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Impact of aftershocks and uncertainties on the seismic evaluation of non-ductile reinforced concrete frame buildings

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ABSTRACT

There is increasing interest in sophisticated seismic performance evaluation that encompasses the ability to incorporate aftershock hazard. This paper presents a methodology to examine the seismic performance of two non-ductile reinforced concrete frame buildings with consideration of the interaction between the aftershocks and various post-quake decisions. The assessment investigates the direct loss, downtime, fatalities, and total loss for each of the buildings. A total of 60 recorded mainshock–aftershocks sequences are utilized. The variations in results between the method with and without consideration of aftershocks are compared. The characteristics of mainshock–aftershock sequences which may be the cause of the difference are discussed and identified. Important uncertainty sources for the post-quake decisions are also investigated through a sensitivity study.

1. Introduction

Current seismic performance assessment methods allow the estimation of the direct loss (repair cost), downtime (non-operational time), and fatalities of buildings with consideration of mainshocks. However, a number of earthquake aftershocks can occur following the strike of a mainshock, many of which also have large magnitudes and intense ground motions (e.g. [1–4]). They have also been reported to have caused additional damage to buildings that survived a mainshock [5–7]. Thus, based on these evidences, it can be surmised that aftershocks can increase the direct loss, downtime, and fatalities of buildings during an earthquake sequence.

Previous preliminary studies on aftershocks revealed that the additional building damage and loss due to aftershocks can be significant [8–11]. However, many of these studies used simplified methods and building performance models with limited ability to represent the actual seismic performance of buildings. In addition, they generally focused the direct loss without insight investigation of downtime and fatalities, which are also of great interest to engineers and building owners [12]. Finally, they did not incorporate post-quake decisions which may have a substantial influence on the seismic performance of buildings and have been considered in many current mainshock based assessment methodologies [12–14]. The post-quake decisions mainly include: (1). whether the building will collapse; (2). whether the occupants will be evacuated; (3). which kind of placard will be tagged to the building after the safety evaluation; (4). whether the building will be repairable; (5). whether the repair cost will be too high that the owner will decide to replace it instead.

This study examines the influence of aftershock hazard and post-quake decisions on the seismic performance of two non-ductile reinforced concrete (RC) frame buildings in term of direct loss, downtime, and fatalities, which are extensively recognized as the major metrics of seismic performance [12,13]. The detailed building models and analysis methods are employed in a manner consistent with the contemporary mainshock based assessment methodologies [12–14]. The characteristics of mainshock–aftershock (MS–AS) sequences that have the potential to cause additional direct loss, downtime, and fatalities, are identified. A sensitivity study is also performed to examine the influence of the uncertainties for the post-quake decisions on the seismic performance metrics.

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2. Post-quake decisions and their interaction with aftershocks

Post-quake decisions depend on human factors as well as the post-quake condition of the building. All these post-quake decisions play an important role in the mainshock based seismic performance assessment except the decision of whether the occupants will be evacuated, since evacuation will have no impact on the seismic performance if no following aftershocks are considered [12–14]. When aftershock hazard is considered, these post-quake decisions may become more important because they have an interactive influence with aftershocks, as introduced in the following paragraphs.

Fig. 1 presents the procedure for the post-quake decisions when only a mainshock is considered (solid lines) and when a mainshock and aftershocks are all considered (solid lines and dash lines). For the scenario without aftershocks, the building is initially determined to have either collapsed or survived after the mainshock. If the building collapses, the debris will be cleared and a replacement building is assumed to be built. If the building survives the mainshock, occupants will make the decision whether to evacuate based on the building damage condition. Then structural experts will perform a safety evaluation of the building, leaving a placard indicating "inspected", "restricted use", or "unsafe" (also known as green, yellow, or red tagged) [13,15]. The preparation time for

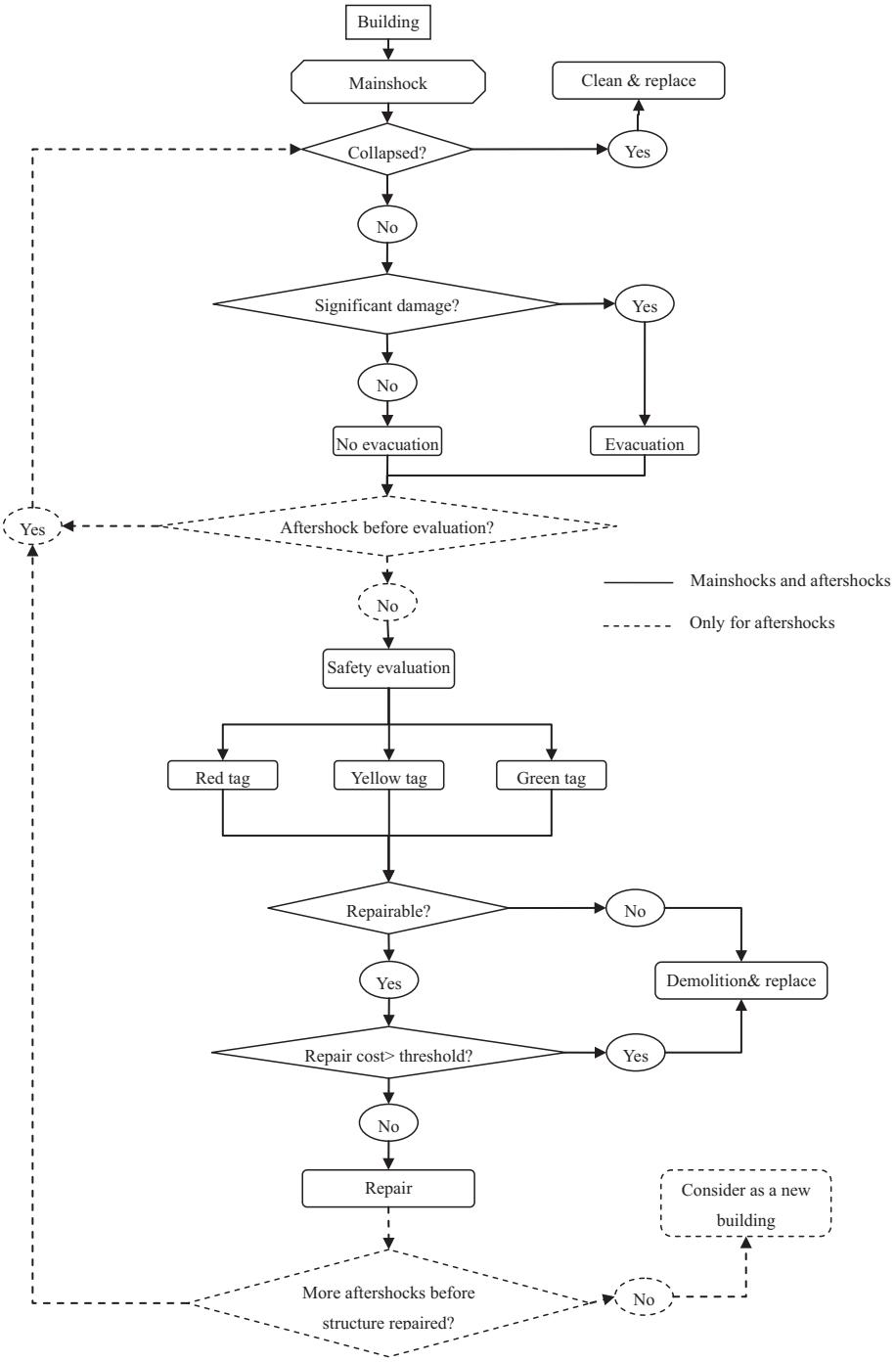

Fig. 1. Flowchart of post-quake decisions.