Assessment of the load-carrying capacity of existing structures with corroded smooth reinforcement bars

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ABSTRACT
Reinforced concrete bridges are common in Sweden and often damaged by reinforcement corrosion that reduces the safety of the structure. This issue has been addressed in several research projects with, however, a strong focus on ribbed bars, while further knowledge about smooth bars is still needed. Edge beams from a bridge in Gullspång with naturally corroded smooth bars will be studied so as to provide benchmark data for the assessment of the load-carrying capacity of existing structures with corroded smooth bars. Structural tests are carried out on several beams, with varying amounts of corrosion damage, measuring anchorage properties such as applied load and end-slip.
Key words: Cracking, Corrosion, Modelling, Bond, Anchorage, Smooth Reinforcement, Testing.

1. INTRODUCTION
Nowadays, a lack of models capable of assessing the load-carrying capacity of existing structures with corroded smooth reinforcement bars, may result in unnecessary strengthening measures or even in the replacement of the structures.
Reinforced concrete bridges are common in Sweden and often damaged by reinforcement corrosion, the most common cause of deterioration [1]. Corrosion of reinforcement affects the structure in two ways: a) volume expansion of corrosion products, which affects the bond between reinforcement and concrete, causing the concrete cover to crack and spall, and b) area reduction and change of ductility of the reinforcement bars. Both effects reduce the safety of the structure. Many existing structures already show significant corrosion damages; Wang [2] analysed the impacts of climate change and showed that the deterioration of concrete structures is expected to become even worse than today. In addition, the demand for load-carrying capacity often increases over time. Thus, there is a growing need for reliable methods to assess the load-carrying capacity and remaining service life of existing structures. The issue of reinforcement corrosion has already been addressed in several research projects, such as Duracrete [3], Contecvet [4], and Sustainable Bridges [5]. Existing research has, however, a strong focus on ribbed bars, while structures built before 1940 have smooth bars. Ribbed bars started to be used towards the end of the 1940s, and for many years, ribbed and smooth bars were used in combination. Very few experiments on the bond of corroded smooth reinforcement exist; the only ones found in literature are [6-9], all of which used accelerated/artificial corrosion processes set up in laboratory conditions. A major disadvantage with almost all research available on the subject today is, in fact, that it is based on artificially corroded specimens, through the application of electric current. There are several uncertainties concerning how well that corresponds with corrosion that takes place in real structures. Accordingly, experiments with naturally corroded specimens are needed. Furthermore, the results from previous research show a strong dependency of the bond capacity on the presence of transverse reinforcement that needs to be investigated.

2 EXPERIMENTAL STUDY
Edge beams from a bridge in Gullspång with naturally corroded smooth bars will be tested to produce benchmark data and to assess the load-carrying capacity of existing structures with corroded smooth bars.

2.1 The Gullspång bridge
The bridge was built in 1935, and torn down in February 2016 due to heavy corrosion damages. The edge beams taken from the bridge were carefully inspected and documented before the bridge was demolished. The edge beams were then cut off, into 4-metre-long segments, and kept for research purposes, resulting in a total of 20 beams with varying amounts of corrosion damage (see

Fig.1). The specimens are naturally corroded and spalling, crack patterns, and crack widths of the surrounding concrete on the bridge were observed and documented.

Figure 1 – On the left, the bridge in Gullspång before removal, photo from below showing the bottom side of the edge beam. On the right, a close-up of an edge beam and one of the edge beams after removal, note the hooks.

The specimens are made of concrete with a required strength of 30 MPa and smooth reinforcement bars with end hooks, as typical of the time of the construction of the bridge; similar materials are used in numerous structures. The cover, which is about 30 mm, is common for structures of that age as well. The edge beams have been exposed to deicing salts and freezing, which is typical environment for bridges, and parking garages. Furthermore, harbour structures are exposed to salt as well; the specimens are thus relevant for many more structures than this specific bridge, making the results of this study of a general nature.

2.2 The experimental set-up

A four-point bending, asymmetrical and indirectly supported, test configuration (as can be seen in Fig.2), is being taken into consideration for the performance of structural tests on the beams, similar to the set-up used for testing of edge beams from Stallbacka bridge [10]. The aim is to reach anchorage failure after the development of a shear crack. The set-up allows to avoid gripping of the bars, that could potentially modify the bond-slip capacity, as well as to avoid external transverse pressure acting in the anchorage region: for a thorough discussion see [10]. The asymmetry of the set-up is due to the need of knowing the anchorage failure side, on which DIC will be used for monitoring the bars slips. This test setup is being confronted with several other possible solutions. The edge beams have one reinforcement bar with 16 mm diameter in each corner, and stirrups that are open on one side: some beams will be tested in the same direction as when placed on the bridge; others will be tested upside down. This enables the study of varying confinement effects of the stirrups and the effect of top-cast and bottom-cast bars. Furthermore, the smooth bars have hooks at the ends, as was common to improve anchorage (as can be seen in Fig.1). For specimens with less corrosion damage, X-ray scanning will be used to locate the position of the hooks before cutting the specimens, to test specimens both with and without end hooks. Before testing, the edge beams will be grouped per similar damage pattern, in terms of cracking and cover spalling. During the tests, the applied load, deflection and end-slip will be measured and the crack pattern carefully documented. After structural testing of the beams, material tests will be performed on undamaged concrete, as well as on the corroded reinforcement bars. The aim is to investigate anchorage capacity of the corroded smooth bars, and, ultimately, to link bar properties, such as anchorage capacity, corrosion level, tensile capacity and ductility, to the documented visible damage, so as to provide guidance on how to obtain the load-carrying capacity of structures from visual inspection.

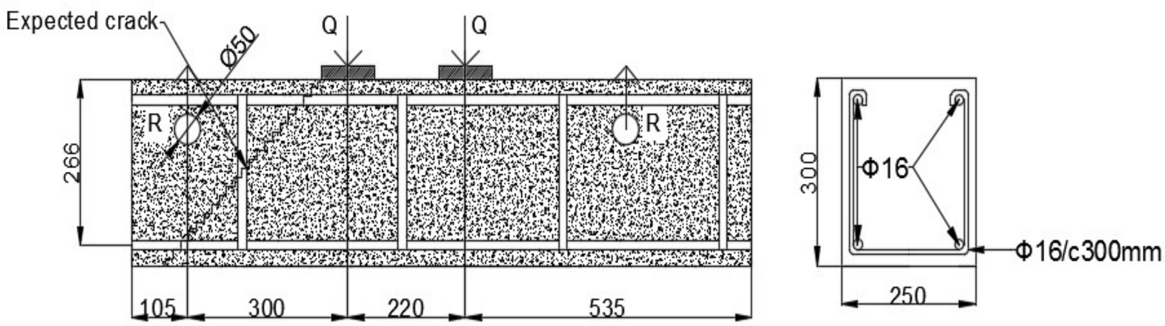

Figure 2 – Left: Planned test set-up with expected crack. Right: Cross-section of the edge beams. Measurements in mm.

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