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Adaptive Decision Framework for Civil Infrastructure exposed to Evolving Risks

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Abstract

Adaptive decision-making (ADM) is a structured process of learning, improving understanding, and ultimately adapting management decisions in a systematic and efficient way, aimed at reducing uncertainties over the course of the management timeframe. This approach holds a great potential for dealing with the challenges faced by civil infrastructure facilities, especially those exposed to evolving risks caused by changes in environmental and urban settings, evolving expectations and preferences of the public, tightening budgets, and unpredictable political circumstances over their lifetime. This paper suggests ADM as a way of continuously reevaluating the risks and providing more adaptive and flexible management actions to enhance infrastructure resilience under dynamic changes and evolving conditions. The proposed ADM is illustrated with a benchmark problem based on a testbed residential community in Kathmandu, Nepal to explore the effect of incremental building expansion on the seismic risk to a community and examine the feasibility and effectiveness of ADM in improving resilience.

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Keywords: Resilience; Decision-making; Adaptive management; Earthquake Engineering; Risk assessment; Building expansion; Structural Engineering

1. Introduction

Decisions aimed at ensuring the adequate performance and operational integrity of civil infrastructure exposed to

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natural hazards have strong implications to the health and financial well-being of the communities that they serve. Quantitative risk-informed decision methods are required to assess the effectiveness of engineering strategies – design, maintenance and rehabilitation – in mitigating the risk to civil infrastructure over their service periods (through risk assessment) and to establish investment priorities within financial constraints (through optimization techniques). Although current probabilistic risk assessments have enabled informed management and decision-making of civil infrastructure, in many cases, such analyses are static, focusing more on understanding current risks. Disaster risks to civil infrastructure, however, have been increasing rapidly due to continually changing urban environments, increasing operational and social demands, technology development, and global climate change. For example, incremental building expansion in many developing countries plays a significant role in increasing their seismic collapse vulnerability [1]. Also, in recent years, there has been growing evidence that global climate change may result in more frequent and increasingly severe extreme natural hazard events, such as hurricanes, tsunami, floods, droughts, etc., which trigger more damage to civil infrastructure and the associated economic and human losses [2]. In this context, disaster risks to civil infrastructure are not static, and continuous reevaluation over time is required to move towards a more resilient future.

Resilient development has become a new standard for civil infrastructure design and maintenance, as well as community development. Its interpretation may vary depending on its application, but seismic resilience of system/community often is thought of as including three measures: reduced failure probabilities, reduced consequences from failures, and reduced time to recovery [3]. This paper places emphasis on the first two measures of resilience, which relate to pre-disaster mitigation, by enabling decision-making process to incorporate the effects of dynamic conditions and evolving risks in life-cycle performance assessment and to become more adaptable to those changes and surprises. Due to our incomplete knowledge of dynamic conditions in hazard, exposure and vulnerability (and the associated uncertainties), unintended consequences may occur and challenge the resilience of civil infrastructure systems and the community functions that they support. Adaptive decision-making (ADM) arises out of the need for flexible and responsive approaches to managing the risk to civil infrastructure exposed to changing environments. Such decision methods will be able to respond successfully to evolving risks and future changes and to achieve their short/medium-term and long-term resilience objectives.

To begin with, this paper briefly introduces an adaptive decision method as a way of continuously reevaluating the risks and, where necessary, updating decisions over time. The proposed ADM is demonstrated based on a changing urban environmental condition, where incremental building expansion and population growth occur simultaneously, to show its feasibility in reducing seismic collapse vulnerability of buildings and eventually improving the resilience of a community.

2. Adaptive decision-making and its application: a residential community of Kathmandu Valley, Nepal exposed to evolving risks due to increased exposure and vulnerability due to growing populations

2.1. Adaptive decision-making

Decision-makers are challenged by inherent uncertainties and an incomplete knowledge base, especially when making decisions involving changing conditions. Surprises and changes lead decision-makers to adjust plans and strategies as new information accumulates over time and to incorporate improved understanding in risk-informed decision-making. Adaptive management is a structured process to make this learning in a systematic and efficient way, aimed at reducing uncertainties. The goal of adaptive management is to improve decision-making through learning processes. It provides flexible and responsive management protocol, which evolves over time through an iterative process of planning, monitoring, and adjusting strategy (as shown in Fig. 1): goals and objectives are set; the management action is implemented; the effects of the action are monitored and evaluated to collect new information; and the action is adjusted based on monitoring results [4]. Through this process, adaptive management explicitly recognizes evolving conditions and reduces the uncertainties by incorporating lessons learned into future decisions through explicit mechanisms for linking new information from monitoring to the decision.