A novel approach for the assessment of the deterioration of RC structures by means of non-invasive tests supported by numerical models

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Economic, political, and social implications related to the safety of reinforced concrete structures and infrastructures pose significant and unavoidable challenges. As regards only the economic aspect, the global non-destructive testing market is projected to grow from $6,80 billion in 2022 to $16.66 billion by 2029, at a CAGR of 13,66% [Report, online resource].

Deterioration phenomena affecting concrete and/or reinforcements cause physicochemical and mechanical variations, difficult to detect and localize by using conventional diagnostic tools and methods, which are often low-resolution, invasive, cost, and time-consuming. Moreover, numerical models can support the safety condition assessment of reinforced concrete structures but to date, there isn't a consolidated approach for deteriorated materials.

It is evident how coupled with semi-destructive and destructive tests and/or other well-known non-destructive tests, geophysical methodologies can play a fundamental role in RCS corroded RC structures inspecting and monitoring [Vasanelli et al.]. For this reason, the development of innovative strategies for corrosion diagnosis based on a combined and integrated use of geophysical and other NDT methodologies is strongly required [Maierhofer et al., 2010; Capozzoli and Rizzo, 2017; Capozzoli et al., 2021]. Nowadays, protocols for the diagnosis of deteriorated RCS are not fully established, as they depend on the specificity of the case studies under investigation. Moreover, the potentialities of geophysical methodologies, alone or integrated, are not fully unleashed.

From a structural point of view, a lot of efforts in performing experimental tests and in assessing theoretical models on corroded RC members are still needed, due to the amount of random parameters governing the physical problem and the chemical processes. In detail, a lack of well-established formulations to employ in FEM-based structural analyses of aged structures is emerged, even if some statistically assessed formulations are available [Coccia et al. 2016; Imperatore et al., 2017; Imperatore and Rinaldi, 2019; Benenato et al., 2022; Imperatore, 2022].

In this framework the two CNR Institutes ISPC (Institute of Heritage Science) and IMAA (Institute of Methodologies for Environmental Analyses) and UNICUSANO University are working on the two-year Research Project of National Relevance (PRIN-2022) ICARUS which aims at exploring the contribution that geophysical methodologies can give for detecting and monitoring the main degradation phenomena affecting RCS, considering both the concrete and the reinforcements deterioration.

ICARUS proposes the development of an innovative multiscale and multisensor geophysical methodology based on integrating empirical relationships between physical and mechanical parameters in different deterioration conditions. The project's objective will consist of developing an innovative strategy based on integrating geophysical analyses, conventional NDT and DT, and advanced statistical analyses to identify the material decay evolution and upgrade existing corrosion damage models. In addition, novel structural assessment approaches for deteriorated RCS will be proposed. At this aim, improved bond-slip and tension-stiffening laws will be developed to assess how corrosion affects the steel-to-concrete interaction at both local and global levels. The outcomes, coupled with empirical relationships based on geophysical measurements for cracked concrete and corroded reinforcements and proper finite element approaches, will allow the evaluation of the structural behaviour of deteriorated reinforced concrete structures.

ICARUS will try to accomplish mainly two goals:

1. Development of a non-invasive and multiscale approach for the geophysical characterization and monitoring of degradation, and development of damage empirical models, through the analysis of correlations between geophysical parameters and mechanical properties of concrete and RC elements with damage progression.

2. Modelling of the mechanical response of RCS at different damage levels due to deterioration phenomena. In detail, the attention will be focused on the decay of the mechanical properties of the concrete and the steel-to-concrete interaction using experimental, analytical, and numerical approaches.

In order to accomplish its mission, ICARUS will analyze the degradation mechanisms occurring in concrete and their simulation in small-scale samples with different geophysical methodologies, DT and NDTs will be applied to degraded samples, accurately selected on the basis of aging procedures and specimens' dimensions. The accuracy of each geophysical methodology in defining the degradation level will be step-by-step analyzed by laboratory measurements, at different damage levels starting from the sound conditions of the material. Microstructural, physical, chemical, and mechanical characterization tests at different stages of decay will support the tests.

Further, damage assessment of corroded RC members by means of destructive tests and geophysical methodologies will be accurately evaluated through a step-by-step laboratory procedure; then the variations of the geophysical response due to the artificial corrosion of rebars will be analyzed. The microstructural/physical properties of the corroded samples and their mechanical response will be examined to characterize the degradation phenomena. Artificial corrosion degradation of RC elements to obtain different crack patterns and/or corrosion levels will

be implemented for evaluating the mechanical performance of the corroded steel-concrete elements subjected to different corrosion levels.

Fig. 1 - The innovative multi-scale and multi-sensor based approach of ICARUS

The outcomes of ICARUS have economic potential as its activities may reduce the costs of restoration and rehabilitation interventions. Moreover, the approach is focused on the extension of the service life of structures by providing a more accurate diagnostic of the RC buildings and infrastructure conditions according to Cluster 5 of Horizon Europe 21-27 Program.

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