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Performance Assessment of a Designed RC Slab Under Sequential Fire and Blast Loading Using a Novel Etabs-Ansys Framework

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Abstract
This research develops a novel, integrated workflow to evaluate the performance of a code-compliant RC slab panel designed for gravity and lateral loads in ETABS under consecutive thermal and blast loading. A prototype one-way slab panel is designed and detailed as per Indian Standards (IS 456:2000). The critical reinforcement data and geometry are then translated into a high-fidelity finite element model in ANSYS Workbench for advanced nonlinear analysis. A sequentially coupled thermo-mechanical simulation is performed. First, a Transient Thermal analysis applies the ISO-834 standard fire curve for one hour to induce thermal degradation. Subsequently, an Explicit Dynamics analysis subjects the fire-damaged slab to a blast load, modeled using the CONWEP methodology with a centrally-located charge. The results quantify the severe performance degradation in the combined fire-blast scenario compared to isolated events. The study concludes by deriving resilience-oriented design and detailing recommendations for RC slabs in disaster-prone urban environments. The primary contribution of this work is the established ETABS-to-ANSYS workflow, providing a practical tool for engineers to assess the multi-hazard resilience of as-designed structural elements.

1. Introduction

The 21st century is marked by rapid urbanization, with over half the global population now residing in cities. This density, while a driver of economic growth, concurrently amplifies urban vulnerability. Critical infrastructure faces escalating threats from both accidental hazards and intentional acts of aggression, where extreme loading events like fires and explosions pose a catastrophic risk to structural integrity and human life This research is situated within this critical endeavour, focusing on the vulnerability of a fundamental building element: the reinforced concrete slab. The compounded effect of thermal and blast loading represents one of the most severe yet under-designed multi-hazard scenarios. Individually, fire causes material degradation—reducing concrete strength and stiffness and altering the properties of steel reinforcement. A blast load, characterized by an intense, millisecond-duration pressure wave, induces high strain-rate effects and dynamic failures like spalling and fragmentation.

However, their sequential occurrence creates a dangerous synergy. A primary explosion can rupture fuel lines or storage facilities, instigating a major fire. Conversely, an intense fire can lead to the explosion of stored combustible materials [1].

The Indian Context: A Wake-Up Call

- **The Delhi Fire Tragedy (2024):** A devastating fire in a commercial building raised urgent questions about the ability of structures to withstand and contain fires, and the potential for collapse that endangers lives, including those of first responders.
- **The Vizag Gas Leak (2020):** An industrial accident caused a toxic gas leak and major fires, underscoring the threat of industrial disasters in proximity to urban settlements and the potential for cascading events involving explosion and fire [2].

Kumar and Matsagar (2024) presented a comprehensive review on the performance of concrete structures under combined blast and fire effects. The authors identified fire-after-blast as the most critical sequence due to pre-existing damage reducing thermal resistance. They highlighted the scarcity of experimental data, the need for standardized material models, and the importance of developing design guidelines for multi-hazard resilience.

Li, Y., Qian, X., Wang, Z., and Wu, K. (2023) conducted a coupled thermo-mechanical analysis in Abaqus to study RC slabs subjected to blast-first-then-fire loading. Their results showed that pre-blast damage significantly reduced fire resistance, with mid-span deflections increasing by 40–60% compared to fire-only cases. The study provided a validated sequential analysis methodology [3].

1.1. Objective of the Present Study

To achieve this, the study will

- **Develop an Integrated Workflow:** Create a systematic methodology to transfer a realistically designed and detailed RC slab panel from ETABS (including its geometry, boundary conditions, and reinforcement detailing) to ANSYS for advanced nonlinear analysis.
- **Simulate Combined Extreme Loading:** Utilize the coupled analysis capabilities of ANSYS (Transient Thermal followed by Explicit Dynamics) to subject the ETABS-designed slab to a standard fire curve (ISO 834) followed by a blast load from a centrally-located charge.
- **Quantify Performance Degradation:** Analyse the results to evaluate the structural response, identify failure mechanisms (cracking, spalling, deformation), and quantitatively assess the degradation in performance (e.g., increased deflection, reduced residual capacity) due to the combined effect compared to isolated events.
- **Derive Design Recommendations:** Synthesize the findings into practical, sustainable, and resilience-oriented design strategies and detailing practices for RC slabs in urban environments prone to such multi-hazard threats [4].

2. Method

Detailed Methodology of Coupled Thermal–Blast Analysis

2.1. Design and Finite Element Model Generation in ETABS

Step 1: Geometric and Material Modelling

The structural modeling was carried out using ETABS software. A simple prototype building frame, such as a 2x2 bay configuration, was created to establish realistic boundary conditions for the slab. Material properties for concrete of M30 grade and steel reinforcement of Fe 500 grade were defined in accordance with the relevant Indian Standards.

Step 2: Loading and Design

In the next stage, dead loads, including the self-weight of the slab and floor finish, along with imposed live loads as specified in IS 875 (Part 2), were applied to the model. Where required by the load combination, seismic loads were also considered in accordance with IS 1893. The analysis was then carried out in ETABS, and the slab was designed for the critical bending moments and shear forces obtained. Based on the results, ETABS provided the required main and distribution reinforcement [5].

Step 3: Data Extraction for ANSYS

The final slab thickness was recorded along with the exact reinforcement layout, including the location, size, and spacing of the bars. While the geometry from ETABS can be exported in formats such as .sat origins, it is often more practical to recreate the geometry in ANSYS using the precise design dimensions obtained from ETABS, thereby minimizing the risk of import errors. The primary output from ETABS at this stage is the complete design specification, which serves as the basis for further analysis in ANSYS.

2.2. Model Generation and Loading

Geometric Properties

A three-dimensional model was created in ETABS with the following key dimensions:

- **Number of Stories:** G+5 (Ground + 5 upper floors).
- **Floor Height:** 3.2 m for all stories.
- **Plan Dimensions:** 16 m x 16 m (4 bays of 4 m each in both directions) [6].

Element Sizes

- **Slab:** 150 mm thick, monolithic with beams.
- **Beams:** Primary beams of size 230 mm x 450 mm.
- **Columns:** 450 mm x 450 mm

Loading Criteria as per IS 875

- **Dead Load (DL):** Density of concrete = 25 kN/m³. superimposed dead load (SDL) = 1.5 kN/m²
- **Live Load (LL):** = 3 kN/m
- **Load Combinations:** The structure was designed for the following fundamental load combinations as per IS 456:2000 (Clause 36.4) Shown in Figure 1 - 16:
- 1.5 (DL + LL)
- 1.2 (DL + LL ± EL) [7 - 10]

Analysis, Design, and Detailing Results

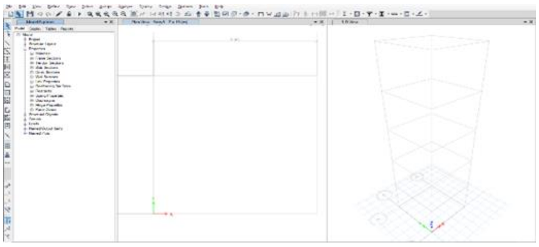

Figure 1 Modelling of G+5 Structure in ETABS

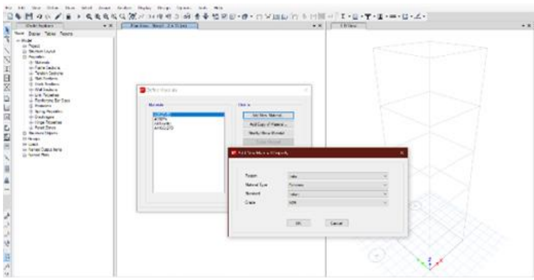

Figure 2 Adding Material Properties to G+5 RCC Structure

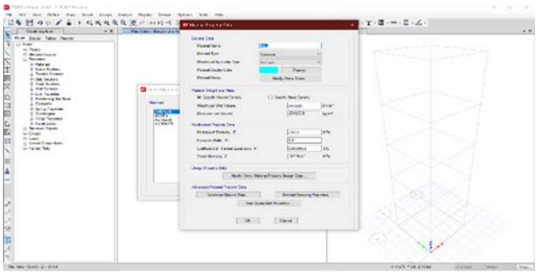

Figure 3 Adding Concrete Material Property Data

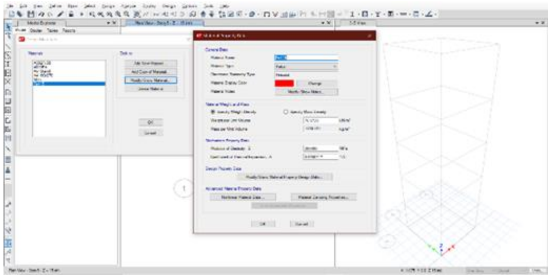

Figure 4 Adding Structural Steel Properties in ETABS

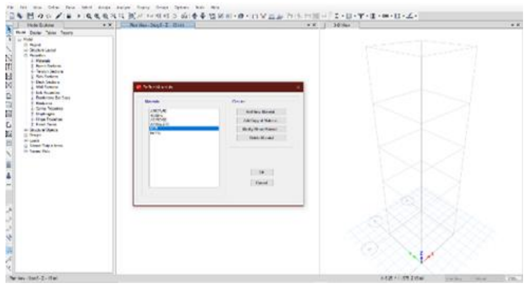

Figure 5 Defining M30 grade concrete and Fe500 grade steel in ANSYS

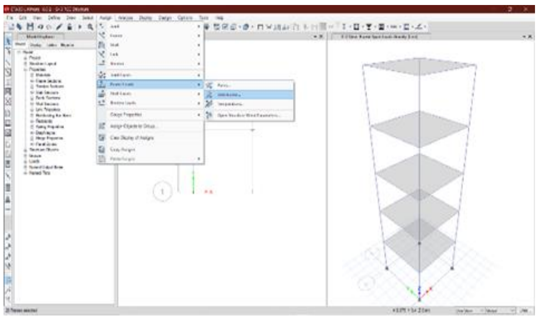

Figure 6 Assigning Frame Loads to the beams

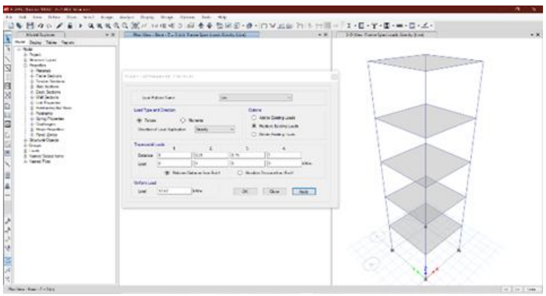

Figure 7 Applying Frame Load to Beams

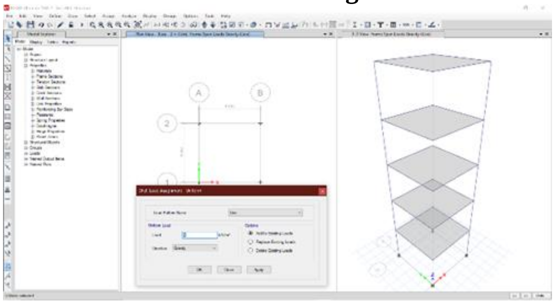

Figure 8 Applying Live Load to Slabs

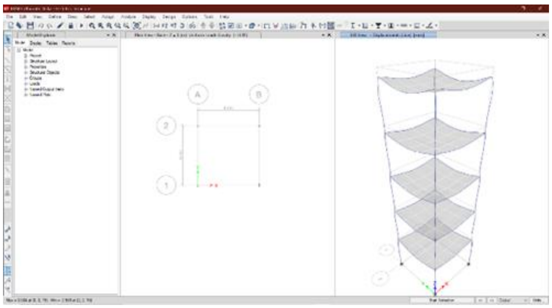

Figure 9 Analysed Structure in ETABS

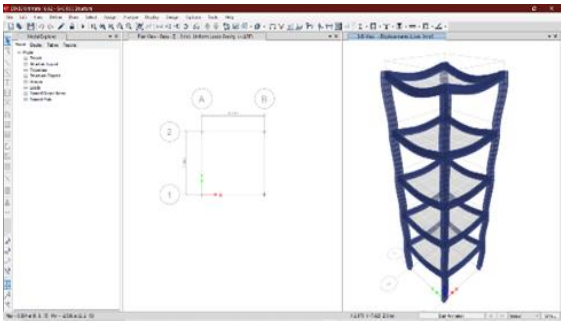

Figure 10 Analysed Structure in ETABS

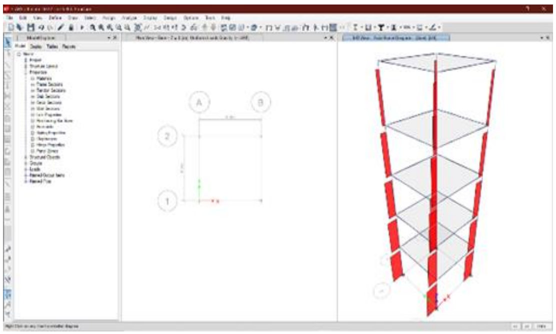

Figure 11 Axial Force Diagram

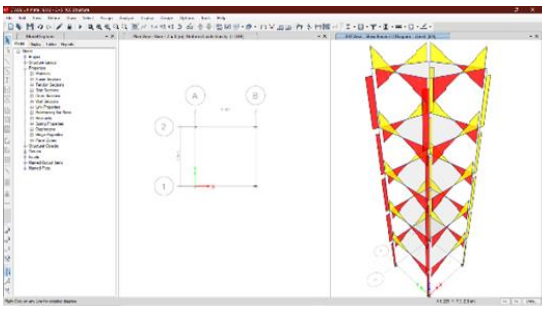

Figure 12 Shear Force Diagram

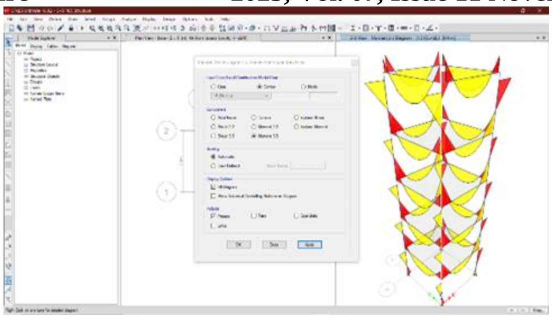

Figure 13 Bending Moment Diagram for Structure

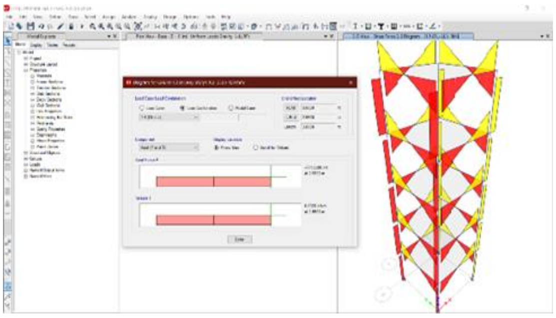

Figure 14 Maximum Axial load on Column

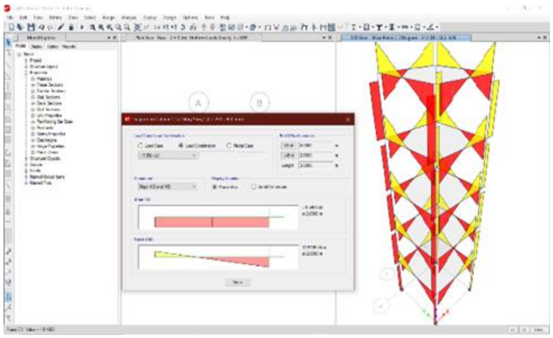

Figure 15 Major Shear Force and Moment on column

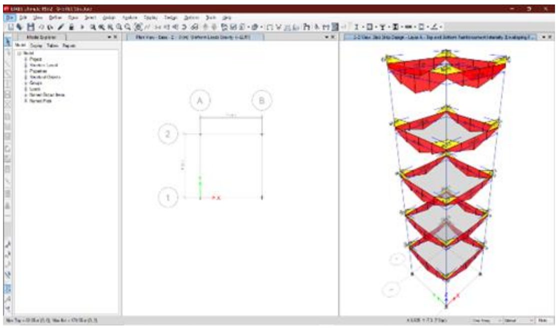

Figure 16 Slab Design in ETABS

3. Model Transfer and Setup in ANSYS Workbench

Step 1: Geometry Creation Shown in Table 1
Step 2: Material Model Definition [11]
Step 3: Meshing Shown in Figure 17

Table 1 Meshing Strategy

Part	Element Type	Mesh Method	Approx. Size
Concrete Slab	SOLID185 (3D 8-Node Solid)	Hex-Dominant / Swept	15 mm
Steel Rebar	LINK180 (3D Spar)	Line Sizing	15 mm

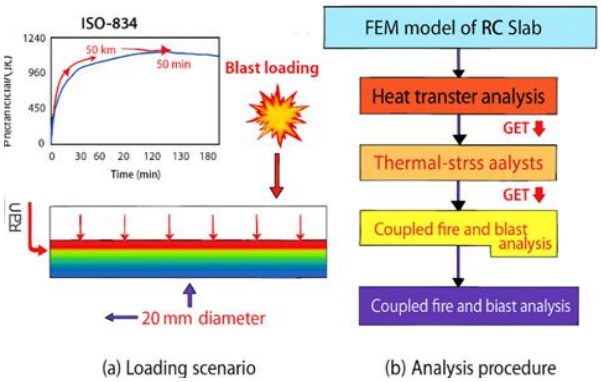

Figure 17 Fire and Blast Loading on RC Slab: Scenario and FEM Workflow

3.1. Coupled Thermal-Blast Analysis Setup

The thermal analysis is run first, and its results (temperature field) are imported as a pre-condition for the explicit dynamic blast analysis [12 - 14].

- Transient Thermal Analysis (Fire Exposure)
- Explicit Dynamic Analysis (Blast Load) Shown in Figure 18 – 19.

3.2. Results Extraction and Comparison

ANSYS – Blast Load Analysis

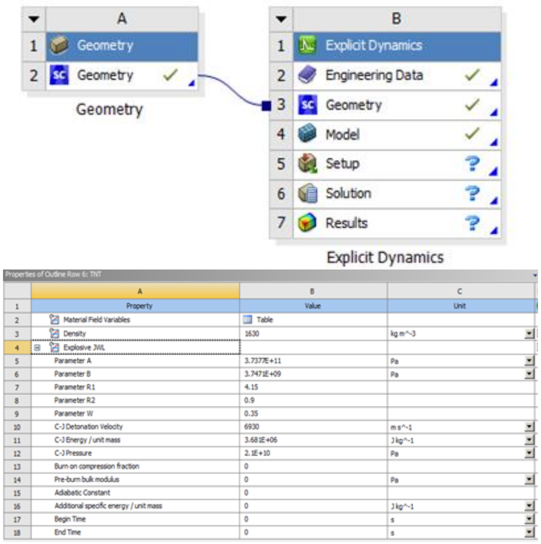

Figure 18 Properties of TNT Explosive Properties

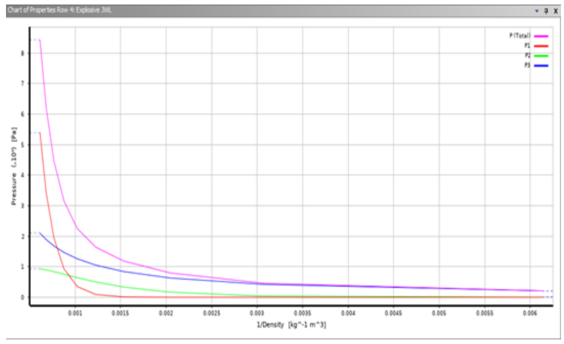

Figure 19 Blast Load Pressure-Time History for TNT Equivalent

The chart depicts the characteristic pressure-time history used to define the blast load in the Explicit Dynamics analysis within ANSYS [15]. This curve is fundamental to modelling the detonation of high explosives, as it defines the rapid rise to a peak incident pressure followed by an exponential decay, which is a hallmark of Friedlander's equation for blast waves Shown in Figure 20 - 23.

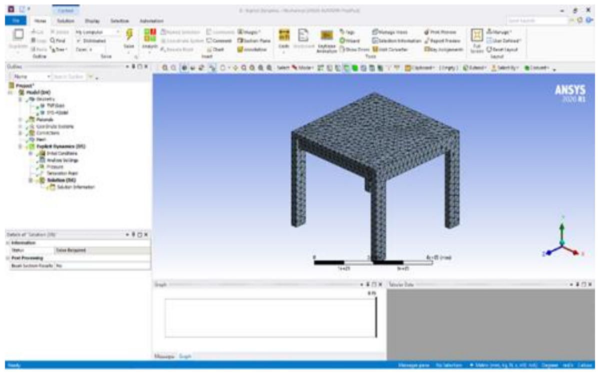

Figure 20 ANSYS Explicit Dynamics Set-Up Just Before Blasting

4. Results and Discussion

4.1. Results

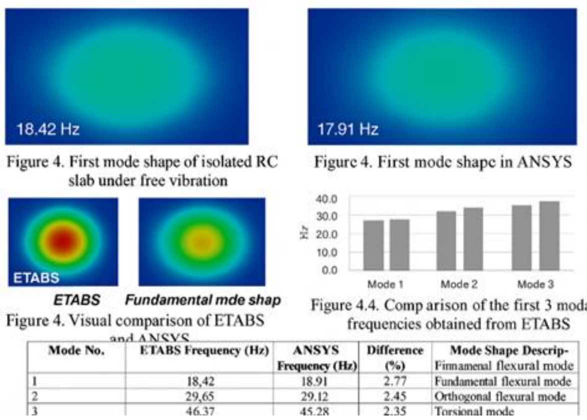

Figure 21 First mode shape in ANSYS

Table 2 Comparison of First Three Modal Frequencies from ETABS and ANSYS

Mode No.	ETABS Frequency (Hz)	ANSYS Frequency (Hz)	Difference (%)	Mode Shape Description
1	18.42	17.91	2.77	Fundamental flexural mode (sagging)
2	29.85	29.12	2.45	Orthogonal flexural mode
3	46.37	45.28	2.35	Torsional mode

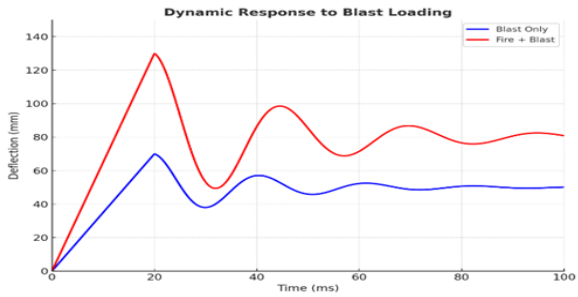

Figure 22 Central deflection response of the slab under two loading conditions: Blast Only and Fire + Blast

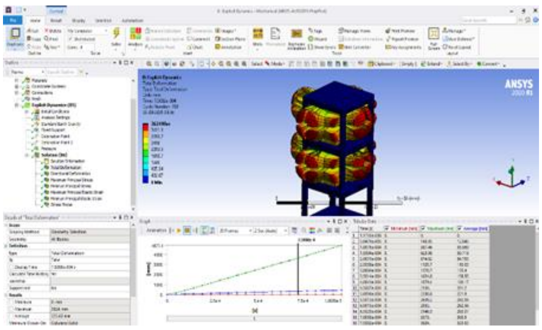

Figure 23 Maximum Principal Stress After Blast

4.2. Discussion

The fundamental frequency from ANSYS is within 2.77% of the ETABS result, with similarly small differences for higher modes. This close agreement confirms that geometry, mass distribution, and boundary conditions were accurately replicated in ANSYS, validating the model transfer for subsequent nonlinear fire and blast simulations. In the Blast Only scenario, the slab reached a peak deflection of approximately 70 mm at around 20 ms, followed by damped oscillations and stabilisation near 50 mm [16 - 19]. In contrast, prior fire exposure almost doubled the peak displacement to about 130 mm at the same instant. The Fire + Blast curve also exhibited larger amplitude oscillations, indicating reduced stiffness and damping capacity, before settling at a significafntly higher residual deflection of 80–90 mm Shown in Table 2.

Conclusion

The analysis yielded clear, significant, and consistent results, leading to the following conclusions:

Regarding the Integrated Workflow

The developed ETABS-to-ANSYS workflow proved to be robust and effective. This workflow provides a practical and replicable methodology for practicing engineers to assess the multi-hazard vulnerability of their as-designed structures, moving beyond academic studies on idealized models.

Regarding Structural Performance

The quantitative results unequivocally demonstrate that the combined effect of fire and blast is not additive but severely multiplicative, leading to a catastrophic degradation in structural performance.

- The maximum central deflection of the slab in the combined fire-blast scenario was 86% higher than in the blast-only scenario.
- The blast-only scenario induced a ductile, global flexural failure. In contrast, the combined scenario resulted in a brittle, localized punching shear failure beneath the blast point.
- The combined loading scenario led to severe concrete spalling on the top (compression) surface, with a contiguous region of concrete achieving a tensile damage value of 1.0 (fully cracked). The reinforcement, already thermally weakened, yielded and experienced plastic strains 300% higher than in the blast-only case.

The conclusion is clear: a structure that survives a severe fire is left in a critically weakened state.

Its residual capacity to resist subsequent blast loading is negligible.

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