Reliable Engineering Assessments of Corroded Concrete Structures

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ABSTRACT
Corrosion of steel reinforcement is a large and increasing problem for reinforced concrete structures. Simple and reliable assessment methods are required to use the full capacity of existing infrastructure. In this paper, a reliable engineering assessment method is outlined. A model for anchorage has been developed and verified against a large database of bond tests. Also the influence of corrosion on the bending and shear capacity is to be included, and a probabilistic model will be established. The outcome of this work will enable practising engineers to perform reliable assessments of concrete structures with corroded reinforcement.

Key words: Corrosion, Reinforcement, Concrete, Bond, Modelling, Assessment, Sustainability.

1. INTRODUCTION

This paper presents an overview of the development of a bond model for corroded reinforcement in concrete structures meant for engineering purposes. In this introductory section, first a general introduction is given, followed by a summary of previous work on the topic and the section is ended with a description of how the development is to be performed.

1.1 General

Concrete structures under service conditions are unavoidably exposed to processes that with time may affect their ability to fulfil the structural requirement, corrosion of steel reinforcement being the most common [1]. Although many of society's large investments, e.g. bridges in reinforced concrete, already show significant corrosion damage with cover cracking and spalling of the concrete cover, the deterioration is expected to become more severe in the future due to climate change [2]. The demands for load-bearing capacity are nevertheless often increasing with time. In order to meet future needs in an environmentally friendly and economic way, without unnecessary re-constructions, advances are needed in the methods for structural assessment of existing structures.

Main consequences of reinforcement corrosion in concrete structures

The reinforcement in structural concrete is originally covered by a passivating layer, due to the alkalinity of the surrounding concrete. The corrosion process can begin only once the passivation is broken, due to e.g. ingress of chloride ions or carbonation [3]. Reinforcement corrosion affects a concrete structure in several ways, the most important being:

- Loss of reinforcement bar cross section
- Loss of reinforcement ductility and strength
- Loss of bond between reinforcement and surrounding concrete
- Cracking and spalling of the concrete cover

On the structural level, the local effects mentioned above reduce the load-bearing capacity for shear forces and moments, influences the tension stiffening of the member and thus also the deflection and crack widths. Furthermore, the capacity for plastic rotation is affected, consequently also the moment redistribution in indeterminate structures, the robustness and seismic resistance [4]. Reinforcement corrosion may lead to an abrupt collapse instead of the desired ductile failure sought in the design of structures. For example, bond failures can occur in anchorage zones and curtailment ends of bridge beams, leading to an abrupt collapse as a consequence.

1.2 Previous developments

In previous work, a simple analytical model for the assessment of anchorage in corroded reinforced concrete structures was established based on the local bond-slip relationship in *fib* Model Code 1990 [5]. Later verifications include test results from naturally corroded specimens, and 3D NLFE analyses and experiments of highly corroded specimens with spalled off cover [6]. The practical importance of the model, denoted ARC1990, has been shown in a pilot study of two bridges [7]. Approximately €3 million was saved by avoiding unnecessary strengthening for these two bridges alone, indicating that more widespread use of simple models for assessment can lead to enormous cost savings for society.

1.3 Approach

The development of a reliable model for assessing the structural effects of reinforcement corrosion and evaluating the remaining service-life of bridges with corroding reinforcement has been divided into three main points:

- Enhancing and validating the ARC1990 model for structural assessment of concrete brides with corroded reinforcement for engineering purposes;

- Establishing a probabilistic framework by incorporating uncertainties to enable reliability based structural assessments and calibrating safety factors for deterministic analysis;
- Demonstrating the use of the model through a case study.

2. DEVELOPMENT OF STRUCTURAL ASSESSMENT MODEL

In a recent work, the analytical model for bond strength assessment, mentioned in Section 1.2, has been further developed; *fib* Model Code 2010 has been implemented and the model has been verified against a database of 500 bond tests [8]. A comparison between the relative average bond strength (i.e. corroded divided by uncorroded strength) from the database compared to the developed model, denoted ARC2010, can be seen in Figure 1 for cases with stirrups.

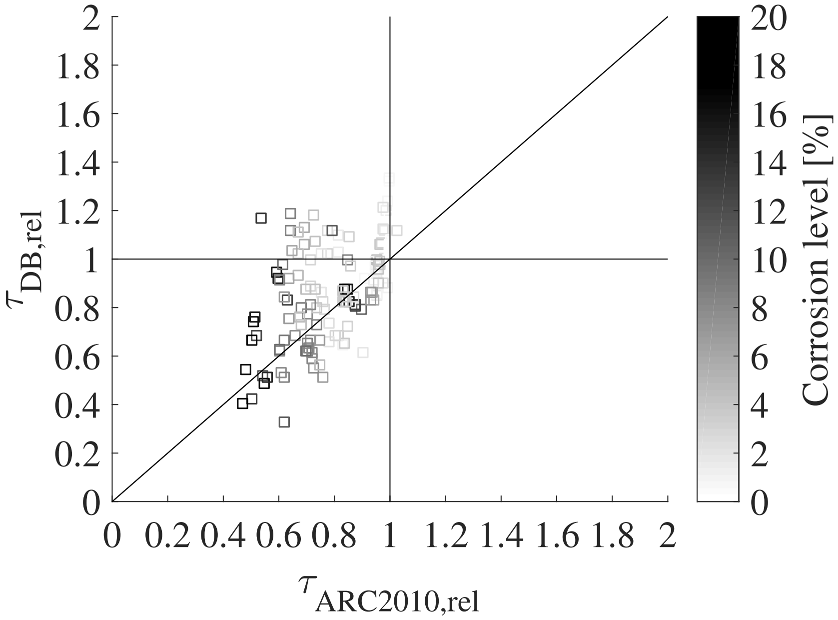

Figure 1: Comparison between bond test database and ARC2010 in terms of relative bond strength.

Current work includes studying the confining effect of stirrups dependent on the position of the bars, corner versus middle positions, as well as the reinforcement layer in a multilayer rebar configuration. Furthermore, the effect of corroding reinforcement on the shear capacity is investigated, mainly focusing possible changes of the admissible shear angle and the effect of stirrups carrying additional tensile stresses induced by corroding main reinforcement bars.

3. PROBABILISTIC MODELLING

The design of new structures as well as analysis of existing ones are affected by many uncertainties; both the applied load and the load-carrying capacity of a structure are uncertain [9]. As a consequence, the probability of failure for a structure will never be zero; instead a finite probability of failure should be met.

The analytical model presented in Section 2 will be established within a probabilistic framework, where uncertainties of the input parameters are accounted for. Uncertainties can be categorized as e.g. physical uncertainty, statistical uncertainty and model uncertainty. Physical uncertainty refers to the randomness in nature e.g. the variation in concrete strength; statistical uncertainty describes the uncertainty in parameter estimation based on available data; and model uncertainty refers to the fact that the model itself is an imperfect representation of reality.

The uncertainties of the basic variables for the model (physical and statistical uncertainties) will be described using data from literature, e.g. JCSS Probabilistic Model Code [10]. The modelling uncertainty of the calculation model will be estimated using the bond test database mentioned in Section 2. Use of Monte Carlo simulations will enable establishing the distribution function of the load-bearing capacity. The probabilistic model will be used for calibrating modification factors for the deterministic resistance model for use within a semi-probabilistic safety concept, e.g. Eurocode. The probabilistic model will also be used for service life predictions. A schematic view of the probabilistic model can be seen in Figure 2.

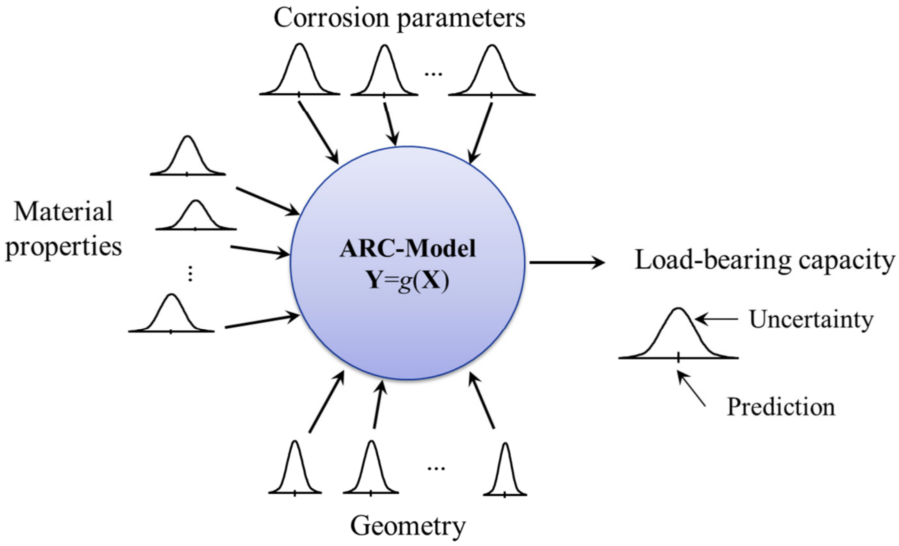

Figure 2: Illustration of the uncertainties of the input variables and the model output as a distribution

3. CASE STUDY

The relevance of the model in a practical context will be verified by application in a case study of an actual corroded concrete bridge. The study will include analysis of inspection data, existing drawings and previous calculations, and the assessment method will be applied to both estimate load-bearing capacity and to make a service-life evaluation of the studied bridge. The case study will give valuable information concerning application of the assessment method, and life cycle analyses will be used to quantify the method's environmental and economic impacts.

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