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Flexural experiment and stiffness investigation of reinforced concrete beam under chloride penetration and sustained loading

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HIGHLIGHTS

- We investigate the effect of corrosion and sustained load on structural behavior of reinforce concrete beam.
- The results indicate that load levels have a significant effect on the rise of steel corrosion level, and the decrease of flexural stiffness and degradation of flexural capacity.
- The formula of the ratios of the different position of steel bar corresponding with different sustained loading levels was given.
- The equation was deduced to calculate the flexural stiffness of corroded reinforced concrete.

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ABSTRACT

This paper presents an experimental study conducted to characterize the effect of corrosion and sustained load on structural behavior of reinforced concrete (RC) beam. The effects of loading level on corrosion of reinforcing steel, the flexural deflection and residual loading capacity of the test beams were investigated. In the first scenario, two non-corroded beams were tested to determine the maximum load levels that were required by the beams to reach their deflection limits and that were also tested for the sustained levels of the applied loads. For the second experiment, the corrosion was accelerated through the application of external direct current whilst the beams were under the load equivalent to 0%, 50%, 65% and 80% of the ultimate load. The results indicate that load levels have a significant effect on the rise of steel corrosion level, the decrease of flexural stiffness and the degradation of flexural capacity. The mechanical properties like the strength and ductility are significantly impaired due to simultaneous effect of loading and corrosion in comparison to the effect of the single parameter at a time. Considering the corrosion situation of different position of steel bar, the formula of the ratios of the different position of steel bar corresponding with different sustained loading levels was given. An equation was deduced to calculate the flexural stiffness of corroded reinforced concrete and can be served as a reference for deflection calculation of corroded reinforced concrete beams.

1. Introduction

Reinforcement corrosion is one of the major causes for structural deterioration of reinforced concrete bridges [1,2]. The mechanical performance, residual strength, the frequency of use, maintenance, and service life of these structures with corroding reinforcements should be fully understood for the economic and robust design and construction.

Several experimental studies have been carried previously on the corrosion of reinforcement in reinforced concrete dealing with various issues which included corrosion process, its initiation, damaging effects of corrosion, and the prediction of time-to cover cracking of concrete due to corrosion [3–7]. These studies have found that the bond stiffness increases with corrosion up to a certain level of reinforcement corrosion, but with further increase in corrosion, the bond stiffness progressively decreases. However, previous studies were carried out in such a way that the reinforcements in concrete beams were first corroded to an expected extent, before the concrete beams were loaded to failure to assess the variation of their mechanical behavior due to corrosion. These concrete beams were subjected to a separate loading test and reinforcement corrosion. However, the corrosion of reinforcement occurs simultaneously with the applied loads in the real practice; the previous studies have only considered it separately.

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Heavy loading is now one of the common ways to maximize the benefits in China. However, the heavy load results in the emergence of cracks within the concrete surface causing the stiffness to reduce of the cracked section. Thus, the deflection limit of the beam is reached earlier than under the normal loading conditions and would cause the beam to no longer satisfy the requirements for its serviceability limits. The AASHTO road test result [8] also indicates that if the axle load increases twice, the damage to the road could be 16 times higher. The engineering practice shows that although the accidental heavy load does not necessarily cause significant structural damage on bridge, but effect of repeated heavy load would cause the damage of bridge aggravated, which increases the failure risk of structures, and improve the cost of maintenance.

Recently, the effects of load and corrosion on the structural performance have been reported [9–13], these investigations are mainly focused on the behavior of concrete beam at its corrosion propagation, surface cracks, instead of ductility, ultimate strength, and the relationship between loading and corrosion. In addition, the investigations for the simulation of reinforcement corrosion are mainly focus on the middle span [9–13], and the effect of shear reinforcement corrosion were ignored, and the level of sustained loads applied on the beams was only about 8% and 12% of beam ultimate capacity [11–12], which are smaller than that in actual structures. Malumbela et al. [11] have however shown that for beams that are corroded whilst under a sustained load, after a certain level of corrosion, the stiffness of the beams become degressive with a continued increase in the level of corrosion. However, it does not show the model which can be used to calculate the deflection of corroded RC beams.

This paper presents the results of experiments conducted to investigate the structural behavior of reinforced concrete beams subjected to simultaneous sustained load and reinforcement corrosion. Investigation on deflection, residual capacity, and ductility rate of an RC beam is also carried out. The corrosion of different regions of an RC beam is also compared and theoretical model of the flexural stiffness is proposed.

2. Experimental program

The experimental program consists of three parts: (a) test program; (b) data collection and analysis and c. formula derivation and model examination. The complete methodology has been shown in Fig. 1

2.1. Beam specimen and material properties

Twelve reinforced concrete beams with a dimension of 150 * 250 * 2000 mm were tested in this program. The reinforcement details of the beams are shown in Fig. 2. Each beam was reinforced with two 22 mm deformed bars in tension, and two 10 mm plain bars in compression. The concrete cover is 30 mm. and 10 mm stirrups with a space of 100 mm within the shear span. There are no stirrups in the middle span. The stirrups were wrapped by epoxy resin to avoid corrosion.

The concrete was designed to yield a 28 days compressive strength of 40 MPa. The water cement ratio was 0.42 and the maximum aggregate size of the concrete was 20 mm. The fine aggregate was the sand that the fineness modulus was 2.8, quality of the concrete mix ratio equal to w(cement): w(sand): w(pebble): w(water) was 1:1.42:3.15:0.42. The compressive strengths, elastic modulus of the beams, the yield strength, and ultimate strength of the steel were shown in Table 1.

2.2. Testing program

In the previous studies, the levels of sustained loading applied on the beam were usually smaller than the actual loading. In order to investigate the mechanical properties of the RC beam under normal state, there is a need of determination of the sustenance level of the beam for the applied load.

The first experiment was designed to test the strength and deflection of two concrete beams only for loading levels without being tested for corrosion with the chloride penetration. The testing was conducted using the testing Rig 3 under the displacement control. The flexural behavior of RC beam consists of three distinct

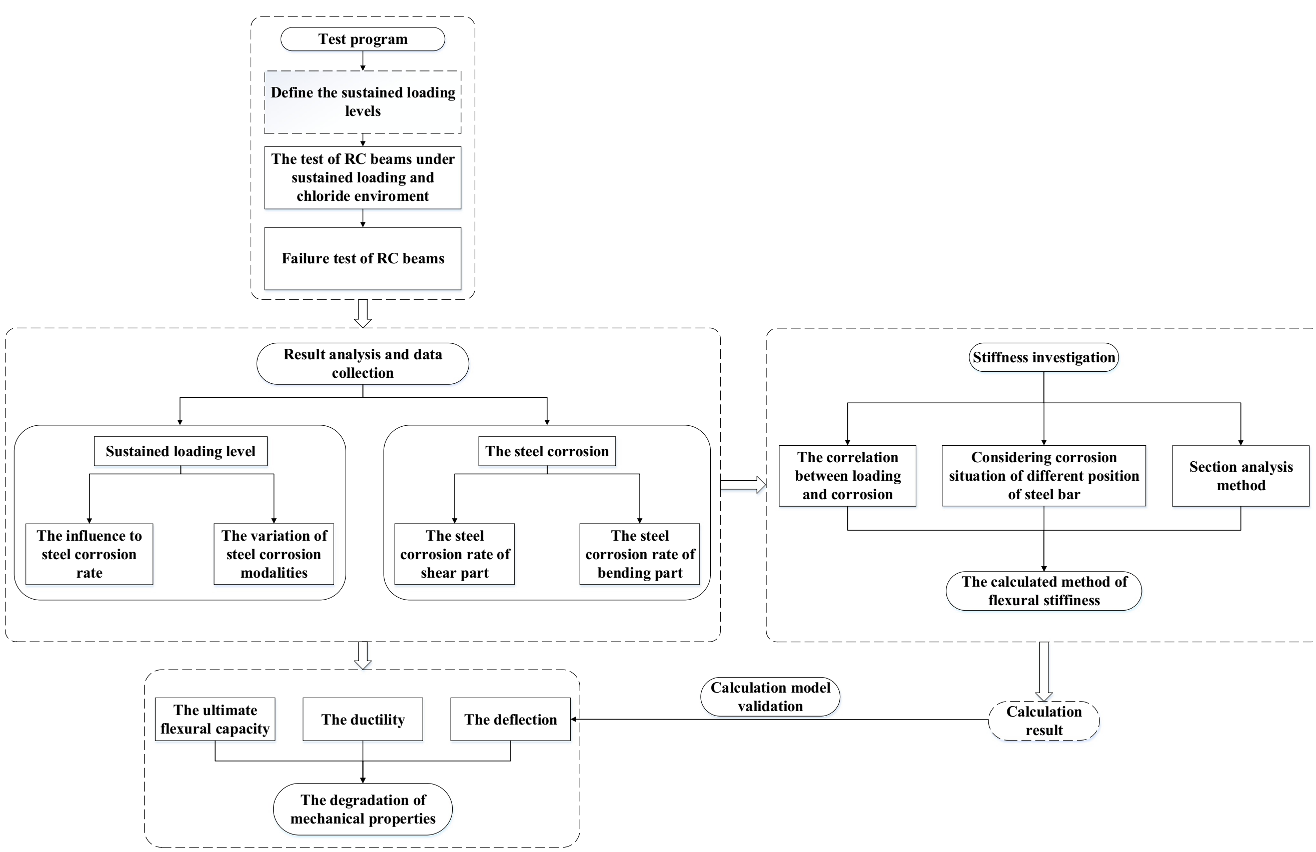

Fig. 1. The work sequence.