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Numerical analysis and normative considerations regarding thermal actions on compact metallic structures.

Numerical analysis and normative considerations on thermal actions in compact steel structures

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Summary

This work investigates the effects of thermal variation on metallic structures with different geometric configurations and stiffness levels, through numerical modeling in the RSTAB software. The analysis considers exclusively indirect thermal actions, applied to models of low mezzanines rigidly connected to a structural platform. Structures with different heights and with or without intermediate bracing were evaluated in order to quantify the impact of the restriction on thermal deformation on internal stresses. The results demonstrate that, even in structures of reduced dimensions, the limitation of free expansion can generate significant internal stresses, especially in systems with rigid supports. The comparison between the models shows that the overall stiffness of the structure directly influences the redistribution of thermal stresses. The conclusions reinforce the importance of following the guidelines established by technical standards such as ABNT NBR 8800:2024, EN 1991-1-5:2003 and ANSI/AISC 360-22, which recognize thermal action as a relevant indirect variable in the design of metallic structures.

Keywords: Thermal variation. Metallic structures. Internal stresses. Structural stiffness. Numerical modeling.

Abstract

This study examines the effects of thermal variation on steel structures with different geometric configurations and stiffness levels through numerical modeling using RSTAB software. The analysis focuses exclusively on indirect thermal actions applied to low mezzanine models rigidly connected to a structural platform. Structures with varying heights and with or without intermediate bracing were evaluated to quantify the impact of thermal deformation constraints on internal forces. The results show that even in compact structures, restrictions on free expansion can generate significant internal stresses, especially in systems with rigid connections. The comparison between models highlights that the overall stiffness of the structure directly influences the redistribution of thermal forces. The findings underscore the importance of adhering to technical standards such as ABNT NBR 8800:2024, EN 1991-1-5:2003, and ANSI/AISC 360-22, which recognize thermal action as a relevant indirect variable in the design of steel structures.

Keywords: Thermal variation. Steel structures. Internal forces. Structural stiffness. Numerical modeling.

1. Introduction

Thermal variation is recognized by technical standards as an indirect action that can to influence the structural behavior of metallic systems. Its relevance depends on factors such as thermal amplitude, material properties, boundary conditions and freedom for deformations (Pfeil & Pfeil, 2017; Fakury et al., 2015).

In isostatic structures, thermal effects tend to be negligible. However, in systems... In hyperstatic structures or those with rigid constraints, restriction of expansion can induce internal stresses. Significant. The ABNT NBR 8800:2024, EN 1991-1-5:2003 (Eurocode 1 – Part 1-5) and standards ANSI/AISC 360-22 treats these actions as indirect variables, recommending their consideration. when there are impediments to the free movement of structural elements.

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This work aims to investigate, through numerical modeling, the impact of Thermal variation on internal stresses in simple metallic structures, with different geometric configurations and stiffness levels. The analysis seeks to quantify the degree of influence of the Thermal actions on structural behavior, based on normative and technical criteria. contributing to the understanding of the thermal response in metallic systems.

2. Theoretical Framework

2.1 Thermal Actions on Metallic Structures

Thermal variation is classified as an indirect action that can induce internal stresses. relevant in metal structures, especially those with rigid connections or a high degree of Hyperstaticity. The expansion or contraction of structural elements, caused by variations in Temperature can generate internal stresses, displacements, and redistributions of forces that affect the... overall performance of the structure. These effects are more pronounced when there is restriction to free movement. Deformation of the elements, as occurs in welded structures or structures with high continuity.

2.2 Normative Approaches

The main technical standards recognize the importance of thermal actions, although they adopt different approaches. The European standard EN 1991-1-5:2003 (Eurocode 1 – Part 1-5) presents a detailed modeling, distinguishing between uniform and differential temperature components, as well as to provide typical thermal profiles for different types of structures. The Brazilian standard ABNT NBR 8800:2024 treats thermal variation as an indirect variable action, referring to NBR 6120:2019. for defining characteristic values and weighting coefficients. The American standard ANSI/AISC 360-22, in turn, advises that thermal effects should be considered whenever... There may be restrictions on the movement of the elements, although it does not provide specific thermal profiles.

A comparison between these standards reveals that, while the Eurocode provides more guidelines Complete for thermal modeling, NBR 8800 and AISC 360-22 adopt a more comprehensive approach. generic, requiring technical judgment on the part of the designer. This difference can have an impact directly impacts how thermal effects are considered in practical designs.

The ABNT NBR 8800:2024 standard, which governs the design of steel and composite structures in Brazil, It also recognizes the effects of temperature variation as indirect variable actions. Although not Provide specific details on thermal profiles, referring to NBR 6120:2019 for definition of Actions and weighting coefficients. NBR 8800 establishes that, in industrial structures, the distance The distance between bracing substructures should not exceed 60 m when the thermal variation is not explicitly considered in the analysis, recommending the use of expansion joints and devices.

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relief of thermal stresses (Fakury et al., 2015).

Additionally, the American standard ANSI/AISC 360-22 treats thermal actions as Indirect loads that must be considered when there is a restriction on the movement of the elements. Although it does not provide specific thermal profiles, it suggests that thermal effects be included. In structural analysis, whenever factors that could influence the limit states of resistance or serviceability are considered. The standard also highlights the importance of considering the compatibility of deformations in structures. composites and systems made up of different materials.

2.3 Technical Considerations Regarding Constraints and Deformations

Authors such as Pfeil & Pfeil (2017) and Fakury et al. (2015) highlight that the restriction to dilation Thermal stress can generate significant internal stresses, even in small systems. The presence of rigid connections, the absence of expansion joints, and high structural continuity are... factors that intensify these effects. In isostatic structures, thermal displacements tend to can be accommodated without generating significant effort. However, in hyperstatic systems, the Incompatibility of deformations can compromise serviceability limit states and integrity. of the connections.

Therefore, the decision to consider or not consider thermal action should be based on an analysis. A careful consideration of the boundary conditions, the geometry of the structure, and the expected temperature range. use of devices such as sliding supports, expansion joints and proper detailing of Connections are effective strategies to mitigate the effects of temperature variation.

3. Materials and Methods

The methodology adopted is based on numerical modeling, focusing on the influence of Different factors were compared regarding stiffness, boundary conditions, and element geometry. Structural configurations, with and without consideration of thermal actions, as stipulated in the standards. applicable techniques.

The simulations were performed using the Dlubal RSTAB 8.28 software, which is widely used in... Structural engineering for the analysis of truss structures. The models were built with Three-dimensional bar elements, with six degrees of freedom per node, allowing for consideration. of axial forces, bending, torsion, and lateral displacements. The material used was structural steel. ASTM A36, with a modulus of elasticity of 210 and a coefficient of thermal expansion of ÿ 12 × 10ÿ6 ° ÿ1 .

3.1 Structural Models

Four main models were developed, all representing metal structures.

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of low mezzanine floors with a square floor plan of 2000 mm × 2000 mm. The models differ by total height of the structure (250 mm, 500 mm and 1000 mm) and by the presence or absence of a beam Intermediate horizontal bracing at mid-height of the column. This geometric variation allows for evaluation. The impact of overall stiffness and structural configuration on the effects of thermal variation.

3.2 Analysis Conditions

The analysis was conducted focusing exclusively on indirect thermal action, without considering gravitational or usage actions. This choice aims to isolate the effects of temperature variation on the structure, in accordance with the guidelines of EN 1991-1-5:2003 (Eurocode 1 – Part 1-5).

A uniform temperature increase of 30 °C was applied to all elements. structural issues, representing a critical condition of intense solar exposure. This value was adopted. based on typical sun exposure in tropical regions of Brazil, such as Belo Horizonte, Salvador and Rio de Janeiro. The thermal action was modeled as an indirect load, generating stresses. internal factors due to the containment of thermal displacements.

3.3 Parameters Evaluated

The simulation results were analyzed with a focus on the structural response to variation. thermal, considering the following parameters:

- Axial elongation of the beams;
- Axial forces in beams;
- Bending moments in the columns, connection nodes with the analyzed beams;
- Difference in thermal expansion between structural elements.

Numerical analysis seeks to identify whether structural elements exhibit expansion. compatible with each other, allowing for harmonious overall thermal expansion, or if there is incompatibilities that result in significant internal efforts. This assessment is essential for to understand how the overall stiffness of the structure and the boundary conditions influence the redistribution of thermal stresses.

The modeling was conducted based on normative guidelines and evidence from the literature. technique. As highlighted by Pfeil & Pfeil (2017), the presence of rigid links and the absence of Relief devices, such as expansion joints, can generate significant internal stresses, even in Reduced-scale structures. When comparing different geometric configurations and levels of stiffness, The aim is to understand to what extent temperature variation affects internal stresses and displacements, contributing to more informed design decisions.

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3.4 Computational Modeling

3.4.1 Configuring Models in RSTAB 8.28

Computational modeling was performed using Dlubal RSTAB 8.28 software. Three-dimensional bar elements with six degrees of freedom per node. The structural model is composed of two subsystems: the metal mezzanine and a floor platform, the latter representing part of an industrial building. The platform was modeled with solid bars of 250 mm × 250 mm square section in ASTM A36 steel, with rigid connections between themselves and with the Mezzanine elements.

The mezzanine consists of vertical columns and horizontal beams with a solid square cross-section. 100 mm × 100 mm, also in ASTM A36 steel. The connections between all elements were considered completely rigid, simulating field welds. Figures 1 to 4 show the The geometry of the simulated models varies according to the height of the structure and the presence or absence of... Intermediate bracing beam for the columns.

Figure 1 *- Geometry of the model with a height of 250 mm (without intermediate bracing) (Source: (Written by the author himself)*

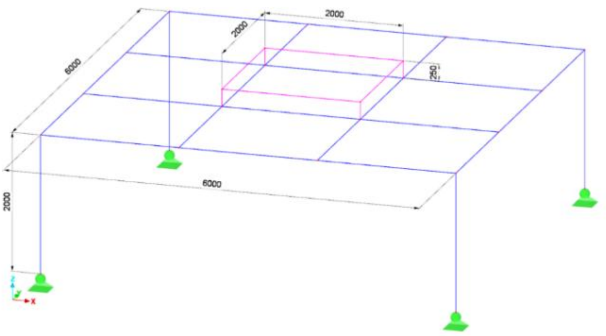

Figure 2 *- Geometry of the model with a height of 500 mm (without intermediate bracing) (Source: (Written by the author himself)*

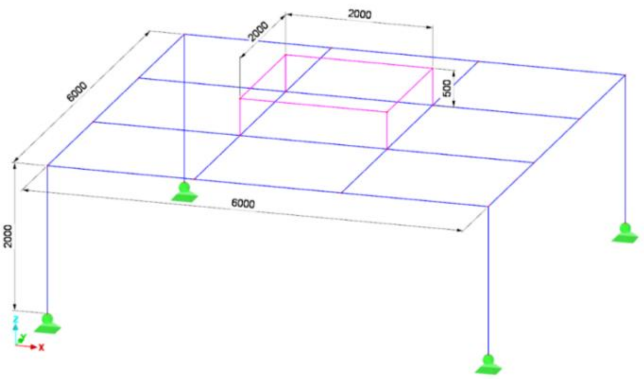

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Figure 3 *- Geometry of the model with a height of 1000 mm (without intermediate bracing) (Source: Prepared by the author)*

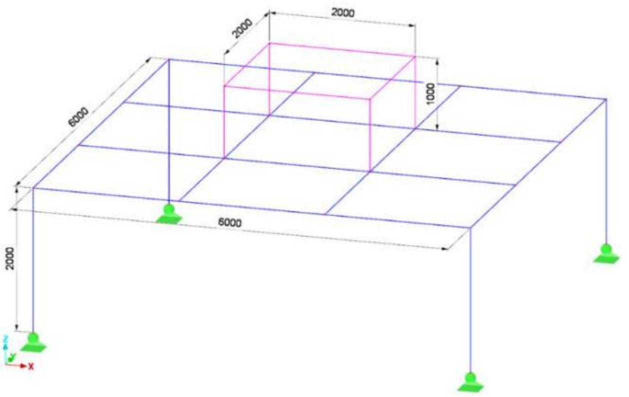
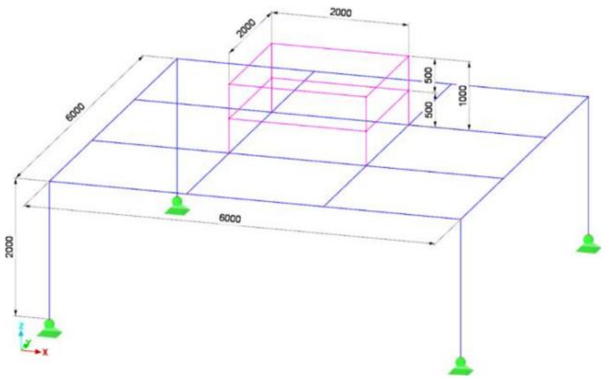


Figure 4 *- Geometry of the model with a height of 1000 mm (with intermediate bracing) (Source: (Written by the author himself)*



Including the tie beam in the 1000 mm high model allows for its evaluation. influence on the redistribution of thermal stresses. The comparison between the models provides supporting information. to understand how the overall stiffness of the structure affects the compatibility of deformations and the generation of internal stresses under thermal variation.

3.4.2 Application of Actions

The main objective of this study is to evaluate the effects of thermal variation on structures. metallic structures with varying degrees of rigidity. For this reason, only actions were applied. Indirect thermal factors, without considering gravitational or usage actions.

The thermal action was modeled as a uniform temperature increment of 30 °C. Applied to all structural elements. This value represents a critical exposure condition. Intense solar radiation, in accordance with EN 1991-1-5:2003 guidelines, and is compatible with temperature variations. observed in tropical regions of Brazil.

The theoretical value for thermal elongation of a structural element was calculated based on In the classic equation for linear expansion:

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ÿ = ÿ $_0$ ÿ ÿ Eq. 1

Where:

ÿ = linear elongation (mm);

= coefficient of linear thermal expansion of steel (ÿ 12 × 10ÿ6 ° ÿ1);

$_0$ = initial length of the element (mm);

ÿ = temperature variation (°C).

3.4.3 Analysis Strategy

The analysis was conducted in the static linear regime, considering elastic behavior. The linear nature of materials and the absence of second-order effects. This approach is suitable for the initial assessment of thermal effects in structures with rigid supports, allowing identification displacements and stresses induced exclusively by the restriction of thermal expansion.

Furthermore, the normal thermal stress generated in an element with restricted expansion It can be estimated by the equation:

= ÿ ÿ ÿ Eq. 2

Where:

= induced axial force ( );

= modulus of elasticity of steel (210);

= cross-sectional area of the element (²);

= coefficient of linear thermal expansion;

ÿ = temperature variation (°).

This relationship shows that, for the same temperature variation, elements with a larger cross-sectional area... Cross-sector teams will develop greater internal efforts.

Table 1 presents the main results obtained in the simulations, including the elongations. thermal and normal stresses developed in the upper, lower and, where applicable, beams in the intermediate bracing beam.

Table 1 - Summary of the analysis results in the software

Model	Description of the bar	Elongation (millimeters)	Normal effort (kN)	Bending moment in the column (kN.m)
Mezzanine height 250mm	Beam above the column	0.7242	4.19	-0.01
	Floor beam below the column	0.7194	-4.32	1.03
Mezzanine height 500mm	Beam above the column	0.7214	1.47	-0.04
	Floor beam below the column	0.7198	-1.64	0.69
Mezzanine height 1000mm	Beam above the column	0.7204	0.44	-0.05
	Floor beam below the column	0.7200	-0.62	0.39
Mezzanine height	Beam above the column	0.7198	-0.28	0.01

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1000mm (with locking mechanism)	Column tie beam	0.7220	2.06	-0.16
	Floor beam below the column	0.7196	-1.95	0.74

Table 1 summarizes the results obtained for the different simulated models, allowing to observe how thermal variation affects internal stresses even in structures of small dimensions. reduced. Note that, although all elements are composed of materials with the same coefficient of thermal expansion, the effects of the restriction imposed by the boundary conditions - Especially fixed connections – generate deformation incompatibilities between the beams. upper and lower columns. This incompatibility is more pronounced in models with higher columns. short, which indicates the rigidity of the assembly formed by the floor beam, columns, and top beam. (behaving like a rigid framework) directly influences the redistribution of efforts. thermal. In the model with intermediate locking, it is observed that part of the expansion is absorbed. through the tie beam, altering the internal equilibrium of the system. These results demonstrate that, Even when materials have similar thermal properties, the structural configuration and The relationships adopted can generate significant internal tensions, which reinforces the need for Consider the effects of heat when designing structures.

4. Results and Discussion

Analysis of the results presented in Table 1 allows us to assess the effects of the variation. Thermal stress in metal structures with different geometric configurations and stiffness. Even in In small-scale structures, the application of a uniform thermal variation was able to induce Significant internal efforts, especially in systems with rigid constraints. The comparison Among the models, it is evident that the height of the structure and the presence of intermediate bracing are important factors. They directly influence the distribution of normal stresses and thermal elongations. confirming the hypothesis that restricting expansion can generate significant internal stresses.

In models without intermediate locking, it was observed that the reduction in height of the The mezzanine intensifies the compressive forces in the floor beams and the bending moments at the base of the... columns. For example, in the model with a height of 250 mm, the upper beam exhibited an axial force of 4.19 kN, while the floor beam reached -4.32 kN, with a bending moment of 1.03 kN·m at the base of the column. In addition, the elongation of the upper beam was 0.7242 mm (0.0042 mm above the value The theoretical value would be 0.7200 mm if calculated according to Eq. 1), indicating that the imposed restriction... Shorter columns intensify the redistribution of deformations.

In the model with intermediate bracing (model 4), the bracing beam absorbed part due to thermal deformation, exhibiting a tensile force of 2.06 kN, while the upper beam showed slight compression (-0.28 kN) and elongation of 0.7198 mm (0.0002 mm below the theoretical value). The beam of

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The locking mechanism, in turn, lengthened by 0.7220 mm, 0.0020 mm more than expected, showing that part The thermal expansion was redistributed to this intermediate element. This redistribution also This was reflected in the bending moments along the column, with values of 0.74 kN·m at the base and -0.16 kN·m at the base. at the intermediate node and 0.01 kN·m at the top.

According to Pfeil & Pfeil (2017), metal structures with rigid connections and continuity High temperatures are particularly sensitive to temperature variations, since the expansion of the elements is constrained, generating internal stresses even in the absence of external loads. Fakury et al. (2015) reinforce that the consideration of thermal actions is essential in hyperstatic structures, a since omitting these effects could compromise the service limit states and the integrity of the connections.

Furthermore, the results obtained show that, when installing a new structure on top of a existing platform - even though both are made of steel and share thermal properties Similarly, the overall system configuration changes, modifying the stiffness matrix and, Consequently, internal efforts. This reinforces the need to evaluate the structure as a considering the interactions between the subsystems and the indirect effects of temperature variation.

Final Considerations

The results obtained in this study demonstrate that thermal variation can induce stress. significant internal factors, even in small metal structures, when subjected to rigid links and high continuity. Numerical analysis showed that the overall rigidity of The structure, influenced by the height of the columns and the presence of intermediate bracing, affects directly affects the compatibility of deformations and the redistribution of thermal stresses.

Although the materials used share similar thermal properties, such as The coefficient of expansion, the structural configuration, and the boundary conditions impose restrictions that... result in significant internal tensions. These findings reinforce the importance of considering Thermal actions in the design of metal structures, as guided by ABNT standards. NBR 8800:2024, EN 1991-1-5:2003 and ANSI/AISC 360-22.

As highlighted by Pfeil & Pfeil (2017), “thermal expansion, when prevented, generates "Efforts that should be considered in the design, even in small structures." This statement, aligned with regulatory guidelines, supports the need for a careful approach in assessment of thermal effects, avoiding both the omission of relevant actions and the oversizing.

Therefore, it can be concluded that the consideration of thermal variation should be incorporated into the analysis. structural issues arise whenever there are significant restrictions on the free deformation of the elements. Regardless of the scale of the structure. The adoption of normative criteria and the use of tools.

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Proper design is essential to ensure safety, durability, and efficiency.

of structural solutions.

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