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A REVIEW ON FIRE DAMAGE ASSESSMENT OF REINFORCED CONCRETE STRUCTURES OF A BUILDING

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Abstract- Performance-based engineering methods have been recently developed for fire hazards providing enhanced prediction of the structural response and subsequent damage and loss assessments. In this context, this paper presents an overview of the fire damage and loss assessment of reinforced concrete structures under fire hazards by utilizing performance-based assessment methodologies. Hence, fire hazard models and the stages of fire initiation, propagation, and decay are discussed. Then, a six-step methodology is formulated comprising hazard modeling, structural modeling, performance modeling, collapse fragility assessment, building response assessment, and loss assessment. Finally, the methodology is illustrated by utilizing a four-story building model built in the OpenSEES framework.

Keywords- Buildings, Damage, Fire-hazard, Performance-based, Reinforced-concrete

1 Introduction

Fire hazard-related accidents can significantly damage the structure and could result in catastrophic failure due to extreme heat that could result in structural and material degradation [1]. The building structures could experience a fire hazard during the service life of a structure and hence it is crucial to understand the fire behaviors during an event of a fire hazard. The fire hazard may significantly enhance the degradation process of the structures and could result in socioeconomic and environmental consequences increasing the risk of the built environment [2].

Performance-based methods could be utilized to assess the structural response to the fire hazard and subsequently assess the damage to the buildings. The damage assessment requires fire hazard modeling and structural modeling to determine the engineering demand parameters including drifts, and deformations, among others resulting from the additional loads due to fire hazards. Furthermore, fire hazard scenarios also reduce the structural strength of the building that also needs to be addressed. The structural analysis of the structure given fire hazard scenarios can then be correlated with the damage to the building by utilizing fragility functions that are lognormal cumulative distribution functions providing the probability of damage to the building structure given fire hazard scenario [3]. The fragility functions are represented for different damage states including slight, moderate, extensive, and complete damage states. Also, fragility functions can be developed for collapse state or irreparable states to assess the repair, maintenance, or demolition conditions in the post-hazard conditions [4].

Concrete is a relatively durable material that can comparatively perform well under fire scenarios due to several reasons including its low thermal conductivity and relative incombustibility as compared to other structural materials such as timber, wood, and steel, among others. Furthermore, reinforced concrete structures that are designed according to the recent building design codes and according to the required construction quality with adequate reinforcement steel can reasonably perform well in the event of a fire by redistributing the loads from the damaged part of the structure to the relatively undamaged part of the structure due to reinforcement yielding and stiffness degradation of the structural members [5].

Subsequently, the probability of complete collapse of the reinforced concrete structures is relatively minimized. Nonetheless, reinforced concrete structures still could witness severe damage that may significantly affect the functionality of the structure and often require subsequent rehabilitation or repair. Post-hazard repair may be economically viable as compared to demolition of structures and building new construction. Furthermore, socioeconomic and environmental consequences resulting from new construction are significantly higher as compared to repair of the structure. Also, considering the economic constraints of developing countries, repair and rehabilitation of reinforced concrete structures in the post-hazard condition is often seen as a viable approach. Nonetheless, before making these decisions, a comprehensive assessment of the structures under fire hazard scenarios needs to be considered [6].

In this context, this paper presents the overview of the performance-based assessment approach to assess the structural response of reinforced concrete buildings under fire hazards and subsequent repair and rehabilitation strategies that could be utilized depending upon the level of damage to the building. The framework is provided by utilizing a four-story building under a fire hazard scenario. The subsequent section discusses the performance-based assessment methodology for fire hazard scenarios to assess the damage to reinforced concrete buildings.

2 Performance-based methodology for fire hazard

The performance-based methodology originally proposed for the seismic hazard scenarios to assess the structural response, damage to the buildings, and subsequent socioeconomic and environmental consequences can be utilized to assess the fire hazard scenarios with modifications. Conventionally, performance-based methodology requires steps including hazard assessment, structural analysis, damage assessment, and consequence assessment. Herein, we propose a performance-based assessment framework for fire hazard assessment that consists of six steps as shown in Figure 1. The first step includes fire hazard modeling which is the crucial step in the performance-based methodology. Then, a structural model is built to assess the structural response given the fire hazard scenario. Also, building performance models are developed for considered structural and non-structural components of a building to assess the damage states for all the components given the fire hazard. The collapse fragility is utilized to determine and probability of collapse of a structure and structural response is utilized to determine engineering demand parameters given fire hazard and structural model. Finally, component damage, repair costs, and total costs of damage can be determined in the loss assessment step. A detailed discussion of the individual steps can be seen in the study conducted in.

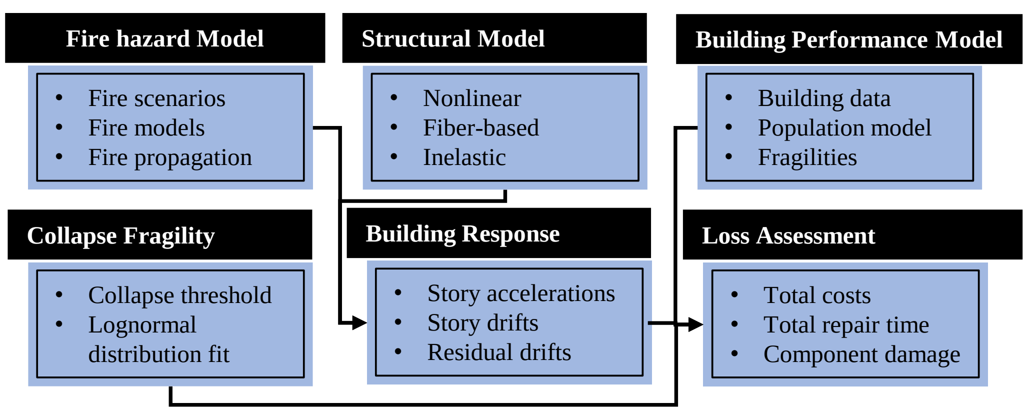

Figure 1: Performance-based assessment methodology for damage and loss assessment given fire hazard scenarios

3 Fire hazard modelling

The fire models vary from considering just a fully developed fire assuming that structural fire resistance of structures under fire only depends on the post-flashover fire. Nonetheless, recent models have been developed that considered localized and traveling fire scenarios that are in the initial stages, spreading stages, or the pre-flashover phase. However, most of the data gathered related to the stages is based on empirical and experimental evidence. Subsequent analytical formulations developed are also based on the empirical evidence gathered from the real-life fire hazard scenarios observed during and after a fire hazard event. There has been a recent trend to realistically model the fire hazard scenarios to accurately predict the structural analysis and damage under fire events. Realistically representing fire hazard load requires some key issues to be resolved including defining the boundary conditions for the heat transfer of fire load, and accurately modeling the temperature differences around the structural components, fire durations, and geometry of burning conditions, among others [7]. The most important parameter to determine the structural damage of the buildings under fire hazard is the fuel load. The fuel load can be regarded as the structural load that can be utilized to determine the structural response by utilizing performance-based assessment methodologies. The fire hazard can be divided into several stages including pre-flashover and post-flashover as shown in Table 1.

Table 1 Fire stages for the fire hazard in a compartment

Investigated time	**Pre-Flashover**	**Post-Flashover**
First part	Initiation	Fully developed
Second part	Growth	Decay

The pre-flashover fire stages include the initiation stage and the growth stage as shown in Figure 2. After the growth phase, a flashover threshold is reached when the fire gets fully developed and enters a post-flashover stage where it remains fully developed for a given time and then starts to decay. Various fire hazard models exist that could be utilized in performance-based engineering for structural fires including zone models, traveling fire models e.g., Clifton's model and Rein's model, ETFM model, among others [8]. For instance, traveling fire models representing near and far field developed by the Reins model is shown in Figure 3.

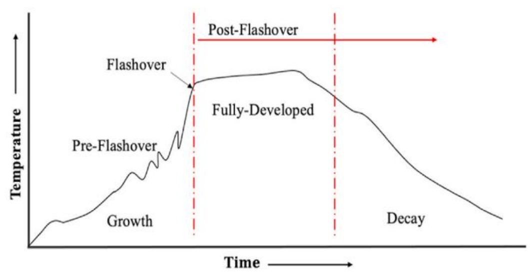

Figure 2: Fire stages for the fire hazard in a compartment

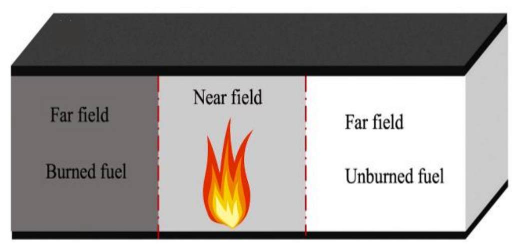

Figure 3: Travelling fire representing the near and far field [7]

4 Loss assessment

The finite element structural models are required to assess the structural response of reinforced concrete structures under fire hazards. For that purpose, nonlinear structural models could be built that are capable of modeling the post-yield behavior of structures. In this context, an OpenSEES model is built that is capable of assessing the nonlinear structural response of the considered structure. The model is utilized to determine engineering demand parameters that can then be correlated to assess the structural damage. For instance, structural response a four-story building model under increasing fire hazard can be seen illustratively in Figure 4.

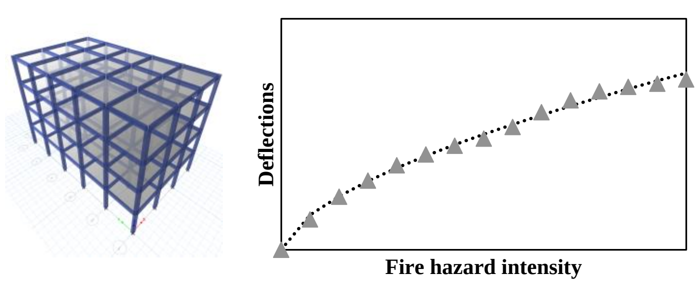

Figure 4: Structural response in terms of story deflections under increasing fire hazard

The structural fire response of a building by utilizing the finite element models can then be utilized to assess the structural damage of the building by utilizing fragility functions that can provide the probability of a damage state given the fire load intensity [9]. This information can be utilized to assess the losses resulting from the considered fire hazard scenario and for the subsequent repair and rehabilitation works. An illustrative representation of the fragility function and loss assessment given the fire hazard is shown in Figure 5.

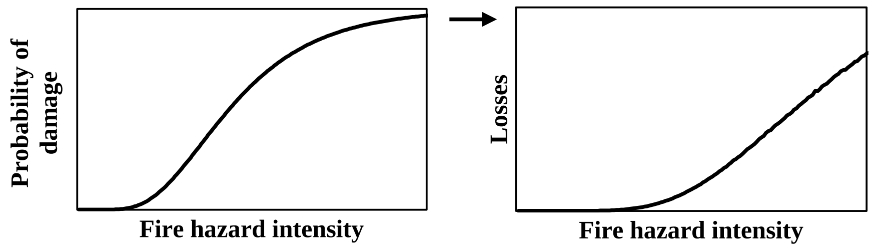

Figure 5: Structural response in terms of story deflections under increasing fire hazard

5 Conclusion

This paper provides an overview of fire damage assessment of reinforced concrete buildings under fire hazard by considering performance-based methods. In this context, a performance-based approach is formulated that consists of six steps including fire hazard modeling, structural modeling, building performance model, collapse assessment, building response assessment, and loss assessment. Subsequently, fire hazard modeling of the performance-based assessment methodology and discusses various stages of the fire and different fire hazard models utilized in the performance-based assessment methodology. Finally, the loss assessment part is discussed by utilizing a four-story reinforced concrete building as an illustrative example.

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