EFFECTOFFIREPARAMETERSON STRUCTURAL BEHAVIOUR OF A RESTRAINED STEEL BEAM

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Research Article

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ABSTRACT
When it comes to public and structural safety, fires are becoming a frequent hazard. Understanding the structural reaction of various elements exposed to fire resulted from the growing concern for structural fire safety. This starts with fire modeling, which simulates a fire scenario as fire curves of time temperature fluctuation and subsequently analyzes the reaction of structure for these fire curves. The opening factor, which measures the openings in a compartment; the thermal inertia of the compartment surroundings; and the fireload density, or the quantity of combustible materials available per unit floor area of a compartment, are some of the factors that are used to formulate the interpretation of fire scenarios as fire curves. Any change in these variables has an impact on the fire curve and, therefore, a structure's reaction. This work examines the impact of opening variation. The impact of thermal inertia, fuel load density, and factor on a beam's structural reaction. The variance in axial forces and deflections is its primary emphasis. Even though the percentage variation in its value is much higher (269.94%), the residual forces and deflections only varied by 0.4% and 2.13%, respectively, indicating that thermal inertia has the least effect on the beam's structural response. This is because the same is found to be higher for a comparatively lesser variation in the magnitudes of other factors.

1. OVERVIEW A universal hazard is fire. It occurs significantly more often and is more commonly a local phenomena. Therefore, fire has no geographic boundaries, while other risks are more likely to strike certain locations that are vulnerable to these occurrences. It is a global menace to the built environment. Fires have the capacity to do harm. It may harm the infrastructure, endangering the structures' structural stability. Understanding the temperatures of the gases in the environment to which a building is exposed becomes crucial for analyzing the structure exposed to fire. This is referred to as fire modeling. Afirescenario is modeled as fire curves that show the evolution of gas temperatures over time, with temperature on the vertical axis and duration on the horizontal axis. In a compartment, fire growth begins as local burning and, with sufficient fuel and air, progressively develops into a fully fledged fire. This transition, known as a flashover, is seamless. The pace of burning lowers when fuel or oxygen is used up, signifying a cooling phase or decay. Thus, fire in a compartment depends on the opening factor, fire load density, and boundary thermal inertia. These factors affect the compartment fire's maximum temperature, rate of development, and duration. Radiant heat energy is released by burning materials during the first ignition. The nearby flammable substance warms up and ignites. The temperature of the compartment rises as a result of the constant burning of this extra fuel and the significant thermal energy released. The kind and quantity of flammable material in a compartment affects the temperature and the rate at

which the fire spreads. Fuel combustion also produces more hot gasses, which are gathered close to the compartment's roof. Hot air seeks to push down the cold air below and escape through the apertures as a result of the pressure created. However, since there isn't much cold air underneath the hot gasses, cool air from the outside enters the compartment, making it impossible for hot air to leave. Enough oxygen is present in the air flowing inward to support more burning. This illustrates how the opening factor affects compartment fire. The complicated process of fire development also relies on how the fire interacts with compartment borders. The material's susceptibility to temperature changes is known as the compartment boundary's thermal inertia. It indicates the rate at which the body temperature rises to the gas temperature. The density, specific heat capacity, and thermal conductivity of the material a compartment border is composed of determine this. This characteristic affects how a compartment fire spreads. Consequently, changes in any of these factors would affect the compartment's fire development, which in turn affects the structural behavior. The opening factor relies on the geometry of the compartment, and the thermal inertia depends on the boundary enclosure's characteristics, which are readily calculated for a particular compartment. However, because of the uncertainty in predicting its value, determining the fire load density is a difficult process. The fire load density may not accurately reflect the actual fire situation since it is mostly dependent on the kind of occupancy assessed by the regulations and standards. Because the 80% fractile number suggested by the rules and standards is deterministic, it would be the same for all occupancy types even if the size and quantity of fuel accessible would vary significantly between inside an occupancy type's compartments.

[1] illustrates this difference in the fire load densities. The author devised a probabilistic technique for analyzing the fire load densities after summarizing several office building fire load assessments that showed a significant variance in the fire load densities based on the region and usage. Numerous more developments have been made in the direction of performance-based studies to estimate fire load densities [2], their impact on fire temperatures, the impact of openings [19,22], and the various boundary materials [16,17,18,21]. Although the bulk of the research in the body of current literature has focused on the impact of these fundamental factors (fuel availability, geometry, apertures, and thermal inertia) on the spread of a fire inside a compartment, little is known about the comparable impact on the structural behavior. Therefore, with one of these factors changing every time and a primary emphasis on deflection and axial forces, the present research evaluates the impact of opening factor, fire load density, and thermal inertia on the structural behavior of a beam element subjected to fire.

2. PROBLEMDEFINITION

2. ABAQUS, a well-known finite element program, is employed for analysis in order to meet the goals of this research. A steel beam with a cross-section of W21x50 and a length of 9.14 m with partial fixity (75 percent rotational constraint) is taken into consideration for the study; these measurements are obtained from [15]. Both live and dead load components of a uniformly distributed load of 11.844 kN/m were applied to the beam.

3. 3. The Fire Model Getting the design fire is the first step in analyzing buildings that are being threatened. The parametric time-temperature relations outlined in Eurocode1[3] are used to compute the fire temperatures. Any combination of fire load, opening factor, and boundary materials results in a time-temperature relationship according to this equation. Three distinct scenarios are taken into consideration in order to examine the impact of these three factors. a) Three values—0.04 m1/2 for Design Fire 1, 0.06 m1/2 for Design Fire 2, and 0.08 m1/2 for Design Fire 3—are taken into consideration in order to examine the influence of opening factor. For all three scenarios, the fuel load density of 420 MJ/m2 and the thermal

inertia of 840 J/m2s1/2K remain unchanged. [Figure 1] shows the fire curves that were so produced.

b) To examine the impact of fire load density, values of 609 MJ/m2, 546 MJ/m2, 483 MJ/m2, 420 MJ/m2, 357 MJ/m2, 294 MJ/m2, and 231 MJ/m2 are used. The multiples of these values varied by 15% above and below the fire load (420 MJ/m2) taken into consideration in the prior scenario. Throughout, the opening factor and thermal inertia of 0.04 m1/2 and 840 J/m2s1/2K, respectively, are used and kept constant. [Figure1] displays the related fire modeling findings. b) The thermal inertia of 432.5, 720, 840, and 1600 J/m2s1/2 K Kare utilized the technique to examine the impact of thermal inertia while taking into account various walllinings. Throughout, the fuel load density of 420 MJ/m2 and the opening factor of 0.04 m1/2 remain constant. [Figure 3] displays the same findings. All of these fire parameter values come from various pieces of current research [14, 15, 20].

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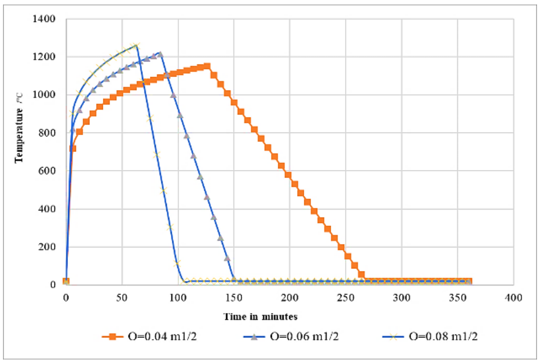

Figure1 Gastemperaturewithtimefordifferentopening factors

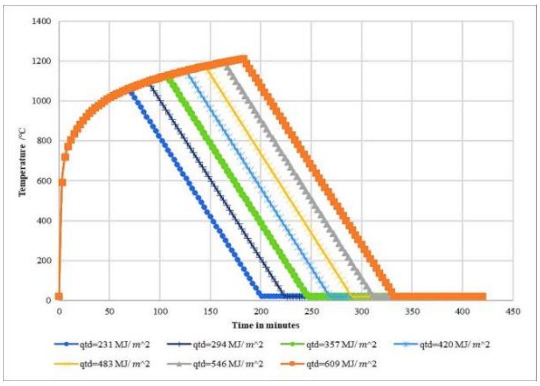

Figure2 Gastemperaturewithtimefordifferentfireload densities

1. THERMALANALYSIS

When exposed to these temperatures, the beam temperatures likewise increase, varying with depth and duration. Heat transfer analysis is done in the beam's cross section to determine how nodal temperatures vary over time. The beams are equipped with fire protection material of the spray-applied fire resistance material (SFRM) type. The SFRM characteristics are derived from [14]. The study uses SFRM, which has a density of 300 kg/m3, a specific heat capacity of 1,200 J/(kgK), and a conductivity of 0.12 W/(mK). These characteristics would significantly impact the nodal temperatures. By taking into account the limiting deformation as a failure criterion, it is intended to have a thickness of 10 mm in order to attain a fire resistance rating of 2 h. The BS476 standard's deformation criteria [10] are applied. According to this specification, the failure is thought to happen when the member's maximum displacement surpasses L/20 (mm). A thinner thickness may have been employed to meet the necessary fire resistance rating based on this failure criteria.

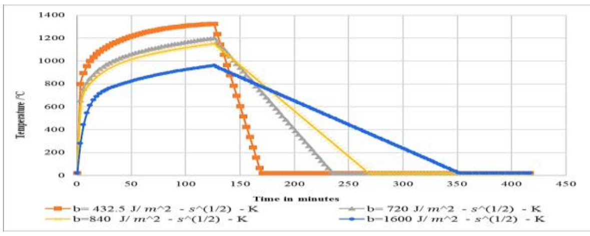

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Figure3 Gastemperaturewithtimeforboundariesofdifferentthermal inertia

However, a minimum thickness of 3/8 inch is necessary in accordance with AISC [5] guidelines. Using surface film parameters and radiative interaction conditions in ABAQUS, the fire temperatures acquired from the fire modeling are applied to the beam's fire-exposed surfaces. These temperatures are then provided as an input in thermal analysis. Under normal fire exposure, the convection heat transfer coefficient "h" is 25 W/m2K, while under natural fire exposure, it is 35 W/m2K. Throughout the study, the unexposed surfaces in the beam are exposed to ambient temperatures. Three-sided exposure is considered in the present research [Figure 4]. The 4-noded quadrilateral DC2D4 element is used to discretize the cross-section of the fire-exposed surface, including the fire insulation. To guarantee that the nodal temperatures in the steel section and the insulation are equal at the interface, a tie constraint is applied at the steel-insulation interface. It is anticipated that the insulation will remain intact for the length of the fire exposure. The Stefan-Boltzmann constant was 5.67×10-8W/m2K4, and the thermal characteristics of the metal (specific heat [J/(kgK)] and thermal conductivity [W/(mK)]) are thought to be temperature dependant [Figure 5] and [Figure 6]. In order for the output temperature to be utilized as input data for the structural analysis, it must be stored at five temperature points (for the I-section). [Figure 7] displays the nodal temperature change over the depth at these 5 sites with opening factor = 0.04 m1/2, fire load density = 420 MJ/m2, and thermal inertia = 840 J/m2s1/2K.

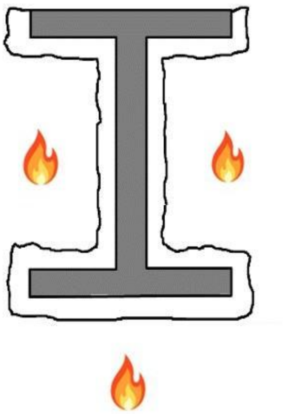


Figure4 Crosssectionofprotectedsteelbeamexposedtofire

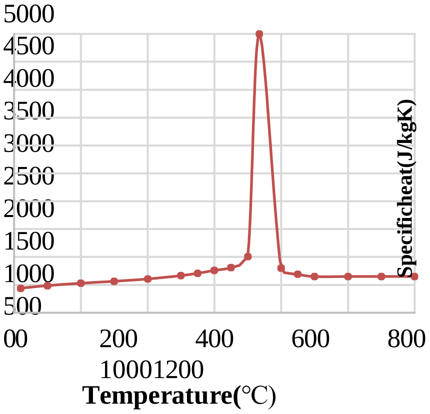


Figure6 VariationofSpecificHeatofsteelwithtemperature

Other combinations also followthesametrend but, to showthe comparison between them the temperature variations at TP1 (being the highest) are plotted [Figure 8,Figure 9,Figure 10].

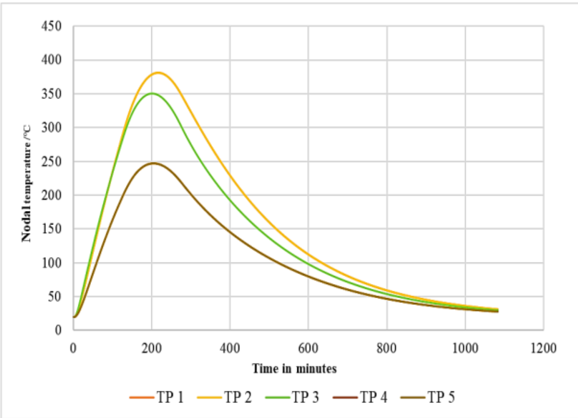


Figure7 Nodaltemperatureswithtimeforaprotectedsteelbeamatvarioustemperaturepoints

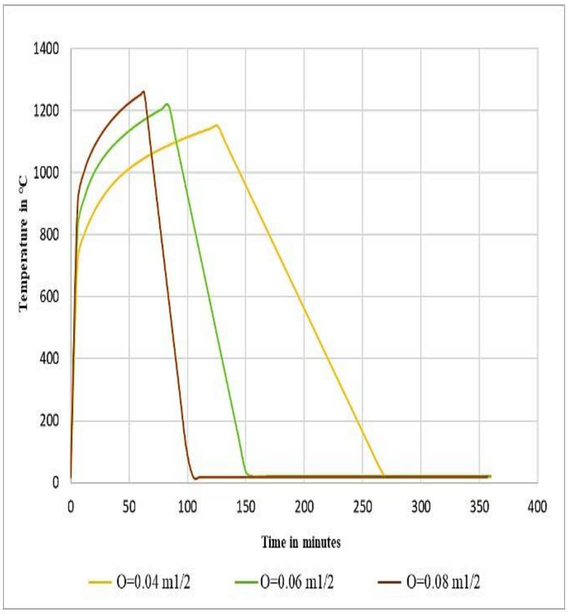


Figure8 NodaltemperatureswithtimefordifferentopeningfactorsatTP1

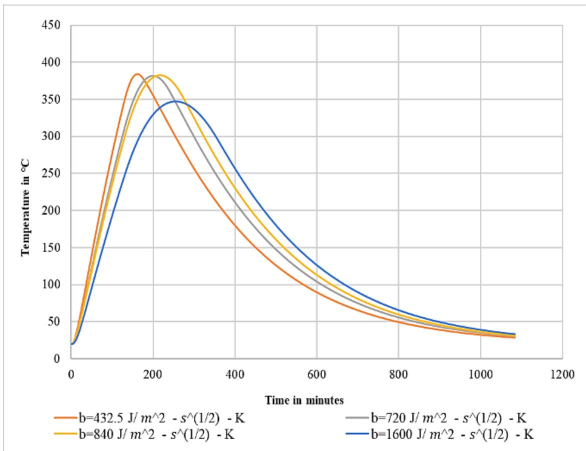


Figure9 Nodaltemperatureswithtimefordifferentthermalinertiaat TP1

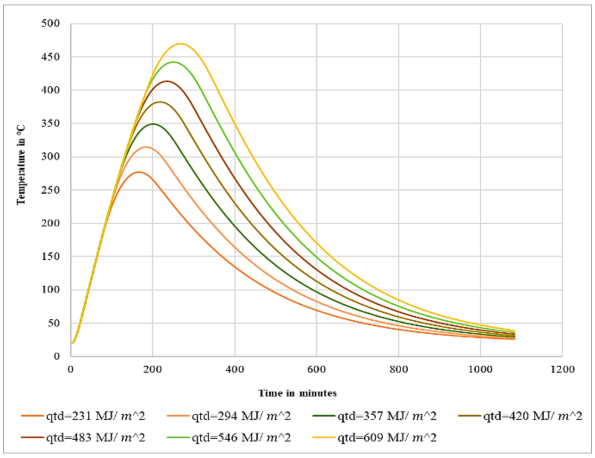


Figure10 Nodaltemperaturewithtimefordifferentfireloaddensitiesat TP1

2. STRUCTURAL EXAMINATION

The nodal temperatures in the beam, the mechanical characteristics of the steel beam, and the amount of the applied load—which includes both dead and liveload components—all affect the structural model. The steel's initial elastic parameters under ambient conditions are as follows: density 7850 kg/m3, expansion coefficient 1.2×10-5 /0C, and Poisson's ratio 0.3. Furthermore, the yield strength and Young's modulus are assumed to be temperature dependent, and their reduction factors comply with Standard EN 1993-1-2:2004. After that, 1D beams are subjected to onlinear structural analysis in order to simulate their performance under fire circumstances. The online geometric parameter (NLGEOM=ON) was created in order to cope with the geometric onlinearity, specifically with the high displacements.

For the three scenarios described above, with varying fire affecting parameter values, the mid span deflection and the axial force at the ends of the beam are determined.

3. OUTCOMES

Openingfactor The findings of fire modeling [Figure 1] show that the gas temperatures rise more quickly for greater opening factors, suggesting quicker burning rates because of the increased oxygen supply, which speeds up combustion and cooling. However, when insulating material is present, this pattern is inverted in the case of the beam's nodal temperatures. [Figure 8] shows that at larger opening factor values, the fire has already subsided and gas temperatures have returned to ambient levels by the time the temperatures reach their peak. Therefore, the compartment with the lowest opening factor is shown to have the highest nodal temperatures. Deflection of Effects [Figure 11] demonstrates that all of the curves first line up during the heating phase and then separate after the maximum deflection is reached. The maximum deflection rose by 80% (from 0.05912 m to 0.10649 m) and the permanent deflections increased by 37.84% (from 0.0444 m to 0.0612 m) when the opening factor was changed from 0.08 m1/2 to 0.04 m1/2.

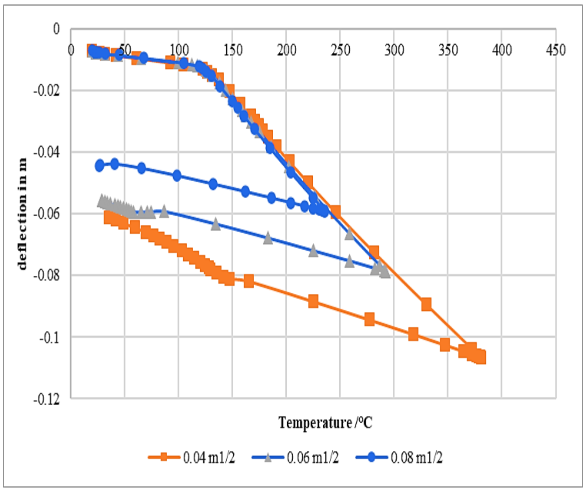


Figure 11: Temperature-dependent variations in deflections for various opening factors and their impact on axial forceThere is no discernible change in the axial force fluctuation with temperature during the heating phase for varying values of opening factors. The axial force decreased by 6.11% (from 1933.92 kN to 1815.58 kN) and the residual forces rose by 8.58% (from 2130.282 kN to 2313.136 kN) as a result of the opening factor modification from 0.08 m1/2 to 0.04 m1/2 [Figure 12].

Fireload Density In a fire model, the maximum temperature and duration obtained are greatly influenced by the fireload density. clearly demonstrates how a reduction in fire load density results in a drop in maximum temperature and duration.

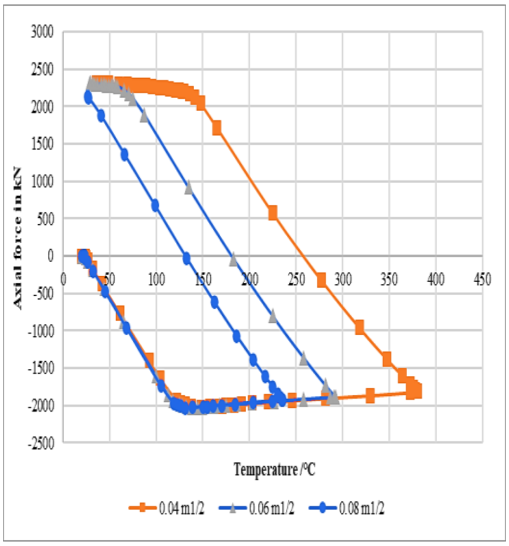
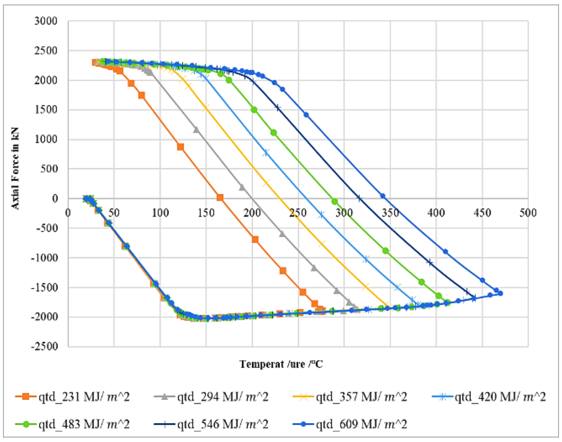


Figure12 Variationofaxialforceswithtemperaturefordifferentopeningfactors



Following heat transfer analysis, the same pattern is also seen in the odal temperatures. The maximum temperature and duration obtained decrease as the fire load density decreases, as seen in [Figure 10]. Deflection of Effects Throughout the heating phase, the deflections for all the values of the load densities follow a similar pattern, and they diverge after they reach the corresponding maximum deflection. [Fig. 14] Maximum deflection fell by 45.68% with a reduction in fire load density from 609 MJ/m2 to 231 MJ/m2, as a result of lower nodal temperatures, while permanent deflections decreased by 20.08% (from 0.0682 m to 0.0545 m). The impact of axial force There is no discernible change in the heating phase's axial force fluctuation with temperature for varying fire load densities. Maximum axial force rose by 0.36 percent (from 2025.0.5 kN to 2027.9 kN) and residual force dropped by 0.82% (from 2316.38 kN to 2297.6 kN) as a result of the shift in fire load densities from 609 MJ/m2 to 231 MJ/m2. [Fig. 13]. Thermoinertia

A barrier between two compartments with lesser thermal inertia rapidly catches fire and achieves its maximum temperature. The maximum temperatures derived from the fire modeling decreased when comparing the materials with the lowest thermal inertia (432.5J/m2s1/2K) and the greatest thermal inertia (1600432.5J/m2s1/2K) [Figure 3].

Figure13 Variationofaxialforceswithtemperaturefordifferentfireloaddensities

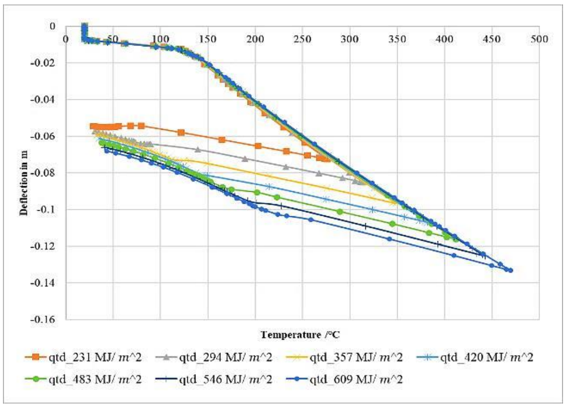


Figure14 Variationofdeflectionswithtemperaturefordifferentfireloaddensities

A similar trend is observed for the nodal temperatures but, maximum nodal temperatures got reduced due to the presence of SFRM. [Figure 9] depicts that nodal temperatures are higher for the material with least thermal inertia.

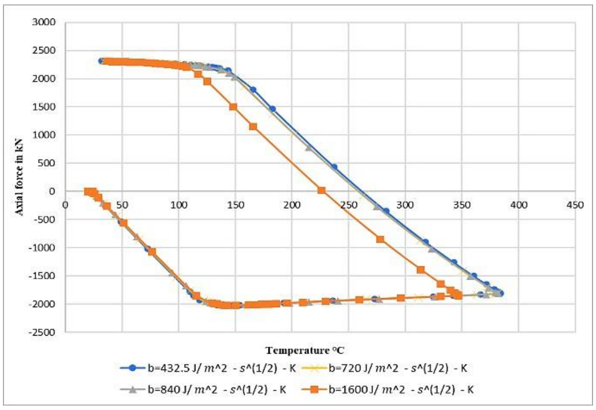


Figure15 Variationofaxialforcewithtemperaturefordifferentthermalinertia

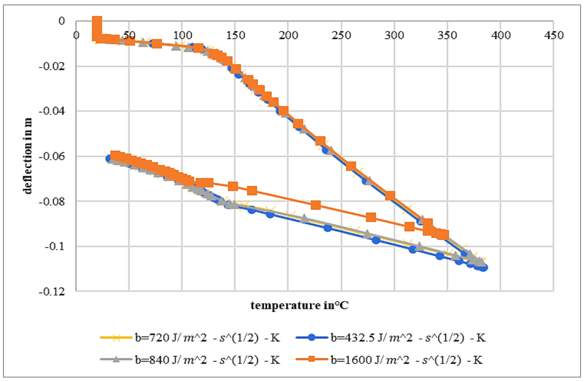


Figure16variationofdeflectionwithtemperaturefordifferentthermalinertia

• EffectonDeflection [Figure 16] illustrates how deflections for varying thermal inertia values do not initially differ significantly during the heating phase, but they do diverge after maximum deflection is reached. There is a 13.17% drop in the maximum deflection (from 0.1093m to 0.0949m) and a 2.13% decrease in the permanent deflection (from 0.061m to 0.0597m) when the materials with the lowest (432.5J/m2s1/2K) and highest (1600J/m2s1/2K) thermalinertia are compared.

The impact on axial forceThere is no discernible change in the axial force fluctuation with temperature during the heating phase for varied levels of hermalinertia. When the lowest (432.5J/m2s1/2K) and highest (16007J/m2s1/2K) thermal inertia materials are compared, a 0.4% drop in residual force (from 2317.17 kN to 2307.24 kN) and a 0.2% decrease in maximum axial force (from 2027.9kN to 2023.7kN) are seen [Figure 15]. 3. FINAL RESULTS By creating a nonlinear finite element model that provides insulation and drastically lowers the nodal temperatures, a numerical modeling research is carried out to comprehend the reaction of a steel beam under natural fire exposure with changing fire influencing factors. The percentage change in the structural reaction for the equivalent percentage variation in the fire parameters was shown in the study's findings. Variations in the fire parameters were shown to have little effect on the structural reaction during the heating phase, but they do affect how long they last and to show variations in the cooling phase and maximum values. It is noted that the beam suffers two tensile stresses and permanent deflections that were not there before, even if the temperatures at the conclusion of the scenario had reverted to ambient. When designing steel beams for fire resistance, these factors are crucial. Consequently, it is necessary to compare the magnitude of these forces and deflections to the allowable values for the fire resistant design. Comparing the findings, it can be seen that the change in residual forces and permanent deflections for a 100% increase in the opening factor is 8.58% and 37.24%, respectively. In contrast, the same is determined to be 0.4% and 2.13% for an increase in thermal inertia of 269.94% and 0.82% and 20.08% for an increase in fire load density of 163.637%.

Consequently, even though the percentage change in its value was much more than that of the other two parameters, it can be said that of the three, thermal inertia had the least impact on the structural reaction of the beam in question.

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