ANALYSIS METHOD FOR MULTI-HAZARD PROTECTION OF STRUCTURES FROM EARTHQUAKE, WIND, BLAST, AND FIRE

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ABSTRACT

Multiple hazards, such as, earthquakes, strong winds, blasts, and fire outbreaks have caused extensive global devastations to civil structures since centuries in terms of physical and socio-economic losses. The rapid growth of infrastructure advancements in the last few decades has significantly increased the vulnerability of the structural systems under these multiple hazards. The increased vulnerability due to the multi-hazard (MH) scenario has been causing a major setback for the scientifically prospering society, thereby resulting in significant hindrance to the socio-economic developments. Although, scientific expertise has been developed to safeguard the existing and new constructed structures against a particular hazard, the new MH engineering is in evolving phase with limited knowledge in protection of structures against the MH scenario. A fundamental difference between the existing design approach and the new MH design approach is that the existing design guidelines, standards, and codes do not incorporate the integrated approach for all the exposed hazards, wherein the current design practice considers the hazards completely independent. In such scenario, the design is being governed by the controlling demand from the exposed hazards, which duly ignores the additional risk arising due to the other hazards. In this regard, the primary objective of the newly emerging MH engineering should consider addressing the effects of all hazard existent in the design life of structures. Hence,

the increased risks under the exposed MH scenarios should be addressed categorically, which calls for devising some efficient frameworks that incorporates the effects of the hazards for achieving a safe and hazard-resilient built environment.

In order to develop efficient and fundamental approaches, it is imperative to recognize the distinguished features of the hazards occurring in a lifetime of a structure. Extreme natural hazards, such as, earthquake and strong winds, are mutually exclusive and collectively exhaustive events, as the probability of simultaneous occurrence for the hazards is zero. Hence, structures exposed to MH scenario of earthquakes and strong winds, experience no more than a particular hazard at one time. Existing approaches are unspoken of the standard risks of exceedance for identified limit states in regions where only earthquakes or winds occur. Moreover, the occurrence of fire outbreaks after an explosion by blast or an earthquake induce significant complexities in the system, as assessment strategies for such cascading scenarios is extremely limited. Post-blast fire (PBF) is a cause-and-effect phenomenon of such explosion scenarios that results in catastrophic failure of structures through intricate cascading effects. In this regard, probabilistic methods have the potential to integrate the complexities in the system in order to quantify the vulnerability induced in the structure for obtaining reliable set of design values under MH scenario. Thus, the MH assessment strategy, therefore, will outstretch the prevailing methodology to ensure adequate safety and serviceability for structural resistance against such extreme forces.

In this PhD Thesis, the concepts of multi-hazard (MH) assessment are discussed with clear focus on the differences between the traditional and MH design. Three MH frameworks are discussed considering specific examples under each proposed framework, which included scenarios such as, earthquake and wind, and blast and fire. Moreover, specific terminologies, such as, ‘cascading hazard’ and ‘post-blast fire (PBF)’ are consistently used throughout the PhD Thesis, wherein the literature lacks clarity in the use of such terminologies.

The MH Framework-I is developed to discuss the increased vulnerability of the S-DOF and M-DOF systems, such as, 9-, 20-, and 25-storey steel buildings equipped with different passive control devices, such as, steel bracing (SB), fluid viscous damper (FVD), and viscoelastic damper (VED) and industrial steel frame structure, when the risks imparted by both earthquake and wind hazards are taken into account. The increased failure probability is discussed in terms of overlapped PDFs of the obtained responses under both the scenarios. Further, fragility curves are constructed to quantify the probability of failure for the considered M-DOF systems under the MH scenario of earthquakes and winds.

The MH Framework-II is developed for estimating the probable earthquakes and winds likely to occur in design life of a structure located in any region. The proposed framework is applied to evaluate the performance of a real-life base-isolated building and base-isolated high-rise buildings located in Japan. Since Japan experiences relatively more earthquake shocks and long duration wind throughout the year, the framework is intended to estimate the non-traditional response parameter, which is the fatigue response of the isolation systems (here, lead rubber bearing). This is achieved by constructing fatigue curve using Manson-Coffin empirical relation, that determines the fatigue performance of the LRBs. Moreover, high-cycle fatigue damage and residual fatigue life of the isolation devices are estimated using the developed MH Framework-II.

The MH Framework-III is developed to study the performance of structural systems, such as RC wall panel under the cascading scenario of PBF. The cascading hazard performance under fire loading scenario is further compared with the responses under normal fire scenario, and additional damaging effects caused by the cascading PBF are compared in probabilistic scale by constructing PDF and fragility curves. Finally, the fire resistance under the cascading hazard scenario of PBF and PEF are discussed and the difference in fire resistance rating is discussed.

Finally, guidelines and recommendations for design of structural systems under MH scenarios of natural and accidental/ manmade hazards, specifically in Indian context. The need and relevance of MH analysis and design of structures are elaborated, and key design strategies during design (service) life for normal civil engineering structures as well as critical infrastructures and facilities are recommended for major regions of India experiencing multiple hazards. Eventually, the proposed MH analysis and design framework tools can be used in other regions also, in order to have risk consistent approach for safety of structures under the extreme MH scenario.