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Accounting for Downtime Effects in Resilience-Based Highway Network Restoration Scheduling

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Abstract : Highway networks play a vital role in post-disaster recovery for disaster-damaged areas. Damaged bridges in such networks can disrupt the recovery activities by impeding the transportation of people, cargo, and reconstruction resources. Therefore, rapid restoration of damaged bridges is of paramount importance to long-term disaster recovery. In the post-disaster recovery phase, the key to restoration scheduling for a highway network is prioritization of bridge-repair tasks. Resilience is widely used as a measure of the ability to recover with which a network can return to its pre-disaster level of functionality. In practice, highways will be temporarily blocked during the downtime of bridge restoration, leading to the decrease of highway-network functionality. The failure to take downtime effects into account can lead to overestimation of network resilience. Additionally, post-disaster recovery of highway networks is generally divided into emergency bridge repair (EBR) in the response phase and long-term bridge repair (LBR) in the recovery phase, and both of EBR and LBR are different in terms of restoration objectives, restoration duration, budget, etc. Distinguish these two phases are important to precisely quantify highway network resilience and generate suitable restoration schedules for highway networks in the recovery phase. To address the above issues, this study proposes a novel resilience quantification method for the optimization of long-term bridge repair schedules (LBRS) taking into account the impact of EBR activities and restoration downtime on a highway network’s functionality. A time-dependent integer program with recursive functions is formulated for optimally scheduling LBR activities. Moreover, since uncertainty always exists in the LBRS problem, this paper extends the optimization model from the deterministic case to the stochastic case. A hybrid genetic algorithm that integrates a heuristic approach into a traditional genetic algorithm to accelerate the evolution process is developed. The proposed methods are tested using data from the 2008 Wenchuan earthquake, based on a regional highway network in Sichuan, China, consisting of 168 highway bridges on 36 highways connecting 25 cities/towns. The results show that, in this case, neglecting the bridge restoration downtime can lead to approximately 15% overestimation of highway network resilience. Moreover, accounting for the impact of EBR on network functionality can help to generate a more specific and reasonable LBRS. The theoretical and practical values are as follows. First, the proposed network recovery curve contributes to comprehensive quantification of highway network resilience by accounting for the impact of both restoration downtime and EBR activities on the recovery curves. Moreover, this study can improve the highway network resilience from the organizational dimension by providing bridge managers with optimal LBR strategies.

Keywords : disaster management, highway network, long-term bridge repair schedule, resilience, restoration downtime
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