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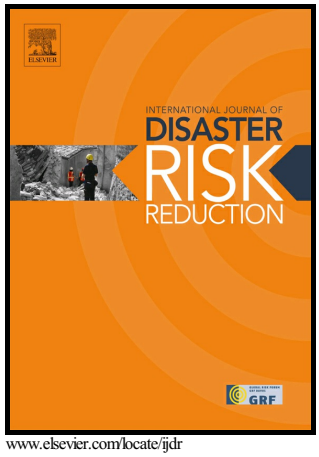

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Risk, Reliability, Resilience (R^3) and Beyond in Dam Engineering: A State-of-the-Art Review

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Abstract

Dams are critical infra-structures whose their failure could leads to high economic and social consequences. For this reason, application of quantitative risk analysis has gained extensive attention in recent years. Dam safety management has become an indispensable part of all dam engineering projects worldwide. The concept of risk is heavily tied to probabilistic methods. From an engineering point of view, a clear definition of the terminologies involved in dam safety, and a comprehensive state-of-the-art review of the current literature are the starting points towards an effective risk-based approach. The first part of this paper provides a systematic review on the fundamental elements in uncertainty quantification. Then, different terminologies in risk-based dam safety are explored and their inter-connections are discussed. More than 300 papers are summarized, and several tables and conceptual plots are used for extra clarification. Since no such a paper is ever published, hopefully this can unify all the future activities and improves our understanding from probabilistic risk analysis.

Keywords: Dams, Sustainability, Fragility, Probabilistic, Failure, Safety, Hazard

1. Introduction

Although dams provide significant benefits to the society, their impacts on the surrounding environment cannot be neglected, which include resettlement, socio-economic impacts, environmental concerns, sedimentation issues, and safety aspects [1]. These concerns should be reduced through a set of inter-organizational planning and the incorporation of different mitigation techniques. Moreover, the failure of dams, although rare, can be catastrophic and may cause immense damage and loss of life. Therefore, the society demands an increase in safety of hydropower systems. The most effective way to address these expectations is to integrate dam's design, construction and operation in the framework of systematically risk management including the aspects such as sustainability, resilience, and public participation [2].

Hydropower is the biggest source of the renewable energy in the US, as of 2017, and over 90,580 dams operate across the country. Based on the Federal Emergency Management Agency (FEMA) classification, the overall number of high-hazard dams was about 15,500 as of 2016, while those considered deficient high-hazard has climbed to about 2,200 [3]. Figure 1 shows a map of all the country's dams. The average age of dams in the US is over 56 years old according to the American Society of Civil Engineers (ACSE) 2017 *Report Card for America's Infrastructure*. Dams as a whole got a "D" grade in the report card. By 2025, 70% of dams in the US will be over 50 years old. It is estimated that it will require an investment of nearly $45 billion to repair aging, yet critical, high-hazard potential dams. It is not surprising that the Association of State Dam Safety Officials (ASDSO) estimates that it will require a combined total investment of $64 billion to rehabilitate the nation's non-federal and federal dams. The US Army Corps of Engineers (USACE) estimates that more than $25 billion will be required to address Corps-owned dam deficiencies, while the US Bureau of Reclamation (USBR) will need to invest $2 billion over the next 15 years to upgrade 20 of its dams. Given the limited budget for repair and maintenance, national codes require a comprehensive emergency action plan for assessment of dam safety [5], [6], [7], and [8].

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