Construction and Building Materials 145 (2017) 411–418

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effects of corrosion on the behaviour of precast concrete floor systems

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HIGHLIGHTS

- Effects of corrosion on precast and pretensioned concrete floor elements were studied.
- Bond degradation was found to be the main cause for impaired structural behaviour.
- Significant reductions of the effective prestressing force were observed (up to 88%).
- Corrosion led to substantial reductions in the load carrying capacity (up to 95%).
- Precast and pretensioned floor elements are highly vulnerable to corrosion effects.

ARTICLE INFO

Article history:
Received 15 February 2017
Received in revised form 31 March 2017
Accepted 7 April 2017

Keywords:
Reinforced concrete
Precast
Prestress
Corrosion
Pretension
Floor systems

ABSTRACT

Corrosion is the most deteriorating phenomenon causing structural deterioration of both prestressed and nonprestressed reinforced concrete structures. Precast and pretensioned concrete floor elements, as solid joists and solid and hollow-core planks, are widely used worldwide for structural floor of small to medium size buildings, including car-parking garages. Although usually considered as secondary structural elements, these are particularly vulnerable to corrosion as they are designed and produced using neither longitudinal nor transverse ordinary reinforcements.

In this paper the structural behaviour of pretensioned concrete solid joists is experimentally investigated. A set of joists specimens is subjected to accelerated corrosion by subjecting it to an impressed electrical current, in order to achieve (theoretical) reinforcement area reductions between 2.5% and 40% of the initial area. Corrosion levels are then experimentally assessed including their variability along the prestressing wire length. The crack development is observed and the equivalent prestressing losses are evaluated based on the counter deflection variation. The mean tensile stresses and strains of the prestressing wires, depending on the corrosion rate, are assessed. Finally, the ultimate loading capacities of the concrete joist specimens are evaluated based on a three point loading protocol.

Results show that the service and the ultimate performance of pretensioned concrete joists are not affected for corrosion levels below approximately 2%. For higher degrees, concrete cracking starts developing resulting into bond degradation and consequent loss of effective prestressing force and counter deflection reduction. Tensile tests of corroded prestressing wires suggest a more relevant reduction of the material average maximum strain than strength. Loading tests of the joist specimens show that for corrosion levels above 15%–20% the ultimate loading capacity can be reduced up to 10% of that of the uncorroded specimens.

1. Introduction

In a study conducted between 1999 and 2001 in the US, by the Federal Highway administration [1], annual direct costs of corrosion were estimated in $276 billion, approximately 3.1% of the nation's Gross Domestic Product (GDP). A very significant percentage of this value (above 70%) is devoted to the infrastructure, transportation and utilities sector. In Portugal, similar levels (2% to 3% of the GDP) were suggested by the Technical Division for the Corrosion and Protection of materials and a similar trend is expected for the most developed countries. The indirect costs were not assessed, but it is known that these are several magnitudes higher than the direct costs. Of the governments' budgets for corrosion, a significant part is devoted to the repair and maintenance of reinforced concrete structures, due to the worldwide dissemination

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http://dx.doi.org/10.1016/j.conbuildmat.2017.04.044

of this structural typology in the housing, infrastructure and transportation sectors. Corrosion has a tremendous impact on the performance of reinforced concrete structures, either prestressed or non-prestressed, accelerating its deterioration and aging, and reducing its safety and expected design service life.

Several research works have been devoted to the topic of corrosion of reinforced concrete structures but few have addressed its impact on the behaviour of pretension concrete flooring elements, such as joists and solid and hollow-core planks, as these are usually considered as secondary structural elements. However, pretensioned concrete flooring elements are significantly vulnerable to corrosion since, traditionally, these are designed using neither longitudinal nor transverse reinforcement. Moreover, the use of pretensioned elements has been spread worldwide in the construction of solid and hollow core flooring systems for small to medium size buildings including car-parking garages, where often de-icing salts are spread. An example is the very recent case of the Algo Centre Mall, in Elliot Lake, Ontario, Canada, which has exhibited a partial collapse in 2012, caused by corrosion. Although the collapse was not triggered by the failure of a precast concrete floor element, the report [2] alerts for the potential risk related to the corrosion of the structural flooring system. Also, according to a Structural Safety (incorporating CROSS, Confidential Reporting on Structural Safety, and SCOSS, Standing Committee on Structural Safety) report [3] there have been a small number of incidents where sections of precast concrete (pcc) floor units have become detached and fallen, due to reinforcement corrosion, warning for the existing potential for heavier consequences.

In this paper, the impact of reinforcement corrosion in the behaviour of a precast concrete floor joist is experimentally investigated. Focus is given to pretensioned elements casted using neither longitudinal nor transversal reinforcement due to their increased vulnerability to corrosion.

2. Literature review on corrosion

Significant research has been devoted to corrosion of reinforced concrete structures, including the chemical mechanism itself and the resulting deteriorating effects. Different contributions have been provided either of experimental or numerical nature. Published experimental investigation is mostly based on accelerated corrosion tests, rather than on "in-situ" corrosion. Published papers [4–8] are among the pioneer experimental studies investigating the role of corrosion on the flexural behaviour of reinforced concrete beams and slabs, including its effect on the mechanical properties of steel bars. The work reported in [9–11] focus on the numerical simulation of the corrosion effect on the behaviour of reinforced concrete structures. The impact of corrosion on the time-dependent reliability and probability of failure including service life prediction has been addressed mostly by [12–16]. The research on prestressed concrete structures subjected to corrosion is scarcer. However, reference needs to be made to [17], which includes an experimental investigation on a 45 years old, naturally corroded prestressed bridge, and the work presented in [18]. The research focusing on the corrosion effects on precast and pretensioned concrete elements for structural floorings, casted without neither longitudinal nor transversal ordinary reinforcement, is even scarcer and almost inexistent, since, and as mentioned, these are usually considered as secondary structural elements. An exception is made to the research shown in [19–21].

Although, corrosion of prestressed and non-prestressed concrete structures requires additional investigation some conclusions, based on the mentioned studies, and many more, can already be drawn. Corrosion of reinforced concrete structures is a very sensitive phenomenon depending on a many fold of factors. Among these, it is important to refer the concrete cover and grade, temperature, humidity, carbonation, chloride contamination. This multiplicity of factors lead to significant scattered data based either on "in-situ" observations or in experimental investigations. Corrosion of reinforcement is mostly due to concrete carbonation and/ or chloride contamination. In the first case, corrosion tends to be generalized and in the second case is more associated with pitted spots. The resulting deteriorating mechanical effects include the reduction of the reinforcement effective area (as the iron oxides exhibit poor mechanical properties), the concrete cracking and spalling, the bond deterioration between steel and concrete and the ductility reduction of the reinforcement bars, either due to the phenomena of hydrogen embrittlement or due to strain concentration in the most pitted sections.

3. Materials and methods

The experimental work described in this paper was planned to: (a) investigate the relation between prestressing reinforcement corrosion, crack development and losses in the effective prestressing force; (b) analyse the influence of corrosion on the average tensile strength and ultimate strain of the prestressing wires; (c) evaluate the impact of corrosion on the ultimate behaviour of concrete flooring joists measured in terms of the ultimate load bearing capacity; (d) study the influence of corrosion on the development of the failure mechanism.

Tested specimens consisted of nine precasted concrete flooring joists with 1.5 m length prestressed with pretension, using neither longitudinal nor transversal reinforcement. The cross section of the specimens is depicted in Fig. 1. A single 5 mm diameter wire per specimen was used. The S1770 steel grade wire was pretensioned up to a tensile strength of 1290 MPa, which resulted in a mid-span counter deflection of 2.5 mm and approximately 20% of prestressing losses. A C30/37 concrete grade according to the Eurocode 2 [22] was used for the casting.

Although smaller specimens than those usually adopted for floor systems up to 5-7 m spans were used in the current work a similar span/section height [25] was considered, yielding a set of results that can be extrapolated to most practical cases.

The experimental protocol consisted on four sequential phases including: (i) an accelerated corrosion period; (ii) an ultimate loading test, (iii) disassembling of the specimens for measuring the

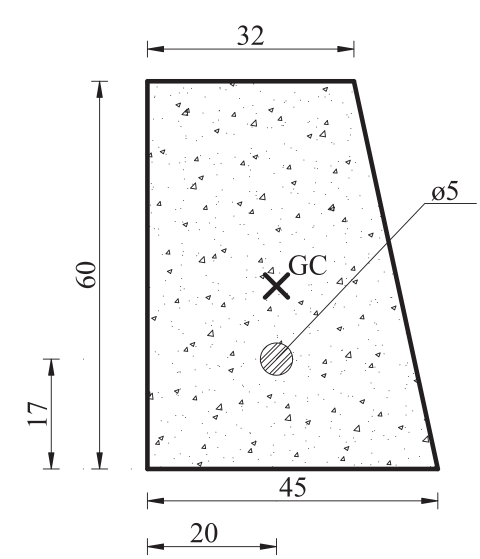

Fig. 1. Cross section of the tested specimens (dimensions in mm).