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Probabilistic seismic vulnerability analysis of corroded reinforced concrete frames including spatial variability of pitting corrosion

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ABSTRACT

A probabilistic framework for seismic vulnerability analysis of corroded Reinforced Concrete (RC) frame structures is developed. An advanced nonlinear finite element modelling technique is used to accurately simulate the nonlinear behaviour of prototype corroded RC frames over their service life. Different sources of uncertainties including modelling uncertainties, geometrical uncertainties and spatial variability of pitting corrosion are considered through Monte Carlo simulation and using Latin Hypercube Sampling (LHS) technique. A set of new seismic damage limit states (SDLS) are defined accounting for multiple failure modes of the corrosion damaged frames by means of pushover analyses. The influence of corrosion on nonlinear dynamic behaviour of corroded RC frames is investigated through Incremental Dynamic Analysis (IDA) of proposed frame structures under 44 far-field ground motions. The impact of considering corrosion damaged SDLS, spatial variability of pitting corrosion, and record-to-record variability on seismic vulnerability of RC frames are explored and discussed in detail. It is concluded that disregarding the influence of corrosion on SDLS significantly underestimates the probability of failure of corroded RC frames. The analyses results show that spatial variability of pitting corrosion does not have a significant impact on global nonlinear behaviour and seismic vulnerability/reliability of corroded RC frames.

1. Introduction

The use of carbon steel as reinforcing bars in reinforced concrete (RC) structures located in coastal regions, leading to material deterioration due to corrosion phenomenon [1]. In the recent decades, corrosion of reinforcement is recognised as the primary reason for premature deterioration of RC structures and bridges. It is reported that among the different deterioration mechanisms in RC structures, chloride attack plays the main rule with approximately 66% participation [2].

Previous experimental studies show that, at material level, corrosion reduces yield strength and ductility of reinforcing bars [3,4], weakens bond strength between concrete and steel interface [5,6] and causes premature delamination and spalling of concrete cover [7]. Moreover, according to studies conducted by Kashani et al. [8], corrosion also affects inelastic buckling behaviour and low cycle fatigue degradation of reinforcing bars. Moreover, a considerable effort has been put to understand the structural performance of corroded RC components [9–12]. All the previous studies [9–12] confirmed that corrosion reduces ultimate capacity and ductility of tested specimens.

Along with the experimental studies, several numerical models have also been developed to simulate the structural behaviour of corroded RC components [13–15]. The majority of these numerical models are based on the uniform cross sectional area reduction of reinforcing bars [13,14] without accounting for the effect of pitting on mechanical properties of reinforcing steel and corrosion-induced damage in concrete. Dizaj et al. [16] developed a new modelling technique using nonlinear fibre beam-column element to simulate nonlinear behaviour of rectangular RC columns, and verified it against experimental test results. This model accounts for the combined effect of corrosion on mechanical properties (strength and ductility), inelastic buckling, and low cycle fatigue of reinforcing bars as well as crack cover concrete and damaged core confined concrete (due to corrosion of confining reinforcement), which is able to predict multiple failure modes of flexural RC columns.

Furthermore, chloride-induced corrosion of embedded reinforcing bars will result in reduction in structural performance of RC structures under seismic and service loads. Moreover, the coupled effect of seismic

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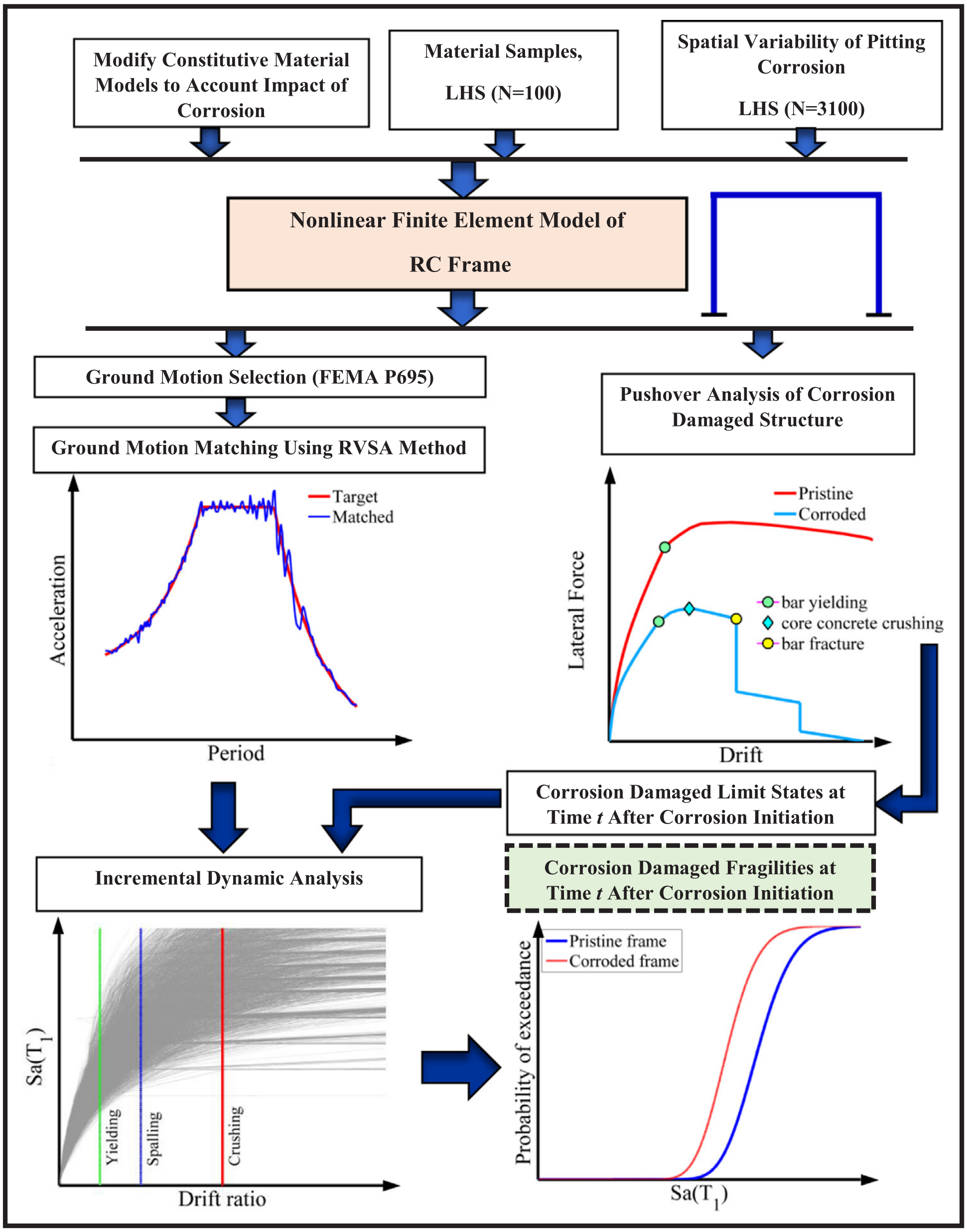

Fig. 1. Overview of the proposed probabilistic framework for fragility assessment of corrosion damaged RC frames.

excitation and aggressive agents may result in undesired failure mechanisms during the lifetime of RC structures [15]. Therefore, many researchers have studied seismic vulnerability of corroded RC components/structures [17–21]. The outcomes of previous studies indicate that corrosion significantly reduces the structural reliability of corroded structures. However, the effect of corrosion on multiple failure modes and seismic damage limit states (SDLS) of corroded RC structures have not been included in any of previous studies. Currently, there is no model to quantify the SDLS of corroded structures/components. In all the previous studies, the fragility assessment of corroded RC structures are conducted using the SDLS of uncorroded structures [21,22]. In a recent study by Dizaj et al. [16], it is shown that corrosion changes SDLS and failure modes of corroded RC components. Therefore, to realistically predict the long-term performance of RC structures exposed to corrosion induced degradation, there is a vital need for numerical models that account for time-variant SDLS.

The non-uniform variation of pitting corrosion along the length of corroded reinforcing bars (spatial variability) is the primary reason for reduction in yield strength and ductility. This issue has been addressed and included in numerical models in previous studies [16], but cross section area reduction of reinforcing bars is considered to be uniform along the length of RC components. However, considering spatial distribution of pitting corrosion along the length of corroded RC components at material level might influence the global seismic vulnerability of RC structures. In other words, disregarding the spatial variability of pitting corrosion in the analyses may result in underestimating the probability of failure of corroded RC structures [23]. A number of studies have focused on reliability assessment of corroded RC members using a probabilistic distribution function to model the location of maximum pitted depth along the length of RC beams [24]. However, there has not been any study to investigate the influence of spatial variability of pitting corrosion along the length of whole structure on the seismic vulnerability of such structure.

The research presented in this paper aims to investigate the seismic vulnerability analysis of corroded RC frames through a probabilistic approach accounting for the influence of corrosion SDLS of damaged structure, and spatial variability of pitting corrosion. To this end, the previously developed Nonlinear Finite Element Model (NFEM) of