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Deflection of RC beams under simultaneous load and steel corrosion

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The deterioration of reinforced concrete due to reinforcement corrosion has been the subject of a large number of investigations. A variety of factors, such as corrosion rate, amount of corrosion, bar type, specimen geometry, concrete quality/porosity, that might influence the behaviour of corroded structures have been identified;¹ relationships between these variables are complex and are not yet fully understood.

In their paper Ballim *et al.* addressed another important parameter in the RC corrosion equation, namely the effect of loading during the corrosion process on deflection and ultimate flexural strength. The results presented in the paper are interesting and meaningful. They also raise a number of questions, to which the authors' answers would be appreciated.

First, it is reported that corrosion increases the time-dependent deflection of concrete beams. Have the authors evaluated the contributions of each corrosion consequence, such as the reduction of bar sectional area, cracking of concrete cover and deterioration of bond between reinforcement and concrete, to the increase of beam deflection? In other words, why does about 0.6% corrosion increase beam deflection by 27%? Could the authors give their results a roughly quantitative as well as qualitative explanation?

Second, could the authors explain how was it decided

that the beams in Series I and II should be corroded for 30 and 35 days under sustained loads of 23% and 34% of load capacity, respectively? What is the significance of the different load and corrosion levels and are the loads related in any way to serviceability conditions?

Third, in the paper, the authors presented only the effects of simultaneous corrosion and load on beam deflections. Without a direct comparison with the results from first corroded and then loaded beams, how was it concluded that the sequential corrosion and load results in a significant underestimation of beam deflection? To what extent, and in which case, are the synergistic effects of simultaneous load and corrosion significant to beam deflection?

Fourth, the authors made a comparison of their corroded to uncorroded beam deflection ratio with Cabrera's. In fact, the authors' beam deflection was time-dependent under a sustained load, but Cabrera's beam deflection was obtained during monotonic loading to failure of beam specimens. Is such a comparison valid?

Finally, the ultimate strength of beams corroded under load are reported to be 20–30% less than those of the non-corroded beams. Given the fact that the Series I and II beams were corroded for different periods of time and under different loads, is it possible to determine any effect of loading during corrosion on ultimate

flexural strength? Results of an investigation by Williamson suggest that the application of a load during the corrosion process only affects the corroded bond strength if the magnitude of the applied load is above that required to cause cracking adjacent to the bar surface.²

Authors' response to contribution by S. J. Williamson, Y. G. Du and L. A. Clark

We are grateful to the contributors for the interesting and important issues and questions that they raise regarding our paper. They correctly point to the fact that there is a wide range of factors that would influence the deflection behaviour of reinforced concrete beams subjected to corrosion. In this regard, the first general response to the questions raised must be that our study did not consider variables such as bar diameter, cover depth, corrosion rate, etc. Our sense is that there is much further work that needs to be done in order to calibrate the issues raised in our paper as well as to more fundamentally understand the process and mechanisms of cracking and its influence on serviceability deflection.

The central point raised by the work reported in our paper is that the simultaneous application of load and reinforcement corrosion causes a synergistic increase in serviceability deflections. The fact that increasing the sustained load results in increased relative deflection (Fig. 7 of our paper) is most likely to be explained by the effect of cracking and steel stress, induced at first loading, in encouraging corrosion and further cracking. Importantly, this is the way that corrosion takes place in many real structures and our results seem to indicate that the test methodology should reflect such a process.

The selection of 23 and 34% of ultimate load capacity delimits a typical range of working stresses encountered in actual structures. These loads were initially based on the theoretical failure strengths of the beams as designed. The stress levels, as reported in the paper, were corrected after the actual failure load of the beams was measured.

With regard to the third question raised, no companion samples were prepared to allow for sequential

corrosion and loading tests. This does detract from our ability to quantify the effect of simultaneous corrosion and loading and, in order to do this, we were obliged to refer to the work done by Cabrera and Ghoddousi as the only reasonably comparable results we could find at the time. We considered a comparison with this work to be reasonable, despite the differences in test conditions, because we wished to illustrate the difference of the two test methods, more in terms of the characteristic shape of the curves than in the magnitude of the differences. The rapid relative deflection during the early stages of corrosion is an interesting aspect of our results and requires further assessment.

In our tests, at the end of the loading period, the serviceability loads were removed from the beams and these beams were transferred to another loading facility where they were then tested to failure. In this process, it was not possible to quantify the separate effects of corrosion and loading on the ultimate flexural strength. However, we must emphasise that such separation may be superfluous since the corrosion process in real structures occurs when load is sustained. Furthermore, without having assessed this aspect in detail, it is likely that our results agree with Williamson *et al.*'s conclusion regarding the effect of corrosion and cracking adjacent to the reinforcement on bond strength. This may go some way in explaining the differences in the load–deflection characteristics and failure mechanisms of the beams tested to failure after the corrosion process.

We hope that the answers provided here assist in addressing the issues raised by the contributors. We would nevertheless be happy to pursue this discussion privately if necessary.

References

1. DU Y. G. *Effect of Reinforcement Corrosion on Structural Concrete Ductility*. PhD thesis, University of Birmingham, 2001.
2. WILLIAMSON S. J. *The Influence of Concrete Cover Properties on the Effects of Reinforcement Corrosion*. PhD thesis, University of Birmingham, 1999.