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Bayesian Network for Structures Subjected to Sequence of Main and Aftershocks

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1. Introduction

An earthquake event may yield a strong ground motion followed by several aftershocks. In general, aftershocks are not as strong as the main shock, so have been considered less dangerous compared to main shocks. However, since a strong aftershock event can occur, the risk caused by aftershocks can be significant especially if structures are damaged during the main shock event. Therefore, it is necessary to perform the seismic risk analysis using sequences of main and aftershock with the effects of main-shock damage considered. Such process should incorporate many factors such as the characteristics of main and aftershocks, and state of the structure under the sequence.

Since there are not enough real records on sequences of main and aftershocks, artificial ground motions are used in this research. The performance of a nonlinear single degree of freedom (SDOF) system with hysteresis described by a Bouc-Wen class model is investigated using the generated ground motions. The structural damage from the main shock is described by stiffness degradation of the Bouc-Wen class model. Finally, Bayesian Network (BN) is constructed based on the results of the time history analyses and the information of the ground motions. The fragility, i.e. the conditional failure probability given seismic intensity, is developed for main- and aftershock sequences using the developed BN.

2. Methods and Results

2.1 Artificial Sequence of Main and Aftershocks

To incorporate effects of the characteristics of the specified earthquake events and site, this study generates artificial ground motions using the approach in [1]. Moreover, sequences of main and aftershock are simulated based on the relationship between main and aftershocks [2]. Figure 1 shows an example sequence of main and aftershock generated in this study.

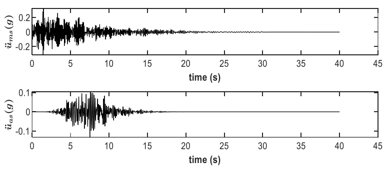

Fig. 1. An example sequence of main and aftershock

The earthquake and site characteristics are described by rupture type, earthquake magnitude, source-to-site distance, and shear-wave velocity of the site, which are denoted by $F, M, R,$ and V_s respectively. From these four values, the parameters of the stochastic model, i.e. $(\bar{I}_a, D_{5-95}, t_{mid}, \omega_{mid}, \omega', \zeta_f)$ can be estimated [1]. Using these model parameters, artificial ground motions having similar characteristics with real records, e.g. non-stationarity of the intensity and frequency content, can be generated. These model parameters are also used in BN to relate seismic intensity, e.g. PGA, and the response of system, e.g. damage measure (DM).

2.2 SDOF Hysteresis Model

As an illustrative example, a nonlinear SDOF system with damping ratio 0.07 and the natural period 1.3 seconds is studied [3]. To describe the damage caused by main shock, a Bouc-Wen Class model [4] in Figure 2 is used. In this study, the stiffness degradation is only considered although strength degradation and pinching effect can be described by the model. Nonlinear time history analysis is performed using generated main and aftershocks. The time history analysis is performed sequentially with a time gap to incorporate residual displacement induced by the main shock (see Figure 3).

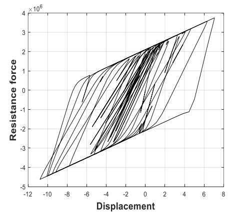

Fig. 2. Example hysteresis with stiffness degradation

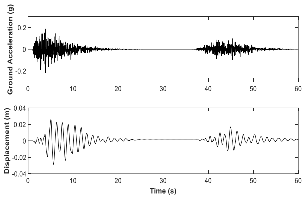

Fig. 3. Sequence of main and aftershock (top) and the results of nonlinear time history analysis (bottom)

2.3 Bayesian Network

BN is a widely-used methodology for compact modeling of joint distribution of random variables. BN provides intuitive description of the relationship between random variables by a directed acyclic graph (DAG). In the graph, nodes and directed arcs respectively describe the random variables and their statistical dependences. Moreover, BN enables probabilistic inference given assumed or observed states of some random variables.

The fragility for upcoming aftershocks depends on the post-main-shock state of system as well as the properties of main and aftershocks. Therefore, numerous variables need to be considered. The BN structure proposed for this problem is shown in Figure 4. The Matrix-based Bayesian Network [5] is used for efficient modeling and flexible inference by the BN.

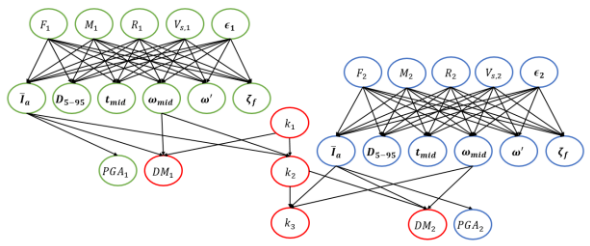

Fig. 4. Bayesian Network structure proposed for structures under sequences of main and aftershocks

2.4 Compound Fragility for Main and Aftershock Sequences

The fragility curve compounding effects by main and aftershocks can be developed by the methodology discussed above (see Figure 5). For several selected ranges of main shock PGA (PGA_{MS}), the fragility curves are plotted as functions of peak ground acceleration (PGA) of aftershock (PGA_{AS}). Though the differences between the curves are small, fragility tends to increase as PGA_{MS} increases. This shows the significant effect of stiffness degradation during the main shock on seismic performance during the aftershocks.

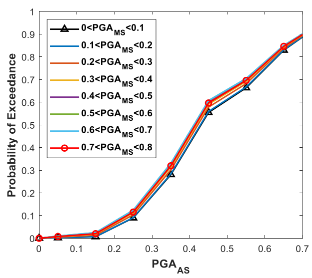

Fig. 5. Fragility for PGA of main and aftershock

2.5 Aftershock Fragility for Earthquake Scenarios

Properties of a main shock and its aftershocks show probabilistic relationships. One of the available models to describe the relationship is the branching aftershock sequences (BASS) model [2]. For some selected scenarios of main shock (Table 1), the characteristics of aftershock are estimated using the BASS model to derive the corresponding fragility (see Figure 6). As expected, the larger magnitude (or shorter distance to the epicenter) the main shock has, the more vulnerable the structure is with respect to aftershock excitations.

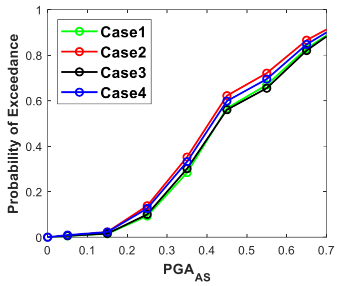

Fig. 6. Aftershock fragility for earthquake scenarios in Table 1

Table 1: Scenarios of main shocks

	M_1	R_1 (km)
Case 1	6	20
Case 2	8	20
Case 3	6	60
Case 4	8	60

3. Conclusions

By constructing BN models based on nonlinear time history analysis of structures under generated sequences of main- and aftershock excitations, the compound fragility can be computed with the effects of main-shock-induced structural degradations fully considered.

Acknowledgements

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