# Robust fire resistance analysis of concrete for aviation structure safety using EUROCODE and ANSYS

Nguyen Phi Long[1,*], Le Trung Phong[2], Nguyen Trung Hieu[3], and Luu Hoang Phong[2]

[1] Department of Construction, Vietnam Aviation Academy;
[2] Department of Civil Engineering, Thuyloi University;
[3] Institute of Construction, Ho Chi Minh City University of Transport;
*Corresponding author: longnp@vaa.edu.vn

■ Received: 29/05/2025 ■ Revised: 02/08/2025 ■ Accepted: 25/08/2025

**ABSTRACT**

*In the context of contemporary urban development, fire safety in public structures, particularly high-occupancy buildings, remains a paramount concern. The fire resistance of reinforced concrete (RC) frame structures, the primary load-bearing components, plays a pivotal role in ensuring life safety and mitigating property damage in the event of a fire. This research focuses on the application of advanced numerical simulation techniques, specifically utilizing ANSYS APDL software, to evaluate the fire resistance of RC frame structures in airport terminals conforming to EUROCODE standards. A detailed numerical model is constructed based on geometrical parameters, material properties, and realistic fire scenarios, enabling a thorough analysis of temperature distribution, stress, and deformation behavior of the structures under elevated temperatures. The findings not only validate the efficacy of ANSYS APDL in fire resistance assessment but also provide critical insights into the structural behavior of RC under fire conditions. Consequently, the research proposes optimized design solutions and engineering measures to enhance fire resistance, thereby ensuring the safety and operational continuity of airport terminals.*

**Keywords:** *Reinforced concrete structures, Fire resistance, Fire safety, Airport structures*

## 1. INTRODUCTION

Fire safety remains a top priority in the design and operation of airport terminal buildings, which accommodate high occupant densities and contain numerous combustible materials. Globally, several severe fire incidents at airport terminals have been documented, resulting in significant loss of life and property, notably the 1996 Düsseldorf Airport fire, the 1999 Rome Fiumicino Airport fire, and the 2016 Dubai International Airport fire. These events not only disrupted aviation operations and caused substantial economic losses but also endangered the lives and health of passengers and airport personnel. In Vietnam, although no major terminal fires have been recorded to date, the risk of fire and explosion persists. Particularly, with the rapid expansion of the aviation sector, terminals are increasingly constructed on larger and more complex scales, thereby introducing heightened fire hazards.

In airport terminal structures, the predominant load-bearing systems are reinforced concrete (RC) and steel structures, with RC offering advantages such as low cost, ease of construction, and excellent load-bearing capacity; however, under elevated temperatures, its load-carrying capacity significantly deteriorates, posing a risk of structural collapse. Reinforced concrete (RC) is the dominant material in the construction industry, widely applied in civil engineering projects and transportation infrastructure due to its cost-effectiveness, superior structural performance, and construction practicality; nevertheless, fire events represent a latent threat causing severe damage by directly impairing the mechanical and physical properties of RC, resulting in reduced load-bearing capacity and compromise of structural safety [1]. Therefore, researching, assessing, and predicting the fire resistance of RC structures is of utmost importance to ensure fire safety compliance and enhance the structural resilience of critical infrastructure such as airport terminals, metro stations, high-rise buildings, and civil structures [2].

Although international standards such as Eurocode 2, 3, and 4 [3] provide detailed guidance on fire-resistant design, current Vietnamese standards, including TCVN 5574:2018 [4], still exhibit significant limitations. This study focuses on evaluating the fire resistance of common reinforced concrete (RC) structural elements-such as beams, columns, shear walls, etc.-using the finite element method (FEM), with objectives to determine temperature field distribution, analyze variation in mechanical properties of constituent materials, develop interaction diagrams, and predict fire endurance of structural components, thereby providing design recommendations for fire resistant RC structures. Within the scope of this study, the analysis is limited to structural elements subjected to single-face heating, neglecting the influence of complex chemical reactions during combustion, and is conducted based on the ISO 834 standard fire curve [5].

Experimental investigations into the fire resistance of reinforced concrete (RC) structures are both costly and complex; consequently, the use of simulation software such as ANSYS APDL for assessing fire performance represents an efficient and cost effective alternative. This study focuses on employing ANSYS APDL to simulate the effects of fire exposure on reinforced concrete structures, combined with Eurocode provisions for calculating the residual load bearing capacity of fire damaged elements, with particular emphasis placed on flexural RC members, which constitute critical structural components in airport terminals. Through a detailed numerical model, the research analyzes the impact of elevated temperatures on the mechanical and physical properties of concrete and reinforcing steel, thereby evaluating the load bearing capacity and structural stability of the frame system. The findings will provide a scientific basis for the design and construction of safe and efficient structures, meeting the increasingly stringent requirements for fire resistance performance.

## 2. THEORETICAL BACKGROUND

### *2.1. Behavior of Reinforced Concrete (RC) Under Elevated Temperatures.*

Under elevated temperatures, reinforced concrete (RC) structures experience substantial degradation in mechanical and physical properties due to complex physicochemical reactions within the concrete matrix and reinforcing steel [1]. The compressive strength of concrete decreases progressively with rising temperature (Figure 1). This reduction becomes pronounced above 200°C and may exceed 50% at temperatures beyond 600°C, primarily attributed to moisture loss, disruption of the cementitious bond structure, and consequent loss of load-bearing capacity. Concurrently, the elastic modulus of concrete diminishes, increasing susceptibility to deformation under applied loads. Although concrete exhibits thermal expansion with temperature rise, this is typically restrained by the reinforcing steel, inducing internal compressive stresses in the concrete and potentially triggering cracking and surface spalling [6]. Spalling not only reduces the load-carrying cross-section but also exposes the reinforcement to direct thermal attack. Reinforcing steel, while more thermally stable than concrete, undergoes significant property degradation at elevated temperatures (Figure 2). Both tensile strength and elastic modulus decrease markedly above 500°C, driven by microstructural phase transformations in the steel. Differential thermal expansion between concrete and steel further compromises the bond integrity at the interface. This loss of composite action impairs the overall structural resistance of the RC member [3].

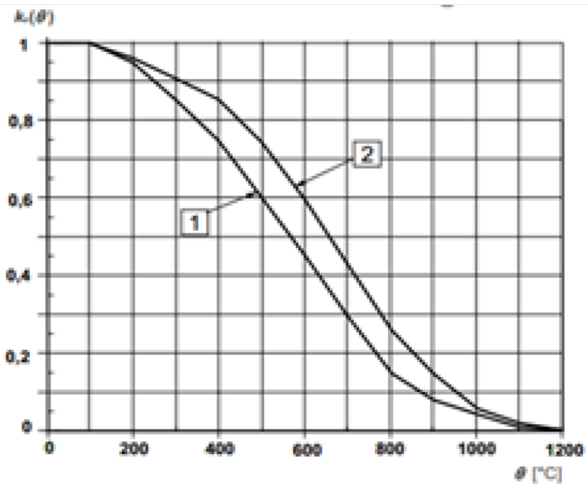


***Figure*** 1. Reduction factors for concrete strength at elevated temperatures[3]:

***Curve 1***: Normal-weight concrete with siliceous aggregates

***Curve 2***: Normal-weight concrete with calcareous aggregates

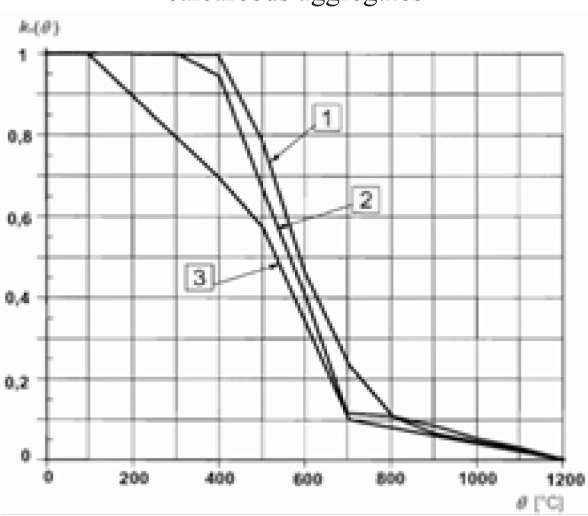


***Figure*** 2. Reduction factors for reinforcing steel strength at elevated temperatures [3]

***Curve 1***: Hot-rolled tension reinforcement for fire-induced straing $\varepsilon s,fi \geq 2\%$

***Curve 2***: Cold-worked tension reinforcement for fire-induced strain $\varepsilon s,fi \geq 2\%$

***Curve 3***: Compression reinforcement and tension reinforcement for fire-induced strain $\varepsilon s,fi < 2\%$

*2.2. Eurocode Provisions for Fire-Resistant Structural Design.*

Eurocode 2 (EC2) provides not only comprehensive European regulations and detailed guidance for the design of reinforced concrete (RC) structures but also critical provisions for fire resistance. Developed on a robust foundation of scientific research and extensive practical experience, EC2 aims to ensure structural safety and performance efficiency, particularly under fire exposure.

EC2 defines the fire resistance (R) of a structure as the duration (in minutes) during which the member can withstand standard fire exposure without loss of structural stability. This resistance is assessed against three primary criteria: load-bearing capacity (R), integrity (E), and insulation (I). The required REI classification varies depending on building type, occupancy, and fire hazard level. For standardized evaluation, EC2 adopts the ISO 834 standard fire curve, ensuring consistent and comparable assessment of fire performance in design.

EC2 provides two primary methods for evaluating the residual load-bearing capacity of structures under elevated temperatures: the tabular method and the advanced calculation method. The tabular method, valued for its simplicity and efficiency, enables determination of strength reduction factors for concrete and reinforcing steel as functions of temperature via lookup tables in EC2, and is commonly employed in preliminary design. In contrast, the advanced calculation method, though more computationally intensive, requires detailed thermal field analysis within the cross-section and explicit evaluation of stress and strain in both concrete and reinforcement, yielding higher accuracy and typically applied in detailed design.

In the fire design of reinforced concrete (RC) beams per EC2, careful consideration must be given to the stress–strain relationships of constituent materials. Engineers may adopt simplified stress–strain models for concrete and reinforcing steel, or employ a rectangular stress block assumption to streamline calculations. The tensile stress in reinforcement is determined from the limiting tensile strain and the distance from the reinforcement centroid to the neutral axis, while the design strength of steel is obtained by dividing the characteristic yield strength by the material partial safety factor [7]. Strict adherence to these EC2 provisions is essential to ensure structural safety and durability of RC elements, particularly under fire exposure.

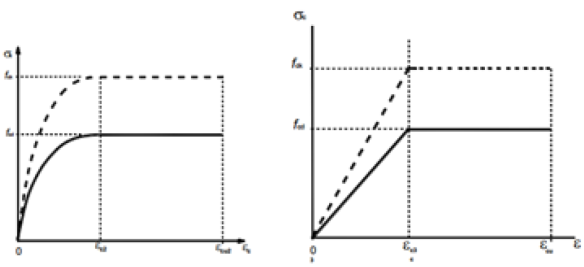

***Figure*** 3. Stress–strain relationships at elevated temperatures using two curves [3]

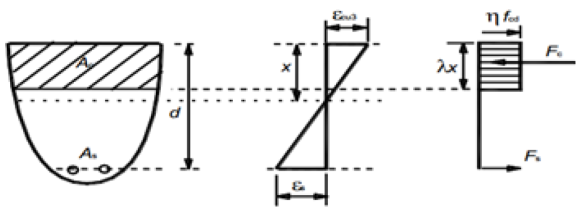

***Figure*** 4. Stress–strain relationships at elevated temperatures using two curves [3]

The tensile force in the reinforcement and the compressive force in the concrete are calculated based on the respective stresses and cross-sectional areas. The neutral axis position is determined using the force equilibrium equation. The bending moment capacity of the beam is computed from either the tensile force in the reinforcement and the corresponding lever arm, or the compressive force in the concrete and its lever arm. The compressive zone depth and reinforcement ratio must be verified to ensure ductile failure.

*2.3. ANSYS Software in Fire Resistance Simulation*

ANSYS is a robust finite element method (FEM) based engineering simulation platform extensively applied in civil engineering for analyzing complex physical phenomena. It enables detailed investigation and prediction of reinforced concrete (RC) structural behavior under elevated temperatures, encompassing heat transfer, structural mechanics, and fluid dynamics, thereby providing a versatile framework for fire resistance simulation and assessment. In fire engineering, ANSYS APDL the parametric design language offers advanced automation and control capabilities, facilitating efficient model generation, load application, and post-processing. The software accurately simulates transient thermal conduction within RC sections under fire exposure, determining temperature fields across the domain while allowing precise specification of thermal loads, boundary conditions, and temperature-dependent material properties. Furthermore, ANSYS incorporates nonlinear material models to capture strength and stiffness degradation in both concrete and reinforcing steel as functions of temperature. It also supports modeling of thermal-induced cracking and concrete spalling due to pore pressure and differential expansion, enabling evaluation of failure initiation and progressive collapse risk. In summary, ANSYS serves as a powerful tool for fire-resistant design, performance-based assessment, and safety verification of RC structures in critical infrastructure.

## 3. STRUCTURAL MODEL

*3.1. Construction of the Structural Model in ANSYS APDL*

Element Selection in ANSYS constitutes a critical initial step in structural model development, as it directly influences computational accuracy, solution time, and the ability to capture complex physical phenomena. For reinforced concrete (RC) beams and columns, BEAM elements are typically employed when the member length significantly exceeds the cross-sectional dimensions, whereas SOLID elements are preferred for stocky members or when detailed sectional analysis is required. This selection must be carefully evaluated based on geometric characteristics and analysis objectives [8].

Following element selection, accurate definition of material properties for concrete and reinforcing steel in ANSYS is essential to ensure simulation reliability. Key parameters include elastic modulus, Poisson's ratio, compressive strength (for concrete) or yield strength (for steel), thermal expansion coefficient, density, thermal conductivity, and specific heat capacity. These properties should be sourced from relevant material standards or determined through specialized testing to accurately reflect real-world behavior [9].

Boundary conditions play a pivotal role in achieving realistic structural response during simulation. These conditions define displacement and rotation constraints at critical locations, such as supports, fixed connections, or pinned joints. Accurate selection of boundary condition types including simple supports, fixed supports, pinned connections, and rigid connections ensures that the numerical model faithfully replicates the actual in-service behavior of the structure.

Thermal loading, applied to the model to simulate fire exposure, must be defined scientifically and accurately. This loading may follow the ISO 834 standard fire curve, which describes temperature–time evolution during a standard fire, or comply with EC2 provisions that specify fire load determination based on fire characteristics and building type [10,11].

*3.2. Analysis of Simulation Results*

Upon completion of the ANSYS simulation, extensive output data are generated, encompassing temperature fields, stress distributions, deformations, and additional parameters characterizing the response of reinforced concrete (RC) structures under elevated temperatures. Thorough analysis of these results is essential for comprehensive fire resistance evaluation. Simulation outputs enable visualization of temperature contours within the structure at discrete time intervals, facilitating identification of critical temperatures at key locations, such as concrete cover and reinforcement layers. This information is fundamental to fire performance assessment, as temperature directly governs strength and stiffness degradation in both concrete and reinforcing steel. By integrating the computed thermal fields with reduction factor tables provided in EC2, temperature-dependent strength and elastic modulus reductions are determined for concrete and steel at specific sectional positions, enabling precise quantification of residual load-bearing capacity. Furthermore, ANSYS results provide stress and strain contours under combined thermal and mechanical loading. Detailed examination of high stress/strain zones typically tension zones in concrete and compression zones in reinforcement is critical for identifying potential failure modes and onset of collapse. Through integrated analysis of temperature, stress, and deformation fields, engineers can deliver a holistic fire resistance assessment, thereby informing targeted design enhancements to ensure structural safety under fire exposure.

*3.3. Load-Bearing Capacity Calculation per Eurocode*

Eurocode2(EC2)providesacomprehensive theoretical framework for assessing the load-bearing capacity of reinforced concrete (RC) structures, encompassing calculation methods for various limit states, including strength, deformation, and deflection. In the context of fire-exposed structural analysis, these methods when integrated with temperature-dependent reduction factors for strength and elastic modulus derived from ANSYS simulations enable engineers to accurately evaluate the residual load-bearing capacity of fire-affected members.

A critical aspect in fire-resistant structural design is the concrete cover to reinforcement [12]. This cover serves as a thermal barrier, shielding the reinforcing steel from elevated temperatures and preserving structural load-bearing capacity. The cover thickness is determined based on the required fire resistance rating (R), concrete type, and reinforcement diameter, in accordance with EC2 formulas and tabulated data. Proper design of the concrete cover is essential to ensure structural safety under fire exposure, prevent rapid strength loss in reinforcement, and maintain stability for the duration necessary for evacuation and firefighting.

*3.4. Integration of ANSYS Results with Eurocode Provision*

ANSYS simulation results provide critical input data for EC2-based calculations, including temperature fields and material property degradation (i.e., reduction factors for strength and elastic modulus of concrete and reinforcing steel). These data enable the determination of the load-bearing capacity at various time intervals, which is compared against applied loads to assess the fire resistance of the structure. The integration of ANSYS simulations with EC2 calculations facilitates a precise and comprehensive evaluation of fire performance.

## 4. APPLICATION EXAMPLE

*4.1. Structural Parameters*

The modeled beam has a span length of L = 3000 mm, a cross-sectional width of b = 200 mm, and a cross-sectional depth of h = 400 mm. Longitudinal reinforcement consists of 4 bars of diameter d = 16 mm..

*4.2. Material Properties*

This study employs steel and concrete as primary materials, with their mechanical properties summarized in Table 1 and Table 2, respectively. Table 1 presents the properties of reinforcing steel: Young's modulus (E) is $2x10^5$ $N/mm^2$, density (ρ) is 7850 $kg/m^3$ and Poisson's ratio (ν) is 0.3. These parameters reflect the high strength, stiffness, and moderate ductility of steel under loading. Table 2 details the properties of concrete: Young's modulus (E) is $27.5x10^3$ $N/mm^2$, density (ρ) is 2500 $kg/m^3$ and Poisson's ratio (ν) is 0.2. Compared to steel, concrete exhibits a significantly lower elastic modulus, indicating reduced deformation capacity. These properties are implemented in ANSYS APDL to simulate and analyze the thermo-mechanical behavior of reinforced concrete (RC) structures under elevated temperatures.

*4.3. Simulation of Heat Transfer Analysis in ANSYS APDL*

Figure 6 illustrates the simulation workflow for evaluating the fire resistance of a reinforced concrete (RC) beam using ANSYS APDL. The fire performance assessment of the RC beam requires the development and analysis of a numerical model following a structured procedure: First, the RC beam model is constructed using SOLID elements for concrete and LINK elements for reinforcing steel, with mesh density optimized to balance computational accuracy and solution efficiency. A sufficiently refined mesh is essential to accurately capture the thermo-mechanical response under elevated temperatures. Next, material properties-including strength, elastic modulus, and thermal expansion coefficient are defined for both concrete and steel in accordance with design standards or experimental data. While ANSYS provides built-in material libraries, custom temperature-dependent models can be implemented to more accurately represent fire-induced degradation, thereby enhancing analysis reliability. Following model setup, boundary conditions are applied appropriately. In this case, simple supports are imposed at both ends, permitting rotation while restraining transverse displacement. Accurate representation of support conditions is critical to ensure realistic simulation of in-service behavior. Applied loads comprise service load and thermal load. A uniformly distributed load of q = 20 kN/m simulates operational loading, while thermal loading follows the ISO 834 standard fire curve, representing temperature–time evolution in a standard fire. This curve is an internationally recognized benchmark for fire resistance evaluation in structural engineering. Finally, the simulation is executed in ANSYS, with runtime dependent on model complexity and computational resources. Post-processed results-including temperature fields, stress distributions, and deformations at various time steps are extracted and analyzed to assess the fire endurance of the RC beam.

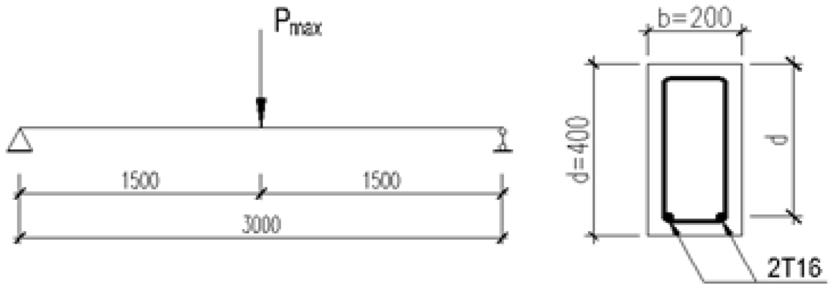


***Figure*** 5. Dimensions of the reinforced concrete beam

Table 1: Properties of reinforcing steel

| Parameter | Symbol | Value |
|---|---|---|
| Young's Modulus (N/mm²) | E | 2x10⁵ |
| Density (kg/m³) | ρ | 7850 |
| Poisson's Ratio | υ | 0.3 |

Table 2: Properties of Concrete

| Parameter | Symbol | Value |
|---|---|---|
| Young's Modulus (N/mm²) | E | 27.5x10³ |
| Density (kg/m³) | ρ | 2500 |
| Poisson's Ratio | υ | 0.2 |

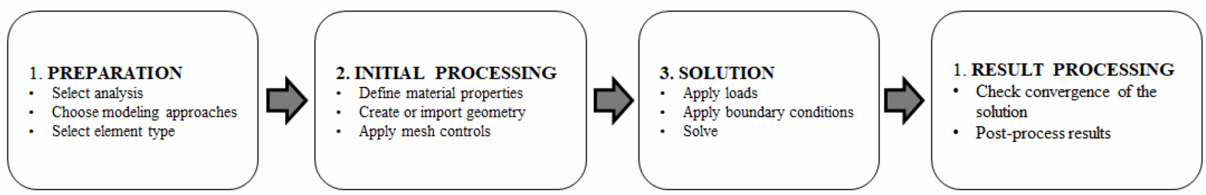


***Figure*** 6. Workflow for simulation in ANSYS APDL

*4.4. Load-Bearing Capacity Calculation per Eurocode*

ANSYS simulation results are pivotal in calculating the fire resistance of the reinforced concrete (RC) beam in accordance with Eurocode 2 (EC2). This process involves determining temperature-dependent strength reduction factors for concrete and reinforcing steel using EC2 tabulated data corresponding to the temperature profiles obtained from the simulation. Accurate evaluation of these reduction factors is critical, as they directly influence the reliability of the residual load-bearing capacity assessment under fire exposure [12]. Subsequently, the bending moment capacity of the beam is computed at various time steps based on the reduced material strengths. Calculations follow EC2-prescribed methods or alternative limit state approaches, explicitly accounting for temperature-induced degradation in strength and elastic modulus. Integration of ANSYS derived thermal data with these analytical procedures enables a more accurate determination of the beam's fire performance. Finally, fire resistance is assessed by comparing the time-dependent moment capacity with the applied bending moment induced by the uniformly distributed load. The beam is deemed safe as long as the residual capacity exceeds the demand moment; conversely, structural failure is imminent when capacity falls below demand. The fire resistance rating (R) defined as the duration during which the beam maintains load-bearing function is thus established as the time interval over which the moment capacity remains greater than the applied moment.

## 5. RESULTS AND DISCUSSION

*5.1. Simulation Results from ANSYS*

ANSYS simulations provide a visual and detailed representation of the thermo-mechanical response of the reinforced concrete (RC) beam under fire exposure, expressed through temperature fields, stress distributions, and deformation patterns. These results are essential for accurate and comprehensive fire resistance evaluation.

Figure 7 presents the 3D finite element model of the simply supported beam developed in ANSYS APDL. This model is employed to simulate and analyze the fire performance of the RC structure under elevated temperatures. In the visualization, the beam is depicted as a prismatic volume with color contours indicating temperature distribution: blue regions denote low temperatures, while red regions signify high temperatures. The resulting thermal field is subsequently used to compute stress and deformation, enabling load-bearing capacity assessment under fire conditions. The use of ANSYS APDL facilitates detailed simulation of transient heat transfer and structural deformation, thereby yielding reliable quantitative insights into the fire endurance of the RC beam.

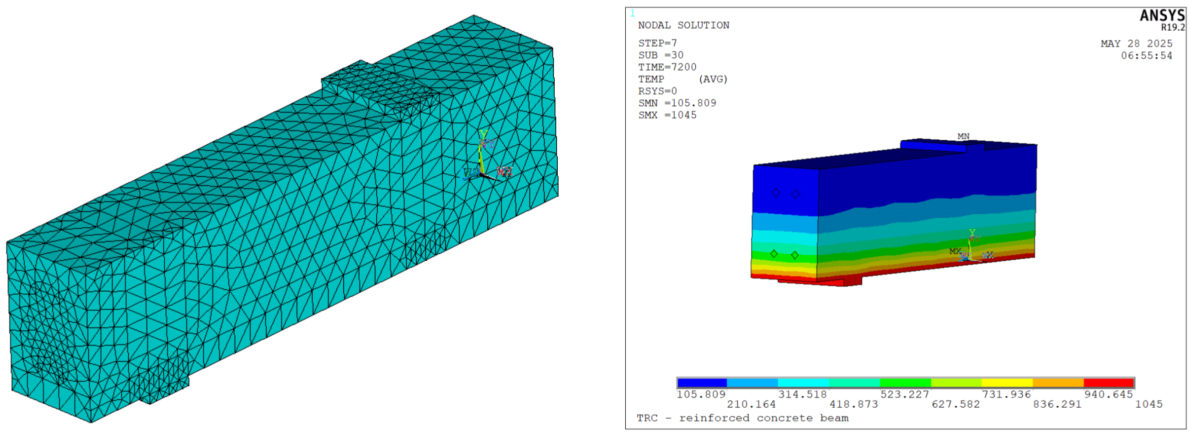


***Figure*** 7. 3D model before and after solution

Figure 8 presents the temperature–time evolution for concrete, reinforcing steel, and the ISO 834 standard fire curve during the fire resistance simulation of the reinforced concrete (RC) beam. The plot reveals a progressive temperature increase in both materials, with steel exhibiting a steeper heating rate than concrete due to its higher thermal conductivity. The ISO 834 curve, representing standard fire exposure, rises continuously; however, concrete and steel temperatures remain below this benchmark throughout the simulation. This discrepancy demonstrates the protective role of the concrete cover in shielding reinforcement from extreme thermal attack. The temperature differential between concrete and steel induces thermal stresses, potentially triggering cracking and spalling in the concrete. Consequently, detailed analysis of this temperature history is critical for robust fire performance evaluation of RC structures.

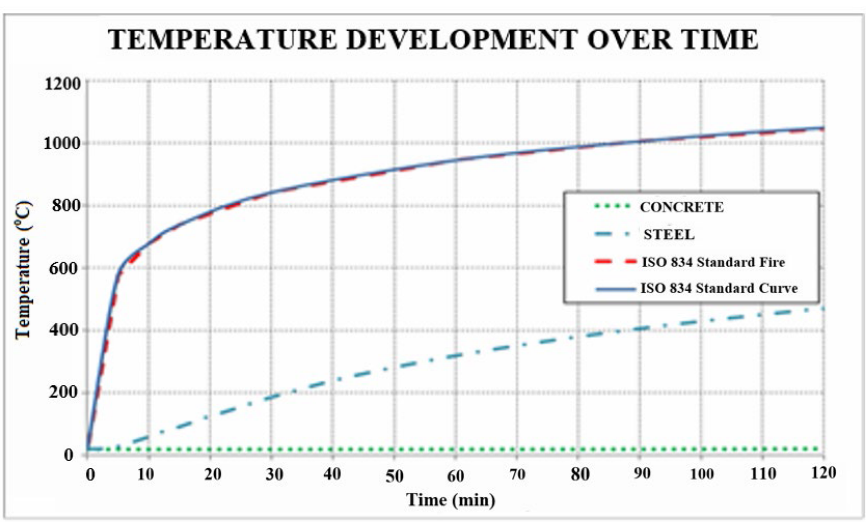


***Figure*** 8. Temperature–time development

Table 3 provides temperature data for concrete, reinforcing steel, and the ISO 834 standard fire curve at discrete time points (10, 30, 60, 90, and 120 minutes) during the fire resistance simulation of the reinforced concrete (RC) beam. The results indicate a progressive temperature rise in both materials, with steel exhibiting a significantly higher heating rate than concrete, consistent with the superior thermal conductivity of steel. Throughout the exposure duration, concrete and steel temperatures remain below the ISO 834 curve, confirming the thermal insulation effect of the concrete cover in protecting the reinforcement. The temperature differential between concrete and steel generates thermal stresses within the section, potentially compromising load-bearing capacity. Consequently, detailed analysis of Table 3 data is essential for accurate fire performance assessment of RC structural elements.

Table 3: Computed temperature fields for the simply supported beam

| Time | 10 min | 30 min | 60 min | 90 min | 120 min |
|---|---|---|---|---|---|
| Concrete | 20°C | 20°C | 20°C | 20°C | 21°C |
| Reinforcing Steel | 59°C | 186°C | 319°C | 407°C | 472°C |
| Iso 834 | 678°C | 842°C | 945°C | 1006°C | 1045°C |

Simulation results reveal a gradual temperature increase within the beam as fire exposure duration extends, with the highest temperatures predominantly occurring in the concrete cover and reinforcing steel. The temperature distribution across the beam is influenced by multiple factors, including concrete type, cover thickness, reinforcement diameter, and fire exposure conditions, resulting in a complex thermal profile within the structure.

*5.2. Calculation Results per Eurocode*

Temperature-dependent strength values for reinforcing steel and concrete are extracted from ANSYS simulations to determine the actual reduced strength of concrete after exposure to standard fire conditions for corresponding durations. This residual strength is applied to calculate the ultimate concentrated load capacity P of the beam, as illustrated in Figure 5. Table 4 presents the load-bearing capacity of the reinforced concrete (RC) beam under ISO 834 standard fire over a 120-minute exposure period. The results demonstrate a progressive reduction in structural resistance with increasing fire duration. Specifically, at the initial condition (t = 0 min), the beam sustains a maximum concentrated load of P=7.72 tonnes. After 10 minutes of fire exposure, this capacity decreases to 7.57 tonnes, corresponding to a 1.94% reduction. The downward trend in load-bearing capacity persists with time. At 30 minutes, the capacity falls to 7.22 tonnes (6.48% reduction from the initial value). By 60 minutes, only 6.08 tonnes remain (21.24% reduction). The rate of capacity loss accelerates thereafter; between 60 and 120 minutes, the load decreases from 6.08 tonnes to 4.00 tonnes, representing a 48.19% reduction relative to the initial capacity. Overall, after 120 minutes of fire exposure, the load-bearing capacity of the reinforced concrete (RC) beam is substantially compromised. This underscores the detrimental effect of elevated temperatures on the mechanical properties of constituent materials, resulting in significant structural degradation. Eurocode-compliant calculations confirm that the flexural moment capacity of the beam decreases progressively with fire exposure duration. The fire resistance rating (R) defined as the duration during which the residual moment capacity exceeds the applied bending moment is governed by multiple factors, including concrete strength class, reinforcement type, concrete cover thickness, and fire exposure conditions.

Table 4: Calculation results at various temperatures

| Time (min) | Temperature at beam bottom per Iso 834 | Reinforcement temperature (°C) | Corresponding load P (T) | Reduction (%) |
|---|---|---|---|---|
| 0 min | 38°C | 20°C | 7.72 | 0% |
| 10 min | 678°C | 59°C | 7.57 | ↓ 1.94% |
| 20 min | 773°C | 125°C | 7.36 | ↓ 2.77% |
| 30 min | 842°C | 186°C | 7.22 | ↓ 1.90% |
| 40 min | 876°C | 239°C | 6.88 | ↓ 4.71% |
| 50 min | 911°C | 282°C | 6.51 | ↓ 5.38% |
| 60 min | 945°C | 319°C | 6.08 | ↓ 6.61% |
| 70 min | 965°C | 352°C | 5.63 | ↓ 7.4% |
| 80 min | 986°C | 381°C | 5.25 | ↓ 6.75% |
| 90 min | 1006°C | 407°C | 4.93 | ↓ 6.1% |
| 100 min | 1019°C | 430°C | 4.63 | ↓ 6.1% |
| 110 min | 1032°C | 452°C | 4.31 | ↓ 6.9% |
| 120 min | 1045°C | 472°C | 4 T | ↓ 7.2% |

Figure 9 illustrates the progressive degradation in load-bearing capacity of the reinforced concrete (RC) beam as a function of fire exposure duration. The plot clearly depicts a downward trend in the critical load (kN) that the beam can sustain over time (minutes). At the initial condition (t = 0 min), the beam exhibits maximum capacity, approaching 8 kN. As fire duration increases, the critical load decreases gradually. This reduction is non-linear: during the early stage (0 to 30 min), the rate of capacity loss is relatively slow. However, after 30 minutes, the degradation rate accelerates significantly. By t = 120 min (2 hours), the residual capacity drops to approximately 4 kN, representing a nearly 50% reduction from the initial value. Thus, the graph unequivocally demonstrates the adverse impact of elevated temperatures on the structural performance of RC beams. The longer the fire exposure, the greater the loss in load-bearing capacity.

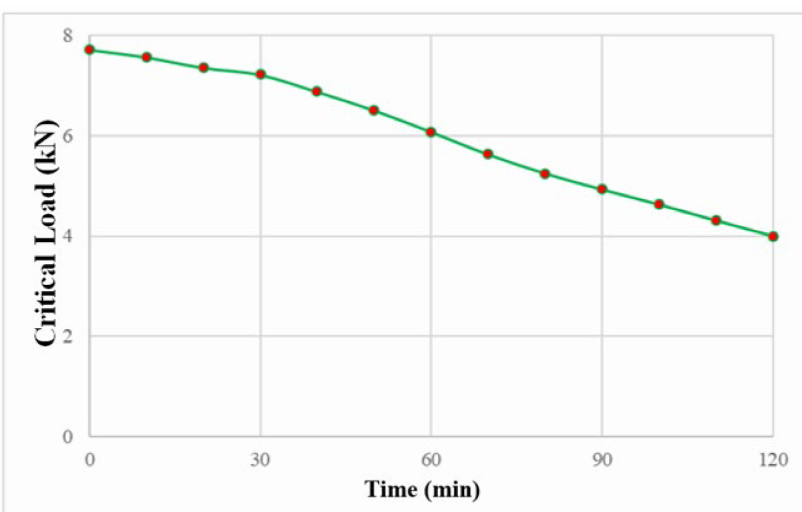


***Figure*** 9. Load-bearing capacity of the structural member over time

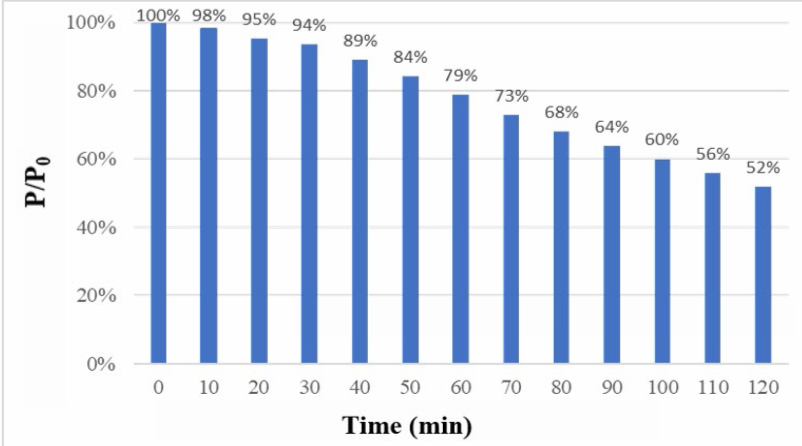


***Figure*** 10. Variation in structural load-bearing capacity with fire exposure duration

Figure 10 illustrates the degradation of load-bearing capacity in the reinforced concrete (RC) beam as a function of fire exposure duration. The ordinate represents the normalized residual capacity ($P/P_0$), while the abscissa denotes fire exposure time (minutes). Overall, the graph exhibits a consistent downward trend in structural resistance. At t = 0 min, the beam retains 100% of its design capacity. As exposure progresses, this ratio declines: 98% at 10 min, 94% at 30 min, and further to 52% at 120 min (2 hours). This substantial reduction highlights the severe impact of elevated temperatures on the mechanical properties of concrete and reinforcing steel, resulting in progressive loss of structural integrity. Figure 10 provides a visual representation of time dependent capacity loss, offering critical insights for fire safety assessment in high-risk infrastructure particularly aviation facilities, where stringent fire resistance requirements are mandatory.

*5.3. Discussion*

This study focuses on analyzing the degradation of load-bearing capacity in reinforced concrete (RC) structures, specifically RC beams, under elevated temperatures. The results reveal a significant reduction in the beam's capacity with prolonged exposure to high temperatures, with nearly 50% loss after 120 minutes under the ISO 834 standard fire curve. This is clearly demonstrated by the maximum load capacity progressively decreasing from 7.72 tonnes at the initial state to 4.00 tonnes after 120 minutes. The rate of capacity loss accelerates over time, with reductions of approximately 8% after 30 minutes and over 20% after 60 minutes.

Reinforcing steel, with its higher thermal conductivity and heat absorption compared to concrete, is typically located near the structural surface and is thus more significantly affected by elevated temperatures. While the steel temperature increases substantially over time, the concrete temperature particularly in inner layers exhibits less variation. This temperature rise directly impairs material strength, with steel strength experiencing a pronounced reduction, thereby substantially diminishing the load-bearing capacity of the member. Although concrete strength also degrades, the extent of reduction is less severe than that of steel.

The study further reveals a strong correlation between fire exposure duration, temperature, and load-bearing capacity degradation in reinforced concrete (RC) structures. The longer the thermal exposure, the greater the capacity loss, primarily due to elevated temperatures inducing significant strength reduction in constituent materials, particularly reinforcing steel. However, it is noted that this investigation is limited to the thermal impact on structural resistance, without fully addressing other critical phenomena such as reinforcement deformation, complex physicochemical reactions, or multi-axial thermal effects on the member. Additionally, the research is constrained by methodological limitations, including simulation duration, budgetary restrictions, and the absence of comprehensive experimental facilities.

In conclusion, this study underscores that the degradation of load-bearing capacity in reinforced concrete (RC) structures under elevated temperatures constitutes a critical design consideration in the engineering and construction of civil infrastructure. Fire resistance assessment of structural elements is essential to ensure life safety and property protection. Structural protection measures, appropriate material selection, and updated standards together with advanced calculation methods are required to more accurately capture the structural response under fire exposure conditions.

## 6. CONCLUSIONS

The research results show that the fire resistance of flexure-dominated reinforced concrete structures in airport terminals is significantly influenced by design factors, including: Firstly, the concrete cover plays a crucial role in protecting the reinforcement from high temperatures, thereby maintaining the load-bearing capacity of the structure. The greater the concrete cover thickness, the longer the fire endurance time of the beam. This is because a thicker cover slows down the heat transfer process to the reinforcement, allowing the reinforcement to maintain its strength and elastic modulus for a longer period. Secondly, reinforcement with higher heat-resistant strength will help increase the fire resistance of the structure. In addition, using reinforcement with a larger diameter can also enhance fire resistance, since larger-diameter reinforcement has a smaller surface area exposed to heat compared to smaller-diameter reinforcement. Finally, concrete with a higher strength grade will have better heat resistance, thereby increasing the fire resistance of the structure.

Based on the research results and analysis of the influence of design factors, several optimal design solutions and technical measures can be proposed to enhance the fire resistance of airport terminals as follows: Firstly, increase the concrete cover thickness. Increasing the concrete cover thickness is a simple and effective measure to improve fire resistance. However, it is necessary to pay attention to the structural and architectural requirements of the project when increasing the concrete cover thickness. Secondly, use heat-resistant reinforcement. Types of reinforcement with high heat-resistant strength should be used, for example alloy reinforcement or reinforcement coated with fireproof materials. Another method is to use high-strength grade concrete. Using high-strength grade concrete will help increase the heat resistance and fire resistance of the structure. In addition, arranging an effective fire prevention and fighting system is very important. The fire prevention and fighting system needs to be designed and installed properly, ensuring that it can detect and extinguish fires in a timely manner, limiting damage to the structure. Even the effectiveness of using fireproof materials to protect reinforced concrete structures, for example fireproof paint, fireproof wrapping panels, fireproof spray mortar can also be analyzed and considered reasonably based on the above simulation method.

This study provides an effective method to evaluate the fire resistance of flexure-dominated reinforced concrete structures in airport terminals. The research results can be used to support the design of fire-resistant reinforced concrete structures for airport terminals. Design engineers can utilize the research results to select optimal design solutions, ensuring that the fire resistance of the structure meets the requirements of standards and regulations. In addition, the research results can be used to assess the fire resistance of existing structures. For existing airport terminals, this study provides a tool to quickly evaluate the fire resistance of the structure, thereby proposing renovation and upgrading measures to enhance fire safety, timely fire resistance and firefighting to meet the progress requirements according to domestic and international aviation safety standards. Based on the quantitative analysis research results as in this paper, new solutions can be developed. This study also serves as a basis to continue researching and developing new, more effective solutions in enhancing the fire resistance for reinforced concrete structures in airport terminals.

## REFERENCES


[1] Kodur V. *Properties of Concrete at Elevated Temperatures*. ISRN Civ Eng 2014, 1–15. DOI: 10.1155/2014/468510.

[2] Qin D, Gao P, Aslam F, Sufian M, Alabduljabbar H. *A comprehensive review on fire damage assessment of reinforced concrete structures*. Case Stud Constr Mater, 2022, 16, e00843. DOI: 10.1016/j.cscm.2021.e00843.

[3] European Committee for Standardization (CEN). Eurocode 2: Design of Concrete Structures – Part 1-1: *General Rules and Rules for Buildings*. European Committee for Standardization, 2004.

[4] TCVN 5574: 2018, *Design of Concrete and Reinforced Concrete Structures*

[5] I.S.O.-834. ISO 834: Fire-resistance tests - Elements of building construction - Part 1: *General requirements*, 1999.

[6] Kodur VKR, Shakya AM. *Effect of temperature on thermal properties of spray applied fire resistive materials*. Fire Saf J, 2013, 61, 314–23. DOI: 10.1016/j.firesaf.2013.09.011.

[7] N.T. Thang, N.T. Trung, *Investigation of the Degradation of Flexural Resistance of Reinforced Concrete Beams under Fire Conditions according to Eurocode*, Journal of Science and Technology in Civil Engineering, 13, 22–34, 2019. DOI: 10.31814/stce.nuce2019-13(4V)-03

[8] Asif A, Dhanapal M, Megha US, Nazar S, Rose Jose S. *Analysis of steel–concrete composite beam using Ansys 18.1 Workbench*. Mater Today Proc 2023, S2214785323029164. DOI: 10.1016/j.matpr.2023.05.285.

[9] Patil AS, Moheimani R, Dalir H. *Thermomechanical analysis of composite plates curing process using ANSYS composite cure simulation*. Therm Sci Eng Prog, 2019, 14, 100419. DOI: 10.1016/j.tsep.2019.100419.

[10] Shalamov PV, Kulygina IA, Yaroslavova EN. *ANSYS Software-based Study of Thermal Drilling Process*. Procedia Eng, 2016, 150, 746–752. DOI: 10.1016/j.proeng.2016.07.098.

[11] Liu C, Zhou B, Guo X, Liu C, Wang L. *Analysis and prediction methods for the static properties of reinforced concrete beams under fire*. Structures, 2023, 47, 2319–30. DOI: 10.1016/j.istruc.2022.12.041.