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Ultimate and nominal shear strength in reinforced concrete beams deteriorated by corrosion

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ABSTRACT

Exposure to aggressive agents such as chlorides facilitates the corrosion process of the transversal reinforcement (stirrups) of concrete beams, as the steel of these reinforcements is closest to the concrete's surface. Two groups of eight beams each were fabricated, and had a separation of either 150 or 200 mm between stirrups for each series. During the first stage, beams were exposed to wetting cycles using a 3.5% NaCl solution, and were then subjected to a drying process until steel depassivation was reached. Subsequently, a 100 $\mu A/cm^2$ printed current was applied for either 80 (moderate) or 120 (severe) days in order to reach different levels of corrosion in the stirrups.

Results showed that the ultimate shear strength was influenced mainly by moderate and severe levels of deterioration, as beams subjected to these treatment levels showed a 30% decrease in ultimate shear strength relative to control beams. Additionally, beam ductility was affected by levels of moderate and severe deterioration of stirrups, and this was evident due to the brittleness and sudden failure observed during beam testing. Finally, our findings indicated that the average remaining section based on the critical diameter of the stirrups was a reliable predictor of ultimate shear strength.

1. Introduction

Deterioration of reinforced concrete structures due to corrosion is caused mainly by a lack of planning, an inappropriate evaluation of the severity of environmental factors and by an inappropriate execution of such evaluations [1]. Aggressive agents such as chlorides favor the corrosion process of reinforced concrete beams, especially in the transversal reinforcement (stirrups), as the steel of the stirrups is closest to the surface of the concrete. Corrosion of the transversal reinforcement results in a reduction of its cross section, volumetric changes and cracks in the concrete cover, all of which modifies steel–concrete bonding conditions and consequently decreases the mechanical resistance of the concrete beam [2,3]. In this regard, it has been shown that the rate of corrosion of stirrups may be up to five times higher than the rate of maximum corrosion in the longitudinal reinforcement, thus influencing shear strength by diagonal tension, ductility and the failure mode of the concrete structure. In addition, deterioration by corrosion affecting shear strength may cause brittleness and sudden failure in the beam [4–7].

The ductile behavior associated with an appropriate bending design in a beam may be altered when the failure pattern by shear strength changes due to diagonal tension. The significance of the concrete beam failure due to diagonal tension has been widely studied through its cracking pattern and shear strength in normal and self-consolidating concretes [8,9]. Diagonal cracks located near the supports can determine the beam's resistance if they reach a damaged section of the stirrups, and thus potentially result in structure failure due to brittleness. Some studies have found that the concrete cover of zones with a high number of stirrups becomes cracked and causes delaminations and/or detachments. In contrast, when stirrups are more separated, damage tends to be more localized [10,6], and it is precisely damaged by localized corrosion which is one of the most destructive processes, being difficult to predict and control [11]. In addition, cracks originated from localized corrosion developed more slowly than those produced by generalized corrosion [12,13].

Cracks have been shown to accelerate the penetration of aggressive agents in the concrete matrix. Previous studies have found that flexural cracks smaller than 0.3 mm do not have a significant influence on the kinetics of the corrosion [14]. In contrast, corrosion intensity increases when cracks are wider than 1 and 2 mm, causing advanced deterioration and affecting the global behavior of the concrete structure [2,15,16].

Bonding between steel and concrete becomes greatest when the concrete cover has no cracks or an incipient level of corrosion. However, the appearance of cracks and concrete delaminations caused by an increase in the level of corrosion will result in a

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