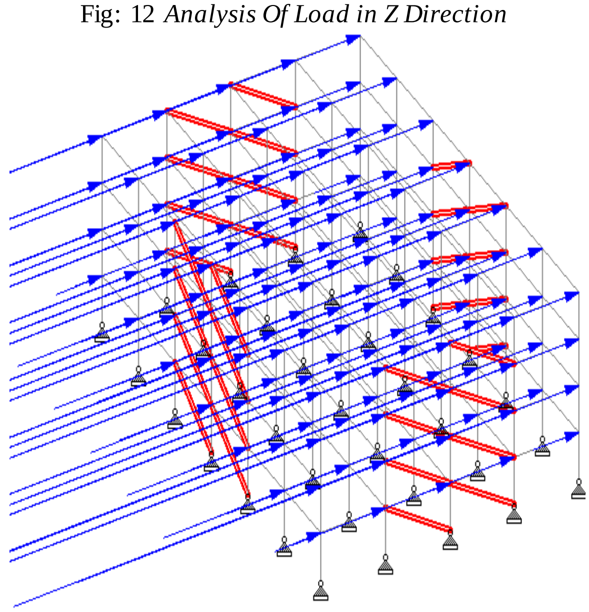

Fig: 13 *Analysis Of Load in X Direction*

## VII.ANALYSIS RESULTS AND DISCUSSIONS

### A .*Displacement Results*

Table: 2 Displacement values bare frame in X and Z directions in mm

| Displacement In X Direction | | Displacement In Z Direction |
|---|---|---|
| Temperature $^0$c | Displacement In Mm | DISPLACEMENT mm |
| -5 | 408.531 | 893.137 |
| -10 | 412.014 | 893.137 |
| -15 | 415.5 | 893.137 |
| 0 | 404.348 | 1339.71 |
| 5 | 404.348 | 896.016 |
| 10 | 404.348 | 899.638 |
| 15 | 404.348 | 903.269 |

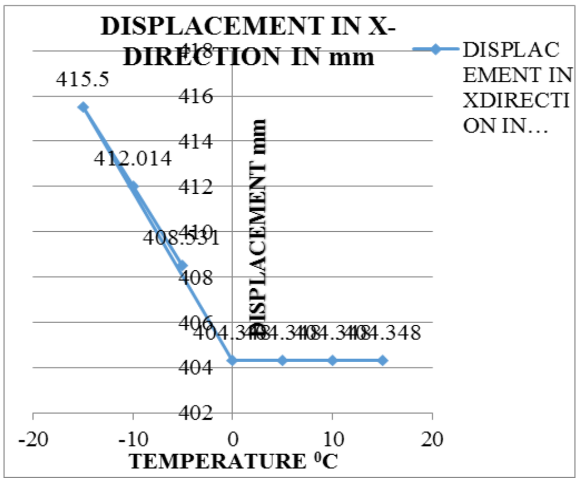


Fig14 *Temperature v/s displacement value in x direction*

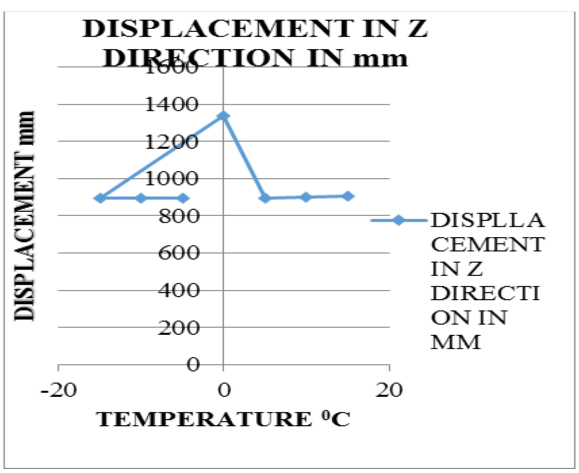


Fig15 *Temperature v/s displacement value in z direction*

Table: 3 Displacement values x braced frame structure in X and Z directions in mm

| Displacement In X Direction | | Displacement In Z Direction |
|---|---|---|
| Temperature $^0$c | Displacement Mm | Displacement Mm |
| -5 | 413.527 | 863.851 |
| -10 | 421.295 | 863.851 |
| -15 | 429.063 | 863.851 |
| 0 | 405.058 | 1295.78 |
| 5 | 407.478 | 866.582 |
| 10 | 409.899 | 863.851 |
| 15 | 412.319 | 870.07 |

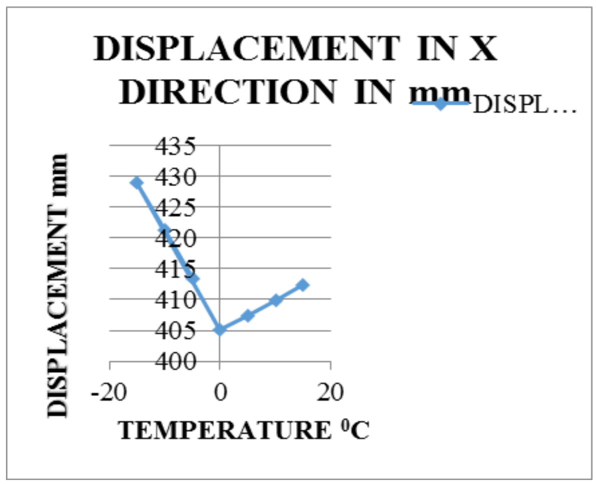


Fig 16 *Temperature v/s displacement value in x direction*

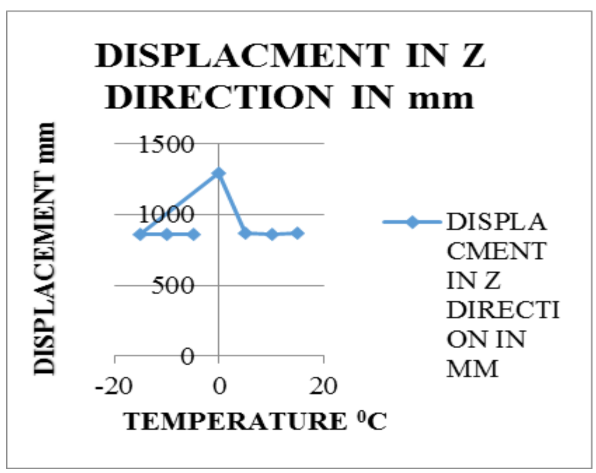


Fig17 *Temperature v/s displacement value in z direction*

Table: 4 Displacement values diagonal braced frame structure in X and Z directions in mm

| Displacement In X Direction | | Displacement In Z Direction |
|---|---|---|
| Temperature $^{0}$c | Displacement In Mm | DISPLACEMENT mm |
| -5 | 405.456 | 755.389 |
| -10 | 405.456 | 755.389 |
| -15 | 405.00 | 755.389 |
| 0 | 608.00 | 1133.08 |
| 5 | 409.389 | 757.663 |
| 10 | 412.6 | 760.759 |
| 15 | 415.81 | 763.855 |

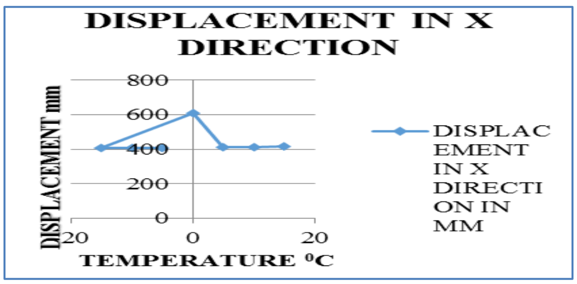


Fig: 18 *Temperature v/s displacement value in x direction*

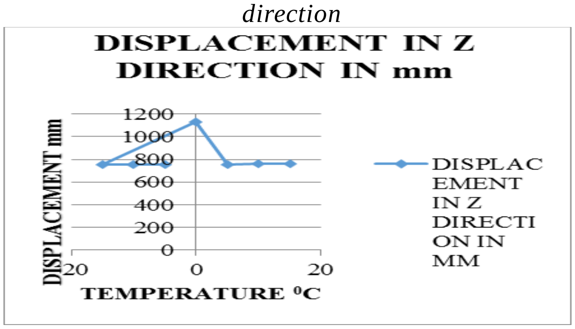


Fig: 19 *Temperature v/s displacement value in x direction*

B. *Bending Moment Results*

Table: 5 Bending moment values for base frame structure in kN/m

| BENDING MOMENT Kn-M | |
|---|---|
| Temperature $^{0}$c | Temperature $^{0}$c |
| -5 | -5 |
| -10 | -10 |
| -15 | -15 |
| 0 | 0 |
| 5 | 5 |
| 10 | 10 |
| 15 | 15 |

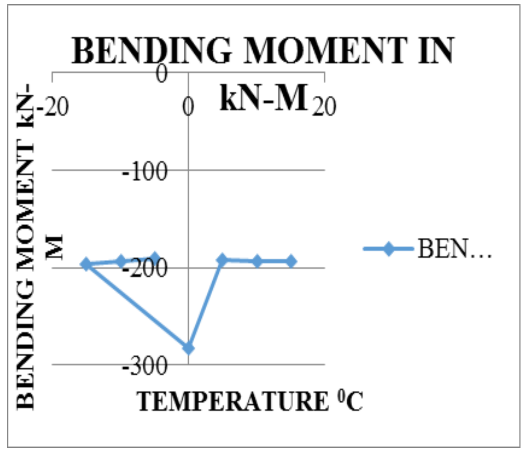


*Fig: 20 temperature v/S bending moment*

Table: 6 Bending moment values for X braced frame structure in kN/m

| BENDING MOMENT Kn-M | |
|---|---|
| Temperature $^{0}$c | Bending Moment |
| -5 | -190.65 |
| -10 | -193.51 |
| -15 | -196.37 |
| 0 | -282 |
| 15 | -191.1 |
| 10 | -193.51 |
| 5 | -193.36 |

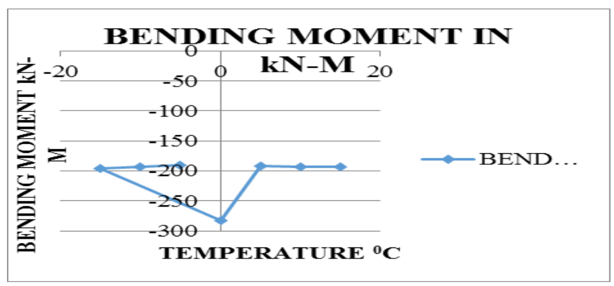


*Fig: 20 temperature v/S bending moment*

Table: 7 Bending moment values for diagonal braced frame structure in kN/m

| BENDING MOMENT Kn-M | |
|---|---|
| Temperature $^{0}$c | Bending Moment |
| -5 | -190.71 |
| -10 | -192.51 |
| -15 | -194.33 |
| 0 | -283.79 |
| 5 | -191.09 |
| 10 | -192.12 |
| 15 | -193.14 |

C. *Thermal Stresses Results*

Table: 8 Thermal Stresses in bare frame structure in N/mm$^2$

| THERMAL STRESSES | | |
|---|---|---|
| Temperature$^0$c | Compression N/mm$^2$ | Tension N/mm$^2$ |
| -5 | 1762.55 | -1500.3 |
| -10 | 591.384 | -582.85 |
| -15 | 1768.86 | -1613.8 |
| 0 | 2467.71 | -2392.4 |
| 5 | 1756.59 | -1613.8 |
| 10 | 1753.77 | -1613.8 |
| 15 | 1750.96 | -1613.8 |

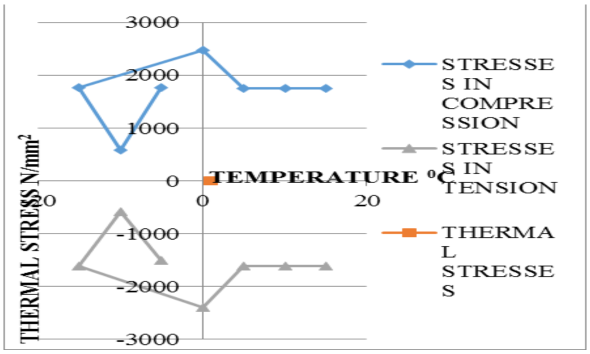


Fig: 21 *Temperature v/S thermal stresses*

Table: 9 Thermal Stresses In X Braced Frame Structure In N/Mm$^2$

| THERMAL STRESSES | | |
|---|---|---|
| Temperature$^0$c | Compression N/mm$^2$ | Tension N/mm$^2$ |
| -5 | 1701.81 | -1552.6 |
| -10 | 1705.5 | -1552.6 |
| -15 | 1709.18 | -1552.6 |
| 0 | 2376.06 | -2284.5 |
| 5 | 1694.97 | -1433.1 |
| 10 | 1691.8 | -1430.1 |
| 15 | 1688.64 | -1427.1 |

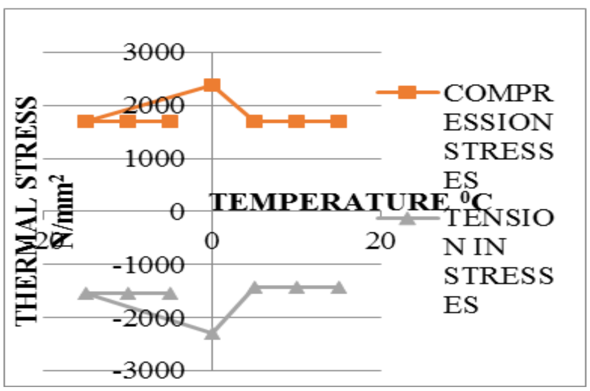


Fig: 22 *Temperature v/S thermal stresses*

Table: 10 Thermal Stresses In X Braced Frame Structure In N/Mm$^2$

| THERMAL STRESSES | | |
|---|---|---|
| Temperature$^0$c | Compression N/mm$^2$ | Tension N/mm$^2$ |
| -5 | 1385.46 | -1240.4 |
| -10 | 1390.15 | -1240.4 |
| -15 | 1394.85 | -1240.4 |
| 0 | 1907.31 | -1832.6 |
| 5 | 1379.45 | -1240.4 |
| 10 | 1377.42 | -1240.4 |
| 15 | 1375.38 | -1240.4 |

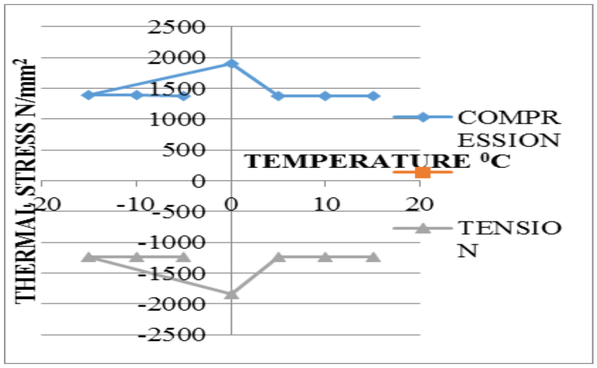


Fig: 23 *Temperature v/S thermal stresses*

## VIII.CONCLUSIONS AND SCOPE OF FURUTHER STUDY

A. *Displacement In X Direction*

1) When the temperature in increase, a maximum reduction displacement in X direction in order to bare frame is observed V bracing and Single diagonal bracing reduces more (33%).
2) When the temperature in decrease, a maximum reduction displacement in X direction in order to bare frame is observed K bracing reduces more (33%).

B. *Displacement In Z Direction*

1) When the temperature in increase, a maximum reduction displacement in Z direction in order to bare frame is observed that K bracing reduces less (0.3%).
2) When the temperature in decrease, a maximum reduction displacement in Z direction in order to bare frame is observed that K bracing reduces less (0.5%).

C. *Bending Moment*

1) Due to the increase in temperature bending moment increases, in order to compare with bare frame structure, braced frame structures reduces

more bending moment. And is observed that Single diagonal bracing (30%) and K bracing (30%) reduces more bending moment.

Whereas decrease in temperature bending moment increases, and is observed that Single diagonal bracing (31%) and V bracing (31%) reduces more bending moment.

D. *Thermal Stresses*

1) By comparing thermal stresses in all the steel structures, it is found that when the temperature increases then single diagonal braced structures decreases (27%) more than compare to other bracing.
2) Similarly by comparing thermal stresses in all the steel structures, it is found that when the temperature decreases then single diagonal braced structures decreases (26%) more than compare to other bracing.

E. *Scope for Future Work*

Within the limited scope of the present work, the broad conclusions drawn from this work have been reported. However, further study can be undertaken in the following areas:

1) Varying the column and beam dimensions for same models can be analyzed.
2) For same models compare with more number of degree variation.

REFERENCES

[1] Brahmanand V. Patil and Prof. Milind S.Ranmgir "study of structural steel members under thermal loading" International journal of science, Engineering and Technology Research, Volume 5, Issue 8,August 2016.

[2] Hemangi K.Patade And Dr.M.A.Chakrabarti "Thermal Stress analysis of beam subjected to fire" International journal of Engineering research and applications, volume 3, Issue 5, Sep-Oct 2013,pp.420-424

[3] Hongbo Liu,Zhihua Chen And Ting Zhou "Investigation on temperature distribution and thermal behavior of large span steel structures considering solar radiation" Advanced steel Construction Vol. 9 No. 1, pp. 41-58(2013).

[4] Milan Sapieta,Vladimir Dekys And Alzbeta Sapietova, "Thermal stress analysis of beam loaded by 3point bending" Procedia Engineering 136(2016) 216-219.

[5] He wang, Ao Wang and Jingsheng Huang "Study on thermal stress distribution of crystalline silicon solar cells in BIPV" Energy procedia 88(2016) 429-435.

[6] H.Saito, H.Useugi and M.Yamaguvchi "Thermal stress and deformation of steel structures of high rise buildings in fire" International association for fire safety science.

[7] A.S. Usmani, J.M.Rotter, S.Lamont ,A.M.Sanad And M.Gillie "Fundamental principal of structural behavior under thermal effects" Fire safety journal 36(2001) 721-744 (22 March 2001)

[8] Web site references
https://www.comsol.com.
https://taxonomy.openquake.org.