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Post-earthquake fire simulation considering overall seismic damage of sprinkler systems based on BIM and FEMA P-58

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ABSTRACT

In this study, a post-earthquake fire simulation method considering the seismic damage of sprinkler systems is proposed to quantitatively assess the impact of the spread of fire owing to such damage. First, a modeling approach is designed to convert a building information model (BIM) to a computational fluid dynamics (CFD) model, thereby creating a high-fidelity model of a building and its sprinkler system in the fire dynamics simulator (FDS) program. Second, a probabilistic method for predicting the seismic damage of sprinkler components (including pipes and drops) is developed according to the next-generation performance-based design method in the Federal Emergency Management Agency (FEMA) P-58 report. Finally, using the seismic damage of the components, a prediction method is proposed to assess the overall seismic damage of the sprinkler system based on a tree data structure. A post-earthquake fire simulation of a six-story dormitory building is performed using the proposed method. The results indicate the level of effect that the seismic damage of the sprinkler system will have on the spreading of a post-earthquake fire. The outcome of this study provides an important practical method for quantitatively assessing the effect of the seismic damage of sprinkler systems on a post-earthquake fire.

1. Introduction

1.1. Research background

Post-earthquake fire is a common secondary hazard induced by earthquakes [1]. Historically, some severe post-earthquake fire events have occurred in major cities worldwide, such as those in San Francisco in 1906 [2], Tokyo in 1923 [3], and Osaka and Kobe in 1995 [4]. Specifically, in case of the Kobe earthquake, the area burnt by the post-earthquake fire was approximately 100 ha, the largest burned area since World War II [4]. The Great East Japan Earthquake in 2011 induced 278 post-earthquake fires, which aggravated deaths and economic losses [5]. Therefore, post-earthquake fire is a significant issue in earthquake disaster mitigation.

Fire sprinkler systems are required to be installed in most modern-day buildings as one of the most important fire-fighting measures. However, sprinkler systems can get damaged during an earthquake, e.g., in the Kobe earthquake, the ratio of damaged sprinkler systems was 40.8% [6]. To date, several studies have been performed to predict the seismic damage of sprinkler components [7–9], but only limited work has been conducted to quantitatively assess the effect of such damage on the post-earthquake fire spreading process. Sekizawa et al. [6] proposed a simplified method to estimate the potential impact caused by damaged sprinkler components on the spreading of a fire. However, because the overall seismic damage of the sprinkler system is not considered in their work, the estimated impact is difficult to be accurately quantified. Consequently, a method considering the overall seismic damage of sprinkler systems is required to quantitatively assess the influences on post-earthquake fires.

1.2. Research challenges

A post-earthquake fire simulation considering the overall seismic damage of sprinkler systems can address the above problem. To implement such a simulation, the following three key challenges need to be addressed: (1) Creation of a high-fidelity numerical model of a sprinkler system using a fire simulation program (e.g., Fire Dynamics Simulator, FDS [10]). Note that a sprinkler system consists of numerous components (e.g., drops and pipes) of different sizes and at various spatial locations, and is therefore quite complex. An efficient model

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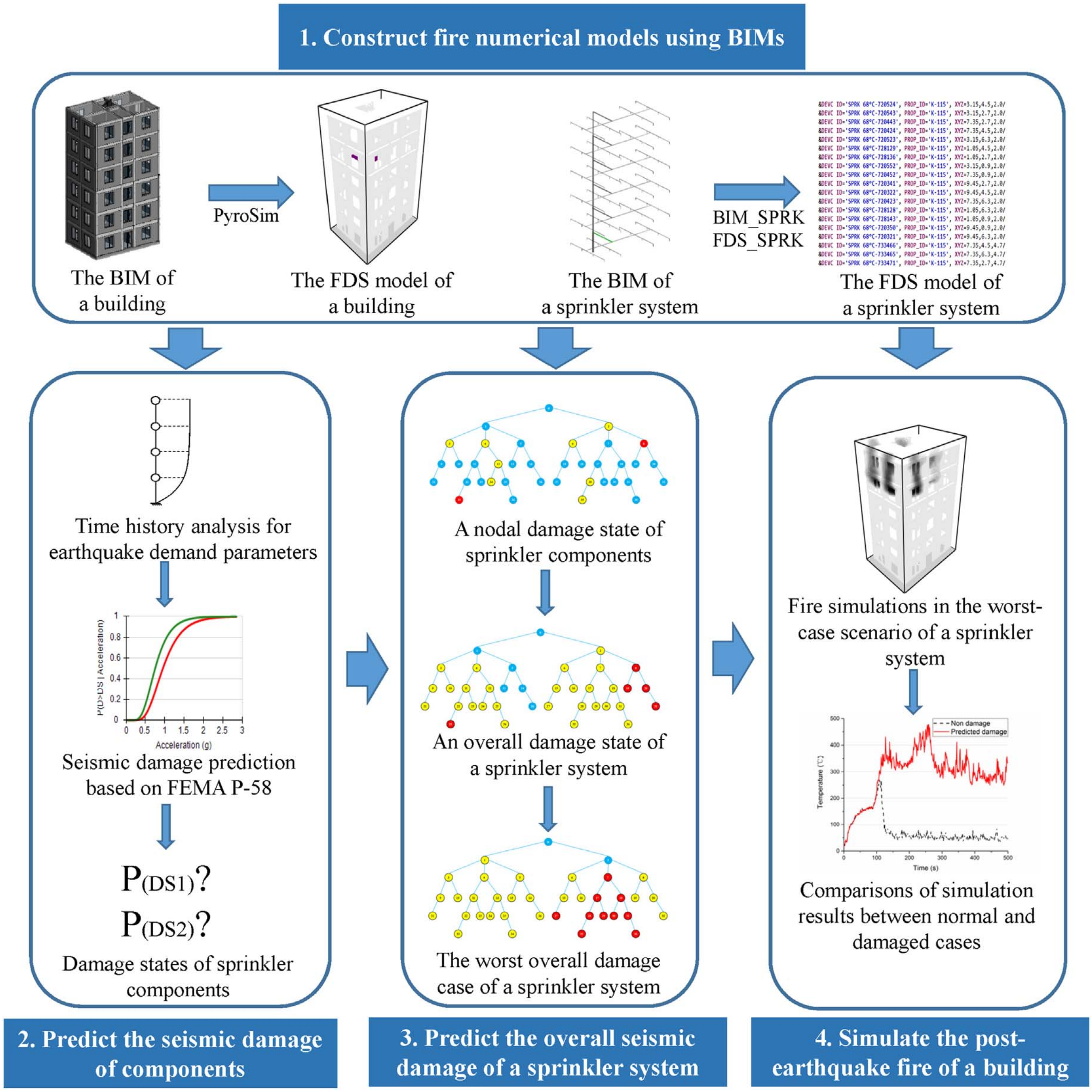

Fig. 1. Framework of the proposed simulation method.

generation method that replicates this complex system is desirable as it will drastically facilitate the fire simulation. (2) Accurate prediction of the seismic damage of the components of a sprinkler system, considering the randomness of such damage. (3) Prediction of the overall seismic damage of a sprinkler system based on damaged sprinkler components.

To deal with Challenge (1), the building information modeling (BIM) technology [11] can be adopted to construct high-fidelity information models of sprinkler systems. Specifically, some existing BIM programs (e.g., Revit and MagiCAD) provide useful libraries with abundant sprinkler components [12,13] with which a refined three-dimensional (3D) sprinkler system can be easily built [14]. In addition, such information models of sprinkler systems can provide detailed attribution data (such as component types and spatial coordinates) required for generating the computational fluid dynamics (CFD) models for fire simulations. Existing software (e.g., PyroSim) can convert a BIM model to a CFD model [15], but such a model conversion is mainly focused on the geometric information, and a large amount of the attributions in the BIM model are lost after the conversion. It is worth noting that some attributions that are essential for fire simulations (e.g., the materials of the building components) must be retained. Therefore, it is important to develop a model conversion method that transfers all the attributions to the fire simulations.

Regarding Challenge (2), various studies have been performed to predict the seismic damage of the components of a sprinkler system [16–19]. Among these, the Federal Emergency Management Agency (FEMA) P-58 report [20,21] published by FEMA, USA can be used as a guideline to predict the seismic damage probabilities of sprinkler components. FEMA P-58 is a methodology for the seismic performance assessment of individual buildings, which includes the implementation methodology and data that are demanded by the methodology. These data have been collected from numerous seismic experiments and simulations over a ten-year work effort [20,21]. In particular, FEMA P-58 provides various fragility curves for different types of sprinkler components. The randomness of the seismic damage of sprinkler systems is also considered in the fragility curves. In addition, the FEMA P-58 methodology is not region-specific because the proposed seismic performance assessments are dependent on the engineering demand parameters (EDPs), which can be calculated for any earthquake [22].

For Challenge (3), no perfect solution is reported in the literature yet. Till date, the research has primarily focused on the seismic damage prediction for sprinkler components [6–9,16–21], whereas the seismic