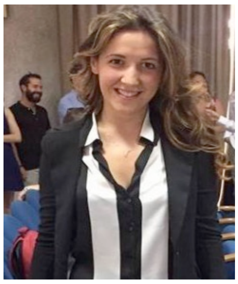
INFLUENCE OF MATERIAL PROPERTIES ON STRUCTURAL ROBUSTNESS OF REINFORCED CONCRETE BUILDINGS



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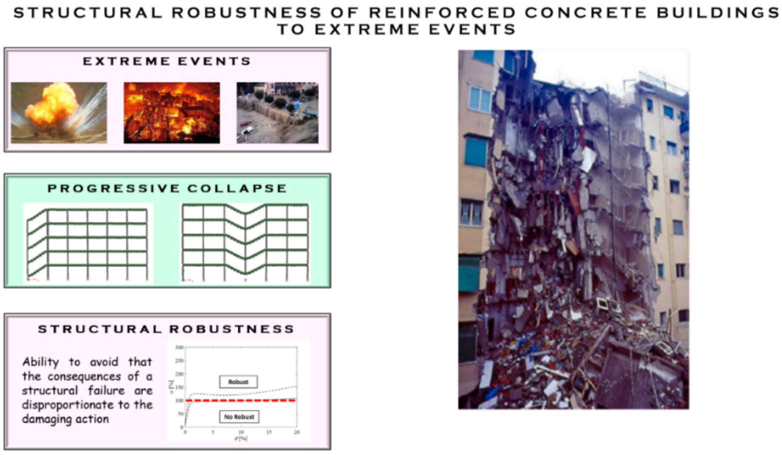
Structural robustness is the ability of a structure to avoid progressive collapse, limiting the propagation of damage to an extent that is disproportionate with respect to the intensity of the triggering event. The awareness of what disproportionate (or progressive) collapse of iconic and public buildings can cause in terms of losses of life and property has triggered significant interest in structural analysis and design under abnormal loads. Progressive collapse may consist of a chain of failures that begins with heavy damage to either a single or a few structural members and then develops throughout the structure, affecting more members. This type of structural collapse can be produced by extreme/exceptional events that are low-probability/high-consequence (LPHC) phenomena, the occurrence of which is expected to cause huge damage to people and property. In this respect, several critical factors further increase the likelihood of future losses, as follows: (i) land misuse (e.g. deforestation, mining, fracking), terrorist/war scenarios and climate change contribute to the increase of extreme hazards, with a complex distribution around the globe; (ii) ageing and misuse of built infrastructure produces rising vulnerability levels (e.g. when existing structures are subjected to occupancy levels, and hence gravity loads, higher than those assumed at the time of design); and (iii) urbanization and global connectivity of business activities increase exposure, even inducing indirect losses in the long term and far away from the site of event occurrence. The amount of research on disproportionate collapse of building structures has been increasing sharply in the past 20 years, allowing the research community to address several issues in modelling, numerical simulation, and performance quantification. Many parameters can influence the progressive collapse resistance, such as mechanical and geometric properties. Material properties play a key role because their variation can significantly influence the progressive collapse resistance. Nonetheless, this issue has still received limited attention so far, hence requiring a comprehensive investigation.

This PhD thesis has the main purpose of assessing the influence of variations in material properties on progressive collapse resistance and structural robustness of reinforced concrete (RC) framed buildings, which are one of the most common types of building structures worldwide and often need to be retrofitted to reduce collapse risk. Therefore, the PhD thesis focuses on RC buildings that were designed to gravity loads, evaluating the effects of structural retrofitting via fibre reinforced polymers (FRP) systems on structural robustness.

The first PhD year dealt with the evaluation of the sensitivity of structural response of cast-in-place RC structures to capacity model properties, after removal of a single column that is a damaging event capable of triggering progressive collapse. The following geometric and material properties were considered as variables: compressive strength of concrete, (ii) yield strength of steel reinforcement, span length of primary beams, span length of secondary beams, longitudinal reinforcement ratio of primary beams and ultimate steel strain. Incremental dynamic analysis (IDA) showed that the maximum load capacity of the structure was significantly sensitive to ultimate steel strain. In addition, it was found that the maximum vertical drift, used as a measure of peak deformation experienced by beams, was not significantly influenced by compressive strength of concrete, with the opposite occurring for the other four material and geometric properties. Specifically, both a reduction in yield strength of steel reinforcement or longitudinal reinforcement ratio of primary beams, and an increase in span length of beams may have a fatal effect consisting in the progressive collapse of the RC structure.

The second PhD year focused on the validation of structural models by numerically reproducing and investigating the progressive collapse that involved a corner of a real RC framed building, which suddenly fell down during structural retrofitting operations in 2001. Eighteen scenarios of structural retrofitting operations were simulated, by varying location and number of ground-floor columns subjected to concrete cover removal and soil excavation around column bases, in order to reproduce the actual conditions which the structure was subjected to at the time of the collapse. Pushdown analysis with displacement control was carried out on two different models of the structure: a complete capacity model and a partial model consisting of the building corner directly involved in retrofitting and progressive collapse. Analysis results show that removal of concrete cover from an internal column resulted in a collapse capacity drop greater than that predicted for the same scenario involving a perimeter or corner column. The maximum load

multiplier of the structure under this retrofitting operation decreased further as the number of involved columns was increased. The maximum reduction of progressive collapse capacity was predicted in the case of simultaneous soil excavation at the base of three columns. The results of the partial capacity model led to rather the same predictions of the complete model, with exception of a single case in which the progressive collapse capacity was underestimated; in addition, a significant reduction of computation time was found. The validation study evidenced that the use of partial capacity models can be a computationally efficient solution to the progressive collapse assessment of building structures subjected to structural retrofitting in some limited parts.
The third PhD year is dealing with the effectiveness of FRP systems to increase both seismic resistance and structural robustness of selected RC buildings, hence addressing structural retrofitting according to a multi-hazard perspective. To this aim, a four-storey, five-bay, RC frame building designed only to gravity loads was numerically investigated. Local strengthening of RC frame structures based on FRP systems can be an effective strategy to mitigate seismic risk. Therefore, frame members prone to shear failure were supposed to be strengthened with Carbon FRP (CFRP) sheets with single or multiple plies, depending on the type and location of the member to be retrofitted. FRP strengthening systems were designed according to CNR-DT 200R1/2013 guidelines. The impact of seismic retrofitting on structural robustness was significant. Local safety checks based on post-processing of both pushdown and pushover analysis results provided evidence that both seismic safety and robustness of the structure can be significantly undermined by possible premature shear failure in beams and columns. Nonetheless, structural robustness can be effectively improved by seismic retrofitting based on CFRP strengthening, underlining the importance of multi-hazard approaches for design, assessment and retrofit of structures.



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