The 2023 World Congress on
Advances in Structural Engineering and Mechanics (ASEM23)
GECE, Seoul, Korea, August 16-18, 2023

Review on Numerical Analysis of Fire Performance in RC, PSC, and PT Concrete Structures

*Kwanwoo Yi[1)] and Thomas Kang[2)]

[1), 2)] *Department of Architecture & Architectural Engineering, Seoul National University, Seoul, Korea*
[2)] *tkang@snu.ac.kr*

ABSTRACT

This paper summarizes various studies on numerical analysis of reinforced concrete (RC), prestressed concrete (PSC), and post-tensioned (PT) concrete structures under fire conditions. The studies utilized the ABAQUS finite element analysis program for simulations of beams and slabs. While the studies have differences in analysis techniques, variations exist in modeling structural elements and their interactions. Different types of tendon elements were used, such as 3D solid elements and linear truss elements, to accurately represent the components. Surface-to-surface contact or embed restraint methods were employed for contact modeling, depending on the case. The analysis methods employed in the studies can be grouped into three distinct approaches. The first approach involves conducting a heat transfer analysis to determine the temperature distribution within the structure, which is subsequently integrated into the loading analysis. In the second approach, material properties are adjusted to account for the effects of fire degradation prior to the loading analysis. The third approach entails simultaneously conducting heat transfer and loading analyses. The accuracy of the analysis methods is validated by comparing failure loads from numerical simulations with experimental results. Overall, the numerical and experimental results exhibit good agreement, with a slight increase in variability at higher temperatures. The reviewed studies offer insights into the behavior of concrete structures under fire and emphasize the importance of considering thermal effects. They present a range of analysis methods for evaluating the fire resistance of concrete structures.

1. INTRODUCTION

Understanding the behavior and performance of concrete structures under fire conditions is crucial for ensuring their safety and resilience. In-depth research and analysis have been conducted to investigate the fire resistance and behavior of various types of concrete structures, such as reinforced concrete (RC), prestressed concrete

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[1)] Graduate Student
[2)] Professor

(PSC), and post-tensioned (PT) concrete structures. These studies employ advanced numerical analysis methods, specifically utilizing the ABAQUS finite element analysis software, to simulate and analyze the response of concrete structures subjected to fire and thermal loads.

2. ANALYSIS METHOD REVIEW

The studies focus on a range of test conditions, including elevated temperatures, fire exposure, variations in concrete compressive strength, static loading, cover thickness, heating time, thermal expansion, and type of coarse aggregate. The analysis methods employed in these studies varied, particularly in the modeling of tendons based on the type of specimen.

For reinforced concrete (RC) and prestressed concrete (PSC) structures, the tendons were modeled using 3D truss elements, and embedded restraints were utilized. This modeling approach aimed to capture the interaction between the tendons and the concrete structure. On the other hand, for unbonded PT concrete structures, the tendons were modeled using 3D solid elements, and surface-to-surface contact restraints were employed. This distinction in modeling techniques may be attributed to the consideration of friction between the tendons and the concrete structure in unbonded PT systems. However, it is important to note that conducting heat transfer analysis and load case analysis using surface-to-surface contact restraints may increase computational complexity.

The analysis methods employed in the studies can be broadly categorized into three approaches. The first approach involves conducting a heat transfer analysis to determine the temperature distribution within the structure, which is then integrated into the subsequent loading analysis. The second approach includes adjusting material properties to account for the effects of fire degradation before conducting the loading analysis. The third approach entails simultaneously conducting heat transfer and loading analyses. These different approaches were employed across the studies, irrespective of other analysis conditions.

Table 1 Selected details of numerical analysis available from the literature

#	Source	Specimen Type	Number of Specimens	Difference in Specimens	Analysis Step	Contact Type	Mesh Type
1	Cai et al., 2020	RC Beam	4	Temperature, Fire Proofed	Integration of Temperature Results into Loading Analysis Following Heat Transfer Analysis	-	DC3D8, DC1D2, C3D8R, T3D2
2	Wang et al., 2023	PSC T-Beam	1	-	Integration of Temperature Results into Loading Analysis Following Heat Transfer Analysis	Embed	DC3D8, DC1D2, C3D8R, T3D2
3	Izzet et al., 2021	Bonded PT Beam	10	Concrete Compressive Strength, Temperature, Static Loading	Adjustment of Material Properties Preceding Loading Analysis	Embed	C3D8R, S8R6, T3D2
4	Park, 2022	Bonded PT Slab	2	Cover Thickness, Heating Time	Simultaneous Heat Transfer and Load Analysis	Embed	DC3D8, DCID2, C3D8T, T3D2T

5	Ellobody and Bailey, 2009	Unbonded PT Slab	6	Temperature, Thermal Expansion, Coarse Aggregate	Simultaneous Heat Transfer and Load Analysis	Surface to Surface Contact	C3D8, C3D6
6	Hekmet and Izzet, 2019	Segmental Unbonded PT Beam	12	Temperature, Number of Segments	Adjustment of Material Properties Preceding Loading Analysis	Surface to Surface Contact	C3D8R

3. ACCURACY COMPARISON

To validate the finite element analysis methods, a comparison was made between the ultimate load of numerical models and physical models in the studies conducted by (Izzet et al. 2021) and (Hekmet and Izzet 2019). Both studies included 10 bonded PT beams and 12 unbonded PT beams, with numerical models compared to corresponding physical models. Each set of beams was subjected to different temperatures within their respective groups.

The comparison between numerical and experimental results revealed a satisfactory level of agreement, with an average error of approximately 10%. However, increased standard deviations of the values were observed at higher temperatures. This suggests that higher temperatures may induce instability in the numerical analysis. Therefore, it is evident that a refined analysis method is required for modeling high-temperature concrete structures.

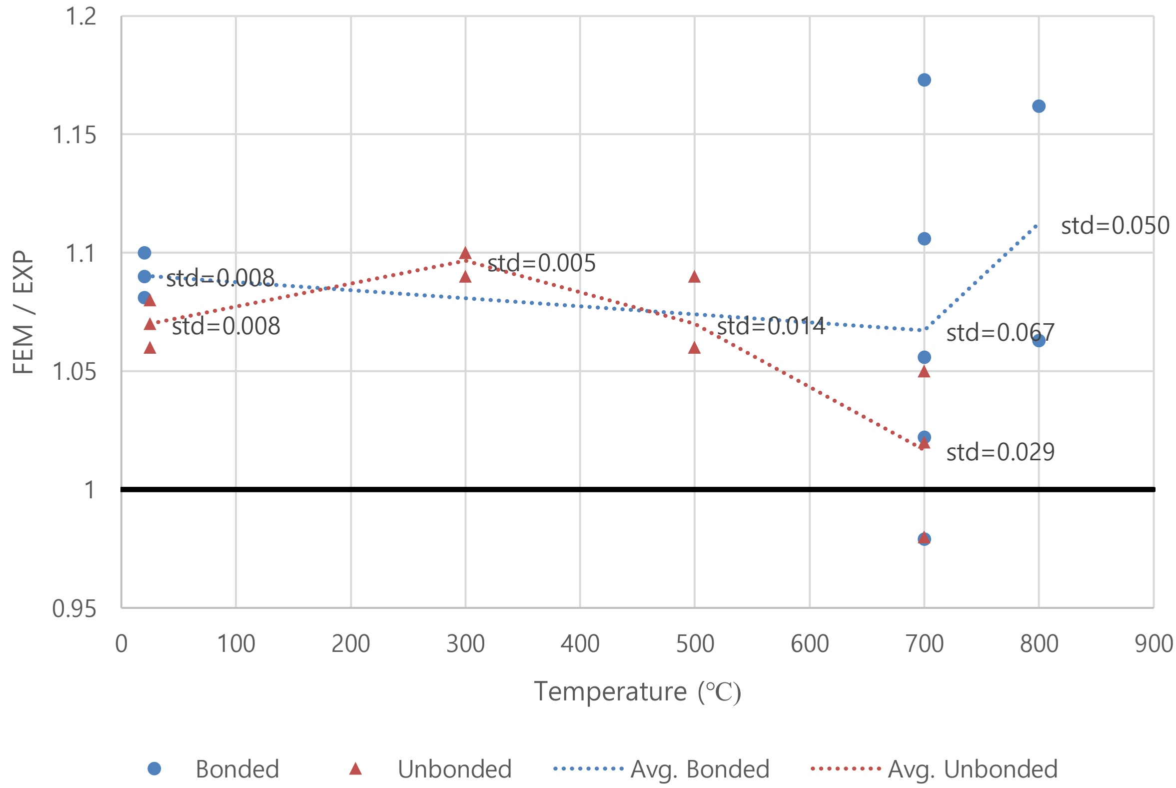

Fig. 1 Comparison of ultimate loads of concrete beams obtained from FEM analysis and experimental tests at different temperatures

4. CONCLUSIONS

Conclusions can be drawn as follows:

1. The studies showcase variations in analysis techniques and modeling approaches, utilizing diverse tendon elements (e.g., 3D solid elements and linear truss elements) for accurate component modeling, while employing surface-to-surface contact or embed restraint methods for contact modeling as needed.
2. The analysis methods used in the studies can be categorized into three approaches: heat transfer analysis integrated with loading analysis, adjustment of material properties to account for fire degradation, or simultaneous conduct of heat transfer and loading analyses.
3. The analysis methods have demonstrated good accuracy in predicting concrete structures' behavior under fire conditions, but higher temperatures show slight variability, underscoring the need for further refinement and development in modeling high-temperature concrete structures.

REFERENCES

Cai, B., Li, B. and Fu, F. (2020) “Finite Element Analysis and Calculation Method of Residual Flexural Capacity of Post-fire RC Beams,” *International journal of concrete structures and materials*, 14(6), pp. 977–993.

Ellobody, E. and Bailey, C.G. (2009) “Modelling of unbonded post-tensioned concrete slabs under fire conditions,” Fire safety journal, 44(2), pp. 159–167.

Hekmet, H.M. and Izzet, A.F. (2019) “Numerical Analysis of Segmental Post Tensioned Concrete Beams Exposed to High Fire Temperature,” Engineering, technology & applied science research, 9(5), pp. 4759–4768.

Izzet, A.F., Oukaili, N. and Harbi, N.A. (2021) “Post-fire serviceability and residual strength of composite post-tensioned concrete T-beams,” SN applied sciences, 3(2), p. 158.

Park, S. (2022) “Fire Behavior of Post-Tensioned Concrete One-Way Members with Different Tendon Configuration.”

Wang, Z., Chen, M. and Liao, Y. (2023) “Analysis of Fire Resistance of Prestressed Concrete T-Beam Based on ABAQUS Numerical Simulation,” Applied sciences, 13(8), p. 4683.