Seismic Performance Assessment of Existing RC Structures with Ageing Effects

Luigi Di Sarno[1*]
[1] *Department of Civil and Environmental Engineering, University of Liverpool, UK*

*Corresponding author: luigi.di-sarno@liverpool.ac.uk

ABSTRACT

An extensive portfolio of existing Reinforced Concrete (RC) structures and infrastructure was designed before the 1970s primarily for gravity loads only and without seismic details. Such structures were reinforced with plain rebars, which have poor bond performance. Additionally, recent surveys have shown that plain bars suffer from damage and deterioration due to highly-aggressive corrosive environments. Corrosion-induced damage to concrete and steel reinforcing bars may significantly affect local and global structural performance thus reducing the capacity to withstand static and dynamic loadings (e.g., seismic events, floods, wind). Therefore, it is of paramount importance to investigate the long-term behaviour of ageing structural systems.

The present work illustrates novel approaches for evaluating the static and dynamic capacity of RC members. It also discusses a robust approach to assess the seismic vulnerability and reliability of RC structures exposed to ageing effects.

Towards this aims, an experimental campaign was carried out to investigate the impact of corrosion on the nonlinear stress-strain response of steel plain bars under tensile loadings. Corrosion was artificially simulated in the laboratory of the University of Liverpool (UoL)using an accelerated corrosion method. A total of 50 test samples were tested in realistic scenarios for ageing. Tensile tests were first performed to investigate ageing effects on the mechanical and geometrical properties of the steel rebars (i.e., yield and ultimate stresses, ultimate strain, elastic modulus, and reduction of the steel diameter). Relationships to account for mechanical response degradation were then obtained based on the experimental results. A constitutive law for steel plain bars with corrosion was provided based on an existing model and Genetic Algorithm (GA). Such an experimental campaign represents a relevant and unique database for the impact of corrosion on plain rebars.

Numerical approaches were the formulated to assess the ultimate capacity of RC components with corroded steel bars subjected to ductile and brittle failure mechanisms. Such methods were compared and validated against experimental and numerical results from the literature. The inelastic buckling of such plain bars was numerically investigated using a refined nonlinear Finite Element (FE) model taking advantage of the limited experimental results from the literature and experimental tests carried out al UoL. Based on the GA and Bayesian update, a multi-step optimisation procedure was proposed to calibrate the main parameters of the most adopted numerical constitutive models for plain rebars across the experimental evidence. Then, a comprehensive parametric analysis was carried out to build a novel analytical model for the nonlinear buckling of plain rebars for more efficient and reliable seismic vulnerability assessments.

A nonlinear Finite Element (FE) model for evaluating the seismic response of RC columns with plain rebars was also developed. This model was validated against experimental results and compared with the most adopted existing FE models.

A seismic intensity measure was presented to perform seismic vulnerability assessments of structural systems with corroded plain rebars. Such an intensity measure refers to the area of the response spectral acceleration between the first natural structural period and elongation period (which is assumed herein to be twice the first natural structural period).

Finally, a comprehensive threefold probabilistic approach is presented for the time occurrence of corrosion initiation, propagation, and deterioration. Such a probabilistic framework is built upon data from climatological-related factors (e.g., minimum and maximum temperature) and existing experimental results on cracking width within various concrete damage stages (cracking initiation, severe cracking, and spalling of the concrete cover).

The proposed methods and procedures were applied to an existing multi-storey RC building and a continuous thirteen-bay RC bridge.

On the one hand, a seismic vulnerability assessment was conducted on the RC building subjected to different seismic scenarios that include: (i) nonlinear time-history analyses, whereas the natural ground motions are characterised by near-field and far-field features, and (ii) nonlinear time-history analyses considering the effects of mainshock-aftershock earthquake sequences. Fragility curves were obtained based on the results of Incremental Dynamic Analysis (IDA) and Cloud methodologies to investigate the effects of various corrosion levels on the seismic vulnerability of the case-study building.

On the other hand, reliability analyses were performed for the RC bridge subjected to spatially-variable corrosion, increasing traffic flow, and climatological effects. Monte Carlo simulations were performed at intervals of 10 years to derive time-dependent reliability profiles, which were compared against standard thresholds to define when the bridge was no longer compliant with current limits and required maintenance interventions. The failure probability for reliability profiles was built on a three-parameter distribution that accounts for possible collapse cases.

Overall, the results highlighted that RC structures could exhibit deficient structural performance over time, depending on environmental exposure. In some cases, the structural response did not reach the targets imposed by design/assessment standards. Such results highlighted the importance of introducing time-dependent structural design approaches and lifetime seismic vulnerability assessments for proper and adequate risk mitigation strategies. Nevertheless, the methodology presented herein improved the capability to evaluate the performance of RC structures with corroded plain rebars. The results of numerical investigations are beneficial for stakeholders to establish adequate proactive maintenance schemes and cost-efficient repair solutions for existing RC structures and infrastructure.

Luigi Di Sarno holds a PhD in Structural Engineering, MSc in Earthquake Engineering and Structural Design and MSc in Structural Steel Design. He is Visiting Professor at the Mid-America Earthquake Center, University of Illinois, Urbana-Champaign, USA. He is Honorary Member Staff at the College of Engineering, University of Bristol, UK, since 2011 and Adjunct Professor in Seismic Engineering at INTEC, Dominican Republic. Dr. Di Sarno has authored about 250 research publications, including refereed journals, conference papers, research reports, book chapters and field investigation reports. He has co-authored with Professor A.S. Elnashai the book: Fundamentals of Earthquake Engineering, edited by Wiley & Sons. Dr. Di Sarno is member of American Society of Civil Engineers (ASCE) Performance Based Design for Structures Committee and also Seismic Effects on Structures Committee. He is also part of the prestigious Disaster Management Advisory Group of the Pan American Health Organization, part of the World Health Organization. Dr. Di Sarno is also a member of the Working Group 11 of the European Association for Earthquake Engineering dealing with the seismic design of bridges and member of the Global Platform for Disaster Risk Reduction of the United Nations. Further details on Dr. Di Sarno's academic activities at the following link: https://www.liverpool.ac.uk/engineering/staff/luigi-di-sarno/.